Climate Change, Agricultural Shocks, and Migration*

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Abstract

Uncertainty surrounding links between climate change and migration is compounded by insufficient theorization of mechanisms and lack of data on migration. Climate change creates negative income shocks, which can influence migration decisions. Studies show a positive relationship between increased income and emigration, but theory and empirical evidence are less clear regarding situations where people face the prospect of persistent decreases in income. We argue that decreases in income, such as those associated with climate change, can also increase emigration. The level of impact may be influenced by availability of internal migration options. We test our hypotheses using subnational data for migrants arriving in family units at the U.S. southern border from El Salvador, Guatemala, and Honduras between 2012 and 2019. We find that departments (states) experiencing more agricultural stress see substantial increases in apprehensions at the U.S. border. In Mexico, where more options exist for internal migration, we find the relationship between increased agricultural stress and migration is also positive, but substantively small. We compare results using different measures of vegetative stress and results using yearly stress data to those using data for a critical growing period. We find that crop-specific measures and those focusing on the critical growing period have the highest association with migration. These results have important implications for scholars and policymakers seeking to better understand and forecast links between climate change and migration.

Keywords: Migration, Climate Change, Agricultural Stress, Income Shock, Central America, Mexico

Highlights:

- Substantively large increases in family migration to the United States between 2012-2019 occurred from areas within El Salvador, Guatemala, and Honduras that experienced higher agricultural stress linked to climate change, which is associated with decreased income and increased food insecurity.

- Increases in family migration as a response to agricultural stress were substantively small from Mexico, perhaps due to its larger geographic and economic size creating more opportunity to absorb migrants internally.

- The finding of an association between negative shocks to income and increased migration is an important contribution to the field of migration studies, which has often focused on the links between increasing income and migration.

- The data show an important demographic shift, from individual migration to family migration, highlighting that climate-related migration may be demographically different from previous forms of migration.

- Programs that increase resilience to climate change and halt income declines may potentially decrease the number of climate-related migrants in the future.

Migration associated with climate change is increasingly observed, as households turn to migration in the wake of sudden-onset and slow-onset climate disasters such as sea-level rise in Bangladesh, flooding in Pakistan, desertification in Africa, and storms and drought in the Americas.[1] Scholars project that without migration, climate change may result in up to one-third of the world's population living in conditions currently found only in places such as the Sahara by 2070 (Xu et al., 2020). In 2021 the United States White House published its "Report on the Impact of Climate Change on Migration," highlighting the geopolitical and security challenges that could result.[2] Despite the growing attention and recognized urgency of the situation, considerable gaps exist in both theory and data that hinder understanding of when people use migration as a response to climate change and which destinations they choose; this is particularly true if climate-related migration differs substantially from other forms of migration.

We provide an important step forward by studying the link between increased agricultural stress related to climate change and family migration to the United States from El Salvador, Guatemala, Honduras, and Mexico. Increased frequency of drought has had a negative impact on income and food security throughout Central America, particularly since 2014 (Nakamura et al., 2024). This same period has seen a sharp increase in migrants arriving as families at the U.S. southern border from El Salvador, Guatemala, and Honduras, but not from Mexico.

Well-established findings overwhelmingly show that increases in income among low- and middle-income countries are associated with increases in international migration until average income reaches a level high enough that migration becomes less attractive (Zelinsky, 1971; Clemens, 2020). This has been called the "mobility transition," "migration hump," or "inverted-U." We advance theory and evidence in the field of migration studies by examining the

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[1] See, for example: De Lellis, Marin and Porfiri (2021) on Bangladesh; Hashmi (2023) on Pakistan; Marchiori, Maystadt and Schumacher (2020) on sub-Saharan Africa; and Abeldaño Zuñiga and Garrido (2020) on Latin America.

[2] Available at https://www.whitehouse.gov/wp-content/uploads/2021/10/Report-on-the-Impact-of-Climate-Change-onMigration.pdf.

relationship between income and migration when a significant proportion of the population experiences declines in income, such as those associated with climate change. We argue that while increases in income are associated with increased migration, decreases in income can also be associated with higher migration. When income rises, it increases the capability to migrate; when income falls, it can increase the desire to migrate (de Haas, 2021; Schewel, 2020). The likelihood of choosing international migration in response to decreased household income may be influenced by the availability of attractive internal migration options.

The analysis presented here uses subnational data from a Freedom of Information Act request on the department (state) of birth for family migrants apprehended at the U.S. southern border between 2012 and 2019, a period encompassing multiple droughts in portions of Central America. As a measure of climate impact, our analysis employs a geospatial measure of agricultural stress from the Food and Agriculture Organization (FAO), calculated using data obtained through remote sensing and aggregated to the department level. The use of subnational data, which is seldom available on migration for multiple countries for the same timeframe, allows us to examine whether areas affected most by agricultural stress are also those that experience the most migration. By comparing Mexico with El Salvador, Guatemala, and Honduras – which are significantly smaller in terms of landmass, population, and economy – we gain insight into the role that a country's geographic and/or economic size may play in determining the relationship between climate change and international, rather than internal, migration.

For each country, we find that areas within the country experiencing more agricultural stress send more migrants to the United States. This relationship is significant and substantive large for El Salvador, Guatemala, and Honduras; it is significant but substantively much smaller in magnitude for Mexico. This is generally consistent with the theory that larger countries are better able to absorb migrants internally when faced with subnational climate impacts that

negatively affect income. A further contribution of the analysis is to examine differences in the relationship between climate and migration across various measures of climate stress.

Along with informing migration theory, the results have important implications for the growing body of work attempting to forecast future climate-related migration.[3] Influential studies suggest that most climate-related migration will be internal, rather than international (e.g., Rigaud et al., 2018). Our findings suggest that the prevalence of internal and international migration may vary significantly across countries. The data presented here show a sizeable demographic shift in migrant populations from Central America in addition to a large increase in migrant numbers, with substantial shifts from single adults to family units migrating. To our knowledge, modeling is not sufficiently incorporating these types of demographic shifts. Understanding these trends will be important for the next generation of modeling to help policymakers respond to potential migration pressures.

Finally, the results have important policy implications. Government rhetoric surrounding foreign aid policy suggests that donors may desire to use aid to decrease migration, and studies show that more aid flows to countries that send higher numbers of migrants to a donor (Bermeo and Leblang, 2015). Using foreign aid to increase resilience to climate shocks and lower income declines might translate into fewer climate-related migrants in the future. The findings also cast doubt on media narratives claiming that U.S. border policies which make it difficult to detain migrant children for long periods of time drove the sharp shift to adults arriving at the border with their children during this period:[4] If U.S. policy was the main cause of this increase, we would expect to see similar demographic shifts in migration from Mexico during this period, which are not borne out by the data.

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[3] See Schewel et al. (2024) for a recent overview.

[4] Victoria Macchi (2019), "Number of Children, Families Crossing US-Mexico Border Jumps in May." *Voice of America:* https://www.voanews.com/a/number-of-children-families-crossing-us-mexico-borderjumps-in-may/4947245.html; and Joel Rose (2019), "Immigration System At The 'Breaking Point,' Homeland Security Official Warns." *NPR:* https://www.npr.org/2019/03/27/707297404/immigration-system-at-the-breaking-pointhomeland-security-official-warns.

1. Migration, Income, and Climate Change

Adverse impacts of climate change can have a negative impact on income, potentially influencing the decision to migrate. Examining the association between negative climate impacts and migration thus contributes to the extensive literature on the relationship between income and migration. Early, relatively simple models of migration argued that individuals move abroad in order to maximize a future income stream. From this perspective, migration occurs if the expected wage in a destination exceeds the expected wage in the home country plus the costs of moving (Sjaastad, 1962). According to this theory, a larger wage gap between home and destination countries would, all else equal, result in higher levels of migration. The simple wage-gap model runs counter to observed fact: as poorer countries develop, they go through a phase of increased migration until they reach a certain income level, after which migration begins to fall again. This idea of a "mobility transition" was hypothesized by Zelinsky (1971) and the relationship between average country income and emigration rates has since been described as an "inverted-U" or "migration hump" with numerous studies finding strong statistical support for this relationship.[5]

Increased migration in a country as average income initially rises has been attributed to multiple factors. At very low average wage rates, individuals who desire migration may face financial constraints that make migration impossible. As wages rise, the wage gap between the home and destination country may decrease but the ability to afford migration increases; the latter may carry more weight than the former for certain segments of the income distribution (Faini and Venturini, 1994; Hatton and Williamson, 1994, 1998). Other scholars look at broader transformations that occur as societies develop. Returns to education from migration may be

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[5] Clemens (2020) provides an overview of the literature; additional studies include Clark, Hatton and Williamson (2004); Clemens (2014); Dao et al. (2018); de Haas (2007); de Haas et al. (2019); Faini and Venturini (2010); Hatton and Williamson (2003); Massey et al. (1993); Skeldon (1997).

higher than returns in the domestic labor market; since education increases with development, the rise in development will be associated with an increase in emigration (Clemens, 2020; Hanson, 2010; Massey et al., 1993). Development can be accompanied by a demographic transition within a country, causing a sharp increase in young workers entering the labor market and resulting in emigration to ease domestic labor supply pressure (Hatton and Williamson, 1998; Hanson and McIntosh, 2010). Migration policies abroad may favor more highly skilled workers, creating increased opportunity for migration as development increases the skills of the workforce (Clemens, 2014). Increased trade linkages, transportation and communication networks, and knowledge gleaned from previous migrants can facilitate migration as a country develops (Massey et al., 1993; Martin and Taylor, 1996; Faini and Venturini, 2010).

Dao et al. (2018) examine the relative impact of individual (micro) and societal (macro) determinants of emigration, finding that for countries with an average income per capita between $1,500 and $6,000, migration is better explained by macro/societal drivers that do not change much in the short-run. While these theories are well-supported by country-level analyses, a drawback of societal-level explanations is that they do not explain well which people choose to migrate, or why the vast majority of people do not choose migration (Schewel, 2020). An important addition is the migrant aspirations-capabilities framework, which theorizes the impact of these factors on individual decisions to migrate (de Haas, 2021).

There are multiple reasons to expect that the relationship between migration and changing income depends on the direction of the income change: while an increase from average income $X to average income $Y may be associated with an increase in migration, it does not necessarily follow that a decline in income from $Y to $X will be associated with decreased migration (see Figure 1). One reason for this comes from a selection effect. As income increases, some people choose to migrate who previously could not afford migration,

but the vast majority of people who experience rising income do not migrate.[6] This creates a latent group of potential migrants: those who can afford migration but have not chosen migration as a response to rising average income. This group is revealed to have different preferences regarding migration than those who were similarly situated and chose migration. For this group, while a rise in income may not have induced migration, a decline in present and expected future welfare in their current location may cause them to reevaluate their decision to stay. Climate impacts that affect both current and expected future income would fall into the category of negative shocks that influence these decisions.
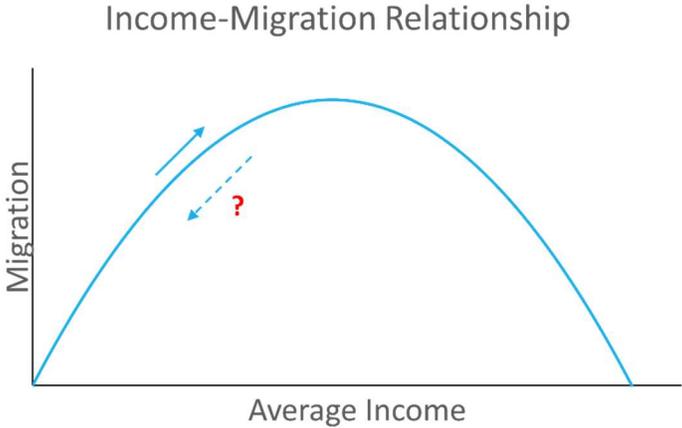

Figure 1: Relationship Between Migration and Income.

A second reason we might expect migration to increase in response to a negative income shock (such as from climate change) relates to the potential future impact on the ability to migrate. If individuals with some accumulated wealth experience income declines that they anticipate will persist, they may choose migration over depleting their assets in an attempt to maintain a certain standard of living with lower income; if they use up resources to maintain the status quo, they may be unable to finance migration in the future. Loss of income may also be associated with a feeling of relative deprivation from the reference point before the shock.

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[6] See International Organization for Migration *World Migration Report 2022,* available at https://worldmigrationreport.iom.int/wmr-2022-interactive/.

Individuals can become more risk-seeking when attempting to restore themselves to their previous level of welfare (Kahneman and Tversky, 1979). In some situations, consistent with what was seen in parts of Central America during the period of this study, people may face a choice between migration and severe food insecurity if they remain.

A final reason we might expect migration to increase in response to a negative climate shock (especially one that may be lasting or recurrent) stems directly from the theoretical expectations related to the wage-gap model. A key reason that the wage gap model fails to explain migration is that as a country develops and wages rise, other societal changes also occur. These changes often have opposite impacts on the likelihood of migration than the declining wage gap between home and destination countries that occurs as countries grow wealthier. Up until a certain income level (estimated by Clemens (2014) at $7000 per capita), these other factors more than offset the declining wage gap, causing more people to migrate. The simple wage-gap model would predict emigration demand well if all else were equal; it is the change of other factors as development occurs that causes the wage-gap model to lose much of its explanatory power at middle-income levels.

The explanatory power of the wage gap model is likely enhanced in the case of shocks. A negative income shock, such as decreasing productivity of cropland due to climate change, can occur without altering the slow-moving societal determinants of migration (at least in the short-term). The income shock occurs and the level of education, social networks abroad, and perhaps even accumulated wealth do not change as quickly. It is as if the wage gap between home and potential destination countries has widened and *all else has remained equal.* Given this, we would expect the predictions of the wage-gap model to hold: the decrease in expected income, holding many societal factors constant, should be associated with an increased desire for migration. Except in situations where migration becomes financially infeasible, we expect that negative income shocks will be associated with higher rates of migration.

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Climate shocks may create a desire to move, but not all movement results in emigration. Researchers at the World Bank predict large increases by 2050 in internal migration due to climate change (Rigaud et al., 2018). A recent report focusing on forecasting climate-related migration in Central America and Mexico concludes that "the climate crisis will drive more people to cities in Mexico and Central America."[7] While modeling is predicting internal migration, the extent to which climate-related income shocks lead to emigration, rather than internal migration, is likely a function of the viability and desirability of internal migration options. These will be associated with geographic size, since larger countries are more likely to have regions less affected by climate change, and with economic activity, as larger and wealthier economies will be better able to absorb internal migrants into other sectors of the economy. We thus expect that the relationship between negative climate impacts and international migration is larger when a country has a small geographic and/or economic size relative to the size of the climate impact.

Previous Findings Linking Climate Change and Migration

While the impacts of climate change on migration can provide insights regarding the role of changes in income for the general field of migration studies, there is also a growing body of work specifically focused on the links between climate change and migration. Studies note differences between slow-onset climate impacts, such as changes in precipitation patterns or sea-level rise, and sudden-onset impacts, such as storms or floods (Brown and McLeman, 2013; McLeman, 2018; Black, Kniveton and Schmidt-Verkerk, 2013). Sudden onset shocks are often associated with migration that is short both in duration and distance (Zickgraf, 2021; Kaczan and Orgill-Meyer, 2020). Longer-term impacts, such as the changes in precipitation patterns leading to recurrent droughts in Central America, are argued to have a multiplier effect, interacting with political, economic, or security drivers of migration and making it

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[7] Mayors' Migration Council, "Climate Migration in Mexican and Central American Cities," February 2022.

difficult to disentangle the impacts of climate change from those of other migration drivers (McLeman, 2014; Sofuoglu and Ay, 2020). Beine and Jeusette (2021) provide a recent review of empirical work on the links between climate change and migration, concluding that factors such as frequency of data on migration and measurement choices for both climate impacts and human mobility influence reported findings.

One element of confusion in the literature on the relationship between climate change and migration stems from the lack of agreement on what constitutes a "climate migrant." Migration from any country may occur for a multitude of reasons, as people face challenges due to safety, climate change, and lack of opportunity, or migrate for family unification. Even for individuals, migration is often a multi-faceted decision. People may leave their home due to climate change but choose international rather than internal migration based on other factors, or climate change may provide the final push toward migration for those who were already considering it for other reasons. This makes it difficult to disentangle the impact of climate change on migration. Surveys of migrants have attempted to fill this gap (Ruiz Soto et al., 2021), but people leaving for a combination of reasons may not mention climate change, even if it is a factor.

We extrapolate away from definitional issues and simply ask whether greater agricultural stress, which will only continue to be exacerbated by climate change, is associated with higher levels of family migration. The unusual availability of subnational data on place of birth for migrants, coupled with newly available measures of agricultural stress aggregated by subnational political boundaries, allows us to directly examine the relationship based on observed values, thus contributing to the body of work studying the links between climate change and migration.

2   Central America: Climate Change, Agricultural Stress, and Migration

Our empirical analysis focuses on migration to the United States of family units from El Salvador, Guatemala, Honduras, and Mexico for the period 2012-2019. The Central American

region is considered highly susceptible to the impacts of climate change, particularly those associated with increased intensity and frequency of storms, sea-level rise, and drought; these effects are expected to increase as climate change becomes more pronounced (Depsky and Pons, 2021). During the period of our study the Dry Corridor of Central America, which runs through portions of each of these countries, experienced multiple years of reduced precipitation, higher surface temperatures, and drought during key times in the crop cycle, with a severe impact on crop yields (Anderson et al., 2023; Nakamura et al., 2024). This created a sharp increase in acute food insecurity, particularly for the large number of subsistence farmers in affected areas.[8] Emergency appeals for food assistance note that farmers in some areas lost between sixty and eighty percent of their crops during at least one harvest.[9] In many areas, crops failed multiple times due to decreased rainfall. Organizations working in the region note that as crops fail (a negative income shock) people list emigration as a coping strategy.[10] The increase in temperatures and variation in precipitation caused by climate change also leads to the growth of coffee leaf rust which decimates coffee crops; scholars have found a more than doubling of migration in Guatemala after an outbreak of the fungus (Dupre et al., 2022).

Three of the countries we analyze – El Salvador, Guatemala, and Honduras – are relatively small in terms of geographic area, population, economic size, and average income. As Table 1 shows, Mexico is much larger on each of these dimensions. Average income in El Salvador, Honduras, and Guatemala is squarely within the range of incomes for countries that are projected to be on the upward portion of the inverted-U that constitutes the migration hump:

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[8] World Food Programme report, "Food Security and Emigration", August 2017.

[9] Food and Agricultural Organization report June 2016: http://www.fao.org/3/br092e/br092e.pdf.

[10] World Food Programme, "Erratic Weather Patterns in the Central American Dry Corridor Leave 1.4 Million People in Urgent Need of Food Assistance," April 25, 2019. Georgina Gustin, "Ravaged by Drought, a Honduran Village Faces a Choice: Pray for Rain or Migrate," *Inside Climate News,* July 8, 2019.

the relationship between income and migration would be expected to be positive, absent a shock.[11]

	Size (sq. km)	Population (2015)	GDP (Constant $Millions, 2015)	GDP/capita (Constant $, 2015)	People Experiencing Severe Food Insecurity (Average 2015-2019)
El Salvador	20,720	6,231,066	$23,438	$3,762	891,639
Guatemala	107,160	15,567,419	$62,186	$3,995	2,818,956
Honduras	111,890	9,294,505	$20,980	$2,257	1,367,233
Mexico	1,943,950	120,149,897	$1,213,294	$10,098	4,371,213

Table 1: Country Descriptive Statistics.
Source: World Bank, World Development Indicators, accessed April 4, 2024.

Food Insecurity Droughts in the region during the 2014-2015 and 2018-2019 growing seasons led to an increase in severe food insecurity. The Food and Agriculture Organization (FAO) began systematically collecting data on severe food insecurity in this region following the 2014 drought, with data available from 2015 onward. As shown in Figure 2, food insecurity in this period never fell below 13% in El Salvador, Guatemala, and Honduras and has reached more than 20% in the latter two countries in recent years. In Mexico, by contrast, food insecurity has remained under four percent of the population. Yet this masks a key fact: given the substantially larger size of Mexico's population, there were many more people experiencing severe food insecurity in Mexico each year than in other countries (the yearly average of people experiencing severe food insecurity for the period 2015-2019 is shown in the last column of Table 1). Yearly changes also show multiple years in which the increase in the number of people experiencing food insecurity was higher in Mexico than in other countries.[12]

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[11] The upward-sloping portion of the inverted-U, where income and migration have been found to have a positive relationship, ranges from approximately $500 to $7,000 (Clemens, 2014; Dao et al., 2018); while there is some variation in these estimates, all studies would include per-capita income at the level observed in El Salvador, Guatemala, and Honduras - but not Mexico - on the upward-sloping portion.

[12] According to the FAO, a household is classified as severely food insecure when at least one adult in the household reports that at times during the year they have been forced to reduce their quantity of food, have
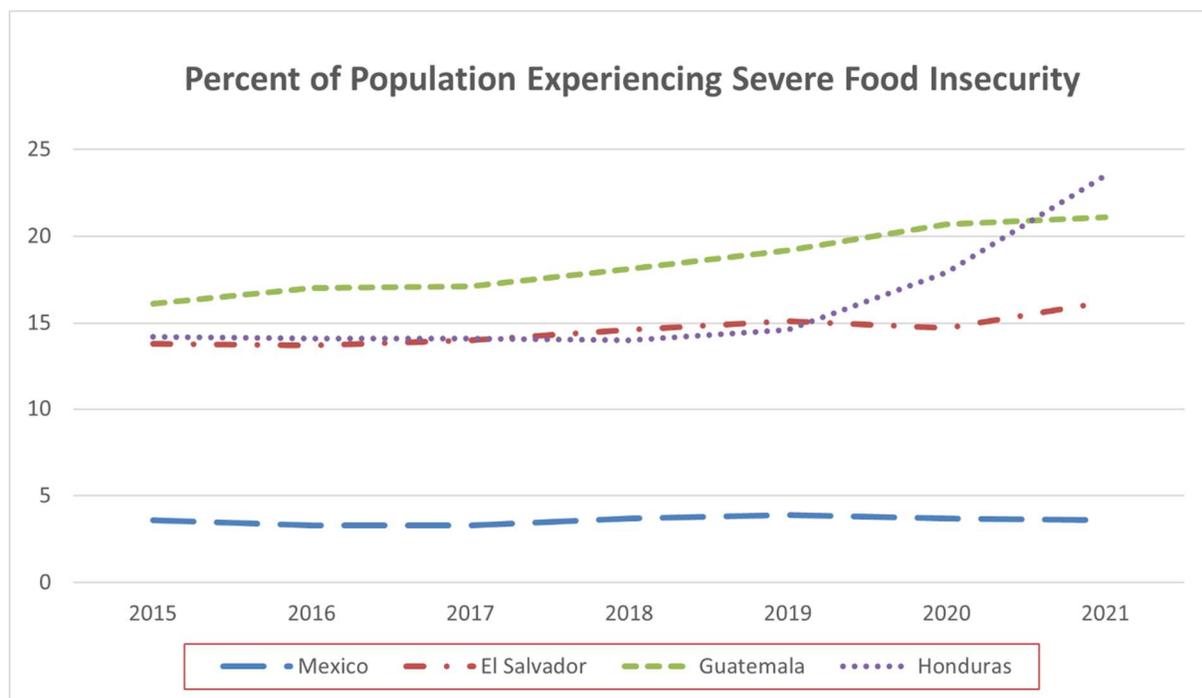
Figure 2: Percent of Population Experiencing Severe Food Insecurity.
Source: Food and Agriculture Organization, accessed through World Bank, World Development Indicators, April 3, 2024.

Family Migration The study is based on data for more than 800,000 apprehensions by United States Customs and Border Protection (CBP) of individuals born in El Salvador, Guatemala, Honduras, or Mexico and arriving as part of a family unit at the US southern border during the fiscal years 2012-2019. The U.S. defines a family unit as at least one adult and one minor child from the same family. The term "apprehension" includes those who voluntarily present themselves to border patrol, in some cases to seek asylum, as well as those who are apprehended between official points of entry. Data were obtained through a Freedom of Information Act request and identify city and department/state of birth for those

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skipped meals, have gone hungry, or have had to go for a whole day without eating because of a lack of money or other resources.

apprehended (department – equivalently "state" in Mexico – refers to the largest subnational political unit in each country).[13] United States fiscal years run from October through September (e.g., fiscal year 2019 ends in September 2019). In related work, Linke et al. (2023) use a subset of these data to study migration trends, excluding Mexico and ending before the large increases in migration in the second half of 2018 and 2019 in response to the 2018 drought;[14] Bermeo and Leblang (2021) and Bermeo, Leblang and Nagle Alverio (2022) examine similar trends individually in Honduras and Guatemala, respectively. To our knowledge, this is the first work to compare family migration across all four countries for this timeframe.

During this period of multiple droughts, both overall migration and migration of family units to the United States increased dramatically from El Salvador, Guatemala, and Honduras, but not from Mexico, as seen in Figure 3.[15] This represents a large demographic shift in the migrant population arriving: in 2012 migration of people in family units to the U.S. southern border made up less than three percent of all migration from El Salvador, Guatemala, and Honduras; after repeated droughts, the percent of migrants arriving as part of family units in 2019 increased to 63% from El Salvador, 70% from Guatemala, and 74% from Honduras, while remaining under 4% for Mexico. Figure 4 calculates the percent of each department/state population that arrived at the U.S. southern border as part of a family unit between 2012-2019. No state in Mexico sees even 0.2% of their population apprehended in family units at the U.S. border, while apprehension rates above 3% are observed for multiple departments in each of the other countries. These calculations represent an under-count of family out-migration from these departments; they only capture people who were counted at the U.S.

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[13] We thank Stephanie Leutert for providing us with access to these data. Where available for comparison, the yearly totals closely align with published country-level totals of family unit apprehensions, verifying that the data obtained through the FoIA request represent the universe of apprehensions in this category.

[14] Linke et al. (2023) include data on less than half of the family unit apprehensions analyzed here (323,579 apprehensions).

[15] We received raw data on family unit apprehensions that had a department of birth specified for more than 80% of apprehensions. When the department was not specified but city of birth was specified, we attempted to match the recorded city to a department. After this process we were able to assign more than 95% of apprehensions to a specific department.

border, while others may have migrated internally, chosen a different destination country, or

not been counted by U.S. officials when entering the country.
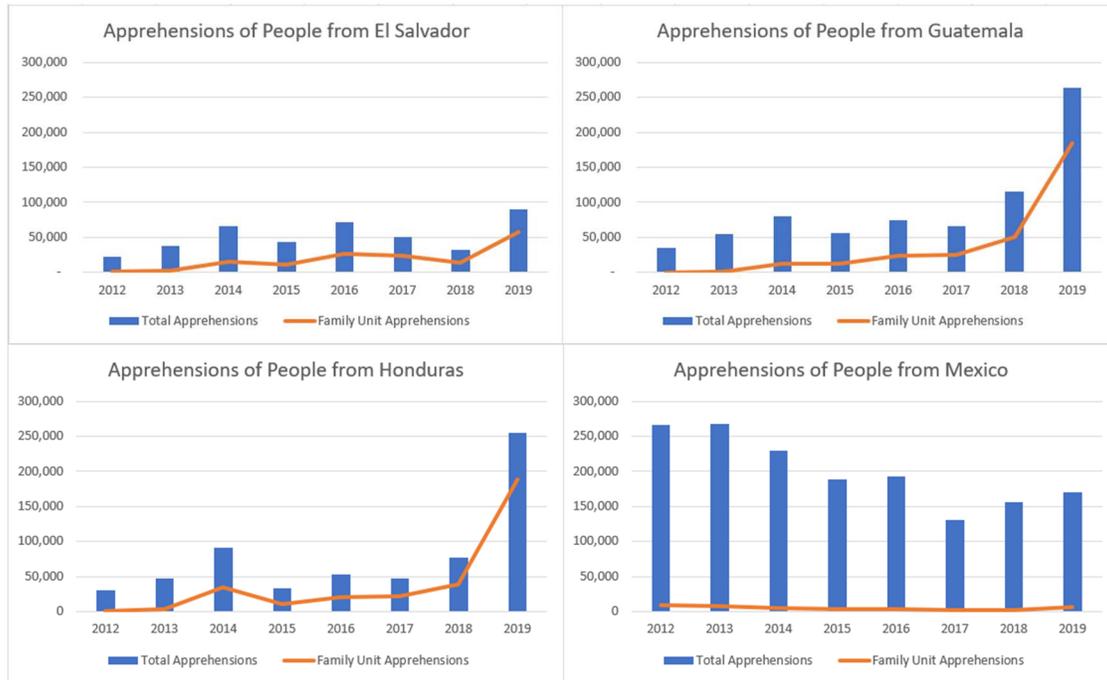
Figure 3: Apprehensions of People from El Salvador, Guatemala, Honduras, and Mexico by the United States Customs and Border Protection Agency. Data for total apprehensions are from the US Customs and Border Protection website. Data on family unit apprehensions are from a Freedom of Information Act request covering the years 2012-2019.

Figure 4: Percent of Department/State Population Arriving as Family Units at U.S. Southern Border between 2012-2019. Each mark represents a single department/state. Population is based on the most recent census value for the beginning of the period. Data on family unit migration is from a Freedom of Information Act request covering the years 2012-2019.

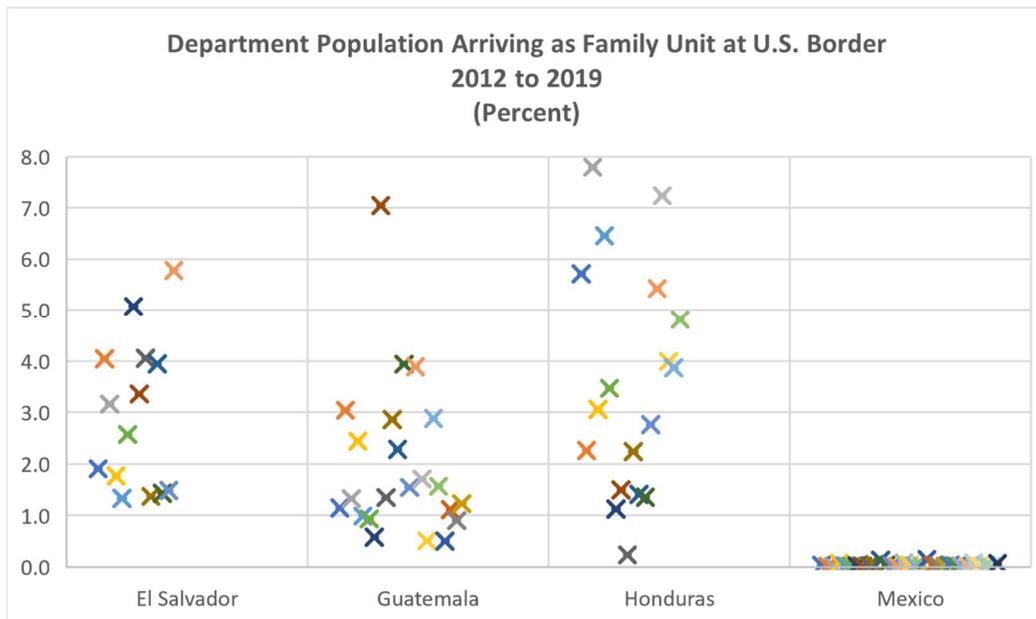One possibility for the lower levels of family unit migrants from Mexico is the relatively large geographic and economic size of Mexico compared to the other countries in this study, creating more opportunities for internal migration when climate shocks affect one part of the country. Data on internal migration are not readily available; we are not able to test this directly and previous studies provide only limited insights. A study evaluating household decisions in Oaxaca, one of the poorest and most drought-affected areas of Mexico, found significant evidence of internal migration as a substitute for international migration (Cohen and Ramirez Rios, 2016). Majlesi and Narciso (2018) examine Mexican municipalities exposed to increased trade competition from China and find that this leads to increases in internal migration to less affected municipalities, but not increased international migration. Studies examining the impact of agricultural stress on international migration from Mexico have found a positive effect, but these have been limited to examining single adults (usually male) and the magnitude of the impacts can be small (Fishman and Li 2022; Zhu et al. 2024).[16] The lack of increase in family migration from Mexico, even in states such as Oaxaca that experienced severe drought in this period, is consistent with the idea that internal migration may substitute for international migration in a larger country such as Mexico. Due to data constraints, we leave it to future research to more comprehensively examine the role of internal migration.

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[16] Fishman and Li (2022) focus their analysis on male heads of household. Zhu et al. (2024) find a significant but substantively small impact on individual migration from Mexico to the United States (they do not examine family migration) in areas that experience dry spells more than two standard deviations from normal during the growing season; they do not compare this to internal migration. The substantively small relationship they find for individual migration (probability of migration increases by 0.3% from "very dry" regions in their Table 1) is in keeping with the significant but substantively small relationship between agricultural stress and family migration in Mexico found in the results below.

3   Data and Variables

We analyze the relationship between family unit migration and agricultural stress for the region and separately for each country, controlling for other potential drivers of migration. The unit of analysis is the department-year (equivalently, the state-year for Mexico; hereafter referred to collectively as department-year). We aggregate the number of individuals apprehended as part of a family unit by department-year. All time-variant right-hand-side variables are lagged by one period. Table A1 in the Supplemental Appendix includes the summary statistics by department for all countries.

Migrant Apprehension Measures In keeping with various measures used in the literature on migration, we estimate models using two separate measures of apprehensions, both based on the sum of family unit apprehensions by department-year. We use the natural log of the apprehension rate, calculated as apprehensions for a department in year *t* per 100,000 population at the beginning of the period.[17] With this measure, it is possible for departments with a small population to have a high apprehension rate and still have low overall numbers of migrants. Alternatively, we use the natural log of total apprehensions from a department in year *t*, without controlling for population. Total apprehensions may be the more meaningful measure for destination countries, making it useful to know if changes in migration are quantitatively important for receiving areas.[18]

Agricultural Stress Variables We measure climatic impacts on agriculture using the Agricultural Stress Index (ASI) from the Food and Agriculture Organization (FAO), available by

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[17] For calculating apprehension rates the census year closest to 2012, the first year of our analysis, is used to obtain a measure of department population.

[18] Although zeros on the dependent variable are often a concern for dyadic migration analysis, that is not the case here where we are measuring total yearly emigration from a department to the U.S. There are only seven observations with zero values, all but one in 2012, and their value is changed to one before taking the natural log.

department in ten-day increments.[19] The measure represents the percent of cropland in a department that is experiencing drought. This measure is more nuanced in detecting crop-specific stress than the often-used Normalized Difference Vegetation Index (NDVI) Anomaly measure. NDVI provides a measure of overall vegetative health in an area. It is calculated from satellite data using the difference between near-infrared and red light with values ranging from -1 to 1 and higher positive values representing more dense, green vegetation.[20] The NDVI Anomaly calculates the difference between the NDVI value observed for a given period (e.g., a specific day or month of the year) and the long-run average of NDVI for that period. The Agricultural Stress Index builds on the NDVI with a few key modifications, including the incorporation of crop-specific coefficients that reflect a crop's water sensitivity at different phenology stages during the growing season. It then calculates the percent of arable land in a department that is affected by drought during the crop season based on this Weighted Mean Vegetation Health Index (wVHI).[21] We expect that the focus of the ASI on specific crops and growing seasons makes it a better indicator of the type of stress likely to be associated with migration decisions. To examine differences across these measures, after our main analysis we present results of models using the NDVI Anomaly measure.

In measuring the impact of stress on agricultural output, extremes often have a larger impact on crop yield than averages. For our first measure of agricultural stress, we take an average for each department-year-month and we use in our analysis the value for the month with the maximum level of stress for each department-year. We refer to this as *Maximum ASI*. The timing of agricultural stress during the growing season is also important. For the areas in this study, a critical time has been shown to be the *canícula,* a recurring dry period during July and August. A dry spell that is longer or drier than average can affect both the harvest of the

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[19] Available at http://www.fao.org/giews/earthobservation/country/.

[20] See https://www.usgs.gov/landsat-missions/landsat-normalized-difference-vegetation-index.

[21] For exact calculations of ASI and its relationship to NDVI see
https://www.fao.org/giews/earthobservation/faq.jsp?lang=en.

first crop and the planting of the second crop, having an outsized negative impact on total agricultural output (and therefore income and food security) across both planting seasons; research has linked the impact of recurrent drought in the 2015-2019 period to rainfall deficits during this critical period (Anderson et al., 2023). For this reason, our second measure of agricultural stress uses the maximum level of stress in either July or August, which we call *Maximum ASI-Canícula*. We log these measures and lag them by one period.[22]

Control Variables Previous research has linked migration generally and from Central America to levels of violence and wealth (Clemens, 2017). We control for the *Homicide Rate* per 100,000 people for each department-year; this variable is logged and lagged.[23] Multiple studies have argued that higher levels of income or wealth increase the ability to finance a migration journey (Faini and Venturini, 1994; Hatton and Williamson, 1994, 1998). We include the mean international *Wealth Index* from Global Data Lab Area Database 4.0 as a proxy for average household resources; this is based on household surveys and is not available annually. The value for the year closest to the beginning of the period of analysis is used.[24] Development theory and recent studies suggest that rural migrants often move to urban areas within their own countries, including in the aftermath of climate shocks (e.g., Selod and Shilpi, 2021). Recent evidence based on surveys of migrants from rural Guatemala suggests that they are less likely to have migrated internally before choosing to migrate internationally (Ruiz Soto et al., 2021). To capture potential differences in rural and urban approaches to migration, we include a measure of *Rural Ratio,* the ratio of rural population to total population, for each

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[22] For observations with maximum agricultural stress value of zero we add .01 to this value before taking the natural log; this is smaller than the minimum positive recorded agricultural stress value of 0.027 (the variable is never negative by construction).

[23] Data on homicides are from official government statistics for each country: El Salvador and Guatemala, original data shared by Stephanie Leutert; Honduras, the Secretaria de Seguridad Policia Nacional; Mexico, https://secretariadoejecutivo.gob.mx//docs/pdfs/tasas%20por%20cada%20100%20mil%20habitantes/Tasas122017.pdf.

[24] Available at https://globaldatalab.org. This measure is available by department for Honduras and Mexico (2015 measure; accessed March 2024) and by region (which includes multiple departments) for El Salvador (2012 measure; accessed February 2024) and Guatemala (2012 measure; accessed March 2022).

department.[25] We include a year trend variable to pick up common trends over time, such as those that might occur as new migrants follow pathways traveled by previous migrants (Massey et al., 1993).

4   Results

Our main models estimate versions of the following equation, using a random effects specification with robust standard errors clustered on department, with x and t indexing department and year, respectively, and γ_x and $\epsilon_{x,t}$ representing random effects and the error term:

$$Ln(ApprehensionRate)_{x,t} = \beta_0 + \beta_1 Ln(MaximumASI)_{x,t-1} + \beta_2 RuralRatio_x +$$

$$\beta_3 Ln(HomicideRate)_{x,t-1} + \beta_4 WealthIndex_x + \beta_5 Year + \gamma_x + \epsilon_{x,t}$$

We estimate variations of this equation that substitute agricultural stress during the *canícula* (annual dry period) and/or use the natural log of total apprehensions as the dependent variable in place of the apprehension rate. Results are presented for the region and for each individual country. Because some of our control variables are not available as a time series, our main models do not include department fixed effects. Instead, we include these in a separate set of models to test robustness (see Table A4 in the Supplemental Appendix) and conclusions regarding the relationship between agricultural stress and migration do not change when department fixed effects are included. We do not include year fixed effects as these would mask the impact of yearly variations in agricultural stress.

Regional Results

Table 2 presents regional results pooled across El Salvador, Guatemala, Honduras, and Mexico. The unit of analysis is the department-year. The dependent variable for the first two columns of results is the natural log of the apprehension rate per 100,000 population; the

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[25] From https://www.citypopulation.de/ for El Salvador, Guatemala, and Honduras; from https://globaldatalab.org for Mexico; this is based on census data and not available annually.

dependent variable for the remaining two columns is the natural log of the total number of apprehensions. Models show coefficients for the maximum monthly level of agricultural stress observed in a department in a year *(Maximum ASI),* or for the maximum monthly level of agricultural stress during the *canícula* period *(Maximum ASI-Canícula).* Country indicator variables are included, with Mexico as the omitted category. Table A2 in the Supplemental Appendix includes these same models without control variables and the results regarding the coefficients on agricultural stress variables are substantively similar.

Across all models, the coefficient on the measure of agricultural stress demonstrates a positive and significant relationship between the maximum level of agricultural stress experienced in a department and apprehensions (measured as either a rate or level) at the U.S. border the following year. For both the apprehension rate and the level of apprehensions, the coefficient on agricultural stress is higher when the measure is confined to the *canícula* period *(Maximum ASI-Canícula).* The percent of a department's population living in rural areas *(Rural Population Ratio)* is positively correlated with the apprehension rate, but not the total number of apprehensions, reflecting the lower level of population in predominately rural areas. People are more likely to migrate from areas with a higher wealth index, in keeping with previous findings that access to resources increases the ability to migrate. The homicide rate in a department does not appear to be associated with higher levels of migrant apprehensions, a finding we discuss further in relation to the individual country results. The coefficients on the country indicator variables are each positive and significant, reflecting the lower number of family-unit migrants from Mexico (the omitted category) compared to the other countries.

	Apprehension Rate		Apprehensions	
Migrant Apprehensions and Agricultural Stress				
Ln Maximum ASI (lag)	0.119***		0.147***	
	(0.00)		(0.00)	
Ln Maximum ASI-*Canícula* (lag)		0.182***		0.209***
		(0.00)		(0.00)
Rural Population Ratio	2.725***	3.019***	1.657	1.967
	(0.00)	(0.00)	(0.19)	(0.13)
Ln Homicide Rate (lag)	-0.165	-0.217	-0.428**	-0.484***
	(0.22)	(0.10)	(0.01)	(0.00)
Wealth Index	0.045**	0.054**	0.063*	0.073**
	(0.03)	(0.02)	(0.06)	(0.04)
Year	0.389***	0.383***	0.386***	0.380***
	(0.00)	(0.00)	(0.00)	(0.00)
El Salvador	4.465***	4.783***	3.225***	3.567***
	(0.00)	(0.00)	(0.00)	(0.00)
Guatemala	3.300***	3.431***	2.341***	2.463***
	(0.00)	(0.00)	(0.00)	(0.00)
Honduras	4.017***	4.156***	3.068***	3.207***
	(0.00)	(0.00)	(0.00)	(0.00)
Constant	-787.992***	-776.029***	-777.949***	-765.730***
	(0.00)	(0.00)	(0.00)	(0.00)
Observations	672	672	672	672

Table 2: **Migrant Apprehensions and Agricultural Stress in El Salvador, Guatemala, Honduras, and Mexico, 2012-2019.** *Combines data at the department/state level for all four countries. Unit of analysis is department-year. Dependent variable is the natural log of the apprehension rate per 100,000 population (models 1 and 2) or the natural log of the total number of apprehensions (models 3 and 4). Country indicator variables included (Mexico is omitted category). Random effects models with standard errors clustered on department; p-values in parentheses. *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.*

Results by Country

While the regional results presented in Table 2 provide support for the association between increased agricultural stress and migrant apprehensions, these may hide important differences across countries. We perform multiple analyses for the individual countries, with full results provided in Table 3 and Table 4, and marginal effects presented in Table 5. Table A3 in the Supplemental Appendix shows the coefficients on agricultural stress for all models when control variables are excluded from the analysis.

Table 3 shows results with the dependent variable measuring the apprehension rate; the top portion of the table includes the measure of maximum agricultural monthly stress for the year *(Maximum ASI)* while the bottom portion confines the measure of agricultural stress to

the *canícula* period *(Maximum ASI-Canícula)*. The coefficient on *Maximum ASI* is positive for all countries, although not significant at conventional levels for Honduras and Mexico (p-values in parentheses). When confining the measure of agricultural stress to the *canícula* period (bottom portion of Table 3), the coefficient on *Maximum ASI-Canícula* is significant and positive for all countries, and the magnitude more than doubles for El Salvador and Honduras compared to the coefficient in the first set of models. This aligns with expectations that agricultural stress during this key period in the crop cycle leads to higher levels of income loss and food insecurity and, therefore, is associated with higher rates of migration.

The top portion of Table 5 shows the marginal effect on the apprehension rate of changing agricultural stress from its value at the 25th percentile to its value at the 75th percentile during the *canícula.* These are substantively important changes: the apprehension rate per 100,000 residents increases from 101 to 219 in El Salvador (116% increase), from 34 to 58 in Guatemala (70% increase) and from 86 to 137 in Honduras (59% increase). Mexico, on the other hand, starts from a very low level of family unit apprehensions and increases by only 0.3 per 100,000 population (11% increase).

Apprehension Rate and Maximum Monthly Agricultural Stress			
	El Salvador	Guatemala	Honduras	Mexico
Ln Maximum ASI (lag)	0.072**	0.092***	0.047	0.042
	(0.02)	(0.00)	(0.18)	(0.23)
Rural Population Ratio	1.703***	3.738***	2.395***	2.823**
	(0.00)	(0.00)	(0.01)	(0.03)
Ln Homicide Rate (lag)	0.087	-0.015	0.392	0.305***
	(0.48)	(0.91)	(0.19)	(0.02)
Wealth Index	-0.021	0.061*	0.085***	-0.019
	(0.16)	(0.05)	(0.00)	(0.45)
Year	0.531***	0.818***	0.750***	-0.167***
	(0.00)	(0.00)	(0.00)	(0.00)
Constant	-1064.867***	-1651.156***	-1515.334***	337.486***
	(0.00)	(0.00)	(0.00)	(0.00)
Observations	112	176	136	248
Apprehension Rate and Maximum Monthly Agricultural Stress *During Canícula*			
	El Salvador	Guatemala	Honduras	Mexico
Ln Maximum ASI-*Canícula* (lag)	0.148***	0.089***	0.147***	0.045*
	(0.00)	(0.00)	(0.00)	(0.09)
Rural Population Ratio	1.941***	3.858***	3.020***	2.798**
	(0.00)	(0.00)	(0.00)	(0.04)
Ln Homicide Rate (lag)	-0.004	-0.003	0.394	0.287***
	(0.97)	(0.99)	(0.12)	(0.01)
Wealth Index	-0.017	0.064**	0.097***	-0.018
	(0.29)	(0.04)	(0.00)	(0.46)
Year	0.524***	0.815***	0.720***	-0.163***
	(0.00)	(0.00)	(0.00)	(0.00)
Constant	-1049.838***	-1643.914***	-1454.873***	329.582***
	(0.00)	(0.00)	(0.00)	(0.00)
Observations	112	176	136	248

Table 3: Migrant Apprehension Rate by Department, 2012-2019. *Unit of analysis is department-year. Dependent variable is the natural log of the apprehension rate per 100,000 population. Random effects models with standard errors clustered on department; p-values in parentheses. *p < 0.10; **p < 0.05; ***p < 0.01.*

Turning to the overall number of migrant apprehensions, results are presented in Table 4. The top portion of the table contains results using the yearly maximum measure of the ASI, while the bottom half uses the measure associated with the *canícula* period. Once again, we observe that the coefficient on agricultural stress is positive across all models, and significant for all countries during the *canícula.* The coefficient on agricultural stress again more than doubles in magnitude for El Salvador and Honduras when the measure is confined to the *canícula.* It is worth noting that these results do not control for population; agricultural stress is associated with increased migrant apprehensions at the U.S. border the following year, even without controlling for the population size of the department.[26] Table A4 in the Supplemental Appendix includes models analogous to Table 4, with the addition of department fixed effects; no meaningful changes in interpretation result from the inclusion of department fixed effects.

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[26] These results hold if a measure of population is included.

Apprehensions and Maximum Monthly Agricultural Stress				
	El Salvador	Guatemala	Honduras	Mexico
Ln Maximum ASI (lag)	0.072**	0.113***	0.058	0.044
	(0.03)	(0.00)	(0.10)	(0.19)
Rural Population Ratio	-1.779**	4.993***	1.032	1.587
	(0.01)	(0.00)	(0.51)	(0.47)
Ln Homicide Rate (lag)	0.053	-0.094	0.551**	0.273*
	(0.68)	(0.61)	(0.04)	(0.05)
Wealth Index	-0.019	0.116***	0.110***	-0.046
	(0.28)	(0.00)	(0.00)	(0.25)
Year	0.532***	0.812***	0.761***	-0.165***
	(0.00)	(0.00)	(0.00)	(0.00)
Constant	-1064.265***	-1639.528***	-1537.616***	339.656***
	(0.00)	(0.00)	(0.00)	(0.00)
Observations	112	176	136	248
Apprehensions and Maximum Monthly Agricultural Stress *During Canícula*				
	El Salvador	Guatemala	Honduras	Mexico
Ln Maximum ASI-Canícula (lag)	0.150***	0.110***	0.150***	0.052**
	(0.00)	(0.00)	(0.00)	(0.04)
Rural Population Ratio	-1.533**	5.138***	1.643	1.554
	(0.01)	(0.00)	(0.30)	(0.48)
Ln Homicide Rate (lag)	-0.035	-0.081	0.549**	0.241*
	(0.75)	(0.67)	(0.01)	(0.07)
Wealth Index	-0.014	0.120***	0.121***	-0.046
	(0.43)	(0.00)	(0.00)	(0.25)
Year	0.524***	0.807***	0.731***	-0.160***
	(0.00)	(0.00)	(0.00)	(0.00)
Constant	-1048.376***	-1630.253***	-1477.787***	329.020***
	(0.00)	(0.00)	(0.00)	(0.00)
Observations	112	176	136	248

Table 4: Migrant Apprehensions by Department, 2012-2019. *Unit of analysis is department-year. Dependent variable is the natural log of apprehensions. Random effects models with standard errors clustered on department; p-values in parentheses. *p < 0.10; **p < 0.05; ***p < 0.01.*

Once again, the marginal effect calculations for agricultural stress during the *canícula* in the bottom portion of Table 5 show a substantively important relationship with apprehensions of migrants in family units at the U.S. border. Changing agricultural stress from its value at the 25th percentile to its value at the 75th percentile during the *canícula* is associated with 410

additional migrants the following year from a department in El Salvador (119% increase), with

comparable numbers of 151 additional migrants from a department in Guatemala (92%

increase) and 200 additional migrants from a department in Honduras (60% increase).

Department Apprehension Rate				
Agricultural Stress During Canícula	El Salvador	Guatemala	Honduras	Mexico
25th Percentile	101.1	34.0	86.3	2.5
75th Percentile	218.5	57.6	137.1	2.8
Percent Increase	116%	70%	59%	11%
Department Apprehensions				
Agricultural Stress During Canícula	El Salvador	Guatemala	Honduras	Mexico
25th Percentile	345.1	165	331.3	70.0
75th Percentile	755.0	316	531.4	78.9
Percent Increase	119%	92%	60%	13%

Table 5: Marginal Effects of Increase in Agricultural Stress on Migrant Apprehensions. The top portion calculates marginal effects based on models in Table 3 and the bottom portion calculates marginal effects based on models in Table 4.

In Mexico, the change in migrants is 9 (13%), again showing a sizably different magnitude

in the relationship between agricultural stress and migration from Mexico to the United States

than the relationship observed for the smaller countries. This occurs despite the fact that the

Dry Corridor of Central America extends into southern Mexico and, for each year in this period

for which there are data on severe food insecurity from the FAO for these countries (2015-

2019), the number of people in Mexico suffering from severe food insecurity outnumbers that

of any of the other countries by more than 1 million people. Multiple departments in Mexico

register significant amounts of agricultural stress and Mexico, alone among these countries,

shares a border with the United States. Yet Mexico did not experience the same spike in

migration of family units to the U.S. that was observed for the other countries.

Control variables, where significant, generally have the expected sign. Increases in the

homicide rate are associated with increased apprehensions in some models. We do not

interpret lack of significance on the homicide coefficient in other models as a lack of importance of violence in determining migration decisions. Instead, violence levels may not vary enough over this short time horizon to have differential impacts on migration decisions. There is some evidence that wealthier regions send more migrants, which is consistent with previous findings that access to resources is important in migration decisions; we do not find any evidence of a nonlinear relationship between wealth and family migration (results not shown). The apprehension rate is significantly higher in departments with high rural ratios, but only in the case of Guatemala is this seen for total apprehension numbers. The fact that rural areas send more family migrants from Guatemala even without controlling for population corroborates the work of international organizations that have documented significant hardship and food insecurity in rural Guatemala, particularly among indigenous communities (International Fund for Agricultural Development, 2012; USAID, 2018).

4.1   Alternative Stress Measure: NDVI Anomaly

As mentioned in the previous section, deviations from long-term average values on the Normalized Difference Vegetation Index (referred to as the NDVI Anomaly measure) are often used to measure deviations in vegetative health. To examine the relationship between NDVI Anomaly and migrant apprehension rates, we first calculate NDVI deviation as monthly NDVI (averaged across 3 dekads per month) minus the long-term average NDVI for the same month (averaged across 3 dekads).[27] Since we are interested primarily in drought, which involves negative deviations from long-term average, we recode positive deviations to be 0 and invert the index so that higher values are associated with more stress (to facilitate comparison with ASI). We then find the maximum negative monthly deviation for either the entire year or for

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[27] Data were downloaded from http://www.fao.org/giews/earthobservation/country/ and are available at the department level by dekad; accessed June 2024.

the *canícula* period. We replace the ASI measures from Table 3 with this NDVI measure and

present the coefficients and p-values on these measures for each country in Table 6.[28]

Department Apprehension Rate				
	El Salvador	Guatemala	Honduras	Mexico
NDVI Maximum Negative Monthly Anomaly	11.267***	-0.702	3.165*	1.436
	(0.00)	(0.80)	(0.06)	(0.20)
NDVI Maximum Negative *Canícula* Anomaly	14.858***	-3.305	4.582**	-0.154
	(0.00)	(0.25)	(0.03)	(0.95)

Table 6: Coefficient on NDVI Anomaly for models analogous to Table 3. *Unit of analysis is department-year. Dependent variable is the natural log of the apprehension rate per 100,000 population. Random effects models with standard errors clustered on department; p-values in parentheses. *p < 0.10; **p < 0.05; ***p < 0.01. Full results available in Supplemental Appendix.*

The NDVI variable has a positive and significant relationship with apprehension rates in El Salvador and Honduras, and the coefficients are larger when the maximum deviation is confined to the *canícula* period. This is qualitatively similar to the results using the ASI measure. The coefficient on the NDVI variable is not significant in either model for Guatemala or Mexico. Comparing results from the models including the ASI measure to those including the NDVI Anomaly suggest that the more targeted ASI measure is more closely associated with migration, at least for some countries.

5   Conclusion

The results of our analysis support the conclusion that climate-related agricultural stress is associated with substantial increased emigration to the United States of family units from El Salvador, Guatemala, and Honduras, geographically small countries in Central America that experienced drought over significant portions of their agricultural land during the 2015-

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[28] Full results available in the online appendix, Table A5. Similar conclusions follow if the dependent variable is apprehensions instead of the apprehension rate.

2019 period. The substantively large increase in family migration to the United States is not observed for Mexico, despite the fact that Mexico borders the U.S., has well-established migration pathways with the U.S., and had a larger number of people experiencing severe food insecurity during this period. This may be attributable to differences in size and variability within countries: the proportion of Mexico and of the Mexican population experiencing these climate impacts was much smaller than in the Central American countries, and the ability to absorb internal migrants (both spatially and economically) was higher in Mexico, due to its larger land mass and economy.

These findings have implications for theories linking income and migration, and highlight the importance of examining subnational patterns and differences across countries. When a change in income is the result of a negative shock, such as those associated with the adverse effects of climate change, decreases in income can lead to increases in migration. This may be masked by long-run studies examining country averages. For each of the countries in this study, average GDP/capita increased during the time period studied,[29] suggesting that these countries fit the general pattern of rising incomes leading to more migration. Subnational analysis reveals a different trend: areas most affected by agricultural stress – where people experienced decreases in income and a rise in severe food insecurity – are the areas driving recent family migration to the United States.

Mexico did not see the same increase in family unit migration during the period examined, perhaps in part because it is better able to absorb migrants internally. If Mexico experiences prolonged climate shocks that affect larger portions of the country, as may be occurring now with the growing water crisis that is geographically widespread, internal migration may be less viable. The steep rise in family unit migration from Mexico to more than 280,000 people in 2024 – more than seven times the number in 2022 – corresponds with a classification of "extreme" or "exceptional" drought for multiple Mexican states since the

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[29] Data from World Bank, *World Development Indicators.*

summer of 2023.[30] Subnational data are not readily available to analyze these trends, but the rise in family migration associated with widespread drought warrants further study.

The results of this analysis advance the study of the links between climate change and migration. For the countries and time period in this study, agricultural stress exacerbated by climate change was associated with significant increases in international migration, which were mitigated when a country had the capacity both geographically and economically to absorb internal migrants. Building measures of absorptive capacity into studies and forecasts of the links between climate change and migration will improve understanding of the relative likelihood of internal versus external migration in response to climate shocks. These findings also highlight what could be an important difference in demographics between climate-related migration and previous migrants: people experiencing repeated climate stress that affects their livelihood and well-being are migrating with their families from Central America, an important demographic shift compared to previous migrants from the region. To the extent that models and forecasts are based on data for previous migration, they may fail to capture these changes. The analysis also highlights the importance of using location-specific insights when compiling measures from geospatial data to study human decision-making: in the results above, the relationship between agricultural stress and migration is both stronger and larger in some countries when the stress happens during the critical *canícula* time.

There are several implications for policy. Studies have questioned the efficacy of foreign aid at decreasing migration, since higher levels of development can lead to increases in migration (Clemens and Postel, 2018). Our findings suggest a different possible relationship: if negative income shocks related to climate change increase migration, and if foreign aid can limit or reverse the adverse consequences of these shocks, then this could decrease migration flows. This is significant as less than two percent of tracked climate finance is allocated for

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[30] See "Drought Parches Mexico" at https://earthobservatory.nasa.gov/images/152908/drought-parches-mexico.

smallholder farmers (Chiriac and Naran, 2020), such as those migrating from Central America, yet there are more than 500 million smallholder farmers worldwide (Lowder, Sanchez and Bertini, 2021) and climate projections show that this population will disproportionately experience the negative effects of climate change (Bezner Kerr et al., 2022). In the case of aid from the United States to Central America, less than eight percent of aid targets the agriculture sector and this has been falling, despite claims by multiple U.S. policymakers of both parties that aid should be used to decrease migration.[31] The conclusions here also reinforce recent calls for better understanding the links between agricultural shocks, on-farm adaptation, and migration decisions (Cattaneo et al., 2019; Mukherjee and Fransen, 2024).

The results presented point to the importance of having better data on migration, both internal and international, in order to understand this multifaceted issue. The subnational data used above on place of birth for migrants are seldom available from sending or receiving governments. The need for higher quality and more frequent data is becoming increasingly urgent as policymakers scramble to respond to a changing climate. The results also show that more precise measures linking climate-related stress to crop production, such as the ASI, may be more useful than less targeted measures in determining links between climate-related agricultural impacts and outcomes such as migration. As more and better data on migration and climate impacts become available, preferably at subnational levels, findings are likely to become more nuanced and precise, forecasting ability will improve, and policymakers will be better able to tailor their adaptation response to the growing impact of climate change on human mobility.

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[31] Based on data for Official Development Assistance (ODA) from the United States to Central America, accessed through stats.oecd.org March 2024.

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