Cross-Border Migration and Climate*

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Abstract

Our work is positioned at the intersection of migration and climate change—two key forces shaping the economic outlook of many countries. The analysis explores: (i) the relative importance of origin-country vs destination-country factors in explaining migration patterns; (ii) importance of climate disasters as driver of cross-border migration; and (iii) the importance of climate-driven migration on the overall impact of climate on macroeconomic outcomes. It arrives at the following main findings. First, origin-country shocks explain large portion of migration inflows into AEs and outflows from EMDEs, having gained prominence for some regions recently, such as LAC. Second, climate disasters explain origin-country migration shocks, albeit less overall migration outflows; while they lead to migration of both genders, they seem relatively more important for males out of LICs. Third, important portion of climate's overall impact on economic outcomes—especially agricultural GDP, remittances, and inequality—is captured via climate-driven migration.

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1 Introduction

Cross-border migration and climate change are two key forces shaping the economic outlook of many countries across the world. Both of them are complex phenomena that keep increasing their relevance for economic, social, and political outcomes. For instance, migration flows respond to a multitude of domestic as well as external factors, including economic and social developments in home countries, differences in welfare relative to potential migration destinations, bouts of instability, conflicts, and other shocks. Overall, some 184 million people live outside of their country of nationality, constituting about 2.3 percent of the global population (*World Migration Report*, 2022). Climate events affect the habitability and income productivity of various countries, and–going forward–are also expected to compound the impact of the other drivers of human mobility and migration, such as poverty, demographics, or political instability. In essence, many people migrate because of a combination of factors, and climate events often amplify the preexisting patterns of movements—circular, seasonal, and or rural-to-urban migration.

Climate change seems to be accelerating internal migration both via sudden- and slow-onset impacts (*World Migration Report*, 2022). While climate change has been found as important driver of internal migration within countries' national borders in many parts of the world (see for example *World Development Report* (2023); Clement et al. (2021)), its direct impact on cross-border migration can be important too. This paper aims to shed light on the impact of climate disasters on cross-border migration and the macro-economic linkages of climate-driven migration. Its focus is on three distinct, though interrelated questions: (i) What is the relative importance of origin-country vs destination-country vs global factors in driving migration? (ii) What is the role of climate in explaining cross-border migration? and (iii) What is the impact of climate change on macroeconomic outcomes through migration in the long run?

The analysis reaches at a set of relevant conclusions. First, the relative importance of factors driving migration outflows differs substantially between EMDEs and advanced economies: while all three shocks–origin-country, and destination-country, and global–contribute to outflows from EMDEs, only the global shocks seem important for advanced economies. Second, climate disasters are found to explain origin-country component of migration outflows (albeit less overall migration outflows), lead to migration of both genders (though are relatively more important for males), and are especially important for migration outflows from LICs and EMEs. Third, an important portion of climate's overall impact on economic outcomes is actually captured via climate-driven migration, which is associated with lower (agricultural) output and higher remittance inflows.

The rest of this paper is organized as follows. Section 2 provides a brief literature context, and Section 3 describes the data used. Section 4 provides a decomposition of the migration outflows. The core part of the empirical analysis, exploring the impact of climate disasters on cross-border migration and economic outcomes, is presented in Section 5. Section 6 quantifies the impact of adaptation policies using the DIGNAD general equilibrium model. Finally, Section 7 provides some concluding remarks.

2 Literature Context

This paper is related to and contributes to three interrelated, albeit different, strands of the literature. First, this paper helps better understand migration patterns by providing a novel and simple decomposition of cross-border bilateral migration outflows into origin-country, destination-country, and global shocks. In this context, it contributes to the extensive literature on the fundamental drivers of migration (for instance, see Carare et al., 2023; Kaczan and Orgill-Meyer, 2020) through the application of the innovative decomposition method by Amiti and Weinstein (2018) to the migration context.

Second, the paper contributes to the literature that looks into climate and cross-border migration via local case studies, descriptive trends and forecasts (Piguet and Laczko, 2014; Black et al., 2011; Coniglio and Pesce, 2015; Burzyński et al., 2021; *World Migration Report*, 2022; Kaczan and Orgill-Meyer, 2020). Beyond estimating the impact of different types of climate events and risks on overall migration flows, it also sheds light on the impact of climate on origin-country and destination-country-induced portions of overall migration flows.

Finally, this paper is related to the extensive literature exploring the impact of climate on macroeconomic outcomes, growth, productivity and reallocation (see, for instance, Bustos et al., 2021, International Monetary Fund, 2021, Bustos et al., 2021; Fernández Corugedo et al., 2023a; Fernández Corugedo et al., 2023b). While most of the studies in this strand focus on the short-term impact of climate events on migration, we take a somewhat longer-term perspective, focusing our analysis on five-year windows. Our contribution to this strand is twofold. On the empirical side, we extract the impact of climate-induced migration on macroeconomic outcomes. On the modeling side, we extend general equilibrium DIGNAD model to allow for endogenous climate-driven migration, analyze long-run responses, and quantify the effect of potential climate adaptation policies through public investment in resilient infrastructure.

3 Data

This paper relies on a set of datasets to explore the link between cross-border migration and climate. The primary data source on cross-border migration is the United Nations Global Migration database. Our main data source on climate is the Emergency Events database (EM-DAT). We complement these datasets using data provided in Sautner et al. (2023), the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), and the World Bank Development Indicators (WBDI).

The United Nations Global Migration database contains comprehensive information on cross-border migration stocks. This dataset provides the bilateral migration stocks in 5-year windows for the period between 1990 to 2020. Data is available for 238 countries and territories. Additionally, the database provides a breakdown of bilateral migration stocks by gender. This paper focuses on the patterns of aggregate cross-border migration at the country of origin but uses the variation in bilateral migration stocks data to decompose aggregate flows into origin, destination, and global factors.

The EM-DAT from the Centre for Research on the Epidemiology of Disasters (CRED) collects information on disasters. This paper uses the number of climatological disasters including droughts, extreme temperature, floods, landslides, storms, and wildfires. We aggregate disasters by 5-year windows to match the frequency of cross-border migration data.

We complement our analysis using data on climate risks from Sautner et al. (2023). We consider firms' exposures to physical and regulatory risks of climate change. We compute country aggregates from micro-data available at the firm level using asset-weighted averages. Data is available for 33 countries and between 2000 to 2022. We use average temperature data and land-use from FAOSTAT to control for initial exposures to climate and data from the WBDI on other economic outcomes and population. We estimate the impacts of climate and climate-driven migration on agricultural GDP and remittances as percent of GDP, employment as percent of total labor force, and the Gini index. We include agricultural GDP growth, GDP per capita, and initial population in our various specifications.

4 Decomposition Method

The econometric approach begins by specifying a general spatial model of migration as the foundation for estimating origin, destination, and global factors that drive cross-border migration. The model exhibits network effects of migration as identified in previous research and can accommodate utility-maximizing migration, migration costs, and other migration frictions featured in quantitative equilibrium models in the literature.[1] Notably, the model does not impose functional forms or further assumptions upon the structure of relevant markets. Instead, it assumes bilateral migration incentives to be summarized in origin, destination, and global factors, and bilateral idiosyncratic shocks.

4.1 Methodology

The following empirical model describes the evolution of bilateral cross-border migration. Let $L_{o,d,t}$ be the stock of migrants from country of origin o in the country of destination d in time t. The bilateral migration outflow is:

$$L_{o,d,t} - L_{o,d,t-1} = \Big(O_{o,t} + D_{d,t} + G_t + \varepsilon_{o,d,t}\Big) L_{o,d,t-1}, \tag{1}$$

where O, D, and G denote origin, destination, and global factors and $\varepsilon_{b,d,t}$ are bilateral idiosyncratic shocks. The origin factor, $O_{o,t}$, reflects push factors or outward migration market access from the country of origin o. For example, the origin factor encompasses domestic conditions such as, inter alia, productivity shocks, wages, amenities. Climate related shocks will likely affect migration flows through the origin factor. The destination factor, $D_{d,t}$, reflects pull factors or inward migration access into country of destination d. The global factor, G_t, reflects global trends that affect migration including openness, global immigration policies, and other common shocks.

For this class of empirical models, we can write the growth in the bilateral cross-border migration stock, $g_{o,d,t}$, as:

$$g_{o,d,t} = O_{o,t} + D_{d,t} + G_t + \varepsilon_{o,d,t}, \tag{2}$$

where $g_{o,d,t}$ is observed in the data, and other factors are unobserved but can be estimated.

[1] See, for example, Artuç et al. (2010), Caliendo et al. (2019), Kleinman et al. (2023), Ahlfeldt et al. (2019)

This paper decomposes the variation observed in the growth rate in the bilateral cross-border migration stocks in the data following the method proposed in Amiti and Weinstein (2018). The decomposition method in Amiti and Weinstein (2018) provides a framework to assign the variation in bilateral growth rates to factors. Amiti and Weinstein (2018) uses this decomposition for bilateral lending between firms and banks. Ours is the first paper that applies this method for cross-border migration.

The method produces an exact decomposition of aggregate cross-border migration flows at the origin and destination levels. [2] More precisely, the growth rate in the stock of migrants of country o is decomposed as follows:

$$g_{o,t}^{\text{Origin}} \equiv \frac{\sum_d L_{o,d,t} - L_{o,d,t-1}}{\sum_d L_{o,d,t-1}} = \underbrace{O_{o,t}}_{\text{Origin}} + \underbrace{\sum_d \phi_{o,d,t-1} D_{d,t}}_{\text{Destination}} + \underbrace{G_t}_{\text{Global}} \tag{3}$$

$$g_{o,t}^{\text{Origin}} = \underbrace{O_{o,t}}_{\text{Origin}} + \underbrace{\tilde{D}_{o,t}}_{\text{Destination}} + \underbrace{G_t}_{\text{Global}} \tag{4}$$

where $\phi_{o,d,t-1}$ is the initial share of migrants in the destination country d and we have defined aggregate destination factor $\tilde{D}_{o,t} \equiv \sum_d \phi_{o,d,t-1} D_{d,t}$. Similarly, the growth rate in the stock of migrants in country of destination d is decomposed as:

$$g_{d,t}^{\text{Destination}} \equiv \frac{\sum_o L_{o,d,t} - L_{o,d,t-1}}{\sum_o L_{o,d,t-1}} = \underbrace{\sum_o \theta_{o,d,t-1} O_{o,t}}_{\text{Origin}} + \underbrace{D_{d,t}}_{\text{Destination}} + \underbrace{G_t}_{\text{Global}}, \tag{5}$$

where $\theta_{o,d,t-1}$ is the initial share of migrants from the origin country o.

The definition of the origin-destination interaction terms imposes that bilateral idiosyncratic shocks, when aggregated, bilateral idiosyncratic shocks don't explain, on average, the growth in cross-border migration stocks at origin and destination levels.[3] While origin-destination specific shocks are useful to understand acceleration in bilateral migration, origin and destination factors can be estimated consistently without modeling or estimating the impact of these interaction terms. Appendix B.1 describes in detail the identification assumption as well as further refinements when origin-destination interaction terms are worrisome. [4]

[2] See Appendix B.1 in Amiti and Weinstein (2018) for further details.

[3] Formally, $\mathbf{E}\left(\sum_d \phi_{o,d,t-1} \varepsilon_{o,d,t}\right) = 0$ and $\mathbf{E}\left(\sum_o \theta_{o,d,t-1} \varepsilon_{o,d,t}\right) = 0$

[4] Indeed, large migration outflows to specific locations following migration crises episodes could

4.2 Regional and Global Patterns

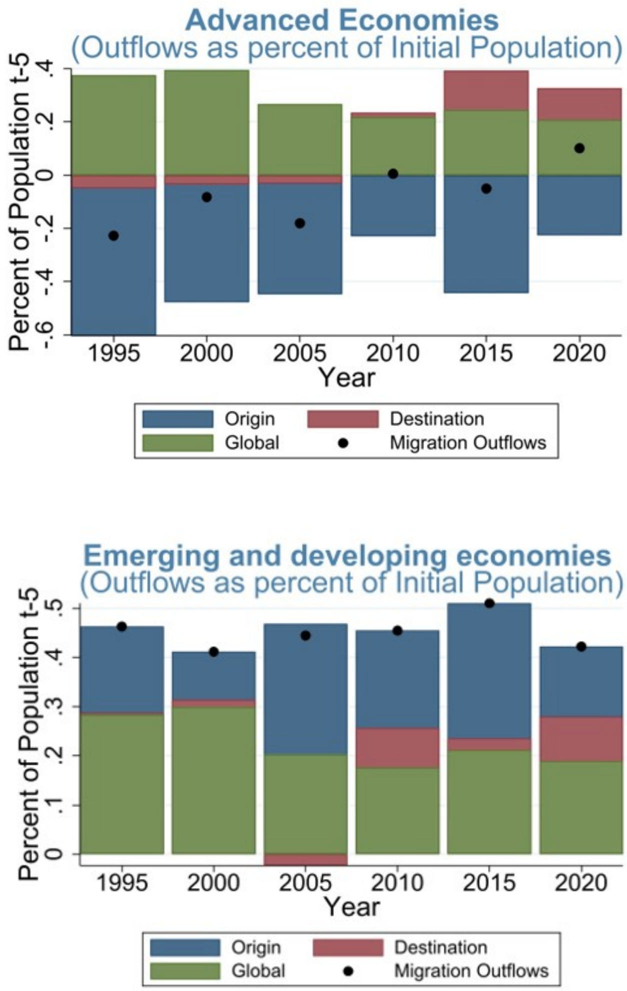


Figure 1. Migration Patterns

Figure 1 provides an overview of the findings from this decomposition exercise applied to the cross-border migration patterns in advanced economies and emerging and developing economies, respectively. Two interesting and contrasting findings emerge from this Figure. First, migration outflows in advanced economies have been mainly driven by global factors, while idiosyncratic domestic factors–as depicted by the "origin" bars and likely reflecting relatively better domestic economic conditions in these economies–have contributed to lower outward migration. In total, these two forces have been roughly balanced over the past decades, resulting in very limited

cause problems when identifying destination-level factors. We use a refinement as noted in Appendix B.1 to control for these episodes.

outward migration from advanced economies. Second, and in contrast to the group of advanced economies, all three shocks–global, origin country, and destination country–have worked in the same direction, contributing to migration outflows from EMDEs. Moreover, origin-country shocks have gained importance over 2005-2015, likely reflecting challenging conditions in some EMDEs that have contributed to pushing more migrants out of their countries of origin.

5 Climate and Cross-Border Migration

5.1 Impact of Climate on Cross-Border Migration

5.1.1 Empirical Setting

The main specification is:

$$\Delta M_{o,t} = \beta C_{o,t} + x_{o,t}\Theta'\delta_o + u_{o,t}, \tag{6}$$

where the unit of observation is country of origin o and period t, measured in 5-year windows.

The dependent variables we consider, $\Delta M_{o,t}$, are the change in migration outflow and the origin-level factor as percent of initial population.[5]. The regressions control for nonlinear differences in migration outcomes by including fixed effects for countries, δ_o. In addition, Equation 6 includes pre-existing country characteristics ($x_{o,t}$) that affect the initial exposure of migration to climate impacts (initial population, previous population change, initial migrant stock as percent of population, previous migration outflows, initial origin factor, first and second lags of natural disasters, lagged average temperature difference with respect to 1950 levels, and initial altering land. The results are robust if we use alternative controls including initial GDP per capita, GDP growth, agricultural GDP growth. Alternative specifications that include time-trends and year-fixed effects to control for non-linear global exposures are also robust.

The main explanatory variable we consider, $C_{o.t}$ is natural disasters. We measure natural disasters as the number of climatological disasters in EM-DAT in the 5-year window. The coefficient of interest is β measures the change in migration outflows due to natural disasters. The OLS estimate of β intends to capture the total impact

[5]We identify the origin-level factor from the growth in bilateral claims as described in section 4. Our dependent variable is constructed as $O_{o,t} \times \frac{M_{o,t-1}}{P_{o,t-1}}$, where $O_{o,t}$ is the origin-factor, $M_{o,t-1}$ is the initial migrant stock, and $P_{o,t-1}$ is the initial population

of natural disasters, including impacts mediated through other economic outcomes.[6] As observed natural disasters measure the backward-looking component of climate, we complement the analysis using data on climate risks from Sautner et al. (2023).

We expand the empirical model to assess heterogeneous impacts of climate on cross-border migration that depend on the country size. Equation 6 estimates the average effect of climate on cross-border migration. Nonetheless, the impacts of climate disasters on cross-border migration might be more pronounced in countries with a smaller geographical area due to limited options for internal migration. The following specification addresses the importance of country size on the impacts of climate on cross-border migration:

$$\Delta M_{o,t} = \beta_0 C_{o,t} + \beta_1 Size_{o,t} \times C_{o,t} + x_{o,t}\Theta'\delta_o + u_{o,t}, \tag{7}$$

where $Size$ is country size measured by land size and initial population. We expect β_1 to be negative.

5.1.2 Results

Impact of Climate Disasters on Cross-Border Migration We estimate Equation 6 via OLS for our panel of 135 countries. Table 1 reports the main empirical findings about the impact of climate disasters on the origin-shocks-driven portion of migration outflows and overall migration outflows. Climate disasters are found to have strong and statistically significant impact on the portion of migration outflows primarily driven by origin-country shocks, with more frequent disasters associated with higher migration out of the affected countries. The effect remains positive when looking at overall migration outflows, not only origin-country-driven, albeit it is smaller and not statistically significant anymore. In a nutshell, the results in Table 1 are aligned with the intuition that climate disasters affecting the country of migrants' origin should be primarily associated with the portion of overall migration assigned to origin-country shocks.

The impact of climate events on origin-driven portion of migration outflows is not only statistically significant, but also economically meaningful. Figure 2 provides an overview of the estimated impact of climate disasters for different groups of countries. The impact is particularly large and statistically different from zero for low-income countries (LICs) and emerging market economies (EMEs), while it is considerably

[6] See Appendix B.2 for a detailed discussion

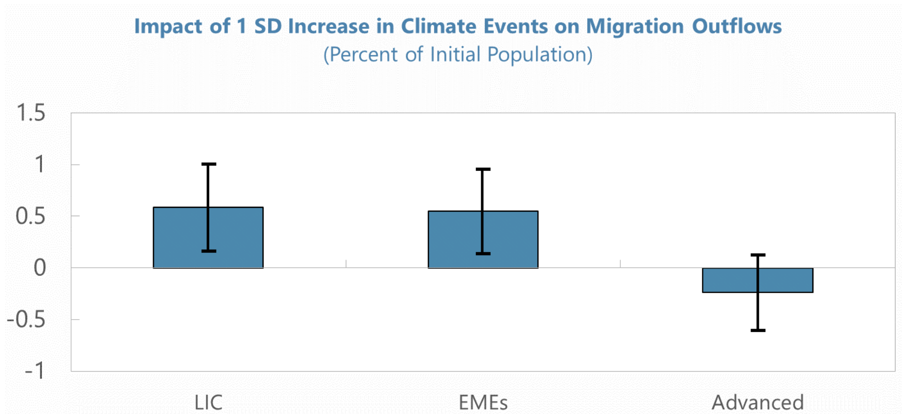
Table 1
Cross-Border Migrant Outflows and Climate Disasters
(Outflows as percent of Initial population)

	(1) Origin Factor	(2) Origin Factor	(3) Origin Factor	(4) Outflows	(5) Outflows	(6) Outflows
Total Disasters	0.0313***	0.0318***	0.0264**	0.0159	0.0180*	0.0180
	(0.0115)	(0.0115)	(0.0123)	(0.0110)	(0.0108)	(0.0119)
Observations	657	657	657	664	664	664
Number of Countries	135	135	135	135	135	135
Country Fixed Effects	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES
Time Trend	NO	YES	-	NO	YES	-
Year Fixed Effects	NO	NO	YES	NO	NO	YES
R2	0.42	0.42	0.42	0.60	0.61	0.61
R2 without Disasters	0.41	0.41	0.42	0.60	0.61	0.61

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

This table presents the regression of migration outflows and origin level factors on natural disasters. Origin stands for origin-level factors as estimated using the method proposed in Amiti and Weinstein (2018) and measured as percent of initial population; Outflows stands for migration outflows as percent of initial population. The explanatory variables are: Natural disasters measured as the number of climatological disasters in EM-DAT in the 5-year window. Regressions control for initial population and previous population change, initial migrant stock, 1st and 2nd lag of natural disasters, lagged average temperature difference with respect to 1950 levels, initial altering land, and lagged outflows. The observation level is country-time, where time is measured by 5-year windows from 1990 to 2020. Sample is selected based on data availability since 1995.

Figure 2. Impact of Disasters on Migration through Origin Factors by Country Group



This figure presents the regression results of the impact of a one-standard deviation shock on climate disasters on origin factors by country group. LIC stands for Low Income Country; EMEs are Emerging countries without LICs; Advanced are advanced economies.

smaller and not statistically significant for the group of advanced economies. Intuitively, the latter group includes countries with better developed infrastructure to address the impact of climate , and thereby, show higher resilience to climate disasters. Moreover, the figure provides estimate about the quantitative impact of climate disasters. On average, a one standard deviation increase in the number of disasters is associated with an increase in outward migration by about 1/2 percent of the initial total population in LICs and EMEs over a five-year period. Translated into actual numbers, this result implies that 3 extra climate disasters per year (one standard deviation) could translate into 1/2 percent of the overall population leaving the country of origin during the five-year window.

Besides the level of income per capita, the degree of economic development, and various socio-economic characteristics, the impact of climate disasters on cross-border migration may critically depend on the actual size of the affected country. For instance, larger countries–either measured by population size or land area–are likely to experience relatively smaller cross-border migration outflows because a large portion of the affected population may migrate internally (*World Development Report*, 2023).

We formally test for the importance of country size for the climate-migration nexus. Table 3 reports the key results from the estimation of Equation 7. As before, more frequent climate disasters are associated with larger migration outflows, and this impact is particularly important and statistically significant for the portion of migration flows attributed to origin-country shocks. In addition, the coefficients in front of the interaction terms, which capture the effect of country size, imply that the impact of climate on outward migration is mitigated by the size of the country: larger economies–either measured by population size or land area–experience relatively smaller increase in outward migration as a result of climate disasters. In essence, these findings confirm the conjecture that climate may be less of a driver for cross-border migration originating from larger economies because their size allows for relatively larger within-country migration of the affected population.

Table 2. Impacts of climate and size

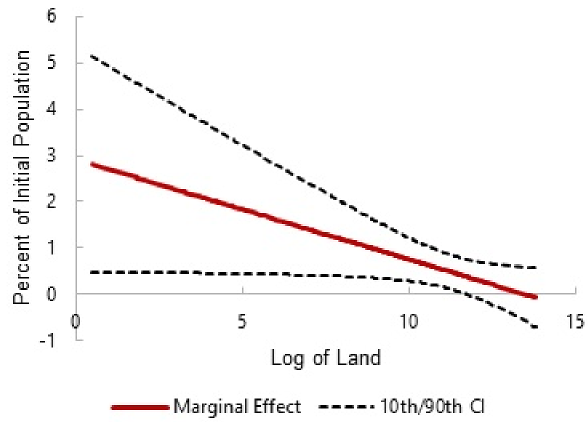
	(1) Origin Factor	(2) Migration	(3) Origin Factor	(4) Outflows
Disasters	0.287**	0.208	0.182**	0.124
	(0.142)	(0.127)	(0.0923)	(0.0827)
Disasters × Log Population	-0.0140*	-0.0103		
	(0.00767)	(0.00687)		
Disasters × Log Land			-0.0135*	-0.00936
			(0.00804)	(0.00721)
Observations	640	646	640	646
Number of Countries	132	132	132	132
Country FE	YES	YES	YES	YES
R-squared	0.420	0.630	0.419	0.629

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

This table presents the regression of migration outflows and origin level factors on natural disasters with heterogeneous impacts across country size. Country size is measured by initial population and land size. *Log Population* is the natural logarithm of the initial population. *Log Land* is the natural logarithm of the country's land size measured in squared miles. Origin stands for origin-level factors as estimated using the method proposed in Amiti and Weinstein (2018) and measured as percent of initial population; Outflows stands for migration outflows as percent of initial population. The explanatory variables are: Natural disasters measured as the number of climatological disasters in EM-DAT in the 5-year window. Regressions control for initial population and previous population change, initial migrant stock, 1st and 2nd lag of natural disasters, lagged average temperature difference with respect to 1950 levels, initial altering land, and lagged outflows. The observation level is country-time, where time is measured by 5-year windows from 1990 to 2020. Sample is selected based on data availability since 1995.

Impact of Climate Disasters on Cross-Border Migration by Type of Disaster The results presented above refer to climate disasters in general, without distinguishing between different types of climate-related calamities. Here we go on step further by zooming into the impact by type of climate disaster. We define two types of disasters: water-related and heat-related. The former category includes

Figure 3. Impact of Disasters and Country Size



The chart shows the impact of 1 standard deviation increase in climate disasters on cross-border migration through the origin factor. Estimated marginal effect uses estimated equation 7 as presented in Table 2

storms, landslides, and floods, while the latter category includes wildfires, extreme temperature events, and droughts.

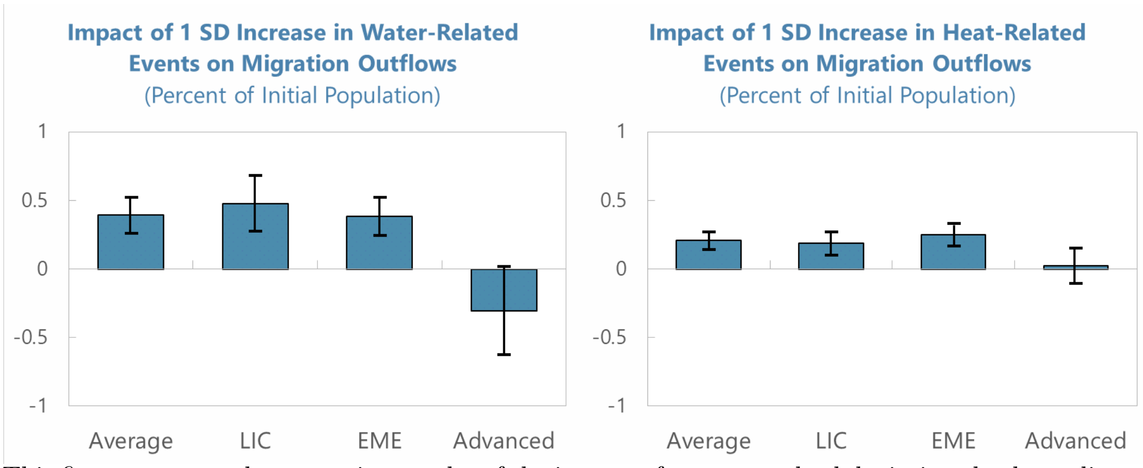
Figure 4 presents the findings for these two types of climate disasters across different country groups. The results for both water-related and heat-related disasters suggest that their impact is especially important for LICs and EMDEs, while the impact for advanced economies is not statistically significant from zero - a result consistent with the findings for the overall sample presented in Figure 2. Moreover, the impact of water-related disasters seems relatively larger than the impact of heat-related disasters for each of these groups of countries.

Impact of Climate Disasters on Cross-Border Migration by Sex Climate change has different impact on males and females and their migration patterns.[7] Household, cultural, environmental and other factors would likely shape the response of males and females to particular climate events, pointing at possibilities of differential impacts across gender. In light of these insights, here we formally explore the differential impact of climate disasters between males and females.

Figure 5 presents an overview of the empirical findings of gender differences across different country groups. These results imply that climate events increase outward migration of both males and females, albeit the impact is somewhat larger for males.

[7] For instance, see Gray and Bilsborrow (2013); Holland et al. (2017); Miletto et al. (2017); Rigaud et al. (2018); Šedová, Čizmaziová and Cook (2021)

Figure 4. Impact of Climate Disasters by Type of Disaster



This figure presents the regression results of the impact of a one-standard deviation shock on climate disasters on origin factors by type and country group. LIC stands for Low Income Countries; EMEs include Emerging countries without LICs; Advanced includes advanced economies. Water-related disasters include storms, landslides, and floods. Heat-related disasters include wildfires, extreme temperature events, and droughts.

Nonetheless, this gender difference is statistically significant only for the groups of LICs.

Impact of Climate Risks on Cross-Border Migration In this section we estimate the impact of climate risks on cross-border migration. Our measure of climate risks aims to capture the forward-looking component and potential implication of climate change. We use firm-level climate risks from the novel dataset in Sautner et al. (2023) and aggregate them at the country level, thereby providing an estimate about the country-wide climate risk.[8] The measures we consider include: (i) overall climate; (ii) physical exposure; and (iii) regulatory risks.

The estimation results for the three types of risks are presented in Table 3. Overall risks and physical exposure risks are both found to be associated with higher origin-shock migration outflows from the corresponding home countries, and both of these results are statistically significant. Turning to overall migration outflows (without distinguishing among origin-country, destination-country, and global shocks), the impact of physical exposure risks to climate remains statistically significant, while the impact of overall climate risks decreases by about half and loses (marginally) statistical significance. These interesting results suggest that not only actual climate events

[8] A drawback of this novel dataset is its limited availability to 33 countries, mainly advanced economies and only a few emerging markets.

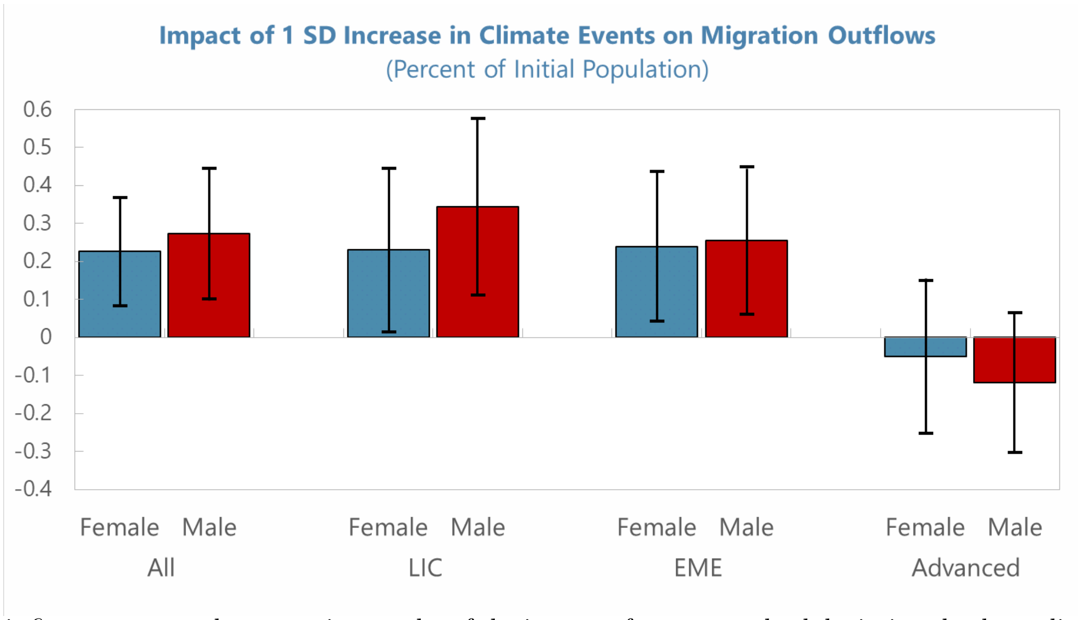
Table 3
Cross-Border Migrant Outflows and Climate Risks
(Outflows as percent of Initial population)

	(1) Origin Factor	(2) Origin Factor	(3) Origin Factor	(4) Outflows	(5) Outflows	(6) Outflows
Total Disasters	0.0313***	0.0318***	0.0264**	0.0159	0.0180*	0.0180
	(0.0115)	(0.0115)	(0.0123)	(0.0110)	(0.0108)	(0.0119)
Observations	657	657	657	664	664	664
Number of Countries	135	135	135	135	135	135
Country Fixed Effects	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES
Time Trend	NO	YES	-	NO	YES	-
Year Fixed Effects	NO	NO	YES	NO	NO	YES
R2	0.42	0.42	0.42	0.60	0.61	0.61

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

This table presents the effect of firms' climate-related risks on migration outflows and origin level factors. Origin stands for origin-level factor as estimated using the method proposed in Amiti and Weinstein (2018) and measured as percent of initial population; Outflows stands for migration outflows as percent of initial population. The explanatory variables are firms' climate-related risks from Sautner et al. (2023). Risks and exposures at the firm level are aggregated using the size-weighted average using total assets. Climate-related risks are measured in basis points. Regressions control for initial population and previous population change, initial migrant stock, 1st and 2nd lag of natural disasters, lagged average temperature difference with respect to 1950 levels, initial altering land, and lagged outflows. The observation level is country-time, where time is measured by 5-year windows from 1990 to 2020. Observations with migration outflows above the 99.5 percentile are removed.

Figure 5. Impact of Climate Disasters by Sex



This figure presents the regression results of the impact of a one-standard deviation shock on climate disasters on origin factors by sex and country group. LIC stands for Low Income Country; EMEs includes Emerging countries without LICs; Advanced includes advanced economies.

and disasters play a role in the migration nexus, but also the anticipation of climate impacts–as captured by firms' perceptions and firms' assessments–are associated with higher migration outflows.

A final note worth mentioning is the lack of significance of regulatory risks. A priori, it is not easy to assign an expected sign about the impact of regulatory risk: on the one hand, firms may perceive higher climate regulatory risk in environments lacking basic regulation about addressing the implications of climate events, and thereby be associated with higher migration outflows from such jurisdictions. On the other hand, however, firms may perceive higher regulatory risks for them when the regulatory adjustment is being swiftly adjusted to address climate issues, and such jurisdictions may be more likely receivers rather than emitters of migrants.

5.2 Impact of Climate Disasters on Economic Outcomes

We estimate the overall impact of climate disasters on economic outcomes. The specification is:

$$y_{o,t} = \beta^y C_{o,t} + x^y_{o,t}\Theta'_y + \delta^y_o + \varepsilon^y_{o,t}, \tag{8}$$

where the unit of observation is country of origin o and period t, measured over 5-year windows.

As dependent variables $y_{o,t}$ we consider agricultural GDP, remittances, employment and the Gini index. The regressions control for non-observed country-specific heterogeneity via the inclusion of fixed effects δ_o^y. In addition, Equation 8 includes pre-existing country characteristics ($x_{o,t}^y$) that affect the initial exposure of economic activity to climate impacts (initial population, previous population change, initial migrant stock as percent of population, previous migration outflows, initial origin factor, first and second lags of natural disasters, lagged average temperature difference with respect to 1950 levels, and initial altering land). We also include initial GDP per capita, GDP growth, agricultural GDP growth, and the lag of the dependent variable as controls. Alternative specifications include time-trends and year-fixed effects to control for non-linear global exposures are also robust.

The explanatory variable $C_{o.t}$ captures natural disasters. The coefficient of interest is β^y, which measures the total change in economic outcomes as a consequence of the occurrence of natural disasters. The OLS estimate of β^y intends to capture the total impact of natural disasters. [9]

5.2.1 Identifying the Impact through Climate-Driven Migration

The empirical model in Equation 8 does not rule out climate-driven migration impacts on economic outcomes. Indeed, β^y should be interpreted as a combination of the effect of climate-driven migration and other direct climate-related factors.

The following empirical setting allows for the identification of the impact of climate-driven migration and links it to the total impact estimated in Equation 8. Consider, without loss of generality, a simplified model of economic outcomes denoted by $y_{o,t}$; migration flows denoted by $\Delta M_{o,t}$; and natural disasters captured by $C_{o,t}$.[10]

$$
\begin{aligned}
y_{o,t} &= \alpha^c C_{o,t} + \alpha^m \Delta M_{o,t} + u_{o,t}^y, \\
\Delta M_{o,t} &= \beta^c C_{o,t} + u_{o,t}^m,
\end{aligned}
$$

Proposition 1. *Suppose $C \perp u^m, u^y$ and but $E(u^y u^m) \neq 0$. Assume exists Z such that $E(Z\Delta M) \neq 0$ and $E(Zu^y) = 0$.*

[9] See Appendix B.2 for a detailed discussion

[10] Appendix B.2 shows how results are robust to the inclusion of additional control variables.

1. *The total impact of natural disasters on economic outcomes y*

$$\frac{\partial y}{\partial C} = \alpha^c + \alpha^m \beta^c, \tag{9}$$

is identified from

$$\tilde{\beta} = \frac{E(Cy)}{E(C'C)}, \tag{10}$$

that is, can be identified by regressing cross-border migration, Y, on natural disasters.

2. *The mediation effect of climate-driven migration*

$$\frac{\partial y}{\partial \Delta M} \frac{\partial \Delta M}{\partial C} = \alpha^m \beta^c, \tag{11}$$

is identified from:

$$E((y - \alpha^c C - \alpha^m \Delta M)C) = 0$$
$$E((y - \alpha^c C - \alpha^m \Delta M)Z) = 0.$$

This is, a 2SLS using Z as instrument when regressing economic outcome y, on natural disasters, C, and the migration flows will identify α^c. Therefore, the mediation effect is identified.

Proof. See Appendix B.2 □

Proposition 1 shows how to identify the mediation effects of climate-driven migration when an instrument for migration is available. This proposition can be extended when allowing for additional feedback-loop effects of economic outcomes on migration. Appendix B.2 provides more details about the interpretation of our results and further extensions.

Our decomposition is also instrumental to delivering a plausible instrument for cross-border migration: destination factors. Such factors are by construction orthogonal to origin-level factors, and hence, plausibly exogenous to unobserved variation that explains economic outcomes. At the same time, destination factors explain about 30 percent of cross-border migration.[11]

[11] That is, when including origin-country and global factors, we can explain 70 percent of the variation of cross-border migration.

Table 4. Impacts of Climate Disasters on Macroeconomic Outcomes

	(1) Agricultural GDP	(2) Gini	(3) Employment	(4) Remittances
Total Impact of Disasters	-0.0559**	0.0423	-0.0401*	0.0051
	(0.0244)	(0.0293)	(0.0219)	(0.0173)
of which				
Mediated through	-0.0083***	-0.023***	-0.001	0.0202***
Climate-Driven Migration	(0.0026)	(0.0083)	(0.0009)	(0.0041)
Other Channels	-0.0476**	0.0657**	-0.0400*	-0.0151
	(0.0218)	(0.0323)	(0.0211)	(0.0214)
Observations	576	453	643	629
Number of Countries	130	120	130	131
Country Fixed Effects	YES	YES	YES	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

This table presents the effect of natural disasters on macroeconomic outcomes. The dependent variables are: Agricultural GDP, measured as percentage of GDP (0-100); gini index (0-100); employment as percent of 15+ population (0-100); remittances as percent of GDP (0-1000. Natural disasters measured as the number of climatological disasters in EM-DAT in the 5-year window. Regressions control for initial population and previous population change, initial migrant stock, 1st and 2nd lag of natural disasters, lagged average temperature difference with respect to 1950 levels, initial altering land, and lagged outflows, and lag of the dependent variable. The observation level is country-time, where time is measured by 5-year windows from 1990 to 2020. Sample is selected based on data availability since 1995. The total effect is measured from the coefficient from the regression of the dependent variables on natural disasters without controlling for migration outflows. The direct impact through other channels is measured as the coefficient on disasters controlling for migration outflows instrumented using destination-level shocks. The indirect effect mediated through climate-driven migration is the residual.

5.2.2 Results

Table 4 presents the estimation results about the impact of climate on macroeconomic outcomes. The first row depicts the overall impact of climate disasters on several important macroeconomic variables, such as agricultural GDP, inequality measured by the Gini coefficient, employment, and remittances. As expected, climate disasters are found to reduce agricultural output and employment, with both of these effects being statistically significant, and increase income inequality and remittances (albeit these findings lack statistical significance). In turn, Table 4 also presents results about the portion of the overall climate impact that is being mediated via climate-induced migration - interestingly, climate-induced migration is found to account for an important portion of climate's overall impact in the case of agricultural output, Gini, and remittances.

There are three key findings worth highlighting. First, higher climate-induced migration is associated with lower agricultural output–accounting for about 15 percent of climate's overall negative impact on agriculture–and this effect is statistically significant. Not surprisingly, in the impact of climate-induced migration is in the same direction as the overall climate impact, reinforcing the other climate components. Second, while climate disasters are associated with lower income inequality–as measured by the Gini coefficient–climate-induced migration actually helps mitigate this overall impact, as migrants displaced due to climate disasters may be more likely to also belong to the bottom segment of the income distribution (hence, their departure may mitigate climate disasters' overall role in raising income inequality). Third, the positive impact of climate-induced migration on remittances offsets the negative impact of the remaining climate-related factors on remittance inflows, thereby explaining the positive–albeit not statistically significant–overall impact of climate disasters on remittances. Overall, these three findings and associated conjectures may deserve more in-depth analysis to understand the underlying reasons when climate-induced migration reinforces or counterbalances climate's remaining impact on macroeconomic outcomes.

5.3 Robustness

Measurement of Climate Disasters A potential threat to identification is the increasing reporting of disasters. Indeed, coverage of less-deadly disasters has increased over time, most notably from 1900 to 1980. The time period we consider is 1995 to 2020[12], less affected by increase in coverage.[13] Furthermore, the sample of countries in our main specifications includes countries that started reporting before 1995.

To address this potential threat, we estimate the impact of natural disasters with reported deaths above 100 and show the results are broadly aligned to our main specification. Table 5 presents the impact of natural disasters on cross-border migration when limiting disasters to those with reported deaths above 100. The estimated impact of disasters is positive and significant on both migration outflows and the origin-level factor. A one standard deviation increase in disasters with more than

[12] Available data on cross-border migration stock starts in 1990. The decomposition method we use leverages the growth rate of the cross-border migration stock, and hence starts in 1995.

[13] For example, the number of reported storms in the Americas in 1990 is comparable to that one in 2010

Table 5. Impact of disasters limited to more than 100 deaths

	(1) Origin	(2) Origin	(3) Origin	(4) Outflows	(5) Outflows	(6) Outflows
Disasters	0.0799*	0.0816*	0.0891**	0.0838**	0.0937**	0.0907**
(above 100 deaths)	(0.0449)	(0.0445)	(0.0447)	(0.0389)	(0.0397)	(0.0394)
Observations	657	657	657	664	664	664
Number of Countries	135	135	135	135	135	135
Country FE	YES	YES	YES	YES	YES	YES
Time FE	NO	NO	YES	NO	NO	YES
Time Trend	NO	YES	NO	NO	YES	NO
R-squared	0.449	0.450	0.453	0.637	0.643	0.644

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

This table presents the regression of migration outflows and origin level shocks on natural disasters excluding disasters with less than 100 deaths. Origin stands for origin-level shocks as estimated using the method proposed in Amiti-Weinstein (2018) and measured as percent of initial population; Outflows stands for migration outflows as percent of initial population. The explanatory variables are: Natural disasters with more than 100 deaths measured as the number of climatological disasters in EM-DAT in the 5-year window. Regressions control for initial population and previous population change, initial GDP growth, initial migrant stock, 1st and 2nd lag of natural disasters, lagged average temperature difference with respect to 1950 levels, initial altering land, and lagged outflows. The observation level is country-time, where time is measured by 5-year windows from 1990 to 2020. Sample is selected based on data availability since 1995.

100 deaths increases cross-border migration outflows by 0.23 percent of the initial population.

Mediated impact of economic-outcomes Macroeconomic outcomes could shape the impact of climate shocks on migration. For example, climate-related declines in agricultural productivity and overall labor demand could lead to persistent drops in wages, and thus affecting migration incentives. Determining the magnitude of these indirect effects is crucial for policymaking, as it can offer valuable insights for targeted policy implementation.

Evaluating the mediation of climate-related shocks via macroeconomic outcomes poses empirical challenges, as it requires exogenous variation in macroeconomic outcomes unrelated to other domestic factors affecting both migration and climate shocks. In other words, identifying the mediation impact requires an instrument for macroeconomic outcomes as in other IV settings. However, given the endogenous nature of migration and macroeconomic outcomes and the link of migration to labor demand,

Table 6. Bounds to Mediation of Macroeconomic Variables

Mediating Variable	Identified Sign	Lower Bound (Percentage of total effect)
Agricultural GDP	Positive	7.87
Confidence Interval		(0.00 -14.32)
Employment	Positive	6.34
Confidence Interval		(0.02-12.47)
Gini	Positive	9.74
Confidence Interval		(3.61-15.87)
Remittances	Not identified	-
Lower Bound of Indirect Impacts	Positive	18
Upper Bound of Direct Impact	Positive	82

finding an appropriate instrument for macroeconomic outcomes is rather difficult.

To address this challenge, we propose a novel approach that provides upper and lower bounds for the estimated mediated effect of key economic outcomes. Our method extends Dippel et al. (2021) by using the exogenous variation from the occurrence of disasters and destination factors that explain migration in a simultaneous equation approach. The bounds we propose identify the share of climate impacts on migration that are explained through macro-economic outcomes. Annex B.2. provides details on the approach.

Our findings suggest that macroeconomic outcomes intensify the impacts of climate on migration. Table 6 shows that overall, identified macroeconomic outcomes could explain at least 18 percent of the impacts of climate on migration. Impacts through productivity are likely large, as mediated impacts of agricultural GDP and employment suggest. Importantly, our findings suggest unskilled-labor intensive sector are likely more affected, as the results on inequality suggest.

Impact of Climate on Immigration An additional question is whether climate disasters in the countries of destination affect migration inflows. We assess this question by estimating the impact of disasters in the country of destination on cross-border migration inflows in the country of destination. Table 7 presents the results of the impacts on inflows and the identified destination factor. The point estimate is negative, reflecting that disasters in the country of destination reduces migration inflows. However, the estimates are not statistically significant.

Table 7. Impact of Disasters in Destination Countries on Inflows to Destination

	(1) Destination	(2) Destination	(3) Destination	(4) Inflows	(5) Inflows	(6) Inflows	(7) Destination	(8) Inflows
Disasters	-0.00114	0.00439	-0.0136	-0.00490	-0.00511	-0.00536		
(In Destination)	(0.0110)	(0.0137)	(0.0159)	(0.00659)	(0.00736)	(0.00700)		
Disasters× Advanced							-0.0192	-0.00674
							(0.0482)	(0.0261)
Disasters× EMEs							-0.0127	-0.00512
							(0.0144)	(0.00639)
Observations	672	672	672	672	672	672	672	672
Number of Countries	135	135	135	135	135	135	135	135
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Time Trend	NO	YES	NO	NO	YES	NO	NO	
Year FE	NO	NO	YES	NO	NO	YES	YES	YES
R-squared	0.217	0.221	0.226	0.588	0.591	0.591	0.226	0.591

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

This table presents the regression of migration inflows and destination level shocks on natural disasters. *Destination* stands for destination-level factors as estimated using the method proposed in Amiti and Weinstein (2018) and measured as percent of initial population; Inflows stands for migration inflows as percent of initial population. The explanatory variables are: Natural disasters at the country of destination measured as the number of climatological disasters in EM-DAT in the 5-year window. Regressions control for initial population and previous population change, initial GDP growth, initial migrant inflow, 1st and 2nd lag of natural disasters, lagged average temperature difference with respect to 1950 levels, initial altering land, and lagged outflows. The observation level is country-time, where time is measured by 5-year windows from 1990 to 2020. Sample is selected based on data availability since 1995.

6 Model Implications

To quantify the impacts of adaptation in alleviating the effects of disasters on cross-border migration, we introduce migration to a medium-size general equilibrium model with disasters, the DIGNAD model (Debt-Investment-Growth and Natural Disasters) that we calibrate using the identified effects of climate on migration. DIGNAD is a workhorse model to study the effects of climate risk due to natural disasters and how investments in adaptation infrastructure can help mitigate these risks. We introduce endogenous locational choices of households and calibrate the key moments of the model using our empirical identified effects of disasters on cross-border migration and other economic outcomes.

6.1 Introducing Cross-Border Migration

We introduce endogenous migration allowing for locational decisions of workers as in other dynamic migration models in the literature (Caliendo et al., 2023). Migration is forward-looking and workers maximize the life-time utility and decide optimally where to locate each period subject to mobility frictions and idiosyncratic taste shocks.

In what follows, we describe the key elements we introduce to the DIGNAD model to allow for endogenous migration choices. Hand-to-mouth Workers maximize the life-time utility. The recursive value function of a worker living in country j is

$$V_{j,t} = \ln c_t^j + z_t^j + \max_{d \in \{origin, abroad\}} \beta \mathbf{E}\Big(V_{d,t+1} - m_{j,d,t} + \nu \varepsilon_{d,t}\Big), \tag{12}$$

where c^j is per worker consumption and z^j is the non-monetary value workers assing to location j. Additional non-monetary moving costs are captured in $m_{j,d,t}$, which are assumed to be zero if the worker stays in the same location. Non-monetary costs allow the model to add an additional motive of migration, besides those captured in the economic benefits related to wages and productivity. Additionally, $\varepsilon_{d,t}$ are idiosyncratic locational shocks, assumed to be drawn from a Fréchet distribution following the trade literature as in Caliendo et al. (2023). The idiosyncratic shocks allow for tractability of the problem and their variance will determine the aggregate elasticity of migration with respect to wages in equilibrium.

To understand the economic motives of cross-border migration, we present here the budget constraints faced by workers in the home country and abroad. The aggregated budget constraint of hand-to-mouth workers living at their home-country is

$$C_t^{origin} = c_t^{origin} L_{origin,t} = W_t L_{origin,t} + Rem_t + T_t, \tag{13}$$

where W are local wages determined in equilibrium, $L_{origin,t}$ are hand-to-mouth workers living at the home-country, Rem_t are remittances received from abroad, T_t are lump-sum transfers. Similarly, the aggregated budget constraint of hand-to-mouth workers living abroad is

$$C_t^{abroad} = W_t^{abroad} L_{abroad,t} - Rem_t, \tag{14}$$

where W^{abroad} are wages in the country of destination, assumed to be exogenous, $L_{abroad,t}$ are hand-to-mouth workers living abroad. We assume remittances are exogenous, but we allow for endogenous remittances as a robustness check. From equations 13 and 14, it is clear that the wage differential will partially determine cross-border migration motives. Besides wages, social transfers and remittances could alleviate cross-border migration.

Finally, the evolution of migrants abroad will be determined endogenously and balancing economic trade-offs of migrating. More precisely, the fraction of workers that migrate is governed by the following expression:[14]

$$\mu_{migrate,t} = \Omega_{migrate}^{-1} \exp(\beta \mathbf{E} V_{abroad,t} - m_{origin,abroad,t})^{1/\nu}, \tag{15}$$

where $\Omega_{migrate}$ is the outward migration market access,

$$\Omega_{migrate} = \exp(\beta \mathbf{E} V_{abroad,t+1} - m_{origin,abroad,t})^{1/\nu} + \exp(\beta \mathbf{E} V_{origin,t+1})^{1/\nu}, \tag{16}$$

and thus defining the stock of migrants abroad as:

$$L_{abroad,t} = (1 - \mu_{repat,t}) L_{abroad,t-1} + \mu_{migrate,t} L_{origin,t-1}, \tag{17}$$

with $L_{origin} + L_{abroad} = \bar{L}$. Note that the migration outflow from country of origin is $\mu_{migrate,t} L_{origin,t-1}$, with $\mu_{migrate,t}$ the fraction of workers that migrate. The repatriation inflow is $\mu_{repat,t} L_{abroad,t-1}$.

6.2 Calibration: From Empirics to the Model

To assess the economic effects of adaptation on cross-border migration and other economic outcomes using a model, it is necessary to discipline the baseline calibration using the identified moments in the data. First, the steady-state should reflect the average cross-border migration of the period in consideration. Second, the baseline responses should match the response of cross-border migration and economic outcomes to a long-term intensification of disasters.

The steady-state calibration matches the stock of migrants to total population ratio. We calibrate the migration costs in the model (m) to match the stock of migrants as percent of total population. In the baseline, non-monetary benefits of migration z are assumed to be zero. Without loss of generality, the remaining parameters follow a standard approach and match the macroeconomic moments.

The baseline response is disciplined to match three important impacts of a one-standard deviation increase in disasters in the long-run: (1) the GDP responses; (2) climate-driven migration; and (3) the mediation through macroeconomic outcomes. First, the baseline response matches about 1 percent decline of GDP in the long-

[14] A similar expression governs the fraction of workers that returns to the home-country $\mu_{repat} = \Omega_{return}^{-1} \exp(\beta \mathbf{E} V_{origin,t} - m_{abroad,origin,t})^{1/\nu}$ with $\Omega_{return} = \exp(\beta \mathbf{E} V_{abroad,t})^{1/\nu} + \exp(\beta \mathbf{E} V_{origin,t} - m_{abroad,origin,t})^{1/\nu}$

term following a one-standard deviation shock in natural disasters, equivalent to the response of the agricultural GDP. Second, the cross-border migrant stock increases by 0.53 percent of the initial population in the long-run in the baseline response. Third, we assume about 20 percent of the migration response is driven by wage differentials, in line with our empirical results.

To discipline the baseline response, the variance of preference shocks and non-monetary benefits of migration are instrumental. The variance of preference shocks governs the elasticity of cross-border migration to migration trade-offs, which is clear from equation 15. Hence, the variance of preference shocks will be key to matching the response of cross-border migration to the intensification of disasters. To balance the share of migration that could be attributed to macroeconomic outcomes, we use non-monetary benefits of migration (z).

We calibrate the model for CAPDR, a region largely affected by disasters and cross-border migration outflows. The initial migrant stock is estimated at 4.2 percent of population for the average CAPDR country. The remaining parameters are standard and match the average CAPDR economy. Appendix A presents the parameters used in the model.

6.3 Counterfactual Analysis: The Effects of Adaptation on Cross-Border Migration

Our counterfactual analysis compares the impacts of a long-term shock in the number of disasters in two economies that differ in public capital adaptation levels. We assume the baseline economy does not invest in adaptation, while 50 percent of public capital is resilient in the counterfactual economy. The shock we consider corresponds to a one-standard deviation increase in natural disasters, associated with a shock in real GDP of 1 percent in the baseline as discussed in the previous section.

Figure 6 presents the counterfactual exercise. Panel a) shows that cross-border migration can be attenuated via resilient infrastructure. Climate-driven migration, estimated at about 0.5 percent of the initial population without resilient capital, could be reduced by about 0.2 percent of the initial population by having invested on 50 percent of resilient public capital. The transmission channels are via lower GDP losses, as depicted in panel b), with important impacts on private investment resiliency (panel d). Significant fiscal gains are reaped. Fiscal deficit and public debt increases moderate significantly when the government invests in resilient public capital (panels e and f).

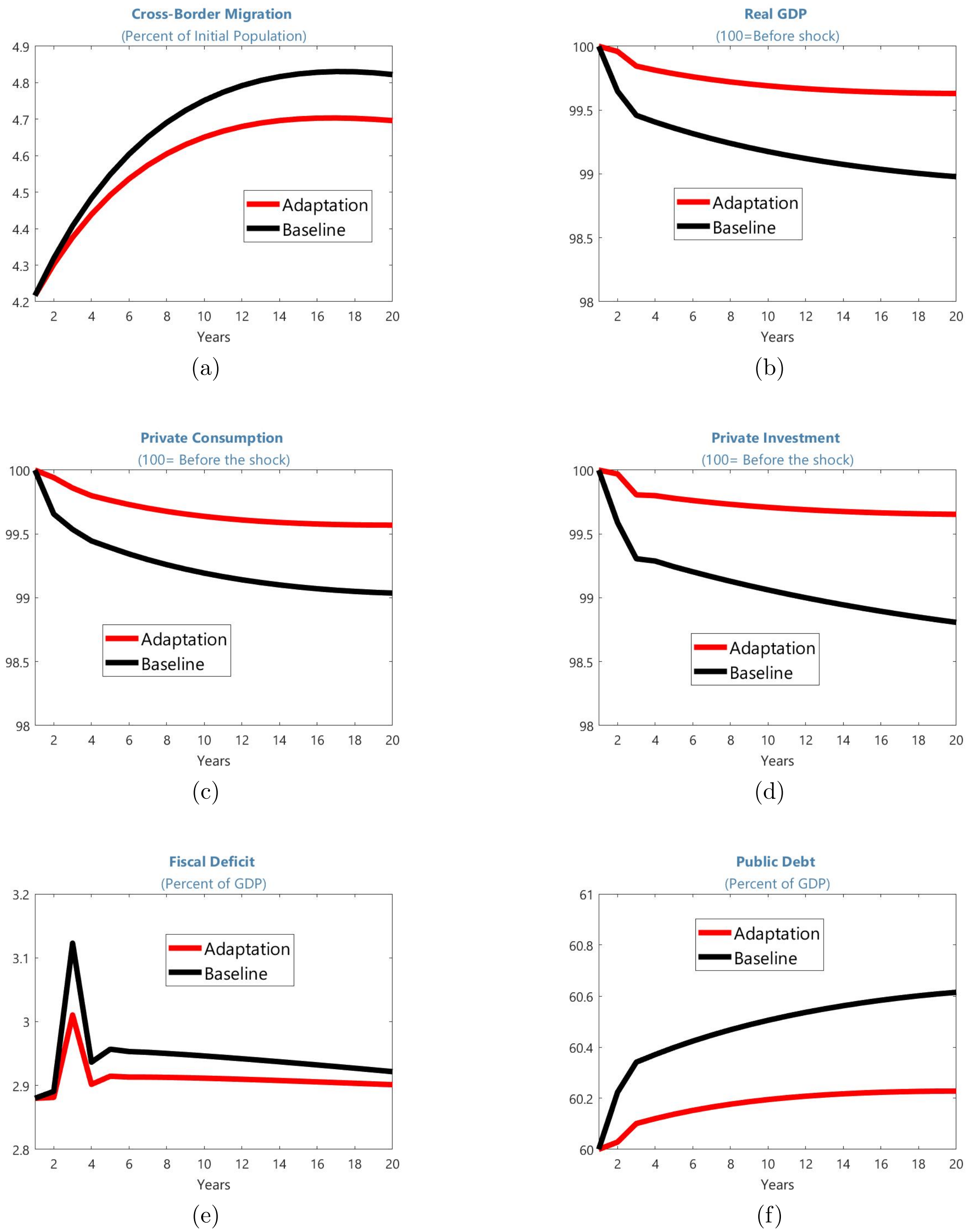


Figure 6. Effects of Adaptation

7 Concluding Remarks

Origin, destination, and global factors have contributed to outward cross-border migration in EMDEs. Our analysis shows origin-country migration shocks are an importance driver of cross-border migration in EMDEs and have gained importance over 2005-2015.

Climate disasters and forward-looking expectations of climate exposures explain origin-country migration shocks, albeit less overall migration outflows. EMDEs migration outflows, through origin-factors, increase about 0.5 percent of the initial population following a one-standard deviation shock in natural disasters, leading to migration of both genders. Furthermore, the impacts are more prominent in small countries.

Our analysis shows that resilient investment can reduce the impacts of climate on cross-border migration. Our estimates indicate that countries that invest in resilient public capital stock experience economic gains via lower climate-driven migration.

Bolstering social safety nets and enhancing climate mitigating measures are key to contain the adverse economic effects of climate shocks. The negative effects of climate shocks on the population and economic output can be sizable, while the accompanying increase in remittances could play an important mitigating role. Nonetheless, it is essential to tread cautiously and seek structured policy responses, as an overreliance on external remittance inflows could give rise to other vulnerabilities. In this context, reinforcing social safety nets to foster resilience and mitigate climate-driven impact on the population takes on a renewed relevance. The likely increase in the frequency and impact of climate shocks in the future would further raise the urgency of such measures.

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A Appendix. Additional Tables

Appendix Table A1. Model Parameters

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Parameter	Values	Parameter	Values	Parameter	Values	Parameter	Values
$iziy$	0.06	0	0	δ_{za}	0.03	λ_5	0.5
$izay$	0	0	0	γ_{zi}	0.5	λ_6	0.5
ho	0.12	0	0	γ_s	0.5	$r^\star$	0.04
hlo	0.1	a_{ratio}	0.8	γ_{ax}	0.5	δ_x	0.05
$share_b$	0.28	s_o	0.5	$pgamma_{rdc}$	0.5	δ_n	0.05
$share_d$	0.05	α_k	0.5	fo	0.05	tau	0.34
$share_{dc}$	0.27	α_z	0.5	λ	0.2	$phhi$	100
$share_{bstar}$	0.2	α_x	0.4	λ_h	0.4	phi	0
ro	0.05	α_n	0.55	$\lambda_h l$	0.4	η	1
$r_d co$	0.06	π_{nd_n}	25	υ	0.5	$etag$	0
$share_{grants}$	0	a_{za}	0.25	λ_1	0.5	xi_n	0
$oilro$	0	$R_z io$	0.25	λ_2	0.5	σ_x	0
$share_{remit}$	0.15	R_{zao}	0.3	λ_3	0.5	σ_n	0
$imp2gdp$	0.48	δ_{zi}	0.075	λ_4	0.5	$nxpsi$	1
						ω	2.41

B Appendix. Methodological Annex

B.1 Refining the Decomposition Method

We refine Amiti and Weinstein (2018) to allow for migration crises heterogeneously affect countries at the border. This disproportionate impact is a stylized fact of massive migration events. Note that in normal times, network effects would be linear and hence unaffected. We allow for this non-homotheticity to capture disproportionate effect during crises only as follows:

$$g_{o,d,t} = O_{o,t}^{border} + O_{o,t} + D_{d,t} + G_t + \varepsilon_{o,d,t}, \tag{18}$$

where $O_{o,t}^{border}$ is an additional factor that captures the non-homotheticity. We identified 11 episodes of massive migration. Table A2 presents these events.

Appendix Table A2. Identified Events

2005 Ecuadorian Revolution
2020 Venezuelan Crisis
2015 Syria's civil war
2005 CAF refugee crisis
2015 CAF refugee crisis
2015 Eritrea's migration crisis
2005 Gambia's massive migration
1995 Rwuandan genocide
1995 Sierra Leone's civil war
1995 Albania's refugee route

B.2 Identification

Let C be natural disasters (or treatment). The equation that governs cross-border migration outflows Y is

$$Y = \beta_C^Y C + \beta_X^Y X + \varepsilon^Y, \tag{19}$$

where ε^Y is an unobserved confounding variable and X is a mediator variable also impacted by C:

$$X = \beta_C^X C + \beta_Y^X Y + \varepsilon^X, \tag{20}$$

where ε^X is an unobserved confounding variable. Note we allow for impacts of cross-border migration on Y through $\beta_Y^X > 0$.

Proof. We prove Proposition 1. Cross-border migration outflows are

$$Y = \beta_C^Y C + \beta_X^Y \beta_C^X C + \varepsilon^X + \beta_X^Y \varepsilon^X. \tag{21}$$

We write

$$Y = (\beta_C^Y + \beta_X^Y \beta_C^X)C + \tilde{\varepsilon}^Y, \tag{22}$$

where $C \perp \tilde{\varepsilon}^Y$. Then, we can identify the total impact of natural disasters via regressing Y on C.

Part 2 of proposition 1 comes from orthogonality assumptions. Note identification requires $\text{corr}(CY) \neq 1$.

Also note that following the Frisch–Waugh–Lovell theorem, regressing cross-border migration, Y, on natural disasters, C, and the mediation variable, X will return the coefficient on X:

$$\beta_x = (\mathbf{X}^\top \mathbf{M}_C \mathbf{X})^{-1} \mathbf{X}^\top \mathbf{M}_C \boldsymbol{Y}, \tag{23}$$

Where $\mathbf{M}_C$ is the complementary projection matrix. Note that

$$\mathbf{M}_C \boldsymbol{X} \xrightarrow{p} \varepsilon^X, \tag{24}$$

and

$$\mathbf{M}_C \boldsymbol{Y} \xrightarrow{p} \varepsilon^Y + \beta_X^Y \varepsilon^X. \tag{25}$$

It follows

$$\beta_x \xrightarrow{p} \beta_X^Y, \tag{26}$$

□

The model implied solution of cross-border migration is

$$Y = m\left(\beta_C^Y + \beta_X^Y \beta_C^X\right) + u_y, \tag{27}$$

with $u_y \equiv m\varepsilon^Y + m\beta_X^Y \varepsilon^X$, and $m = (1 - \beta_X^Y \beta_Y^X)^{-1}$.

Proposition 2. *Suppose $C \perp \varepsilon^X, \varepsilon^Y$ and $\varepsilon^Y \perp \varepsilon^X$. The total impact of natural disasters on cross-border flows,*

$$\frac{\Delta Y}{\Delta C} = m(\beta_C^Y + \beta_X^Y \beta_C^X), \tag{28}$$

is identified from

$$\tilde{\beta} = \frac{E(CY)}{E(C'C)}, \tag{29}$$

that is, can be identified by regressing cross-border migration, Y, on natural disasters.

Proof. Follows from exogeneity assumptions and 27. □

Proposition 3. *Suppose $C \perp \varepsilon^X, \varepsilon^Y$ and $\varepsilon^Y \perp \varepsilon^X$. The OLS coefficient on X after regressing Y on C and X converges in probability to $\tilde{\beta}$*

$$\hat{\beta}_x \xrightarrow{p} \tilde{\beta} \equiv \frac{\beta_X^Y \sigma_{\varepsilon_x}^2 + \beta_Y^X \sigma_{\varepsilon_y}^2}{\sigma_{\varepsilon_x}^2 + (\beta_Y^X)^2 \sigma_{\varepsilon_y}^2}, \tag{30}$$

where $\sigma_{\varepsilon_x}^2$ and $\sigma_{\varepsilon_y}^2$ are the variance of unobserved components as defined in the empirical model.

Proof. We apply the Frisch–Waugh–Lovell theorem noting that

$$\mathbf{M}_C\boldsymbol{Y} \xrightarrow{p} u_y \equiv m\varepsilon^Y + m\beta_X^Y\varepsilon^X, \tag{31}$$

which follows from the model solution. Similarly,

$$\mathbf{M}_C\boldsymbol{X} \xrightarrow{p} u_x \equiv m\varepsilon^X + m\beta_Y^X\varepsilon^Y. \tag{32}$$

Assuming $m \neq 0$ and m bounded, it follows

$$\begin{aligned}\beta_x &= (\mathbf{X}^\top\mathbf{M}_C\mathbf{X})^{-1}\mathbf{X}^\top\mathbf{M}_C\boldsymbol{Y}\\ &\xrightarrow{p} \frac{\beta_X^Y\sigma_{\varepsilon_x}^2 + \beta_Y^X\sigma_{\varepsilon_y}^2}{\sigma_{\varepsilon_x}^2 + (\beta_Y^X)^2\sigma_{\varepsilon_y}^2} \equiv \tilde{\beta}\end{aligned}$$

□

Proposition 4. *Suppose $C \perp \varepsilon^X, \varepsilon^Y$ and $\varepsilon^Y \perp \varepsilon^X$ with β_Y^X and $\sigma_{\varepsilon_x}^2$ known. Then, regarding the mediation impact of X on Y:*

1. *The sign of β_X^Y is identified when sign$(\tilde{\beta}) \times$ sign$(\beta_X^Y) = -1$*

2. *β_Y^X is bounded.*

   a. *(Regions I and II) If $\beta_Y^X < 0$ and $\tilde{\beta} < 0$ the upper and lower bounds are:*

   $$\tilde{\beta}\left(1 + (\beta_Y^X)^2\frac{\sigma_Y^2}{\sigma_{\varepsilon_x}^2}\right) \leq \beta_X^Y \leq \tilde{\beta}, \tag{33}$$

   where σ_Y^2 is the variance of Y.

   b. *(Region IV) If $\beta_Y^X > 0$ and $\beta_X^Y < 0$ with $\tilde{\beta} < 0$ the upper and lower bounds are:*

   $$\tilde{\beta}\left(1 + (\beta_Y^X)^2\frac{\sigma_Y^2}{\sigma_{\varepsilon_x}^2}\right) - \beta_Y^X\frac{\sigma_Y^2}{\sigma_{\varepsilon_x}^2} \leq \beta_X^Y \leq \tilde{\beta}, \tag{34}$$

   c. *(Region III) If $\beta_Y^X < 0$, with $\tilde{\beta} > 0$ the upper and lower bounds are:*

   $$\tilde{\beta} \leq \beta_X^Y \leq \tilde{\beta}\left(1 + (\beta_Y^X)^2\frac{\sigma_Y^2}{\sigma_{\varepsilon_x}^2}\right) - \beta_Y^X\frac{\sigma_Y^2}{\sigma_{\varepsilon_x}^2} \tag{35}$$

   d. *(Region V and VI) If $\beta_Y^X > 0$, with $\tilde{\beta} > 0$ the upper and lower bounds are:*

   $$-\beta_Y^X\frac{\sigma_Y^2}{\sigma_{\varepsilon_x}^2} \leq \beta_X^Y \leq \tilde{\beta}\left(1 + (\beta_Y^X)^2\frac{\sigma_Y^2}{\sigma_{\varepsilon_x}^2}\right) \tag{36}$$

Appendix Table A3. Regions of estimated impacts

	$\beta_Y^X < 0$	$\beta_Y^X > 0, \tilde{\beta} < 0$	$\beta_Y^X > 0, \tilde{\beta} > 0$
$\beta_X^y < 0$	I)	IV)	V)
$\beta_X^y > 0, \tilde{\beta} < 0$	II)	n.a.	n.a
$\beta_X^y > 0, \tilde{\beta} > 0$	III)	n.a.	VI)

Note that economic intuition would imply that the relevant region are I (typical case) and IV (when remittances have positive impacts on GDP)

Proof. First, we note that from the definition of $\tilde{\beta}$, if the sign of $\tilde{\beta}$ and β_Y^X differ, we can identify the sign of β_X^Y. Second, note that from the definition of $\tilde{\beta}$:

$$\beta_X^Y = \tilde{\beta}\left(1 + (\beta_Y^X)^2 \frac{\sigma_Y^2}{\sigma_{\varepsilon_x}^2}\right) - \beta_Y^X \frac{\sigma_{\varepsilon_y}^2}{\sigma_{\varepsilon_x}^2} \tag{37}$$

Third, note that the variance of ε_Y is bounded:

$$0 \leq \sigma_{\varepsilon_y}^2 \leq \sigma_Y^2$$

Therefore, we can provide bounds for β_X^Y. Note also the bounds depend essentially on the identified signs of $\tilde{\beta}$ and β_Y^X. □

Now, note that if we were to have an instrument for Y uncorrelated to ε_Y and C, we could identify β_Y^X. Note this also implies we could identify $\sigma_{\varepsilon_X}^2$.

We argue that a partition of cross-border migration flows is uncorrelated to domestic conditions. In particular, we use destination-level shocks as identified in our setting to instrument for cross-border migration flows. The following assumptions are needed:

- Exogeneity: We require destination-level shocks to be orthogonal to unobserved confounders of domestic variables and only to impact macro-outcomes through migration. Given we have multiple shocks (and we are just aggregating them), we could potentially partially evaluate the exogeneity assumption.

- Relevance: We need to verify that the F-stat in the first stage is larger than 50. A preliminary assessment gives me an F larger than 20.