

# Linkages among climate change, crop yields and Mexico–US cross-border migration

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Climate change is expected to cause mass human migration, including immigration across international borders. This study quantitatively examines the linkages among variations in climate, agricultural yields, and people's migration responses by using an instrumental variables approach. Our method allows us to identify the relationship between crop yields and migration without explicitly controlling for all other confounding factors. Using state-level data from Mexico, we find a significant effect of climate-driven changes in crop yields on the rate of emigration to the United States. The estimated semielasticity of emigration with respect to crop yields is approximately  $-0.2$ , i.e., a 10% reduction in crop yields would lead an additional 2% of the population to emigrate. We then use the estimated semielasticity to explore the potential magnitude of future emigration. Depending on the warming scenarios used and adaptation levels assumed, with other factors held constant, by approximately the year 2080, climate change is estimated to induce 1.4 to 6.7 million adult Mexicans (or 2% to 10% of the current population aged 15–65 y) to emigrate as a result of declines in agricultural productivity alone. Although the results cannot be mechanically extrapolated to other areas and time periods, our findings are significant from a global perspective given that many regions, especially developing countries, are expected to experience significant declines in agricultural yields as a result of projected warming.

human migration | global warming | environmental migrants | agricultural productivity | instrumental variables approach

Climate change presents many critical challenges to humankind (1, 2). One widely cited impact is the displacement of large numbers of people (3–9). Among all potential “climate refugees” or “environmental migrants,” those crossing international borders are likely to be of particular concern for both developing (in many cases, migrant-sending) and developed (i.e., migrant-receiving) countries. Although migration is a normal part of the development process (10, 11), and can be an important risk management strategy for households (12, 13), unmanaged and unexpected climate-related migration could exacerbate a range of problems, including deterioration of ecosystems, slowing of regional economic development, disruption of human and political rights, and increased international conflicts and border fortification (14).

Despite qualitative assertions and some local case studies (7, 8, 15, 16) (*SI Appendix, part 1*), climate-driven migration has not received sufficient attention in the immigration literature. Existing studies of immigration typically emphasize the roles of geographic proximity, relative economic opportunities for potential migrants, social and cultural networks, and political stability as causative factors. Climate factors may play an increasingly important role in the future, given the prospect of global warming. Although the underlying climate/migration relationship is complex and the evidence is sometimes elusive (8, 17–19), policymakers require plausible forecasts to prepare for future immigration flows in response to climate change. For that reason, this study uses an approach that isolates the climate effect—which may have only been secondary—from other drivers of historical migration to provide a basis for the estimation of future international immigration flows.

Several aspects of climate change may drive changes in migration (20). In this study, we focus on the climate acting through its effect on agricultural productivity. Changes in crop yields that result from climate change occur over broad geographical areas (unlike sea level rise, which directly affects only coastal regions), and are likely to lead to long-term population shifts (more so than episodic flooding, for instance, the effects of which tend to be transitory). Such a phenomenon is especially relevant to developing countries, which typically have large rural populations that derive a living directly from agriculture. Lacking resources to adapt, developing countries are also most vulnerable to future warming (21, 22). Furthermore, the possible impacts of climate change on the agriculture sector have been estimated worldwide and are relatively well understood (23–25).

Specifically, we study Mexico for the decade of 1995 to 2005, during which time a substantial increase in out-migration to the United States occurred. Studies have examined numerous factors underlying the so called “great Mexican emigration” (26–31), including negative labor demand shocks, labor supply shocks resulting from demographic changes, US immigration policy changes, migrant networks, and importation of cheap corn and other agricultural products following the North American Free Trade Agreement (NAFTA) (32). Yet to our knowledge no study has directly associated a component of the increase in emigration with changes in climate, despite numerous reports and anecdotes of Mexican farmers fleeing to the United States because they no longer could maintain their previous way of life because of climate-driven crop failures (8, 33). This omission is significant given that the period after 1994 also coincides with a historically rare period of drought in much of Mexico, especially in the north, that is comparable to the great Mexican drought of the 1950s (34).

We chose Mexico for our study because it is one of the biggest migrant-source countries, because there exists state-level data on emigration, and because it has undergone diverse degrees of climate variability across regions. In addition, Mexico is unique in that the relative ease of migration to the United States allows us to better capture the full potential emigration response to changes in crop yields than in many other cases. It is extremely important for policymakers to appreciate the magnitude of the “desired” or “potential” demand for out-migration when evaluating various policy options.

To estimate the sensitivity of emigration to crop yields, we employ a statistical estimator that uses only the portion of variations in crop yields across states that is predicted by variations in climate. Such yield variations, unlike those caused, for example,

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crop yields and migration could also be different in border states because of their proximity to the United States. In part F of Table 2, we exclude the six border states of Mexico. The estimated semielasticities became even larger in magnitudes and remain highly significant.

**Forecasting Future Mexican Emigration Under Climate Change.** Our estimate of the elasticity of migration is conditional on many factors specific to Mexico for the period under study, such as the macroeconomic situation compared with that of the United States, the population share of youths (who are more likely to migrate), farming practices, the relative importance of the agricultural sector, and agricultural policies including responses to droughts and other climatic events that adversely affect crop yields (16). For example, if government policies intended to help subsistence farmers become more effective, or changes in farming practices allow farmers to be more resilient to adverse climatic conditions, the estimated yield/emigration sensitivity may become smaller as well (16, 32). Changes in US immigration policies and border enforcement could also substantially alter the Mexico crop yield/emigration relationship (27, 29, 30).

Keeping these idiosyncratic factors in mind, it is nevertheless instructive to predict future migrant flows for Mexico using the estimates at hand to assess the possible magnitude of climate change-related emigration (Table 3). Our projection exercise does not depend on whether past climate variability in Mexico was caused by greenhouse gas emissions, as long as the migration responses are similar to those that would occur in response to anthropogenic climatic changes.

Specifically, we project the emigration rate of the adult Mexican population (aged 15–65 y) resulting from the predicted changes in crop yields from Rosenzweig and Iglesias (ref. 38; see also [http://sedac.ciesin.columbia.edu/giss\\_crop\\_study/index.html](http://sedac.ciesin.columbia.edu/giss_crop_study/index.html))

and Cline (23) at approximately year 2080. We use  $-0.2$  as the semielasticity of emigration with respect to crop yields.

The first three panels of Table 3 are based on scenarios and crop yield predictions made by Rosenzweig and Iglesias (38), all assuming an eventual stabilization level of atmospheric  $\text{CO}_2$  concentration of 555 ppm, which, under the relatively conservative scenario B1 of the Intergovernmental Panel on Climate Change Special Report on Emission Scenarios (1), approximately corresponds to the year 2080 and represents global mean temperature increase of  $1^\circ\text{C}$  to  $3^\circ\text{C}$  above recent temperatures. The three panels use climate forecasts from different General Circulation Models (GCMs), including those of the Goddard Institute for Space Studies, the Geophysical Fluid Dynamics Laboratory (GFDL), and the United Kingdom Meteorological Office (UKMO). Although, in all cases, Mexico is expected to experience some reductions in crop yields as a result of climate change, the magnitude depends to a large extent on whether the fertilization effect of  $\text{CO}_2$  is included and whether active agricultural adaptation measures are taken. On the one extreme with no  $\text{CO}_2$  fertilization effect and no adaption, crop yields in Mexico are predicted to decline by at least 39% (GFDL), or as much as 48% (UKMO). In that case, the increase in Mexico's emigration as a share of population (i.e., the fraction of all Mexican-born people living abroad) would be between 7.8% and 9.6%. Mexico's population will differ in the future and the elasticity may change if the rural population fraction decreases further, and if the agricultural sector itself changes (i.e., results are sensitive to implicit assumptions about the path of development). Nevertheless, to indicate the broad scope of the phenomenon, we convert these percentages to absolute numbers of emigrants. Using today's population of 70 million as the base for the age 15–65 y population in Mexico, this percentage increase corresponds to an additional 5.5 to 6.7 million emigrants.

**Table 3. Forecast of future Mexican emigration at the national level under different climate scenarios**

Scenario		Change in crop yields, %	Change in emigrants as percent of population, %	Change in no. of adult emigrants, millions <sup>†</sup>
CO <sub>2</sub> effect	Adaptation*			
Rosenzweig and Iglesias (38): GISS <sup>‡</sup>				
No	No	−46	9.2	6.4
Yes	No	−35	7.0	4.9
Yes	Level 1	−27	5.4	3.8
Yes	Level 2	−13	2.6	1.8
Rosenzweig and Iglesias (38): GFDL <sup>‡</sup>				
No	No	−39	7.8	5.5
Yes	No	−28	5.6	3.9
Yes	Level 1	−20	4.0	2.8
Yes	Level 2	−10	2.0	1.4
Rosenzweig and Iglesias (38): UKMO <sup>‡</sup>				
No	No	−48	9.6	6.7
Yes	No	−37	7.4	5.2
Yes	Level 1	−31	6.2	4.3
Yes	Level 2	−15	3.0	2.1
Cline preferred estimates <sup>§</sup>				
No	Not Clear	−35	7.1	5.0
Yes	Not Clear	−26	5.1	3.6

\*Level 1 adaptation includes changes that imply small additional cost to the farmers and not necessary policy changes, such as shifts in planting dates, variety and crop, and increases in water application to irrigated crops. Level 2 adaptation includes higher order adaptations that imply significant additional costs to the farmers, such as large shifts in crop production timing, increased fertilizer application, installation of irrigation systems, development of new varieties, and/or changes in policy.

<sup>†</sup>Assuming that the population aged 15–65 y is 70 million in Mexico.

<sup>‡</sup>The equilibrium scenarios for three major General Circulation Models were used by Rosenzweig and Iglesias (38): the Goddard Institute for Space Studies (GISS), the GFDL, and the UKMO.

<sup>§</sup>The Cline estimates (23) give equal weights to estimates from Mendelsohn-Schlesinger Ricardian model and Rosenzweig and Iglesias (38) crop model. Both assume some levels of adaptation.

The actual effect of CO<sub>2</sub> on crop yields remains very uncertain (39). If CO<sub>2</sub> fertilization effects are taken into account and major (i.e., level 2) adaption measures are taken, there would be only a modest (10–15%) decline in crop yields. In that case, our model predicts that 2% to 3% of Mexicans (or 1.4–2.1 million) would migrate to other countries (mostly to the United States if current conditions persist) because of the climate-driven decline in crop yield.

The last panel of Table 3 presents results based on predictions made by Cline (23), which basically combine estimates from the Rosenzweig and Iglesias crop model and the Mendelsohn-Schlesinger Ricardian statistical model. The Cline estimates use year 2080 as a reference point but are approximately comparable with the 555 ppm CO<sub>2</sub> concentration level used by Rosenzweig and Iglesias (38), and have incorporated a moderate level of adaptation. In this scenario, crop yield in Mexico is expected to decline by 35% without CO<sub>2</sub> effects and by 26% with CO<sub>2</sub> effects, which we forecast would lead 7.1% and 5.1% of the population (or 5.0 and 3.6 million people) to emigrate, respectively.

The median of the forecasted increase in the share of the population expected to emigrate in Table 3 is approximately 6%, which implies that 4.2 million additional adult Mexicans would emigrate as a result of climate change induced crop yields reductions with today's population as the base. It is important to note that our projections should be interpreted in a *ceteris paribus* manner, as many other factors besides climate could potentially influence migration from Mexico to the United States. Demographic changes are especially important in shaping future migration flows. Hanson and McIntosh (26), for example, predict that Mexico will send fewer migrants in the next several decades as a result of a decline in fertility. Our projections are informative, nevertheless, in quantifying the potential magnitude of impacts of climate change on out-migration.

## Discussion

To conclude, we have examined the link between climate-driven productivity changes in the agricultural sector and out-migration with Mexico used as an example. Our results are conservative in at least two respects. First, projected changes in crop yields are considerably larger than those observed in our data. If crop yield affects emigration in a nonlinear fashion, our linear specification would likely underestimate the full impact of climate on crop yields in the future. Second, as we focus on only crop yields, our estimate provides a lower bound for the overall impact of climate change on emigration through agriculture, which could also be affected by changes in the total acreage of land cultivated. Even so, the estimated elasticity of emigration with respect to crop yield changes is statistically significant and large in a practical sense. This suggests that crop yield-induced migration will be a significant issue in many areas of the world that are expected to experience a substantial reduction in yields as a result of climate change, including much of Africa, India, Bangladesh, Latin America, and Australia, among others. Because climate change

may induce out-migration through channels not examined in this study, the overall effect may be larger, particularly if atmospheric greenhouse gas concentration levels continue to increase sharply and countries fail to implement aggressive adaptation measures.

Given these projections, certain migrant-receiving countries, including the United States, are expected to face increased migration streams as a result of existing transnational networks with migrant-sending countries that are particularly vulnerable to climate change. However, some aspects of the Mexico/United States emigration situation are also unique, so extrapolation of our quantitative findings to the global level would be inappropriate. Nevertheless, application of our methods to other regions and other climate-related drivers of immigration, and to internal migration, would provide insights into potential future immigration and migration "hot spots," as well as into the overall magnitude of the looming changes. Additional insights concerning the response of migration sensitivities to trends in climate variables (i.e., whether the semielasticity would decrease or increase in a different climate) may also be gained from study of regions with data sets extending over a longer period. Future research could also use different methods (e.g., ethnography) to complement our statistical approach to deepen our understanding of people's motives to migrate when faced with climate change.

## Materials and Methods

**Data.** We use data on emigration, crop yields, and climate for each Mexican state, all averaged over two consecutive 5-y periods of 1995 to 2000 and from 2000 to 2005 (*SI Appendix, Table S1*). The emigration data are derived from Mexican censuses of 1995, 2000, and 2005. Specifically, we use a residual approach to compute out-migration flows: we start from 5-y population changes and adjust for mortality and internal migration, then calculate percentages of people who migrated within a period among all people aged 15 to 65 y who were in Mexico at the beginning of the period. This measure thus captures relatively long-term population movements rather than more transitory ones. Because of a large number of undocumented Mexican emigrants to the United States (40), all methods aimed at accurately determining emigration rates entail considerable uncertainty. Our method provides the best available estimates of state-level emigration rates, and matches other studies in terms of national totals (40).

To measure crop yields, we focus on corn, because it is the principal food stock of the Mexican diet and the most important crop. Corn accounts for 60% of land under cultivation and agricultural output by value, and provides the main source of livelihood to 40% of people working in agriculture (32). We also examine an alternative measure that combines corn and wheat, as wheat is a major substitute crop for corn and is also widely cultivated in Mexico (41). Yearly information for corn and wheat production and areas of land planted for each state were obtained from the Mexican Ministry of Agriculture, from which we calculate 5-yr average crop yields. Our state-level climate data on annual precipitation, annual mean temperature, and summer mean temperature were obtained from the Mexican National Weather Service (*SI Appendix, part 2*, provides further description).

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