DOCUMENTOS DE TRABAJO

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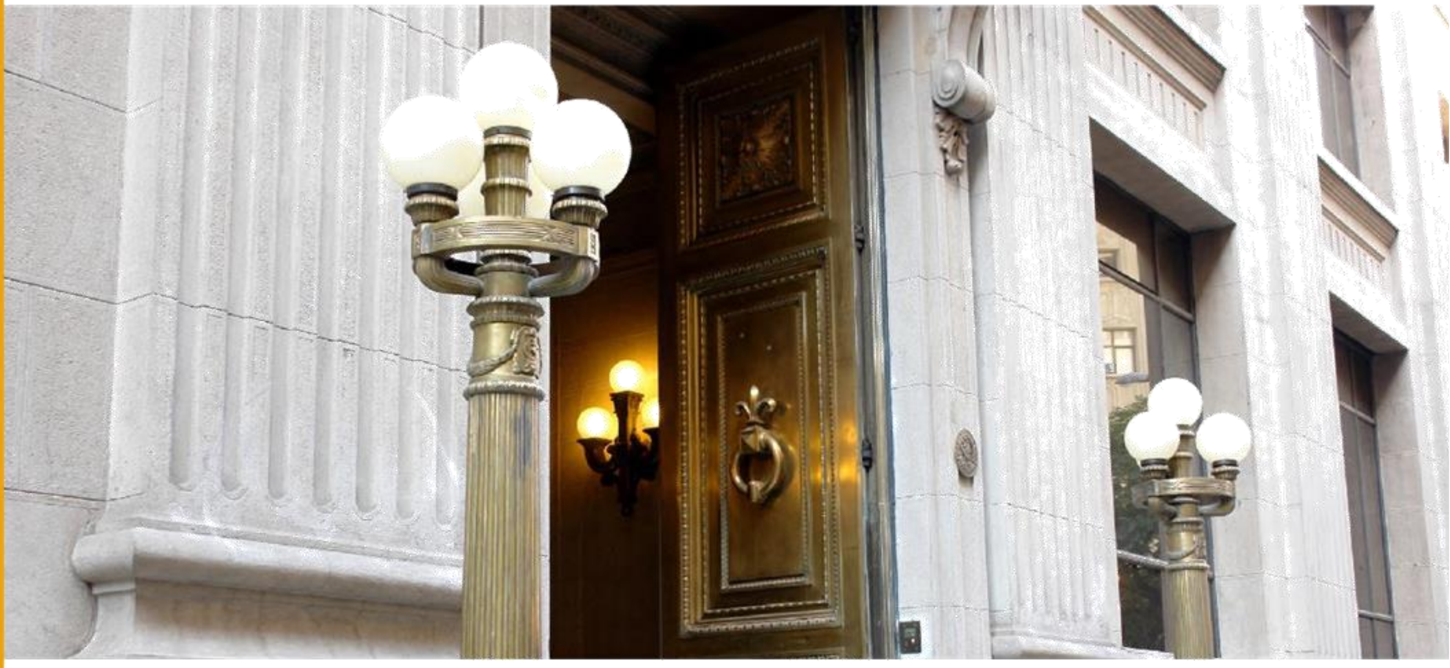
N° 1019 Agosto 2024
BANCO CENTRAL DE CHILE



Documentos de Trabajo del Banco Central de Chile
Working Papers of the Central Bank of Chile
Agustinas 1180, Santiago, Chile
Teléfono: (56-2) 3882475; Fax: (56-2) 38822311

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Through Drought and Flood: the past, present and future of Climate Migration*

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Abstract

This paper studies emigration pressures associated with climate change and sheds light on how they could evolve as climate degrades further. We start with a narrative approach focusing on four historical events. We document that severe climate disruption led to significant outward migration in the past, driven by social conflict, violence, and, in some cases, societal collapse. Then, we turn the analysis to the present. Using a regression panel approach for 154 countries between 1990 and 2020, we find a highly significant and nonlinear relationship between climate change and migration, with a U shape around a "temperature optimum." The nonlinearity is stronger in poorer countries. Indeed, despite tropical climatic zones having experienced the smallest increase in temperature thus far, they exhibit the largest increase in outward migration due to their higher initial temperature and lower GDP per capita (limiting adaptation). Finally, we use the estimated model to project future migration under five IPCC scenarios and for a tipping point scenario (AMOC collapse). We find moderate effects on migration increase under moderate climate scenarios, but that migration would double for tropical areas in the most extreme scenario. In the AMOC collapse scenario, where regions close to the poles will freeze, we find much larger effects, with total outward migration being driven by cold and temperate climate countries. We conjecture that our results constitute a lower bound of the possible effects, given (i) the non-well-captured nonlinearities and (ii) the potential fall in income due to climate damages that limit adaptation.

*We thank Lee Ullman and Daouda Sembene for useful discussions and comments on the historical case studies. We would also like to thank Anouch Missirian and Johannes Strobel for excellent discussions and the participants at the XXVI Annual Conference of the Central Bank of Chile, the Alumni Economic Workshop PUC-Chile, the NGFS 2nd Expert Network Research Seminar at the Central Bank of the People´s Republic of China, and the economic seminar at the Adolfo Ibañez University of Chile for helpful comments. We also thank Augusta Covarrubias for her excellent research assistance. The views expressed are those of the authors and do not necessarily represent the Central Bank of Chile (CBC) or its Board. All remaining errors are ours.

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Resumen

Este trabajo estudia las presiones migratorias asociadas al cambio climático y da luces sobre su posible evolución a medida que el clima se degrade aún más en el futuro. Comenzamos el análisis con un enfoque narrativo de cuatro eventos históricos. Documentamos que disrupciones climáticas severas en el pasado han estado asociadas a fuertes éxodos migratorios, gatillados por conflictos sociales, violencia y, en algunos casos, colapso social. Luego, trasladamos el análisis al presente. Estimando un modelo con datos de panel para 154 países entre 1990 y 2020, encontramos una relación muy significativa y no lineal entre el cambio climático y la migración, con forma de U alrededor de una "temperatura óptima". La no linealidad es más fuerte en los países más pobres. De hecho, a pesar de que las zonas climáticas tropicales han experimentado el menor aumento de temperatura hasta ahora, exhiben el mayor aumento en la migración hacia el exterior debido a su temperatura inicial más alta y su menor PIB per cápita (lo que limita la adaptación). Finalmente, utilizamos el modelo estimado para proyectar la migración futura bajo cinco escenarios del IPCC y para un escenario de *tipping point* (colapso de AMOC). Encontramos efectos moderados sobre el aumento de la migración en escenarios climáticos moderados, pero esa migración se duplica para las áreas tropicales en el escenario más extremo. En el escenario del colapso de AMOC, donde las regiones cercanas a los polos se congelan, encontramos efectos mucho mayores, con una migración mundial impulsada por los países con climas fríos y templados. Conjeturamos que nuestros resultados constituyen una cota inferior de los posibles efectos, dadas (i) las no linealidades no bien capturadas por la data del presente y (ii) la posible caída de los ingresos futuros debido a los daños climáticos que limitan la adaptación.

> The greatest destructions of mankind have been brought about by drought and flood
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> Plato, *Timaeus*

> The lingering cold spells left the pastoralists no other choice but to [. . .] migrate to warmer regions and to [. . .] plunder for their own food. The domino effect was felt [. . .] outside the cold spell [. . .] much more than [where] the cold spell [. . .] were the most severe.
>
> *Ellenblum (2012)*

1 Introduction

Migration from low-income countries has doubled in the last 30 years, a flow increasingly associated with climate degradation in nations heavily dependent on agriculture. This process is often confounded with weak institutions, violence, and strife. Countries at the receiving end have also been affected. With an increasingly negative perception among the general population, migration has contributed to social and political polarization associated with the recent deterioration of the geopolitical landscape. However, the scale of migration thus far will likely pale in comparison with future pressures. As climate further deteriorates, the map of uninhabitable ecosystems – many of which house some of the largest concentrations of people today – will continue to expand. Regions that will suffer the most are often those already degraded, suggesting observed trends may soon become highly nonlinear[1]. Thus, mass migration –the main adaptation mechanism of our species to survive climate change in the past– may constitute a key social tipping point in our modern, overpopulated societies.

This paper aims to study the emigration pressures associated with climate change and sheds light on how it might evolve as climate degrades further under different future scenarios. A key challenge to performing this analysis is that available data on migration goes a few decades back, a period over which the planet has seen a moderate increase of 1.2 degrees Celsius, which seems not to be a significant enough period to fully capture the potential highly nonlinear relationship between environmental degradation and migration.

Considering this limitation and as motivating pieces for our empirical work in the following sections, we start the analysis by performing a narrative approach focused on four events from the past that we consider as informative case studies about the potential relationship between climate events, environmental degradation,

[1] See IPCC Sixth Assessment Report (AR6) for a detailed explanation.

migration flows, and social/institutional dislocations. The four historical events we focus on are: the end of the Bronze Age (circa 1200 BCE), the collapse of the Eastern Mediterranean (circa 1000 ACE), the Bhola cyclone, the Indo-Pakistani war, and the creation of Bangladesh (1971), and the Rwandan genocide, and conflict in the Congo basin (1994-2001). Relying on non-economic sources, we document that severe climate disruption has led to significant outward migration in the past, driven by social conflict, violence, regime change, and, in some cases, societal collapse.

Then, we turn the analysis to the present. To shed light on the current relationship between climate events and outward migration, we perform a quantitative analysis relying on international census data from the United Nations available for 154 countries between 1990 and 2020. Regarding climate data, we identify the maize growing season using data from the FAO, and then we calculate the annual average temperature for those periods for each country. Using this panel data, first, we explore the relationships between the growth of the emigration stock and the average temperature at the country level. Classifying countries by their type of climate (i.e., cold, arid, temperate, tropical), we observe that tropical countries are the ones with the most significant growth in the emigration stock between 1990 and 2020, but at the same time, exhibit the smallest temperature increase.

In contrast, cold countries are those experiencing the larger increase in average temperature but the smallest growth of emigration stock. Given that the initial average temperature in tropical countries in 1990 was 24 degrees Celsius, much higher than the 15 degrees Celsius from the cold countries, this simple comparison suggests a nonlinear component in the relationship between emigration and temperature. We understand this result as suggestive evidence that a marginal temperature increase in already warm countries produces more damage and incentives to emigrate than the same marginal temperature increase in cold countries.

Next, to formalize the analysis, we perform a panel regression approach that relates emigration stock growth with temperature and precipitation. Similar to Missirian and Schlenker (2017), we estimate a reduced-form model including country and time-fixed effects, but we extend the analysis by including GDP per capita as an additional explanatory variable that interacts with the climate variables.[2] This allows us to capture the adaptation channel through which richer countries should be able to spend more resources in ameliorating the damages from climate change, reducing the pressure on its inhabitants to emigrate. The results show a highly significant and nonlinear relationship between climate change and migration, with a U shape around a "temperature optimum." The nonlinearity is stronger in poorer countries. Indeed, despite tropical climatic zones having experienced the smallest increase in temperature thus far, they exhibit the most significant increase in outward migration due to their higher initial temperature and lower GDP per capita, which limits their adaptation capabilities.

Finally, we use the previously estimated model to project future emigration under five IPCC scenarios and an Atlantic Meridional Overturning Circulation (AMOC) collapse scenario. The results show moderate effects on emigration increase under moderate IPCC climate scenarios, but it almost doubles for tropical areas in the most extreme IPCC scenario. Regarding the AMOC scenario, the temperature projections show that while the tropical countries will become warmer, the northern European countries will become colder, translating into an increasing outward migration for both groups of countries. In this tipping point scenario, the projections show a five times increase in total outward migration in the world after the AMOC collapse, going from 200 million in 2020 to 1 billion in 2100. We conjecture that our results constitute a lower bound of the possible effects, given (i) the non-well-captured nonlinearities and (ii) the potential fall in income due to climate damages that limit adaptation.

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[2] Also, Missirian and Schlenker (2017) uses asylum application data to the European Union. In contrast, we use international census data that accounts for the emigration flows to all the countries in the world

2 Related literature

Migration decisions can be influenced by the effect of climate change on the economic and social performance of countries. Carleton and Hsiang (2016) provide an excellent review of the state-of-the-art on this topic. They highlight key methodological innovations and results describing the effects of climate on health, economics, conflict, migration, and demographics. Regarding the economic drivers, one of the most studied channels is the climate-related decline in agricultural productivity. Several works have addressed this relationship at the country level, finding that the increase in extreme weather events (i.e., floods and droughts) has negative impacts on the productivity in this sector (e.g., Auffhammer et al. (2012) Auffhammer and Schlenker (2014), Lobell and Burke (2008), Schlenker and Roberts (2009), Welch et al. (2010)). Regarding labor productivity, there is also growing evidence that increasing temperatures are negatively affecting the ability of workers to perform their tasks around the world due to heat stress (e.g., Hsiang (2010), Heal and Park (2015), Graff Zivin et al. (2018), Graff Zivin and Neidell (2014), Somanathan et al. (2021)). Burke et al. (2015b) provides evidence that economic activity in all regions is being affected by the global climate due to a decline in agricultural and labor productivity, and if future adaptation mimics past adaptation, unmitigated warming is expected to reshape the global economy by reducing average global incomes roughly 23% by 2100. They also find nonlinear responses conditional on the countries' income level, which would lead to an increase in global income inequality relative to scenarios without climate change.

Regarding socio-political drivers, existing literature has shown that increasing temperatures and more frequent extreme weather events relate to a higher likelihood of social unrest. Hsiang et al. (2013) finds that deviations from normal precipitation and mild temperatures systematically increase the risk of conflict. Assembling and examining studies from different social fields post-1950, they find that climate's influence on modern conflict is substantial and statistically significant. Each 1-SD change in climate toward warmer temperatures or more extreme rainfall increases the frequency of interpersonal violence by 4% and intergroup conflict by 14% (median estimates). They conclude that given the large potential changes in precipitation and temperature regimes projected for the coming decades—with locations throughout the inhabited world expected to warm by 2 to 4 SDs by 2050—amplified rates of human conflict could represent a large and critical social impact of anthropogenic climate change in both low- and high-income countries. Similarly, Burke et al. (2015a); analyzing the results form 55 previous studies find that deviations from moderate temperatures and precipitation patterns systematically increase conflict risk. The contemporaneous temperature has the largest average impact, with each 1sd increase in temperature increasing interpersonal conflict by 2.4% and intergroup conflict by 11.3%.[3]

However, how the negative relationship between climate change and socioeconomic performance is translated into migration pressures is still a work in progress area of research. Despite a cross-country analysis seeming to be the most suitable approach to capture potential non-linearities in this relationship, most of the work done so far is focused on studying the influence of climatic factors on human migration at the country level because of data availability reasons. In this line, Feng et al. (2010) examines the linkages among variations in climate, agricultural yields, and people's migration responses using state-level data from Mexico. They find a significant effect of climate-driven changes in crop yields on the rate of emigration to the United States, with a 10% reduction in crop yields leading to an additional 2% of the population to emigrate. Bohra-Mishra et al. (2014), by following the province-to-province movement of more than 7,000 households in Indonesia over a decade and a half, finds that an increase in temperature (e.g., due to natural variations or global

[3] For additional references, see Miguel and Satyanath, 2011, Buhaug (2010), Reuveny (2008), and Bernauer et al. (2012).

warming) and, to a lesser extent, variations in rainfall are likely to have a greater effect on permanent outward migration of households than natural disasters.[4]

To the best of our knowledge, in the literature, there are just a few previous studies focused on understating the relationship between climate change and human outward migration from a cross-country perspective, which are the closest related to ours. Cattaneo and Peri (2016), using data from 115 countries between 1960 and 2000, analyze the effect of differential warming trends across countries on the probability of either migrating out of the country or from rural to urban areas. They find that higher temperatures in middle-income economies increased migration rates to urban areas and other countries. In poor countries, higher temperatures reduced the probability of migration to cities and to other countries, consistently with the presence of severe liquidity constraints. Missirian and Schlenker (2017) consider the effect of temperature fluctuations on refugees coming to the European Union from 103 source countries in the recent past (2000-2014). Similar to our results, they find a nonlinear relationship between emigration and temperature increases. More recently, Cruz and Rossi-Hansberg (2024) characterize migration and innovation as the main adaptation mechanisms for climate change. Developing a dynamic economic assessment model with high spatial resolution, they found heterogeneous welfare effects across countries. In particular, they find that countries in some parts of Africa and Latin America would face the largest losses and pressures for emigration.

Our contribution to this line of work is threefold. First, we extend the number of countries (154) and the time horizon (1990-2020) for the analysis, which should allow us to be more able to capture non-linearities, considering that most of the temperature increase with respect to the pre-industrial era has happened in the last decade. In addition, we extend the analysis by including a group of historical events

[4] Other related work is Marchiori et al. (2012), which examines the effects of temperature and rainfall anomalies in sub-Saharan Africa, and Nawrotzki et al. (2015), which investigates climate change impacts on US-bound migration from rural and urban Mexico between 1986–1999.

through a narrative approach that allows us to inform the non-linear relationship between climate change and migration for episodes. These episodes were selected considering that the temperature changes that characterized them were much larger than the changes that we have seen so far in the present, which we understand as an imperfect mirror of what we might see in the future. Second, we incorporate the level of income interacting with temperature changes as a proxy for the ability of countries to adapt to the physical impacts of climate change. The results show that including this variable is key to addressing the heterogeneous effects across climate zones. Third, as in previous work, we used our estimated model to project future emigration under the SSP climate scenarios developed by the IPCC. However, we also study a tipping point scenario related to the AMOC collapse. In contrast to the usual projections for the IPCC scenarios, where tropical countries are the most affected ones, under the AMOC collapse, cold and temperate countries show the largest outward migration flows.

3 The past: case studies in environmental stress, migration, and social dislocation.

The relevance of climate and environmental stressors in affecting social dynamics have been extensively discussed in the literature, spanning from the disasters in Central Europe during the XVIIth century (Parker, 2013), to the ebb and flow of warfare in Ancient China (Zhang et al. 2007). The link between climate and the environment with migration flows also has attracted significant attention, starting from the fact that early human migration out of Africa coincided with climate events (Beyer et al. 2021).

As motivating pieces for our empirical work in the following sections, we present four historical events that inform the potential relationship between climate events, environmental degradation, migration flows, and social/institutional dislocations.

In this section, we take a narrative approach, aiming to use these case studies as motivating episodes for the main empirical argument in subsequent sections. We recognize that this approach should be taken with several caveats. First, it relies heavily on non-economic sources, using historical, journalistic, and social science resources. Second, many of the topics addressed have not been settled in the relevant literature, so the assertions presented here should be taken as the authors' informed view regarding fields outside of economics. Thirdly, the arguments presented are naturally not structured to offer a formal identification strategy for finding causality, which is the bread and butter of empirical economics, but again, they are offered as motivating stories for the empirical work in follow-up sections.

Having said that, environmental stress and climate events have desirable characteristics for economic research. From the point of view of the affected societies, they can be considered an exogenous source of variation. Therefore, as historical phenomena are typically enmeshed in complicated multi-causal and simultaneous relationships, climate and the environment provide a certain degree of identification. This allows us to illustrate the potential interactions from a broad set of phenomena that seldom are considered jointly in economics, and the just-mentioned exogeneity of climate can describe that. An original climate event shock or environmental degradation can end up severely impacting the livelihood of the affected communities. It occurs through economic impact, life-threatening prospects, or both, such as drought, famine, floods, and pestilence, as common immediate occurrences. This initial impact can be amplified through social dislocation, rebellions, civil war, and general strife in the communities involved. Mass emigration is a result, either directly, to escape a deteriorated livelihood or the violence that plagues the area. In this process, communities often carry their original social norms and informal institutions. Moreover, the military or civilian characteristics of these migratory waves cannot be easily distinguished, as there is no clear-cut distinction between soldierly and civilian migrating groups in pre-modern or fragile societies. Finally, this migrating wave can interact in the new host regions, sometimes creating their social dislocation dynamics, provoking a "domino effect."

The idea that conflict can arise out of the arrival of migrants has been well-known since antiquity. Ancient Near East cultures had a precise identification of the nature of migration flows, stating the differences between diplomatic or mercantile and refugees or invaders (Beckman, 2013). The concept of xenophobia (fear of the stranger), as its etymology suggests, was a well-recognized concept in Ancient Greece. A clear example is the Greek/Barbarian dichotomy, which was "ubiquitous in Ancient Greece" and based on multiple dimensions such as language, intellect or knowledge, and pan-Hellenism. (Papanikos, 2020)

The four episodes we describe share most of the narrative just mentioned above. We take one episode of Antiquity, the end of the Bronze Age, one from the Middle Ages, the societal collapse in the Eastern Mediterranean, and two from contemporaneous times, the creation of Bangladesh after the Indo-Pakistani war of 1971 and the war in Africa that occurred after the Rwandan Genocide in 1994.

The end of the Bronze Age (circa 1200 BCE)

By 1200 BCE, the different peoples of the ancient world, spanning from the Aegean to modern-day Afghanistan, had been experiencing the flourishing of the Bronze Age. Then, over a period of a few hundred years catastrophic events led to the collapse of many of the significant actors that had progressively consolidated in previous ages. (Cline (2014) provides an overview of the events across the region and the scholarly debate on its causes).

Upper and lower Egypt had unified around 3000 BCE, and the kingdom of Egypt had expanded southward into Nubia and westward towards the Levant. In Mesopotamia, the cradle of civilizations after Sumer and Akkad, the Assyrian and Babylonian empires rose as important power centers alongside smaller kingdoms. In Anatolia, the Hatti (Hittite) empire had its capital close to modern-day Ankara, and covered an expanse from the Euphrates river to almost the Mediterranean Sea. Further west, Mycenaean Greece was constituted by several city-kingdoms in the Peloponnese and Central Greece and across the Aegean in Asia Minor. In Crete, the Minoans constituted one of the earliest advanced civilizations, with large multi-level palaces decorated with their well-known frescoes.

These ancient civilizations reached significant cultural advancements through the Bronze Age. For instance, the use of clay tablets became widespread, and the cuneiform script was adapted for communication and administrative recording in several of the era's languages. In Greece and Crete, Linear B provides the first evidence of the written Greek language, clay tablets, and also for administrative records. The Bronze Age also saw, of course, the development of Egyptian hieroglyphs. Religious practices were established and reached higher levels of complexity. There were several religious systems, such as polytheism (e.g., gods of the classical Greece pantheon), in Mesopotamia, Egypt, and Mycenaean Greece. However, dualistic and monotheistic cultures such as Zoroastrianism also arose.

The cultures of the time did not evolve in isolation but were in frequent contact. The Amarna clay tablets show an active diplomatic exchange between Egypt and neighbors Canaan and Amurru in the Levant. The Mari archive of clay tablets also proves that active trade and contacts were established between Mesopotamian kingdoms and the Mediterranean areas further west. The Ugaritic texts show a network of trade and diplomatic correspondence between dignitaries across the Eastern Mediterranean and Mesopotamia. Egyptian hieroglyphs depict instances of diplomatic visits to the Pharaohs by Minoan and Mycenaean delegations. Economic relationships are apparent from archaeological finds of, for instance, lapis-lazuli only available in modern-day Afghanistan, in burials in Egypt, or in Mycenaean-style swords in Hittite locales. Most importantly, using bronze to manufacture artistic, religious, or military artifacts required access to copper, abundant in Cyprus and more extensively present further east into Mesopotamia.

These trading and diplomatic exchanges did not preclude violent confrontations between the major powers of the era. The Mycenaeans invaded and took over Crete around the middle of the second millennium BCE and confronted the Hittites in a series of conflicts that could have inspired the Trojan War of the Illiad. The Hittites projected power into Mesopotamia, facing off against several kingdom confederacies west of Assyria, burning Babylon, and maybe fighting naval engagements against Cyprus. Egyptian tomb hieroglyphs record notable conflicts, such as the battle of Meggido in 1479 BCE, between Thutmose III and the Canaanites, and the battle of Kadesh, close to the current northern Syria-Lebanon border, between Ramesses II and the Hittite Emperor Muwattalli II, in 1274 BCE.

As mentioned, the vibrant Late Bronze Age came to a shuddering halt in a civilization's collapse. Most of the leading civilizations had disappeared within a few hundred years, except Egypt. The Hittite empire remained only a reference in ancient texts until the city of Hatusa was re-discovered in the XIXth century. The Mycenaean kingdom-states vanished, the Assyrian empire declined temporarily, and Babylon lost all independence from the latter. After several hundred years of a dark age, the region moved into the Iron Age, with the emergence of the city-states of classical Greece and the Neo-Assyrian and Persian empires further east. The Kingdoms of Judeah and Samaria appeared in the power vacuum created in the Levant from the collapse of Hatti, Assyria, and the retrenchment of Egypt. What was the cause of this collapse? A combination of mass migration and invasions from the western and central Mediterranean, coupled with severe droughts and other natural disasters, proved to be disruptive enough to take down whole empires. It remains a hotly debated issue in the historical discipline, centered more on the relative merits of specific causes and how they interacted rather than the broad outlines of what transpired.

The archeological record suggests that over a few decades, numerous locales in the eastern Mediterranean, in what is now Syria, Lebanon, Jordan, and Israel, many locales were destroyed in fiery conflagrations. It has been attributed partially to waves of invasions or migration from the so-called Sea Peoples (Sanders et al. 1985), traveling by sea and land. They could have entered areas already depopulated for other reasons or destroyed them as they entered the region. The primary record of their existence is in Egyptian hieroglyphs, depicting the successful repulse of their invasion by Pharaoh Ramesses III. The name given to these groups in ancient texts has been sometimes interpreted as identifying either their origins (such as the *Sherden* originating maybe from Sardinia) or their descendence (such as the *Peleset* foreshadowing the Philistine or the Palestine peoples).

Evidence shows that climate events might have caused these large and disruptive migrations. A significant drought affected the Mycenaean city-kingdoms, bringing about their demise (Carpenter, 1966). Moreover, it has also been argued that droughts affected Central Europe and Northern Italy, leading to a mass migration towards the East and South of more than a hundred thousand people (Kristiansen, 2018). Severe climate events seem also to have contributed directly to the demise of the Hittite empire. Although the record shows they were well used to managing the vagaries of climate fluctuations, around 1200 BCE, a multi-year drought devastated the region. The evidence for this comes from the examination of tree rings. These show a multidecade spell of dry weather, which also coincides with more frequent mentions of famines and grain scarcity (Manning et al. 2023).

Climate events and the Eastern Mediterranean collapse (circa 1000 ACE)

Over the millennia, the Nile River has provided a key source of sustenance to the inhabitants of Egypt, which would otherwise be surrounded by barren deserts and the seas. The regular annual floods of the Nile valley, created as Indian Ocean monsoons enter inland south in Africa, increase the volume of the river, which, as it subsides back, leaves a rich soil where different seeds can be sown. The extent of grain production in the Nile River could reach enough volumes to be stored prudentially or even exported to neighboring areas around the Mediterranean and into the Levant.

Hundreds of miles to the northeast of the Nile Delta, the steppes across the Amu Darya River (currently a part of the border between Turkmenistan, Afghanistan, Uzbekistan, and into Tajikistan, an area known historically as Transoxiana from the river's Latin name Oxus) were home to nomadic and pastoralist Turkic tribes. These tribes depended on the annual migration pattern between winter grounds and more fertile areas.

Significant climate dislocations dramatically altered both areas at the turn of the first millennia. On the one hand, although the Nile River was subject to drought spells of about one drought year every half-century through the six centuries before 900 ACE, around the close of the first millennium, nine episodes of drought, totaling twenty-six years, hit the valley over a period lasting more than a century. It represented a tenfold increase in the frequency of droughts compared to the previous six centuries. As noted in the previous case study, ancient civilizations were able and prepared to withstand regular periods of drought, planning accordingly during the years of abundance. However, the institutional and administrative underpinnings were not generally prepared to deal with periods of food scarcity that lasted more than two years.

On the other hand, and at a similar time, a cold weather anomaly hit the steppes, dislocating the seasonal migration pattern of the pastoralist Turkic tribes. Cold anomalies had been recorded before, but as Transoxania and Mesopotamia were affected now at the same time as Egypt ceased to provide a buffer of grain supply due to the droughts, calamitous famines spread across the whole region including Mesopotamia and Syria (Ellenblum, 2012). As the level of the Nile dropped to shallow levels between 1000 and 1100, the population of Egypt collapsed. While in the centuries, between 700 ACE and 900 ACE, its population hovered around 2.5 million, it dropped to 1.6 million around 1000 ACE (Russell, 1966).

The economic effects of the climate shocks experienced from Egypt to Mesopotamia and Iran are apparent in modern statistical compendiums. According to the Maddison historical database (Bolt & Van Zanden, 2020), GDP per capita in Egypt in 1000 ACE was 18% below 730 ACE, and by 1120 ACE was still 10% below the level three centuries before. In Iraq (that is, Baghdad), income per capita in 1120 ACE was 17% below the level observed 120 years before, while in Turkey, it had fallen 3% over the same period. These magnitudes are even more dramatic if one assesses the gap between workers' incomes and the subsistence level of wages. The historical record shows that the daily wage for unskilled urban workers in Cairo and Baghdad fell from three to four times the subsistence level for a family of four by 800-900 ACE, to two times in Baghdad and one and a half times in Cairo by 1100 ACE (Pamuk & Shatzmiller, 2014).

After the burst of conquests, the Muslim world in the Eastern Mediterranean was organized as independent regional powers or dynasties, such as the Fatimid Caliphate in Egypt, the Buyid Amirates in Mesopotamia and Persia, and the Samanid Amirates further east towards Transoxania. Bordering them in Asia Minor was the remainder of the Byzantine Empire that had withstood the initial Arab Muslim advances. The economic effects that resulted from the climate events described were also the result of amplifications stemming as institutions of government felt the pressure of restive and hungry populations, collapsing tax revenue, and internecine violence anti-Christian as well as Sunni-Shia riots. Land taxation in Egypt fell by a third between the late 9th and the late 11th centuries (Russell, 1966), where riots spread to the unpaid soldierly. Bedouin raids compounded the chaos in Egypt, and the Fatimid dynasty resorted to price controls and the seizure of all the grain traversing the Nile.

Further east, the cold anomalies started to generate sizeable Turkic migration waves, which came to be grouped under the denomination of Seljuk Turks. In their south-westerly advance, Iran collapsed, and Baghdad fell into civil war. The Seljuk Empire ended the centuries-old dominance of the Arab Muslim dynasties from the Levant eastward. As they pushed into Asia Minor, heavy pressure came to bear on the Byzantine Empire and the Christian kingdom of Georgia. The alterations these events provoked for Christian pilgrimages to Jerusalem, alongside the calls from Byzantine emperor Alexios I Komnenos for military assistance, were crucial ingredients for the first Crusades in the late 11th century.

The Bhola cyclone, the Indo-Pakistani war of 1971, and the creation of Bangladesh

The end of the British Raj in 1947 was a tumultuous and violent episode. The promises of independence from the British Empire, exhaustion from the Global War in Europe and Asia, both in the subcontinent and in the United Kingdom, local rebellions, and ethnic and religious tensions all came together and resulted in the division of the Raj among roughly religious lines. This division came through as a turbulent political solution to a tough three-side negotiation between the United Kingdom, which looked to extricate itself from colonial oversight, the Indian National Congress party, which had been advocating since the late XIX century for independence, and the Muslim League, that had been formed early in the XX century to secure political representation for Muslims in the Raj. The tensions between these three leading players were accelerated by ethnic violence between Muslims and Hindus as the date of independence approached, particularly in mixed communities. The resulting violent partition saw the creation of two different countries. On the one hand is India, and on the other is Pakistan, formed by West and East Pakistan (today's Bangladesh). Pakistan was then originally separated geographically by more than a thousand kilometers. In the partition, millions died, and millions migrated (Bharadwaj et al. 2008).

The relations between India and Pakistan remained tense and resulted in several border conflicts, some of which are still latent, such as in Kashmir. The nature of these tensions was and remains multifaceted, ranging from border disputes, geopolitical proxy associations with the USA and the USRR during the Cold War, and contrasting approaches and conflicts with China. The division of the Raj had split the Bengali region among religious lines between India and East Pakistan, a split that also harked back to British rule.(Kalyanaraman, 2022) During the 1960s, these were compounded by ethnic and political divisions within Pakistan. The center of power in Pakistan resided in its Western part, although East Pakistan represented a larger share of the population. This disparate division of political power was further exacerbated by ethnic divisions, as West Pakistani citizens are of Punjabi and Pashtu descent, while East Pakistanis were mostly Bengalis.

After independence, Pakistani institutions were weak, as the country saw a sequence of military coups. This further impaired the possibility of appropriate representation in a country sharply divided by ethnicity and geography. By 1960, demands for higher degrees of Bengali autonomy within Pakistan gathered steam, mainly through the Awami League led by Sheikh Mujibur Rahman. Its main political planks were the recognition of the Bengali language and the push for a much looser Federal organization of Pakistan. Social turmoil in the last part of the decade led to a military government takeover led by the Commander in Chief of the Army, Yahya Khan, who both suspended the Pakistani constitution but also created the conditions for the first-ever elections in all of Pakistan, as a way to defuse internal turmoil. They were scheduled to be held in late 1970.

Into this cauldron of political and ethnic tensions came a natural disaster of historic proportions. The (former) East Pakistani coastline corresponded to the Indian Ocean part denominated the Bay of Bengal. The agricultural activities therein benefit from the fact that the area of modern Bangladesh corresponds to the drainage basin of large rivers, forming the Ganges delta. It is a low-lying area with an average height of just a few tens of meters above sea level. Tropical cyclones form in the Bay of Bengal several times a year, contributing to the monsoon rains that provide critical support for the agricultural areas surrounding the Bay. As in many other South and East Asian areas that share these characteristics, high population density can be supported by and contributes to agricultural activities that are water intensive.

The 1970 monsoon season, however, was extreme. In November, the Bhola cyclone, probably the deadliest in modern records, reached wind speeds of nearly 200 km/h. It made landfall in the Ganges delta, killing hundreds of thousands of people. The whole area was devastated mostly due to tidal waves that ravaged towns and crops. The magnitude of the disaster in East Pakistan, part of a country with weak institutions, was compounded by ineffective support from the central government. On the one hand, the geographical distance between the affected areas and the centers of administrative and political power thousands of km away likely contributed to the lackluster government response. On the other hand, some views indicate that extant political divisions created little incentive for the West Pakistani leadership under Yahya Khan to assist. (Miklian, 2022)

In any case, the resulting political backlash was brutal. In the elections a month later, the Awami League secured most seats in the National Assembly, all from East Pakistani constituencies. In contrast, the Pakistan People's Party (PPP) gained the second most extensive set of seats from West Pakistan. As these results implied that the independence-minded Awami League would have control of the new government, an immediate political crisis occurred. Yahya Khan postponed the National Assembly's inauguration and attempted to mediate between the PPP and the Awami League, but talks floundered. Unrest spread through East Pakistan, and the conflict reached a tipping point in March 1971 when the government decided to crack down on Eastern Pakistani independent and nationalist movements. It has also been pointed out that political dynamics were well on the way to pushing East Pakistan into independence, even without the repression and violence that followed the elections. (Rikhye, 2020) The resulting civil-war conditions created acute internal strife, as the East Pakistani military split along ethnic lines, forming nationalist paramilitary groups such as the Mukti Bahini. Millions of refugees fled across the border to India, joining an already large diaspora from the previous year's exodus from the immediate dislocations created by the cyclone. Moreover, from bases across the border, the Mukti Bahini continued operations into East Pakistan, and an independent Bangladeshi government was established.

The intervention of India in the civil war responded to a multitude of reasons, both internal and external. (Batabyal, 2020) In practice, in late 1971 and within a few days, the East Pakistan military had been defeated, the civil war was over, and East Pakistan was on track to become independent Bangladesh.

Environmental degradation, the Rwandan genocide, and conflict in the Congo basin (1994-2001)

Between April and July 1994, hundreds of thousands of people, mainly of Tutsi ethnicity, were murdered in a genocidal rampage in Rwanda by Hutu gangs.[5] The specific and immediate trigger to this horrendous event was the death of Rwandan President Juvenal Habyarimana, a Hutu, as his plane exploded, apparently from a missile strike, killing also Burundi's President Cyprien Ntaryamira, who was Tutsi. Rwanda's Prime Minister Agathe Uwilingiyimana, a Hutu, was assassinated the next day. In the ensuing power vacuum, a Hutu extremist government took power in April 1994 in Rwanda, inciting and executing the genocide.

It has been noted that the deeper causes of the genocide lay in a complex interaction between environmental degradation, ethnic tensions, and weak institutions. (Diamond (2011), Percival and Homer-Dixon (1996)) In Rwanda, one of Africa's most densely populated countries in Africa, 96% of the population lived in the

[5] The exact number of victims of the genocide might never be known. The range of estimates is wide and has changed over time as well. (Guichaoua, 2020)

countryside, where 90% of the labor force was employed in agriculture. Unsustainable practices led to falling soil fertility, while degradation of watersheds and forest erosion resulted from overcultivation. This dwindling resource base resulted in increased stress between ethnic groups. In pre-colonial times, "Tutsi" and "Hutu" were fluid classifications based not on strict ethnic differentiation but rather on socioeconomic status and the positions within the economic system, mainly between pastoral (Tutsi) and agricultural (Hutu) activities. Colonial rule increased the rigidity of this classification as the Tutsi majority became associated with power and wealth while the Hutu minority with subordination and toiling the fields. Rwandan independence resulted in the perception of a Hutu-dominated state apparatus.

In the early 1990s, several developments helped set the stage for the genocide (Richmond & Galgano, 2019). As the exploitation of available land was reaching its natural limits, aggregate agricultural production fell 20% in per-capita terms between 1980 and 1990. A severe drought affected East Africa and Rwanda in particular, as rainfall totals fell 30%. The international prices of the cash crops, coffee and tea, exported by Rwanda collapsed at the time. Furthermore, from 1990 to 1992, the country was engulfed in civil war as the Rwandan Patriotic Front (RPF), predominantly made up of post-independence displaced Tutsi and their descendants, invaded Rwanda from their bases in Uganda, intending to topple the government. By July 1992, international pressure and governmental setbacks in the conflict allowed for a fragile agreement, signed in August 1993, between the RPF and Habyarimana's government. Tensions, however, lingered because of the existence of radical paramilitary groups associated with the Hutu state apparatus, the mainly Tutsi RPF, and the Rwandan army. The situation blew up into full-scale conflict and genocide less than a year later with Habyarimana's assassination.

The United Nations Security Council authorized in June 1994 a French-led military intervention (Operation "Turquoise"). Three thousand French and African troops entered Rwanda but were ineffective in stopping the genocide. As they left in August, the RPF took power, and shortly afterward, the genocide stopped.

The social and economic dislocations provoked by the genocide were enormous in Rwanda. As mentioned before, many hundreds of thousands of Rwandans died in the genocide (a significant fraction of the estimated Tutsi population). Per-capita output fell 36% in 1994, when the year before it had already fallen by 15%. Moreover, the end of the genocide and the collapse of Hutu rule did not stop regional violence. As the extremist Hutu government was falling under the pressure of the RPF, its cadres fled, alongside close to two million Rwandans of Hutu ethnicity, to neighboring Zaire. They took with them Central Bank reserves and established themselves in refugee camps right across the Rwandan border.(Prunier, 2008)

The existence of those large refugee camps where the Hutu genocidaires escaped proved to be a thorn in the side of some members of the new national unity Rwandan government. Particularly for General Paul Kagame, the head of the RPF and prominent Tutsi leader within the National Unity government. The institutional weakness of Zaire, where Mobutu Sese Seko played the refugee issue for domestic political goals, exacerbated the lingering tensions. In September 1996, General Kagame sent the Rwandan army across the border to deal with the alleged threat the militarized Hutu refugees posed. This invasion occurred in a regional situation where Zaire and its resources were perceived to be up for grabs. Eventually, Burundi, Uganda, and Angola, among others, also participated in the invasion. Hundreds of thousands of the Hutu refugees escaped West and Southwest through Zaire as the conflict flared up. Under the pressure of invasion and civil war, the Mobutu regime collapsed three years after the Rwandan genocide. Laurent Kabila became the leader of the newly denominated Democratic Republic of Congo (DRC), supported by the invading forces. War continued, however, and a fragile status quo was reached in the early 2000s.

The cost of the war in the DRC (formerly Zaire) was very high. Many of the thousands of Hutu refugees who escaped eventually returned to Rwanda. However, the United Nations Refugee Agency reckons that two hundred thousand refugees disappeared, likely perishing during the war. Other estimates point to a figure 50% higher. (Prunier, 2008) The war left the most significant human toll since World War II, with over 5 million deaths, and GDP per capita in the DRC fell close to 40% between the years prior to the Rwandan Genocide and 2001.

4 The Present: Quantitative Analysis

The previous section introduced the potential relationship between climate events and migration through the lens of the past by presenting four historical events. Now, in this section, we turn into a quantitative analysis to shed light on this relationship in the present. As an empirical approach, we propose a reduced-form specification that relates the emigration growth of a country with changes in climate-related variables as well as with the level of income per capita and population, and we estimate it using panel data for 147 countries over the period 1990-2020. Then, in the next section, using the estimated model, we will try to give some insights into how migration pressures will change under different global warming scenarios.

This section starts by describing the data construction and several sources from which we gathered information. Then, we explain the empirical approach used to account for the relationship between international migration and climate-related variables, and we end the section by presenting the results from the estimated model.

Data

Climate classification data. We've employed the latest Koppen climate classification information, revised by Peel et al. (2007), to assign each nation a categorization encompassing the majority of its land. Our approach employs a more comprehensive classification system involving four categories: tropical, temperate, arid, and cold. Please refer to Figure 1 for a graphical depiction of this classification.

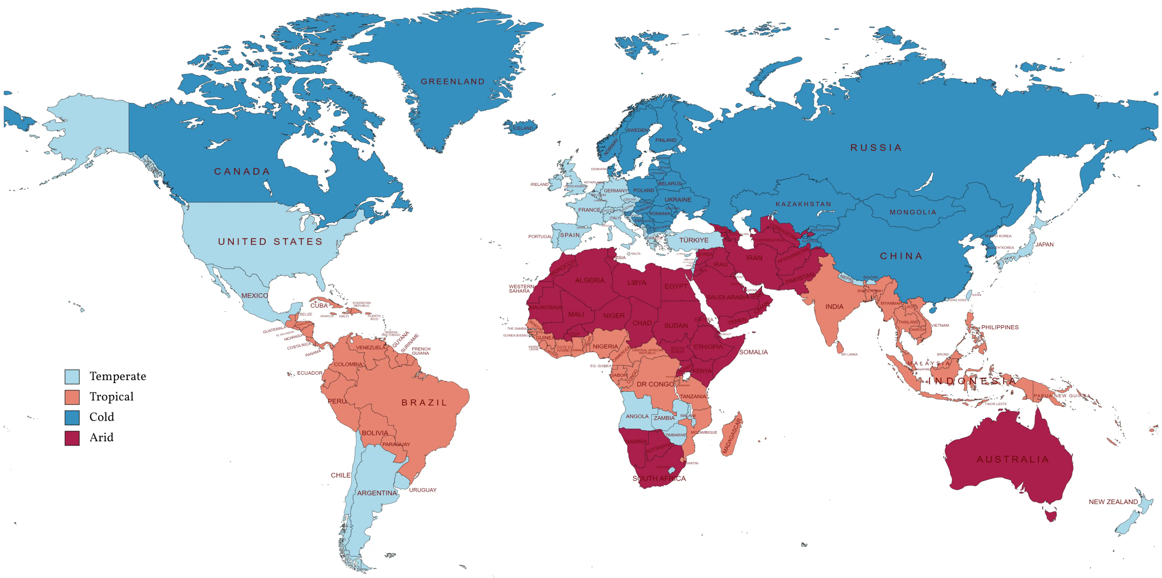


Figure 1: *Climate classification by country. The estimation for each country is defined as the climate classification for the main covering area – see Peel et al. (2007) for more detail. The figure shows the more general classification: tropical, temperate, cold, and arid.*

Migration data. To gain insights into global migration patterns, we rely on census data from the Department of Economic and Social Affairs and Population Division (UNDESA) at the United Nations. This comprehensive dataset covers 1990 to 2020, with a five-year interval, and offers a bilateral accounting of migration stocks between countries. It shows the foreign population residing in each country and their respective countries of origin. Thus, we can create a variable that reflects the number of individuals living abroad based on their birth country.

Agricultural data. The Crop and Livestock Production and Utilization data from the FAO's Data Collection registers the total value for producing different framing goods by country. This data helps us identify the countries that farm maize. Additionally, we use information from the Land & Water section of FAO's database to determine the duration of the growing season of maize and the month when it begins for different climate classifications. By utilizing the classification in Peel et al. (2007), we can build a variable containing the months maize grows for each country.

Weather data. The Climate Change Knowledge Portal, hosted by the World Bank, houses valuable data covering most landmasses (excluding Antarctica) on a 0.5° latitude by 0.5° longitude grid. This information is gathered by interpolating monthly climate anomalies observed at weather stations. We rely on the extensive long-term time series (1901-2020) featuring monthly data by country. Additional details can be found in the Harris et al. (2020).

Economic data. We rely on the World Development Indicators provided by the World Bank, which comprises a time series of various economic variables for each country. Among these variables, we primarily use each country's total population data and the GDP per capita (PPP) in 2017 USD.

Weather projections. We utilized data from the Climate Change Knowledge Portal (Harris et al. 2020) for various scenarios outlined in Table 1.

Projected population. We have utilized the data provided on the *AR6 Scenario Explorer* website, which IIASA hosts. Specifically, we have used version 1.1 of the country-level estimates generated by the IIASAPOP 2.0 model. The model's output has been estimated for different SSP scenarios and their experimental variations.

Trends over time

Despite a brief estimation period, we find a significant and steady rise in temperature. By 2020, the world's mean temperature had risen by 4% relative to the benchmark of 1990 (0.8°C). It is worth mentioning that those nations deemed "cold" experienced the highest rise in temperature, with nearly 8% compared to 1990, while tropical nations had the smallest rise at just under 2.5% compared to 1990 (Figure 2).

Along with the rising temperatures, emigration has also significantly increased – meaning the number of individuals residing in a country other than their homeland. In 2020, there was a global cumulative increase in emigration of nearly 150%. The

Table 1: *Description of the scenarios used for projections (Harris et al. 2020).*

Scenario	**Description**	**Warming range by 2100**
SSP1-2.6	Scenario that supports increasing sustainability with global emissions cut severely but reach net zero after 2050.	1.3°C - 2.4°C
SSP2-4.5	Presents a 'middle of the road' scenario in which emissions remain around current levels before starting to fall around mid-century but do not reach net zero by 2100.	2.1°C - 3.5°C
SSP3-7.0	Presents a pathway in which countries are increasingly competitive, and emissions continue to climb, roughly doubling from current levels by 2100.	2.8°C - 4.6°C
SSP5-8.5	Presents a future based on an intensified exploitation of fossil fuel resources where global markets are increasingly integrated, leading to innovations and technological progress.	3.3°C - 5.7°C

countries with colder climates experienced the most significant increase, with an almost 250% rise, while temperate countries had a more modest increase, less than doubling their emigration stock by 2020. However, it is worth noting that tropical countries have also seen a substantial increase in emigration, with the second-highest growth rate for most of the period examined. The number of people emigrating from tropical countries has tripled by 2020 (Figure 3).

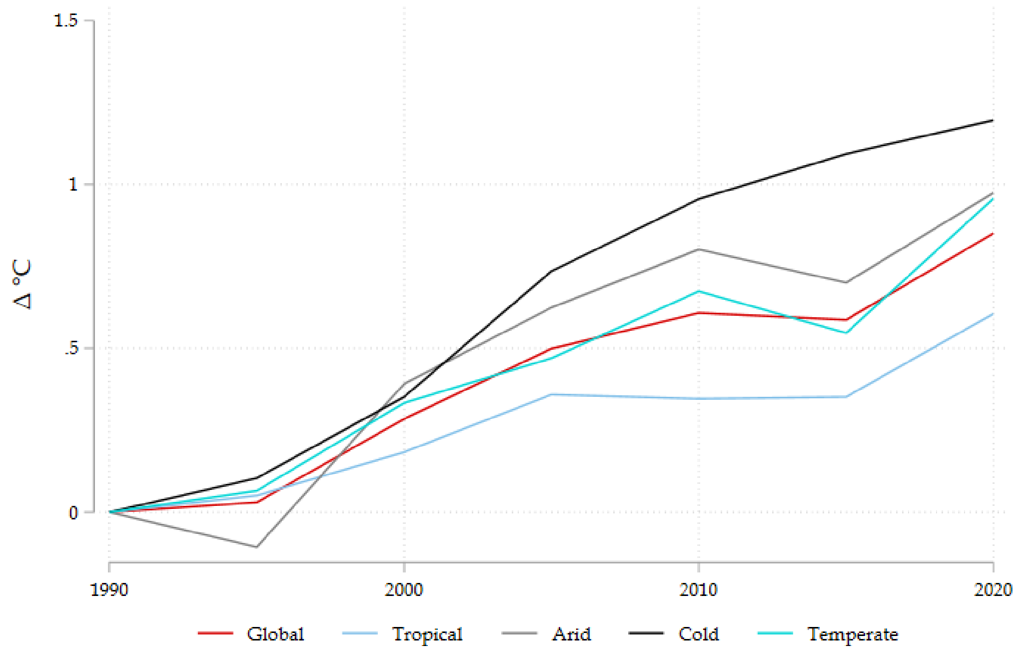


Figure 2: *Cumulative growth rate of the average temperature for the growing season of maize, with respect to 1990. Cold areas show the highest increase in temperature, while tropical areas show the lowest increase in temperature.*

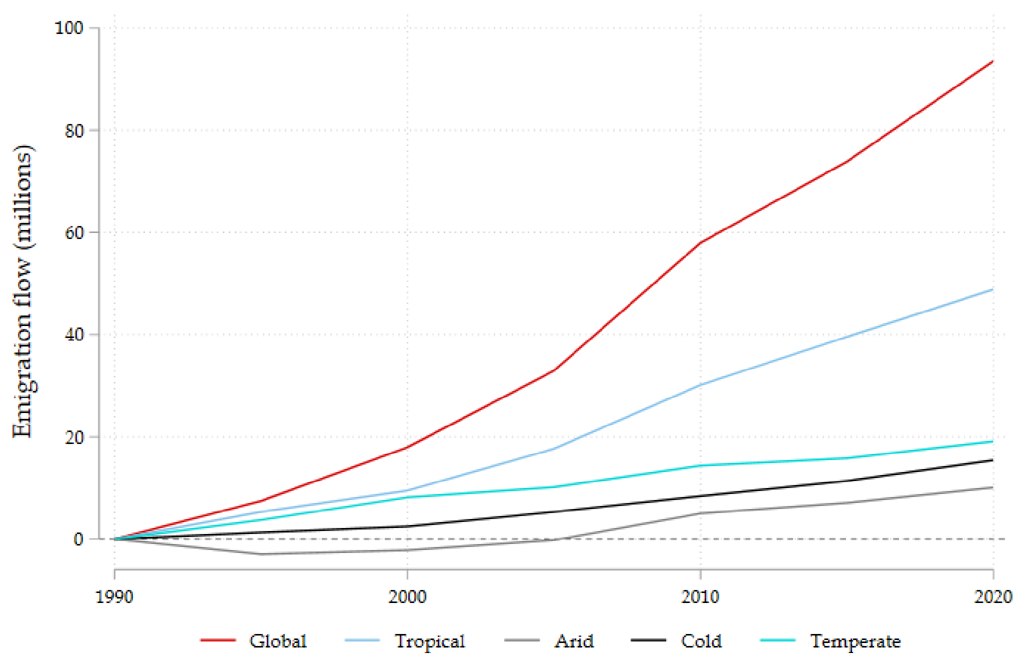
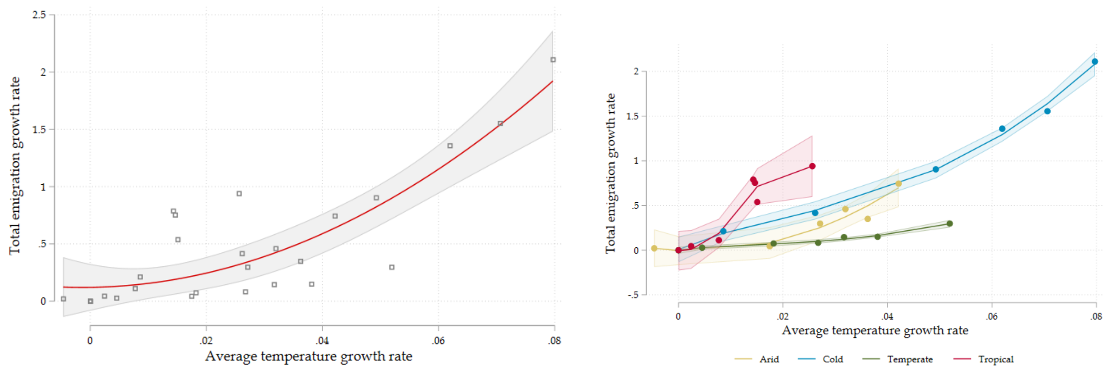


Figure 3: *Cumulative growth rate of the emigration stock, with respect to 1990. Cold areas show the highest increase in emigration, while temperate areas show the lowest increase in emigration.*



(a) *Global* **(b)** *By climate classification.*

Figure 4: *Relationship between temperature and emigration. The scatter plot is constructed using the average of the emigration and temperature growth rate by year and climate.*

Careful analysis of the relationship between emigration and temperature rise during the studied period is vital. Notably, data reveals a significant surge in emigration as temperature continues to climb, highlighting a positive and non-linear correlation between the two factors. This indicates that emigration is particularly sensitive to significant temperature spikes, as depicted in Figure 4a.

It is worth noting that there is a significant variation in the relationship between climate type and emigration. Countries with tropical climates are more susceptible to temperature fluctuations, resulting in a significant increase in emigration despite experiencing the slightest temperature increase among the countries studied (as shown in Figure 4b).

Empirical approach

To account for the relation between international migration and climate-related variables, similar to Missirian and Schlenker (2017), we propose a reduced-form model that relates a migration measure with temperature and precipitation. In the same spirit, we estimate such a model using panel data with country and time-fixed effects, which allows us to control for any time-invariant unobservable that affects migration decisions and correlates with the climate variables.[6]

However, we extend the approach developed by Missirian and Schlenker (2017) in at least three ways. First, instead of using asylum applications of non-OECD countries to the EU, we use census emigration data available in UNDESA –which considers migration from all countries toward the rest of the world–, allowing us to construct the total emigration stock for each country of origin in the world and also grants us more geographical variation to inform the regression. This extension will also be important for the next section, where we will use the estimated model to project emigration under several possible future climate scenarios. Because we are taking into account the total emigration stock for all the countries in the world, the estimated model will allow us to project the total emigration for each country of origin to the rest of the world rather than towards a particular region. Second, Missirian and Schlenker, 2017 work with data between 2000 and 2014, while we are taking advantage of the fact that UNDESA data is available between the years 1990 and 2020 at a five-year frequency, which allows us to capture a larger time variation of the global warming process. Third, and most importantly, we include GDP per capita as an additional explanatory variable. The income level is potentially a driver of emigration, warranting its inclusion in the empirical estimates, as highlighted in Rikani et al. 2022. However, we posit that the interaction of GDP per capita with changes in the climate variables is also a potentially important determinant of migration. The development level influences countries' ability to adapt to climate change, an ability which we expect to increase with the country's income level.

Formally, to link the growth in the total emigration stock to climate variables in the source country, we estimate the following fixed effect regression model:

$$E_{it} = (\beta_1 + \beta_2 y_{it})T_{it} + (\beta_3 + \beta_4 y_{it})T_{it}^2 + \beta_5 y_{it} + \theta Pop_{it} + \alpha_i + \gamma_t + \epsilon_{it}, \qquad (1)$$

[6] For example, the geographical location could correlate with both climate variables and the costs of emigrating.

where E_{it} is the ratio between the emigration stock from country i in year t with respect to the emigration stock from the same source country in the year 1990. T_{it} corresponds to the mean temperature of the maize growth season of country i over a five-year period where the last year is t. y_{it} corresponds the log of the GDP per capita of country i in year t. Pop_{it} is the ratio between the population of country i in year t with respect to its population in 1990. α_i and γ_t are the country and year fixed effects, respectively. Finally, ε_{it} is the error term.

Results

Table 2 presents the OLS estimation for four alternative specifications, which differ in whether we include precipitation on top of temperature as weather variables and the inclusion of the log of the GDP per capita interacting with them. All especifications are estimated with robust standard errors.

Column (1) corresponds to the closest model to the one estimated by Missirian and Schlenker, 2017. Here, we regress the ratio of emigration stock on linear and quadratic terms for temperature, and we control for population growth and country and time-fixed effects. The results, in line with Missirian and Schlenker, 2017, show a negative coefficient for the linear term and a positive coefficient for the quadratic term. These results imply a non-linear relationship between emigration growth and temperature changes, with both negative and positive deviations from an optimal temperature leading to an increase in emigration. In particular, the optimal world average temperature under this specification is 20.7 degrees Celsius. Column (2) adds precipitations as an additional weather variable to the previous specification, but the resulting estimated coefficients are not significant.

The model in Column (3) extends the model from Column (1) by including the log of GDP per capita interacting with the linear and quadratic terms of temperature. The estimated coefficients for these new interactions are positive for the linear relationship and negative for the quadratic one. This implies that the initial positive quadratic effect of temperature is dampened for richer countries.

Table 2: *Baseline regression*

	(1) Only Temperature	(2) Temperature and Rain	(3) Baseline	(4) Baseline with rain
Population norm. to 1990	-0.117	-0.139	0.009	0.034
	(0.13)	(0.14)	(0.07)	(0.07)
5-year average temperature	-1.626**	-1.662**	-5.084**	-5.092**
	(0.58)	(0.59)	(1.83)	(1.91)
5-year average temperature^2	0.039**	0.039**	0.137**	0.135**
	(0.01)	(0.01)	(0.05)	(0.05)
5-year average total precipitations		-0.005		-0.021
		(0.00)		(0.01)
5-year average total precipitations^2		0.000		0.000*
		(0.00)		(0.00)
Log GDP pc (PPP, USD 2017)			-3.929*	-4.091*
			(1.59)	(1.65)
Temperature and GDP linear interaction			0.435*	0.426*
			(0.17)	(0.18)
Temperature and GDP quadratic interaction			-0.012**	-0.012*
			(0.00)	(0.00)
Rain and GDP linear interaction				0.002*
				(0.00)
Rain and GDP quadratic interaction				-0.000*
				(0.00)
Opt. Temp.	20.7	21.1	24.5	24.5
N countries	154	154	147	147
N years	7	7	7	7

Standard errors in parentheses

Weather variables are estimated for the growing season of maize.

* $p < 0.1$, ** $p < 0.01$, *** $p < 0.001$

One plausible explanation for this result is that higher-income countries are more capable of implementing adaptation policies because they have the resources or the

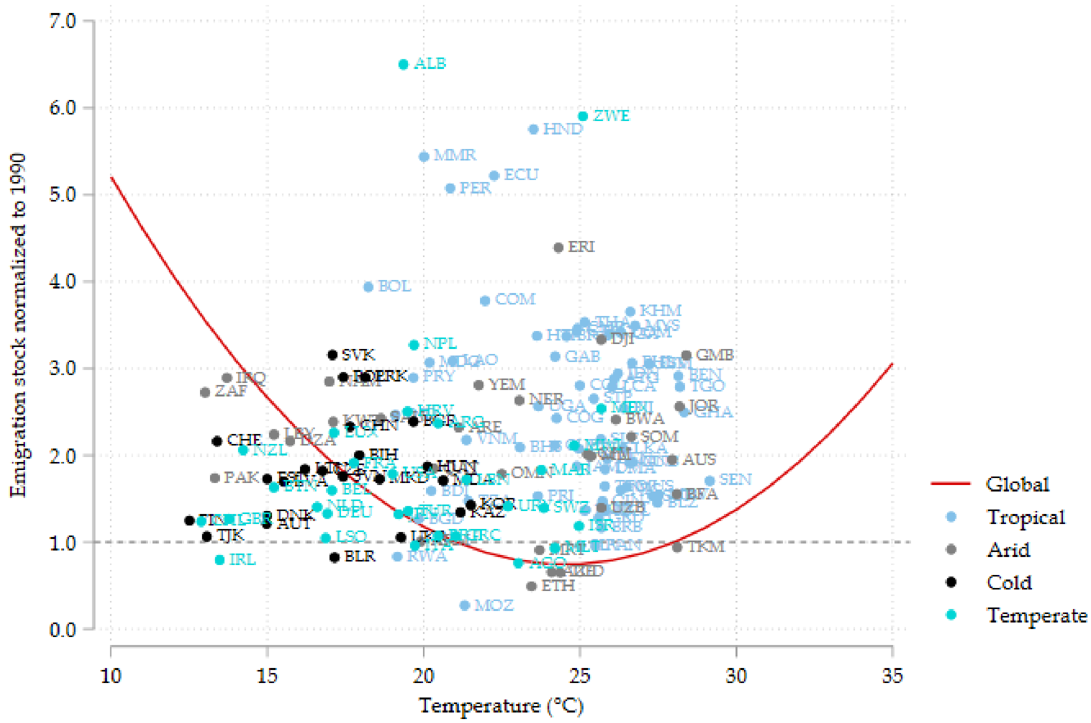


Figure 5: *Relationship between the average temperature for the growing season of maize and the ratio between the emigration stock in 2020 and 1990. The line shows the estimated function of this relationship by our baseline specification, using the average value for population and GDP per capita. Countries are shown by their climate classification (Peel et al. 2007).*

ability to borrow abroad to fund the substantial investment projects required to ameliorate the damages from droughts and floods.

Finally, Column (4) adds precipitations to the specification from the previous model. The resulting effects from their interactions are small. Therefore, our preferred model is the one from Column (3), and this is the baseline model we will use for the analysis performed in the following sections.

We end this section by presenting in Figure 5 the quadratic response of the emigration growth between 2020 and 1990 as a function of the world average temperature using the estimated model from Column (1) in Table 2. We can observe that the optimal temperature is 24.5 degrees Celsius –positive and negative deviations from this threshold increase emigration. In the figure, we also add the emigration growth rate for the countries included in the sample, and we classify them by their type of climate (i.e., tropical, cold, arid, temperate). Most tropical countries exhibit average temperatures that are located in the right part of the quadratic response, which means that a positive change in temperature leads to an increase in emigration. In contrast, countries classified with temperate and cold climates are located in the left part of the quadratic response, which implies that an increase in temperature decreases emigration abroad for such countries. This result suggests that the effects of global warming will be heterogeneous over types of climates. The nonlinear response implies that warmer countries will be the most negatively affected, while cold countries may benefit within a certain range of temperature increases.

Heterogeneity of the impacts by type of climate and income per capita

In this section, to shed more light on the heterogeneity of the effects, we dive deeper into how the type of climate and income per capita of countries shape their non-linear relationship between emigration and temperature.

Figure 6 uses the estimated baseline model (column (3) in Table 1) to compute the quadratic response of the countries grouped in the four types of climates, which differ in their GDP per capita. In 2020, the average GDP per capita of tropical countries was **9,381.4 USD**, for temperate countries was **31,315.2 USD**, for arid countries was **17,294.0 USD**, and for cold countries was **30.945,0 USD**. Because the quadratic positive relationship of temperature and emigration is diminished as the GDP per capita increases, topical countries with a lower income level are less resilient to global warming, exhibiting an upward and strongly increasing relationship for a temperature higher than 23 degrees Celsius. In contrast, cold countries, which are, on average, much richer, exhibit a negative relationship for

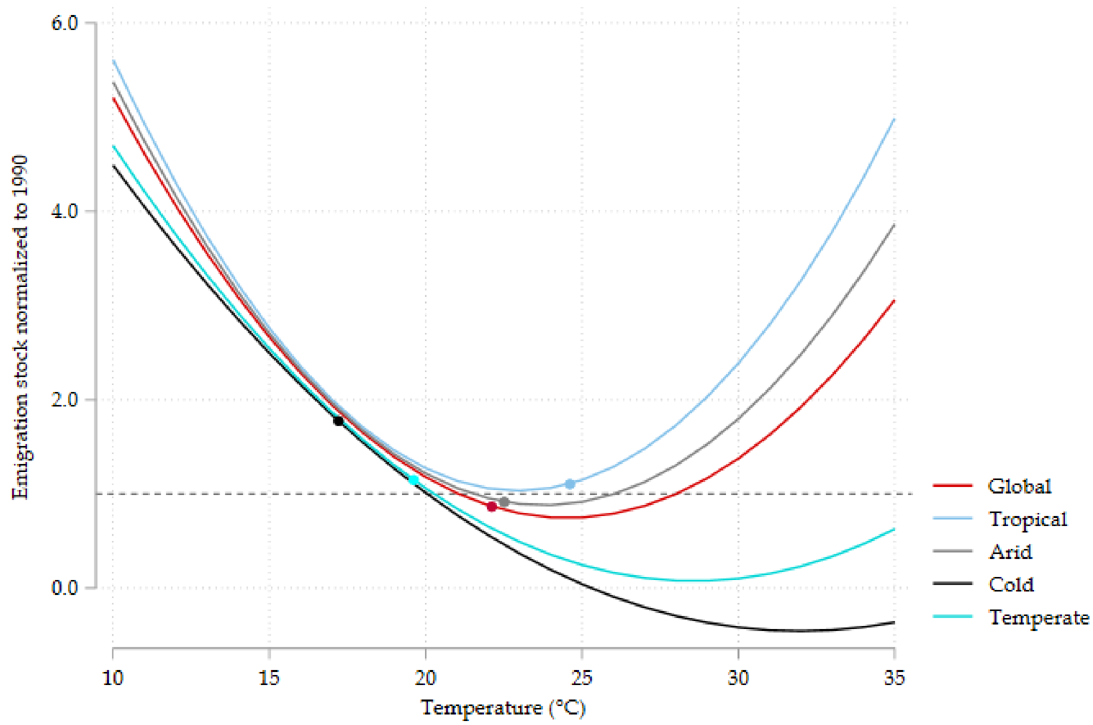


Figure 6: *Relationship between the average temperature for the growing season of maize and the ratio between the emigration stock in 2020 and 1990, by climate classification. The lines show the estimated function of this relationship by our baseline specification for different climates. The dots represent the average temperature in 2020 for each climate.*

any level of temperature below 32 degrees Celsius. A plausible explanation for these results is that the capability of countries to adapt to climate change relates to their income level. By investing more in adaptation, richer countries ameliorate the negative impacts of climate change on productivity, wages, and probability of conflict, reducing the pressures for emigration (Carleton and Hsiang, 2016). Figure 12 in the Appendix presents the baseline model for each type of climate, including the confidence intervals for the estimated quadratic response functions.

However, there is a second source of heterogeneity besides the income per capita of countries: the average temperature. Figure 6 also shows in dots the average temperature for each one of the four types of climate. The average temperature between

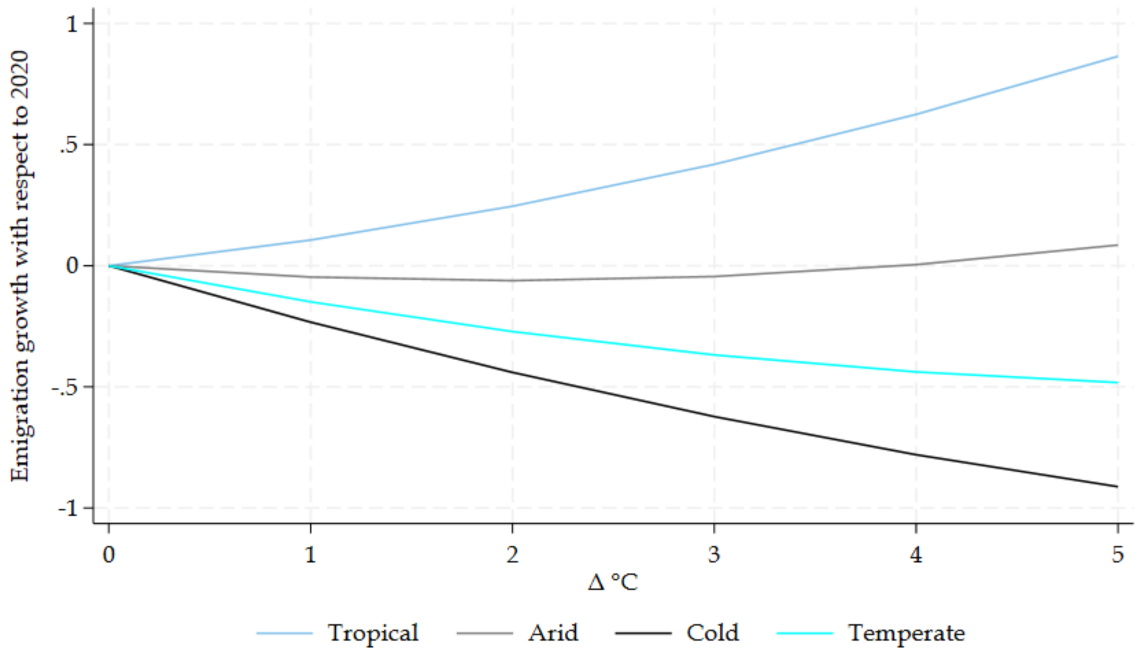


Figure 7: *Estimated growth in emigration for temperature increases of up to 5 degrees Celsius for the average temperature for 2020 by climate classification.*

2015 and 2020 for tropical countries is 24.5 degrees Celsius; for arid countries, it is 23 degrees Celsius; for temperate countries, it is 20 degrees Celsius; and for cold countries, it is 17 degrees Celsius. For a given GDP per capita, tropical countries with higher average temperatures will be located more to the right part of the quadratic response function, meaning they will face a larger increase in emigration for the same marginal increase in temperature than countries belonging to colder climates.

Figure 7 presents the quadratic response functions for each type of climate for increases up to 5 Celsius degrees starting from their average temperature over the 2015-2020 period. Here, we can see in detail the different responses to temperature increases arising from a combination of different levels of GDP per capita and different current temperatures for each type of climate. For tropical countries, a rise of 2 Celsius degrees is projected to increase the total number of emigrants by 50%, while a rise of 4 Celsius degrees would almost double the current stock of emigrants.[7] If we consider that the total stock of emigrants from tropical countries in 2020 is 85 million people, then **under the scenario of a 4 Celsius degrees increase**, we would expect 53 million more displaced people from tropical countries (138 million in total, a 62% increase) due only to climate-related causes. For countries with temperate and cold climates, a decline in the number of emigrants is expected. This result is in line with the findings from previous literature, and it can be rationalized by the increase in labor and agricultural productivity (Cruz & Rossi-Hansberg, 2022).

5 The Future: Projecting Climate Scenarios up to 2100

IPCC Scenarios

In the previous section, we performed an empirical analysis to shed light on the present relationship between climate change and emigration using data from the last 30 years. Using the estimated baseline model in Table 1, we turn the analysis now to project emigration pressures for a selected group of possible future climate change scenarios over a time horizon ranging up to 2100.

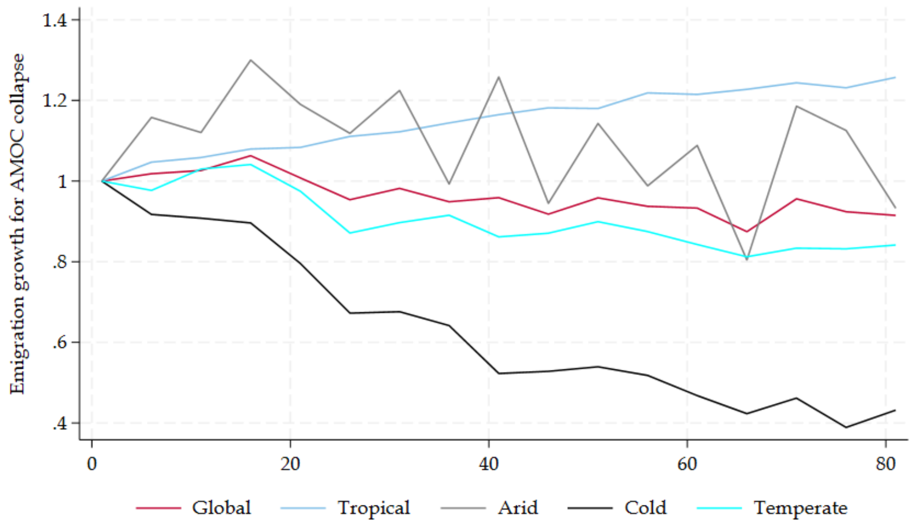
We use the Shared Socioeconomic Pathways (SSPs) developed by the IPPC for this exercise.[8], In particular, we choose the scenarios SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP4-8.5. As explained in Section 4, the estimated global warming of each of these four scenarios by 2100 is 1.8 degrees Celsius, 2.7 degrees Celsius, 3.6 degrees Celsius, and 4.4 degrees Celsius, respectively.

To perform the projections, we feed the estimated baseline model with disaggregated

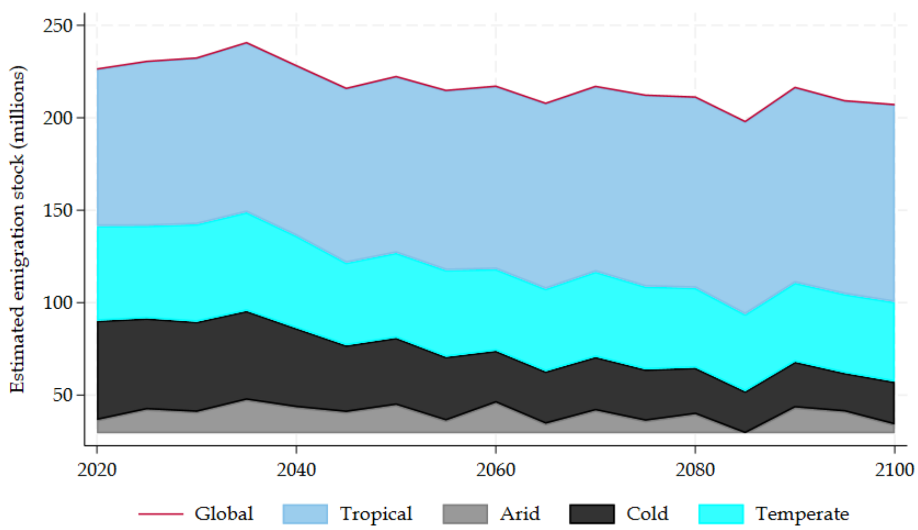
[7] The emigration ratio with respect to 1900 is rescaled to express the increases with respect to the emigration stock in 2020.

[8] The Shared Socioeconomic Pathways (SSPs) are climate change scenarios of projected socioeconomic global changes up to 2100, as defined in the IPCC Sixth Assessment Report on climate change in 2021. They are used to derive greenhouse gas emissions scenarios with different climate policies.

temperature data from the IPCC projected scenarios at the country level for the period 2020-2100. To assess the pure effect coming from global warming, we keep the GDP per capita constant at their 2020 level.[9] This simplification poses a caveat.



(a) *Projected emigration growth by type of climate*

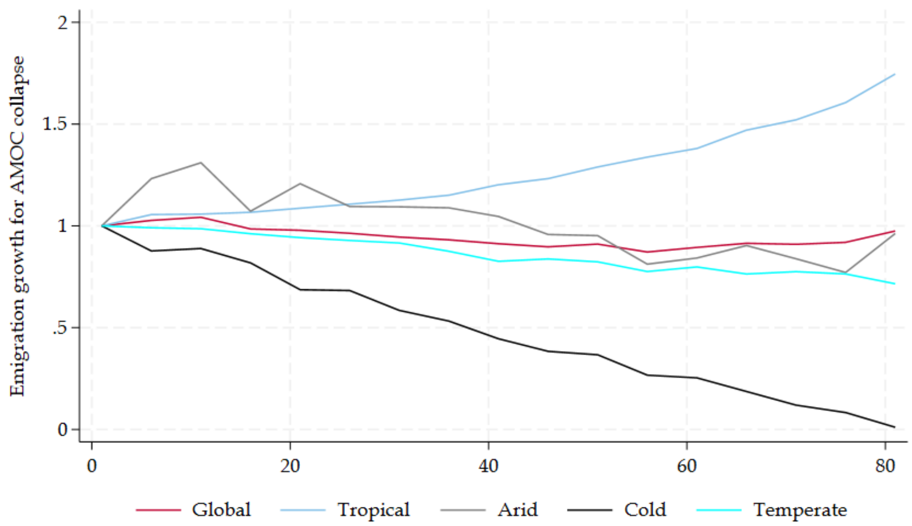


(b) *Projected emigration stock by type of climate*

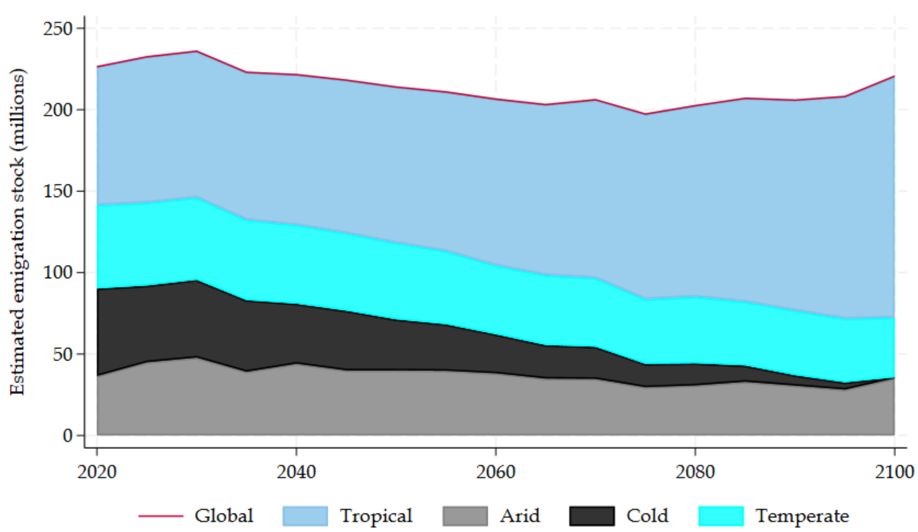
Figure 8: *Projections based on the SSP2-4.5 scenario.*

[9] For this exercise, the population varies according to the projected growth rate for each country.

We are not taking into account that the possible positive income growth of countries might help them to adapt and become more resilient to temperature increases. However, we do this because we are also uncertain about how climate change will affect future GDP growth rates at the country level, which can be negative.



(a) *Projected emigration growth by type of climate*



(b) *Projected emigration stock by type of climate*

Figure 9: *Projections based on the SSP5-8.5 scenario.*

Figure 8 presents the results for the SSP2-4.5 scenario. Projections are shown grouping countries by type of climate. Panel (a) shows the growth of emigration with respect to the stock in 2020. In this optimistic scenario, we can observe that the tropical countries will still face emigration pressures, increasing 20% their emigration stock. In panel (b), which shows the dynamics in terms of stock, the number of people from tropical countries living abroad is projected to increase from 90 million in 2020 to 108 million in 2100. The opposite happens in cold and temperate countries, where emigration decreases at about 60% and 20%, respectively. Two forces drive this decline. First, the number of people emigrating abroad is reduced, and second, and most importantly, people who are originally from cold and temperate countries and were living in countries with other climates (e.g., tropical) return to their countries of origin with cold and temperate climates. Such change in composition can be better understood in panel (b), where the stock of emigrants from cold and temperate countries is drastically reduced.

Similarly, Figure 9 presents the results for the SSP5-8.5 scenario. The projected emigration dynamics in SSP1-2.6 become stronger for the SSP5-8.5 scenario with a higher average world temperature increase. In this most extreme IPCC scenario, the projected emigration from tropical countries increases by 91%, i.e., goes from 90 million in 2020 to 172 million people in 2100. On the other hand, there will be almost no emigration left from cold and temperate countries by 2100. Scenarios SSP1-2.6 and SSP3-7.0 are presented in the appendix in figures 13 and 14.

Tipping Point Scenario - AMOC Collapse

This scenario is characterized by the Atlantic meridional overturning circulation (AMOC) collapse, which could have global ramifications, including abrupt cooling across large parts of the northern hemisphere, changes in tropical rainfall, and non-linear changes in sea-level rise in the North Atlantic Ocean.

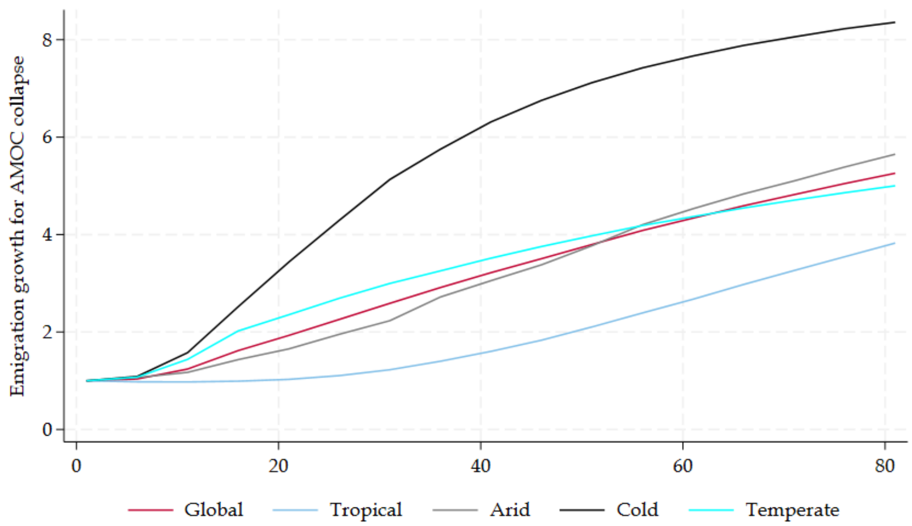
The North Atlantic's thermohaline circulation is a linchpin in harmonizing temperature disparities between its realms and the equator. Operating on the premise of salinity-induced water movement, it serves as a conduit for heat transportation from equatorial zones to polar regions. An AMOC collapse is poised to disrupt this delicate balance, jolting tropic ocean temperatures while cooling northern seas. This ripple effect extends to surface temperatures, prognosticating a stark shift, such as a notable chill in northern Europe and North America. Therefore, if the AMOC collapses, not only would tropical regions face emigration pressures due to the increase in temperature as in the IPCC scenarios, but also cold and temperate countries freeze, leading to an increase in the emigration flows from these countries. Recent work underscores a steeper decline in AMOC than previously envisaged, nudging forward the potential collapse timeframe (now 2050 rather than post-2100)[10].

To assess the emigration impacts of the AMOC collapse scenario, we rely on the results in temperature change projected by Orihuela-Pinto et al. 2022 in the aftermath of an AMOC shutdown, and we feed our previously estimated model with such changes. The simulations from several climate models provided by Orihuela-Pinto et al. 2022 are performed with high spatial resolution, much more granular than the country-level data that we used to estimate our model. Thus, to be able to link the AMOC scenario data with our model, we adapt the data in a two-step procedure. First, given that there is no probability distribution associated with each model, we use just the simple average temperature change across the models as the temperature change to run the projections in our model. Second, we perform a search and matching algorithm to find the coordinates in the AMOC shutdown simulation data closest to each country's capital city.[11] This allows us to map surface temperature trajectories from the AMOC shutdown simulation data to each country in our sample over a period of 100 years after the AMOC shutdown.

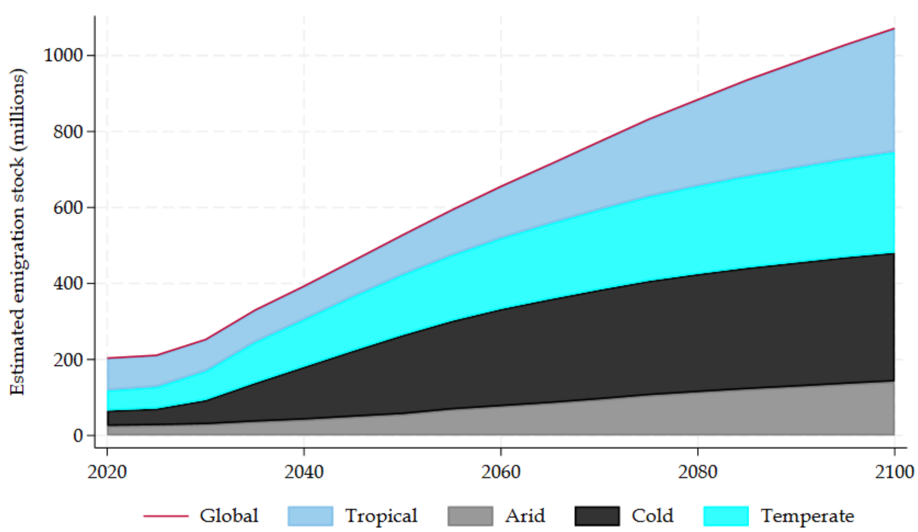
[10]For a more detailed explanation see Ditlevsen and Ditlevsen, 2023 and Orihuela-Pinto et al. 2022.

[11]We get the coordinates of each capital city in our sample from the Simple Maps' World Cities Database.

Next, in a similar fashion, as we did to simulate the IPCC scenarios, we feed our estimated model with the temperature changes from the AMOC shutdown scenario. Figure 10 shows that, under the AMOC shutdown scenario, the total outward migration would increase significantly for countries across all the climates.



(a) *Projected emigration growth by type of climate*



(b) *Projected emigration stock by type of climate*

Figure 10: *Projections based on the AMOC collapse scenario.*

Panel (a) presents the growth of emigration with respect to the stock in 2020 for countries grouped in each climate following the AMOC shutdown that is assumed to happen in 2025. We can observe that the repercussions extend beyond tropical regions grappling with heightened temperatures, akin to IPCC scenarios. Now, cold and temperate countries face the brunt as the freeze prompts a surge in emigration flows, followed by arid and tropical countries. In panel (b), which shows the emigration dynamics in terms of stock, the number of people from cold and temperate countries living abroad is projected to increase from 50 million in 2020 to 450 million and from 50 million to 250 million in 2100, respectively. The increase for people living in tropical countries goes from 90 million in 2020 to 125 million in 2100. The total number of people living in places different from their country of origin in the world is projected to increase from 200 million to more than 1 billion between 2020 and 2100.

Figure 11 shows the emigration growth projections disaggregated at the country level. It is possible to observe that cold and temperate countries in North America, Europe, and South America, as well as Russia, India, and China, would be strongly affected if the AMOC shutdown occurs because these are the countries that would face larger temperature decreases leading to stronger emigration pressures.

6 Conclusions

In this paper, we study the emigration pressures associated with climate change and shed light on how it could evolve as the climate degrades further in the future. A key challenge to address this question is that the available data on migration goes a few decades back, which seems not to be a large enough time span to fully capture the potential highly non-linear relationship between environmental degradation and migration. Recognizing this data limitation, we start the analysis with a narrative approach focusing on four historical case studies. Relying on non-economic sources,

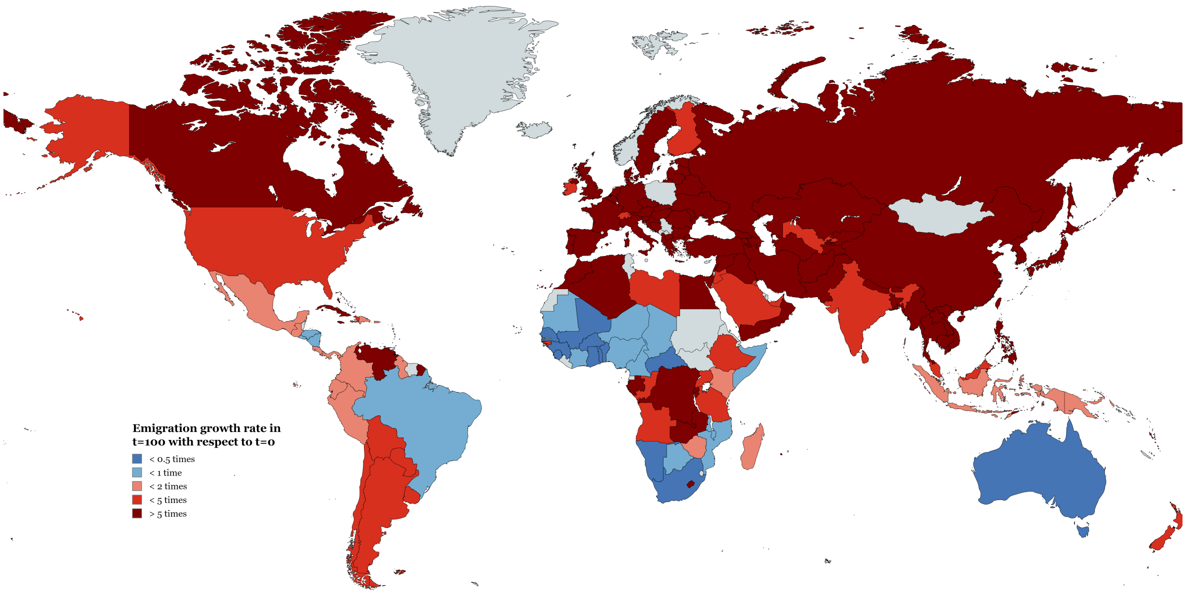


Figure 11: *Emigration growth by country for AMOC collapse scenario.*

we document that severe climate disruption has led to significant outward migration in the past, driven by social conflict and, in some cases, societal collapse.

Then, we exploit the available international census data on migration stocks to perform a regression panel approach in order to estimate the present relationship between emigration and climate change. We find a nonlinear relationship between climate change and migration, with a U shape around a "temperature optimum." The nonlinearity is stronger in poorer countries (limited adaptation).

To speak of future possible climate-related migration trajectories, using the estimated model, we project five different IPCC scenarios and a tipping point scenario associated with the AMOC collapse. We find moderate effects on migration increase under moderate climate IPCC scenarios, but migration would double for tropical areas in the most extreme scenario. Regarding the AMOC collapse scenario, the total emigration in the world would increase from 200 million in 2020 to 1 billion in 2100, mostly driven by the increasing emigration from cold and temperate countries. This result differs from the projected IPCC scenarios, in which emigration pressures arise mostly in tropical countries. We interpret our results as a lower bound of the possible effects, given (i) the non well-captured nonlinearities and (ii) the potential fall in income due to climate damages that limit adaptation.

The challenges posed by climate change are multidimensional. In this paper, we have focused on the specific issue of migration driven by climate. The interaction of these migration flows with societal tensions and conflict is apparent from the historical record, and its empirical relevance from a contemporaneous perspective is left for future work. As highlighted in our work, understanding the effects of climate change in societies requires a multidisplinary approach, both to inform the empirical strategy as well as to devise eventual policy interventions to mitigate its effects.

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Appendix

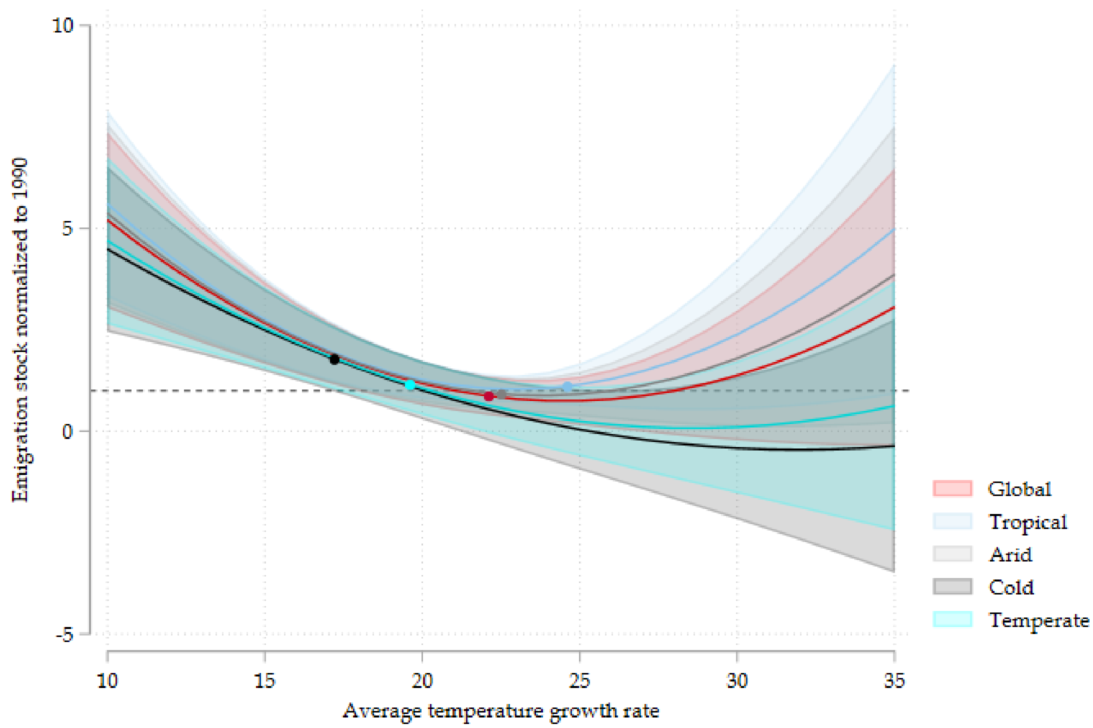
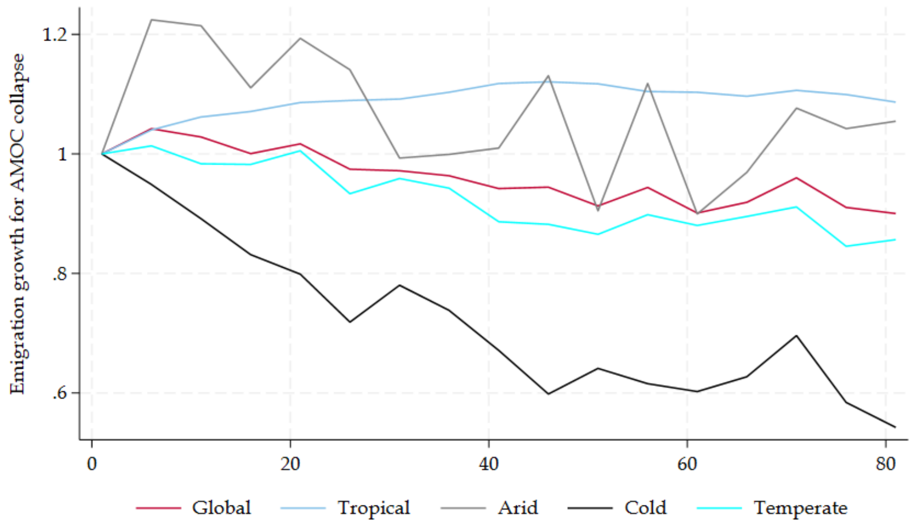
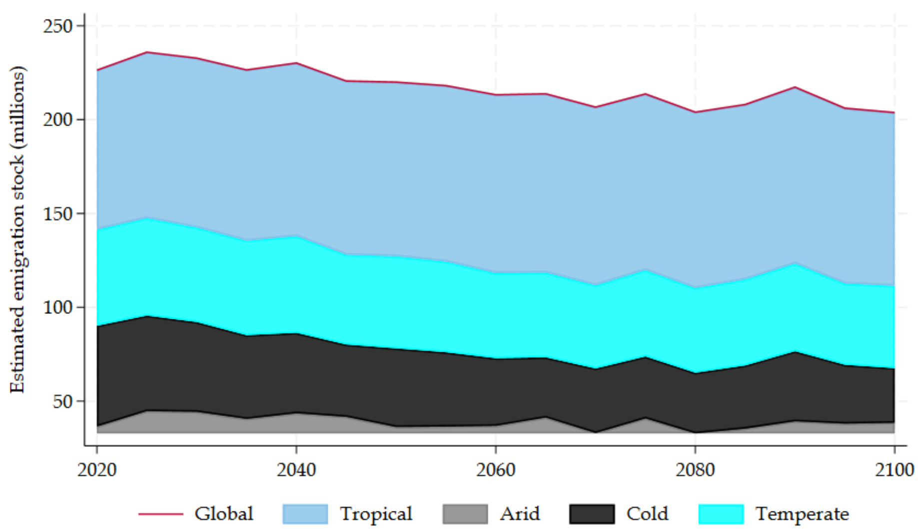


Figure 12: *Relationship between the average temperature for the growing season of maize and the ratio between the emigration stock in 2020 and 1990, by climate classification. The lines show the estimated function of this relationship by our baseline specification for different climates. Confidence intervals at 90%.*

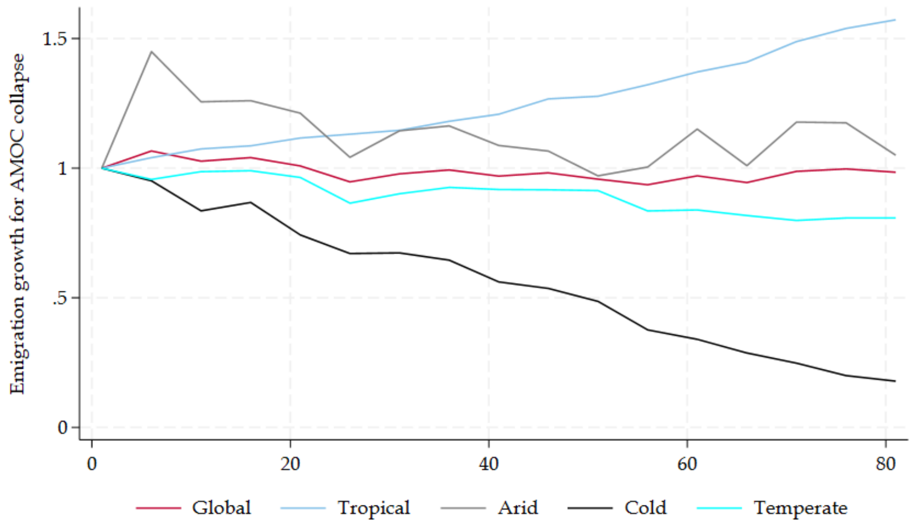


(a) *Projected emigration growth by type of climate*



(b) *Projected emigration stock by type of climate*

Figure 13: *Projections based on the SSP1-2.6 scenario.*



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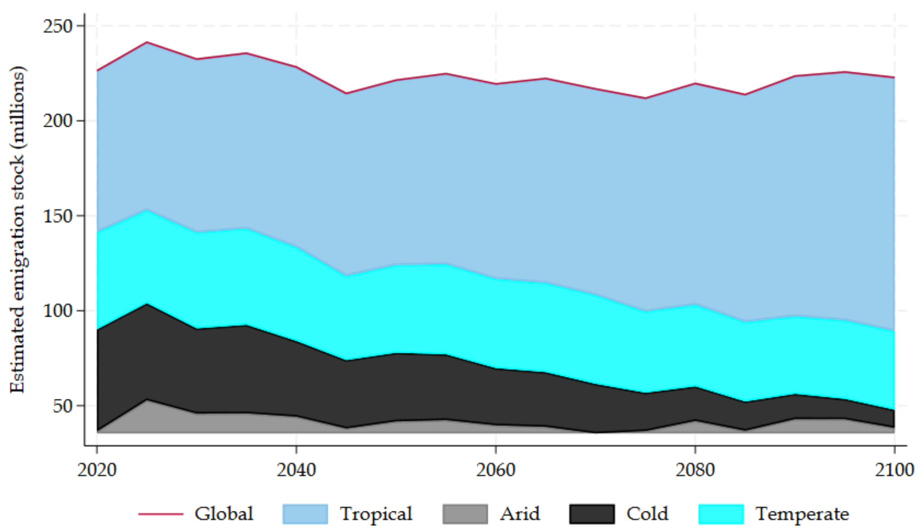

(b) *Projected emigration stock by type of climate*

Figure 14: *Projections based on the SSP3-7.0 scenario.*

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