Historical climate risk and international migration*

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Abstract

We study how pre-industrial climate risk in the form of variability in precipitation and temperature (over the period 1500-1800) influenced today's international migration stocks and historical bilateral inward migration flows. We exploit two new datasets covering eight European countries which provide data at a very high resolution (with 0.5 degree grids). We find that a one-unit increase in the standard deviation of historical precipitation decreases the share of today's migrants in a given cell by 0.04 percentage points and also negatively influences historical bilateral migration flows. In addition, the combination of historical temperature and precipitation variability has a joint negative effect on today's migration stocks. We find that the results only hold in localities that were historically rural and during periods corresponding to the growing season of major crops, suggesting that these long-run relationships are driven by agriculture. While our results are unable to pinpoint the exact sequence of mechanisms at play, we find suggestive evidence that historical climate risk has a persistent effect on current migration patterns through network effects and past income levels.

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1 Introduction

The current literature has explored extensively the role of contemporary push and pull factors in shaping international migration flows.[1] However, despite an increasing number of studies, the environment-migration nexus and its underlying mechanisms remain poorly understood [Hoffmann et al., 2020]. Moreover, even though the literature agrees that the effect of climate on migration varies depending on the context and time frame [Cattaneo et al., 2019, Berlemann and Steinhardt, 2017, Millock, 2015], we know little about how and why historical factors affect current migration patterns. Given that migration is an important response to climate change (and climate variability) today, it is important to understand how such a relationship may have evolved historically, and why. Such an investigation is even more relevant since some studies focusing on the contemporary link between climate and migration find a positive relationship, while others find no relationship or a negative one [Beine and Jeusette, 2021]. In addition, since both climate patterns and migration are highly persistent, studying the possible connection between the two phenomena over the long term provides an important contribution to the current scholarship.

This paper fills this knowledge gap by focusing on the long-run impact of pre-industrial climate risk (proxied by standard deviations in temperature and precipitation)[2] on contemporary and historical migration. While the existing literature has explored how contemporary extreme climate events in the origin country affect out-migration (for example,[Beine and Parsons, 2015, Cai et al., 2016, Mastrorillo et al., 2016, Coniglio and Pesce, 2015]), in this paper we focus on the role of historical climate risk in the destination country. To investigate the relationship between current and past migration patterns and historical climate risk, we use locality-level data (with cells of approximately 56 square kilometers, equivalent to about 0.5 degree grids) in seven EU countries (France, Germany, Ireland, Italy, Netherlands, Portugal, Spain) and the UK, while controlling for other important geographical drivers and location-specific factors.

Pre-industrial climate variation had an important influence on crop yields, the demand for temporary agricultural workers and the availability of food, and constituted a major economic risk ([Campbell, 2010], van Bath [1963]). As a result, climate risk affected the demand for and supply of temporary migrants, who came every year along the same route (see [Galloway, 1986], [Deschacht and Winter, 2015b], Klein and Van Lottum [2020]). When the harvest was bad, migration was low since no extra workers were needed and since the low yields could not feed both the local and migrant populations. Conversely, when harvest was good, the demand for agricultural workers increased. Moreover, climate risk also influenced the attractiveness of

[1] The economic determinants of migration (employment, wages, social security, inequality, and the size of the labor market) have been identified as push and pull factors in the international and domestic migration contexts. Ortega and Peri [2009]; Hatton and Williamson [2002]; Hatton and Williamson [2002]; and Mayda [2010] provide an overview of this literature. Other factors influencing the cost of migrating, such as network effects, cultural links, distance, and language are studied by Mayda [2010] and McKenzie and Rapoport [2007], among others.

[2] In this paper, we will refer to climate risk and climate variability interchangeably.

a particular destination for would-be migrants: high climate variability meant more uncertainty, and thus a lower supply of potential migrants. Since potential migrants will consider wages and and climate risk in both the sending and receiving locations, identifying the overall direction of the effect of past climate variation on current migration is ultimately an empirical question. While our preferred specification unfortunately does not have information on climate variation in the sending location, our genealogy-based specifications do allow us to control for origin conditions via origin-destination fixed effects, and it is reassuring that our results are consistent across the two specifications.

There are various mechanisms through which historical climate risk could have had a persistent effect on today's migration patterns. First, today's migrants are likely to be prefer locations where their ancestors or their ancestors' peers were located due to network effects. Historical evidence shows that seasonal migrants did occasionally settle down (Collins [1976]), and that peer effects were important drivers of historical migration in Europe (Klein and Van Lottum [2020]). Second, climate risk may lead to conflict,[3], which in turn could have deterred migrants from conflict-prone destination locations. By contrast, more volatile climate conditions may have created a culture of cooperation and potentially more accepting attitudes towards foreigners Buggle and Durante [2021][4], both in the short and long term[5], thus attracting more migrants to such locations. Furthermore, more open attitudes and higher levels of social capital in places with high climate risk and trust could have created migrant-friendly and persistent institutions and policies. Past climate risk might have affected current migration through past and present economic development and and growth [DO WE HAVE ANY REFERENCES/]. We explore the importance of these mechanisms in our conceptual framework and in the empirical analysis.

We exploit two novel migration datasets. The first dataset provides information on current international migration patterns (i.e, stocks) in the destination locations. Our main empirical specification uses this data to regresse the share of migrants in a particular locality in 2011 on historical climate variation, measured by the standard deviation in precipitation and temperature over the period 1500-1800. In addition, we control for other location characteristics, including variables capturing other climate factors, such as mean precipitation and temperature over the same period, while geographical controls include land suitability for agricultural activities, whether the cell is located in a coastal region, on a river, its distance to coast, its altitude, its area size, and its latitude and longitude. In order to proxy for economic activity, we also use population density in a given cell. In addition, we also include a control for whether the cell is a (historical) city or rural area. To make sure that our results are not confounded by region-specific factors (such as economic conditions, cultural and historical factors, including past colonial ties) we also include region (i.e., NUTS-1) fixed effects.

[3] See Burke et al. [2015] for a review of relevant empirical evidence)

[4] Similarly, Giuliano and Nunn [2017] shows that societies where temperature is more variable today value traditions less and are more open towards change.

[5] Evidence shows that cultural attitudes tend to persist over the long-run, see for example Voigtländer and Voth [2012]

We find a negative relationship between the pre-industrial variability in precipitation and the share of migrants in 2011 measured at the locality level. A one-unit increase in the standard deviation of historical precipitation decreases the share of migrants in a given cell by 0.04 percentage points (with the mean share of migrants in the sample being 7%, while the standard deviation of precipitation is 56.22). In addition, the combination of historical temperature and precipitation variability has a joint negative effect on today's migration stocks. We find that these results only hold in localities that were historically rural and during periods corresponding to the growing season of major crops, suggesting that these long-run relationships are likely driven by agriculture. We also find evidence of a non-linear relationship between migration and precipitation variability, indicating a slightly U-shaped relationship between historical climate variation and today's migration, with extreme variation leading to a slightly positive effect on migration.

Our second migration data set captures historical genealogy-based bilateral migration flows and covers the same period (1500-1800). We are also able to aggregate the data to the same detailed local level (i.e., 0.5 by 0.5 degree grid). While this data is not representative at the country level, it allows us to control for origin cell-time varying factors, bilateral cell-specific factors, and destination cell-specific factors, and to exploit the time dimension of the data. Once again, we find that there is significantly less in-migration to locations with higher pre-industrial climate risk. When undertaking a placebo test using future climate variability, we do not find any significant relationship, which indicates that are our results are unlikely to be driven by omitted variable bias or reverse causality.

We investigate four main potential channels through which historical climate risk could affect today's patterns of migration stock in the destination, and find suggestive evidence that social network effects and historical development likely drive the impact of historical climate risk on today's migration patterns. In line with Buggle and Durante [2021]), we find that climate risk created more open institutions and more welcoming attitudes towards migrants, and that better institutions and attitudes are positively correlated with current migration patterns, which would imply a positive relationship between current migrants and climate risk. However, we find that locations with higher past climate risk have fewer migrants today. In addition, we also find no evidence that historical conflicts drive the results.

Our work builds on and contributes to a broad literature which demonstrates that land suitability, agricultural productivity, and environmental factors can have long-run consequences for various societal and economic outcomes. Nunn and Qian [2011] find that the introduction of the potato explains a significant share of differences in population increase and urbanization during the eighteenth and nineteenth centuries. Furthermore, Iyigun et al. [2017] highlight that a permanent increase in agricultural productivity has long-run effects on conflict. In addition, Galor and Özak [2016] use the Columbian Exchange (i.e., the expansion of suitable crops for cultivation) as a natural experiment to investigate the impact of pre-industrial agro-climatic characteristics. They find that climate had a significant impact on economic behavior, such as technological adoption, education, saving, smoking and time preferences. There is also evidence that a country's relative suitability for wheat vs. sugarcane affects inequality, economic development, institutions, and schooling [Easterly, 2007], and countries that historically adopted plough agriculture have more unequal gender norms today [Alesina et al., 2013]. [6] In addition, migration can play a role in smoothing the impact of climatic or environmental variations and shocks. Hornbeck [2012] analyzes the short- and long-term impact of environmental catastrophes by focusing on the 1930s American Dust Bowl. He finds that there can be long-term consequences of such shocks, with the economic adjustments occurring mostly through large relative population declines, driven by both out- and in-migration.

Our paper makes a number of important contributions to the literature. First, our novel and highly detailed datasets allow us to pinpoint the relationship between *historical* climate variation and contemporary and past inward migration, and to explore some of the suggestive mechanisms behind it. By using a very detailed spatial data, we are able to go beyond country-level determinants, and exploit spatial heterogeneity within countries. While much of the previous work focuses only on temperature and precipitation levels only (Dell et al. [2014], Dell et al. [2012]), we use both both the levels and standard deviations of temperature and precipitation in our analysis, and show that it is variation, rather than levels that ultimately matter for migration. In the spirit of Kahn et al. [2021], such a specification allows us to explicitly model changes in the distribution of weather patterns, including not only averages of climate variables but also their variability.

Our paper contributes to a small but important literature on the link between climate and migration, which, however, has largely ignored the long-run effect of climate and the European context due to the lack of data. A further innovation of this work is that we study climate risk as a driver of *inward* migration, as opposed to *outmigration*, the latter being the focus of most existing studies.[7] Since outward and inward migration may have different drivers and consequences, mapping the link between climate variation and inward migration is essential for fully understanding how climate affects migration. While we show that past climate risk is an important

[6] Acemoglu et al. [2020] find that extreme climate events (e.g., a drought) can have persistent effects on economic outcomes.

[7] For example, [Cai et al., 2016] only investigate outmigration, using data at the country, rather than local level data. They find a positive relationship between temperature and international outmigration only (using current, rather than historical data) in the most agriculture dependent countries, consistent with the adverse impact of temperature on agricultural productivity.Dell et al. [2014] review several papers on outmigration, and conclude that outmigration appears to be a common response to declines in local agricultural productivity. Weather-induced migration may lead to conflict as well, particularly when resources are scarce. For instance, Anderson et al. [2017] find that colder temperatures in pre-modern Europe led to more Jewish persecutions. Boustan et al. [2012] find that while US residents in the early twentieth century moved away from areas that experienced floods, they moved into areas associated with floods, which may be related to efforts by the government to rebuild the affected areas and make them more flood resistant.Beine and Parsons [2015] examine natural disasters and long-run climatic factors as potential determinants of international migration, implementing a panel dataset of bilateral migration flows from 1960 to 2000. The authors find no direct effect of long-run climatic factors on international migration across the entire sample. Rather, they uncover evidence of indirect effects of environmental factors operating through wages: there is strong evidence that natural disasters beget greater flows of migrants to urban environs.

determinant of today's migration patterns in Europe, as we discuss in the next section, climate risk is of course not the *only* determinant of migration, and the findings in this paper should not be interpreted as supporting environmental determinisim [Pei et al., 2022].

In the next section we outline a simple conceptual framework outlining the link between climate variation and past and current migration patterns. This is followed by a description of the data we use. Next, we discuss our empirical specification and the results, while our final section offers concluding remarks.

2 Conceptual framework: migration and climate variation

In this section, we outline how historical climate risk (captured by climate variability) influenced inward migration, and how the identified relationship influenced today's migration patterns.[8]

2.1 Importance of climate variation in pre-industrial times

In Europe, industrialization and urbanization were not fully felt until the mid-1800s, when the industrial revolution had a real effect.[9] For centuries before, the vast majority of the continent was rural, and most of the population depended on agriculture for subsistence [Ladurie, 1971]. As a result, climate variation constituted an important economic risk, since it was linked linked to crop yields and the availability of food [Parker, 2001], [Davis, 1973]. Most agricultural activity in Europe involved crops whose growing season is generally in the spring and summer[10], and weather variation, particularly in these periods, had important consequences. For example, according to [Davis, 1973] *"The changing climate, apparent in the slow worsening and the slow improvement, over many decades, of the 'average' weather conditions around which each year's weather fluctuated, was a factor of the utmost economic importance.* [QUOTE - WHICH YEARS ARE COVERED?] As a further example, [Galloway, 1986] notes that a two-week period of intense rain during autumn can destroy an entire harvest, and demonstrates a significant correlation between seasonal weather fluctuations and yearly yields in the preindustrial period.

[8] Although our framework focuses on inward migration, much of it can also be applied to the study of internal migration. Nevertheless, due to data limitations, our focus is on international migration.

[9] See, for example, [Bairoch et al., 1988].

[10] These crops include barley, wheat, rapeseed/canola, sugar beets, potatoes and oats (Northern Europe); wheat, barley, maize, rapeseed/canola, sugar beets and grapes (Western Europe); and wheat, barley, maize, sunflower, pulses, potatoes and olives (Southern Europe) [Leff et al., 2004].

2.2 Demand and supply forces

In traditional migration models, the individual makes a one-time decision whether to migrate or not, by evaluating the return to moving in the new location, net of any costs, relative to the return of staying in the home location.[11] However, the type of migration that prevailed in Europe during pre-industrial times was very different, as it involved temporary agricultural workers moving periodically along the same route. Importantly, this seasonal migration depended heavily on fluctuations in agricultural yields. [12] Therefore, applying the Roy-Borjas model in our context requires considering not only migrants' wages in the sending and receiving locations, but also climate risk as one important measure of wage uncertainty over time. When climate risk is high, the earnings of potential migrants in the new location will be very uncertain, therefore prompting at least some migrants to stay at home. Conversely, with low climate risk, wage uncertainty will also be low.

Throughout European history, seasonal migrants were indispensable for agricultural production. In 1607, Baron de Sancy asked how the Spanish could work the land without the French, if the French did not come to help and settle. Who would harvest if more troops of French did not come? And who would serve the Spanish in the fields and cities if these same French did not? (as cited in Moch [2003]). Oris [2003] discusses how different locations can be thought of a system where there is a mutual symbiosis between the native population and temporary migrants. While certain locations regularly needed additional migrant workers, there were other origin locations from where migrants regularly arrived. Similarly, Bade [2002] observes that there were geographical areas which depended on additional workforce periodically to reduce risks, and that long-distance seasonal migrants regularly migrated along the same routes. Klein and Van Lottum [2020] also notes that international migration in the pre-idustrial era consisted mostly of people traveling in search of occasional work, with most of them being agricultural migrants [Moch, 1995].

In the same vein, Grantham [1993] emphasizes the important dependence in pre-modern agricultural economies on temporary/seasonal workers. Similarly, Hochstadt [1999] shows that migration in Germany was as frequent in pre-industrial Germany as today. Hochstadt [1983] writes that *"Each spring the roads of Europe came alive as peasants streamed out of their villages and fell in with the bands from other villages to seek work in distant places, and the roads teemed again in late autumn when the workers began their homeward trek. From Spain to Russia migratory peasants linked disparate economic systems.* Lucassen and Lucassen [2009] states that both permanent and temporary migration was very important in early modern Europe, with a

[11] See, for example, [Roy, 1951], [Borjas, 1987], and [Grogger and Hanson, 2011].

[12] As Auffhammer and Schlenker [2014] point out, weather variability is extremely important for agricultural output, since weather is a direct input in the production function. Similarly, Colmer [2021] shows that in present-day India, weather-induced agricultural shocks (due to an increase in temperature) are associated with a reduction in agricultural production and, in turn, the employment and wages of agricultural workers. While agricultural shocks do not induce migration of the local population, the paper highlights an alternative coping mechanism that was not available in the historical context which we study: an offsetting movement of workers in the manufacturing and services sectors.

significant demand for large numbers of seasonal migrants over long distances, often driven by higher wages due to great demand during harvest times. Klein and Van Lottum [2020] also notes that long-distance (several hundreds of kilometers) migration was not rare in Europe. For instance, Moch [2003] discusses a broad movement of workers who came to work in the Netherlands during this time period, originating in an arc that reached from the French Calais up to the German States on the North Sea. In the second part of the seventeenth century Lucassen and Lucassen [2009] estimates that about 8% of Europeans (excluding those in Russia) could be considered an international migrant. For example, according to Van Lottum [2007], 1 in every 10 people born in Scotland around 1650 was living abroad. Hahn [2000] states that already before industrialization seasonal labour migration across national borders was important. An important reason behind the popularity of migration was that in Europe, around 10-20 percent of men and women remained unmarried and were thus able to move around (compared to Asia, where marriage was nearly universal) [Moch, 2003].

Seasonal agricultural workers were a convenient way to deal with labor shortages, since they were not hired when agricultural output was low, thus reducing the number of people who needed to be sustained with the resulting lower yields, lessening the economic and social consequences. Deschacht and Winter [2015a] ooks at the 1840 crisis triggered by bad yields (leading to famine and disease) and notes that there was a reduction in seasonal migrants, while locals did not out-migrate, even though they were free to move within the country or abroad [13] Similarly, Dribe [2003] finds that in preindustrial Sweden out-migration was not practiced (even in case of landless people) as a response to harvest failure resulting in economic stress.

During pre-industrial times, there were many seasonal agricultural migrants willing to move often to distant locations across countries (see for example Hochstadt [1983] , Hochstadt [1999], Bade [2002]). For example, a large share of the population of a German region bordering Dutch areas spent every summer in Holland doing agricultural work (Hochstadt [1983]). Just like in the case of the demand for agricultural workers discussed in the previous subsection, climate risk will also affect the willingness of seasonal agricultural migrants to move to specific locations. When there is a high variation in yields, the availability of work, wages and food will also fluctuate accordingly, thus impacting the attractiveness of the location for seasonal workers. According to Bade [2002], long-distance seasonal workers often followed routes which were based on “migratory traditions, experimented on for generations”. Therefore, migrants will be less likely to prefer locations with high climate risk, due to lower individual utility from migrating through increased costs and potentially varying (or lower) welfare in the destination.

Given this framework, climate variation can influence an individual's expected welfare in the destination country, and hence his or her decision to migrate to a specific location.[14] When there is a bad season in the host country leading to *decreased*

[13] See also Jacquemyns [1928], Vandenbroeke [1979] on locals not responding by moving out during the crisis. Mueller et al. [2020] also find that in today's Africa climate variability doesn't affect rural out-migration.

[14] One example where climate is integrated into this framework as a factor influencing the indi-

yields, there will be less demand for agricultural workers, along with lower (expected) income for migrants in the destination, resulting in fewer migrants choosing the destination location, or in existing migrants leaving the country (to go back home or to another destination). Therefore, immigrants will be less likely to prefer locations with high climate variability, at it would lower individual utility from migrating through increased costs and potentially varying (or lower) welfare in the destination.

The discussion further illustrates that the *net* effect of *past* climate variation on *past* migration will depend on demand and supply forces. While demand as a result of climate variation fluctuated, long-term supply likely gravitated towards location with less climate risk. Since potential migrants will consider wages and and climate risk in both the sending and receiving locations, identifying the overall direction of the effect of past climate variation on current migration is ultimately an empirical question. While our preferred specification unfortunately does not have information on climate variation in the sending location, our genealogy-based specifications do allow us to control for origin conditions via origin-destination fixed effects, and it is reassuring that our results are consistent across the two specifications.

2.3 Explaining today's migration

The second building bloc of our argument is that the historical link between *past* climate risk and *past* seasonal agricultural migration persisted until today, and that it explains patterns in the *contemporary* migration stock. There are several channels that may be behind the patterns that we observe, and the existing literature offers some clues on what these may be.

A first potential channel is through **network effects**. Past migration patterns (either in the form of permanent settled migrants or seasonal migrants regularly returning to the same location) could have permanent impact on current migration patterns through network effects, whereby today's migrants are attracted to locations to which their ancestors or their ancestors' peers went, thus reinforcing the direct impact of climate variation and land suitability. Occasionally, pre-industrial seasonal migrants settled down in the destination location. As documented by several historians (see for example Bade [2002], Collins [1976]), these migrants often returned to the same locations, possibly due to social ties. Indeed, according to Collins [1976] *"An integral feature of many village economies in central England was the travelling "bands" of workmen who created their own special circuits and trod year after year the same elliptic path,* noting that some of these seasonal workers, often Irish (in England), remained. There are also examples of legal or economic incentives to retain permanently seasonal workers (see Grantham [1993]). For example, in Scotland seasonal workers were given a cottage with garden, in exchange for one woman from the family working for free during the harvest (Devine [1984]). Klein and Van Lottum [2020] looks at migration flows at the period between 1700-1800 using maritime data and find that past migration is among the most robust and quantitatively important

vidual decision to migrate is [Beine and Parsons, 2015].

driver of cross-country historical migration. [15]

A potential second channel involves **social norms**. [16] For instance, Buggle and Durante [2021] show that norms of generalized trust developed in pre-industrial times as a result of experiences of cooperation triggered by the need of subsistence farmers to cope with climate risk. The authors show that social norms persisted over time, even after climate had become largely unimportant for economic activity. It is also plausible that in areas with low climate risk, pro-migrant attitudes coexisted along with norms of trust, thus making communities that historically attracted migrants welcome destinations for migrants today.

Another possible mechanism could have included the adoption of inclusive political **institutions** early on in areas with high climate risk, with these (formal) institutions persisting until today. For example, Grantham [1993] discusses the importance of evolving institutions in pre-industrial times in order to ease the hiring of seasonal agricultural workers. Moreover, the literature highlights a strong link between norms of cooperation and trust, and the quality of institutions (see for example Tabellini [2010], Tabellini [2008], Guiso et al. [2016], Greif and Tabellini [2010], Nannicini et al. [2013]). Such inclusive (extractive) institutions may have interacted with the pro-(anti-) migrant norms to once again encourage (discourage) contemporary migration. In this vein, Litina [2016] shows that natural land productivity in the past, and its effect on the desirable level of cooperation in the agricultural sector, had a persistent effect on the evolution of social capital, the process of industrialization and comparative economic development across the globe. Similarly, Ager and Ciccone [2018] demonstrate that in the nineteenth-century US, counties with higher agricultural risk, proxied by rainfall risk, had a higher share of religious communities, as a way to insure against such risk. Even though our results show that climate risk *decreases* in-migration, religious communities - via their emphasis on cooperation and assistance - may have been particularly well-suited for migrant arrivals in places with low climate variation.

Another scenario involves past **conflicts.** In locations where there was higher climate variation, the likelihood of conflicts was higher (see Hsiang et al. [2013] and Burke et al. [2015] for a review of this literature). In turn, this could have led to lower inward migration to these locations, thus potentially influencing today's migration patterns.

Similarly, climate risk may affect income levels. Damania [2020] reviews the recent literature and concludes that while variations in rainfall and water availability have significant negative impacts on sectors such as agriculture, human capital and conflict, the impact of climate risk on aggregate economic activity remains ambiguous, though this may be due to issues related to spatial correlation and measurement. In fact, Damania et al. [2020] use annual subnational gross domestic product data to show a concave relationship between precipitation and local gross domestic product growth

[15] For contemporary migration, Beine et al. [2011] find that social networks explain about 71% of the variation of the observed variability in migration flows (see also Manchin and Orazbayev [2018]).

[16] It could be that inmigration also brings a dynamic of cultural convergence between the origin and the destination countries, which itself fuels further migration. Unfortunately, our data does not permit us to examine this mechanism.

between 1990 and 2014. The paper also shows that when the data are aggregated at larger spatial scales, the impact decreases and eventually vanishes. Likewise, Kotz et al. [2022] use a global panel of subnational economic output for 1,554 regions worldwide over the past 40 years to show that monthly standardized deviations of rainfall have a concave relationship with economic growth, while economic growth rates are reduced by increases in the number of wet days and in extreme daily rainfall.

We explore the importance of the mechanisms discussed in this subsection in subsection 4.4, and find suggestive evidence that migration networks and historical GDP per capita levels are likely to explain our findings.

3 Data

Current migration

Our analysis exploits several high-resolution datasets, which allow us to undertake the empirical analysis at a very disaggregated (0.5 degree grid) level. For our main specifications, we use a dataset on migration from the European Commission (EC). More specifically, the original dataset contains information on the country of origin of the population at 100m by 100m resolution, with accompanying latitude and longitude coordinates for eight European countries (France, Germany, Ireland, Italy, Netherlands, Portugal, Spain and the UK) for the year 2011. We aggregate these data up to a 0.25 degree grid which allows us to match with other data. [17] The uniqueness of the dataset stems not only from the high level of spatial resolution, but also from the extensive geographical coverage that includes almost 45,000 local administrative units. The definition of country of origin varies between the countries in the sample, with some countries defining migrants based on country of birth, citizenship or both[18]. In our work we will use the country of origin reported by EC (whether it is a country of birth, citizenship or both) to define 'nationals' as all persons having a country of origin that is the same as the country of destination, and to define 'migrants' as persons whose country of origin differs from the country of residence (as recorded in EC data). The dataset allows us to obtain the share of migrants and population density for each location (i.e. 0.25 degree grid).

Historical climate risk

Our main independent variables of interest capturing climate risk over the last five centuries were obtained from a historical data on precipitation and temperature [Pauling et al., 2006, Luterbacher et al., 2004]. The data we use is from the European Seasonal Temperature and Precipitation Reconstruction (ESTPR) [Pauling et al., 2006, Luterbacher et al., 2004], and contains seasonal temperature and precipitation for the period between 1500 and 2000. The grids in the data have a width of 0.5 degrees (approximately 56 kms near the equator). This data is not based on actual weather station records, but instead have be reconstructed through a complex set of indirect

[17]Alessandrini et al. [2017] describe the construction of the dataset.

[18]See Table 1 in Alessandrini et al. [2017] for further details.

proxies (suchh as ice cores, tree rings, lake/ocean sediments, documental evidence etc.).

Using the seasonal weather data, we constructed measures of annual variation in precipitation and temperature. More specifically, we calculated these variables separately for the growing (spring and summer) seasons and non-growing (autumn and winter) seasons, using the standard deviation in the weather (temperature and precipitation) over all years for each cell. The main specifications use the arithmetic mean of the variables at the cell level across time (for 1500–1800). We also calculate variability over specific different periods to undertake robustness checks.

While our main variables of interest are the two climate variation variables, we also control for average climatic conditions by including the average level of temperature and rainfall over our sample period obtained from this database. These average climatic conditions could have had an independent impact on economic development over time, as well as on agricultural activities and methods. While most of the previous work focuses only on temperature and precipitation levels only (Dell et al. [2014], Dell et al. [2012]), we use both both the levels and standard deviations of temperature and precipitation in our analysis, and show that it is variation, rather than levels that ultimately matter for migration. In the spirit of Kahn et al. [2021], such a specification allows us to explicitly model changes in the distribution of weather patterns, including not only averages of climate variables but also their variability. As Kahn et al. [2021] explain, while the level of temperature in Canada is low, the country is warming up twice as quickly as the rest of the world, implying that the effect of climate risk in this case on outcomes such as infrastructure, human health, and ecosystems will be higher than for a country where climate variation is low. Given the differences in resolution between the EC and climate data, the EC data was aggregated to the resolution of the climate data. The first step was to aggregate the high-resolution EC population data to the same 0.5 degree by 0.5 degree resolution of the climate data. This was done by assigning each of the EC population cells to a corresponding climate cell based on whether the EC cell centroid is within the boundaries of a climate cell. [19] In order to aggregate the EC data, we used the latitude /longitude coordinates of each population cell centroid provided by the EC.

Geographical characteristics

Geographical characteristics can influence climate risk/agricultural activities and also migration patterns. Since these can be confounding factors in order to isolate the effect of climate risk on migration we also include controls for these. We also collect information (from Henderson et al. [2017]) on various geographical characteristics, which have been identified in the literature as important for agricultural activities and hence also potentially migration patterns. We include elevation (in meters) and latitude, and variables to capture access to water transport, which has importance for trade, economic and agricultural activity and migration in a region. In particular,

[19] Note that the conversion between physical distance and latitude/longitude coordinates differs depending on the latitude. For example, at latitude of 40 degrees north, one degree of longitude is about 85 km, while at latitude of 80 degrees north, one degree of longitude is about 19 km.

we have data on the distance in kilometers from each cell in our dataset to water, and include controls for being located on a river, on the coast, and the distance to coast. Moreover, to control for the current level of economic activity population density (from the EC data) and as a robustness check night light intensity (again obtained from Henderson et al. [2017]) is used. Finally, we also control for land suitability (from Henderson et al. [2017]) which would also have an important impact on agricultural activities and hence potentialy also on migration. Figures 1,2 and 3 present graphically the geographical distribution of our main variables of interest: variation in precipitation, variation in temperature, and the share of migrants, respectively.

Historical migration

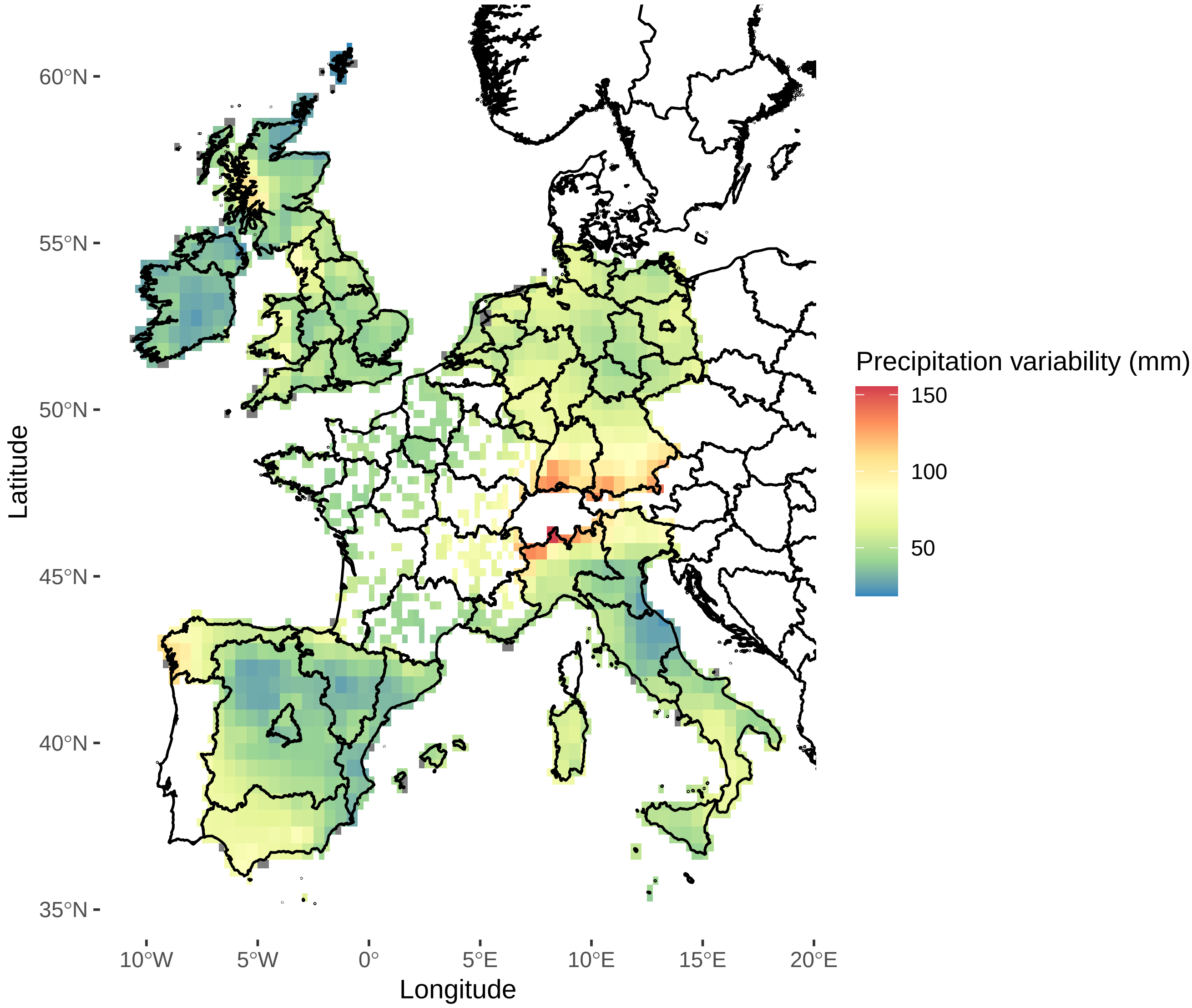
In our empirical analysis, we also use bilateral historical migration flows which were obtained from an alternative dataset. The dataset contains information on births and deaths of individuals taken from Kaplanis et al. [2018], who compiles the data on 86 million individuals from genealogical records maintained by an online genealogy website. The data relies on information from people's family trees. We use the geolocated places of birth and death to assign individuals to specific cells that match the 0.5 degree resolution of the climate data, and their birth/death years to assign them to a corresponding fifty-year intervals. Using this, we compute the number of individuals born within a given time period (e.g., from 1750 to 1850) in a specific 0.5 degree cell, the number of individuals who died within a given time period in a specific 0.5 degree cell, and the share of individuals who were born within a given time period within a specific cell, but pass away in a different cell. This latter variable is then our measure of bilateral migration between two cells over time. The data does not identify the year of migration, as we only have information about the location and year of birth and death. Therefore, we use the year of death as a proxy for the year of migration. In addition, instead of using the annual data, we use intervals calculated over a period of twenty-five years.

Trust, institutions, conflicts

In order to uncover the potential mechanisms behind our results, we add additional variables from three sources. The first is a variable which controls for locations which experienced different types of conflicts in the past, from Dincecco and Onorato [2018]. The conflict dummy variable takes the value of 1 if at least one conflict took place in the cell during 1000–1800, regardless of its type and duration. Furthermore, we include a dummy variable in case the location was historically located in a city with population larger than 10,000 inhabitants (the source for the dataset is Bosker et al. [2008]). Two additional variables were obtained from European Social Surveys for the year 2012, with the data available at the regional level (either NUTS1, 2 or 3 depending on the country). These variables are based on two survey questions capturing the respondent's attitudes towards migrants, and trust in parliament.[20]

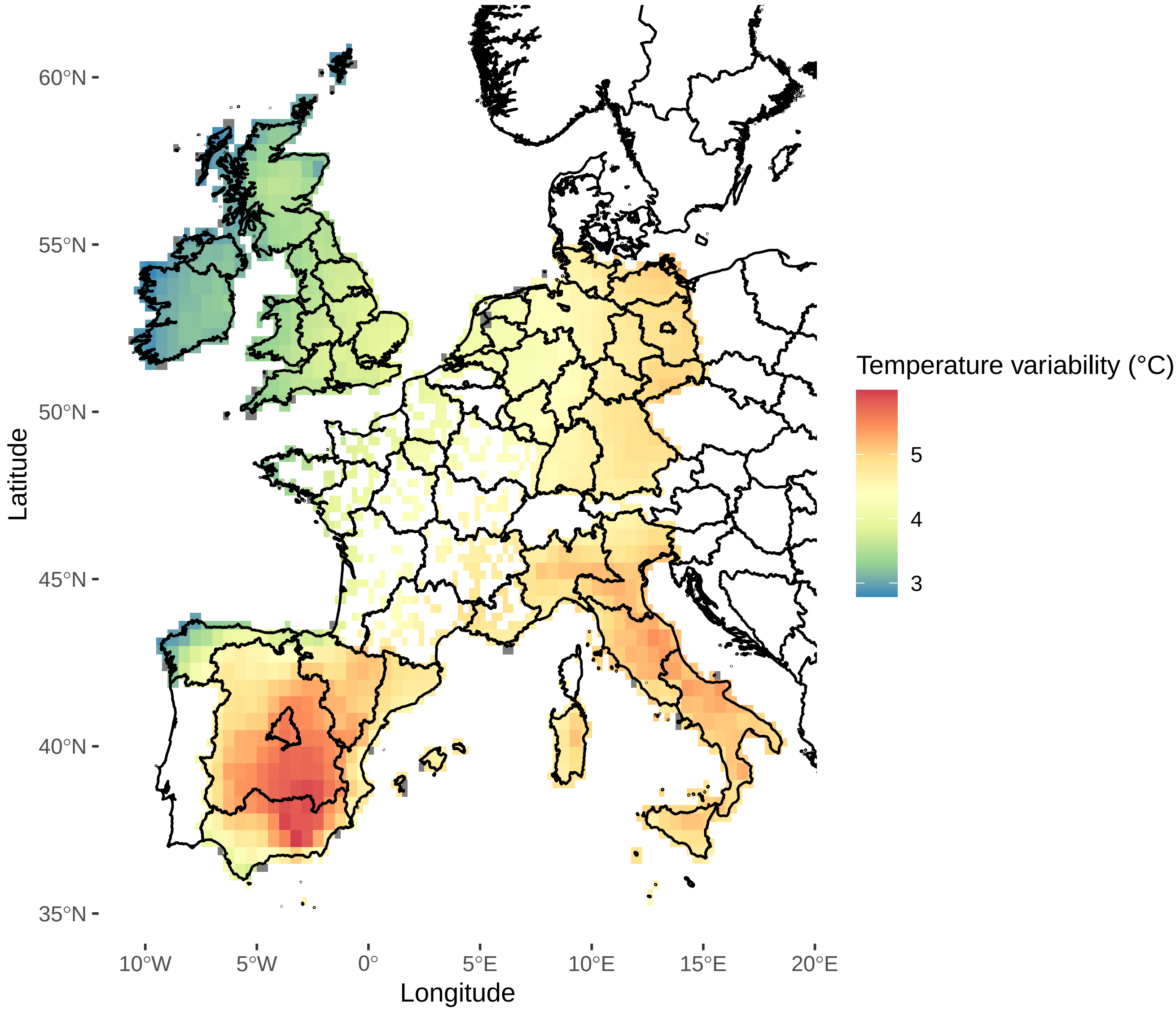
[20] The survey questions are: "Do immigrants make the country a better or a worse place?", and "Do you trust the parliament?".

Figure 1: Variation in precipitation



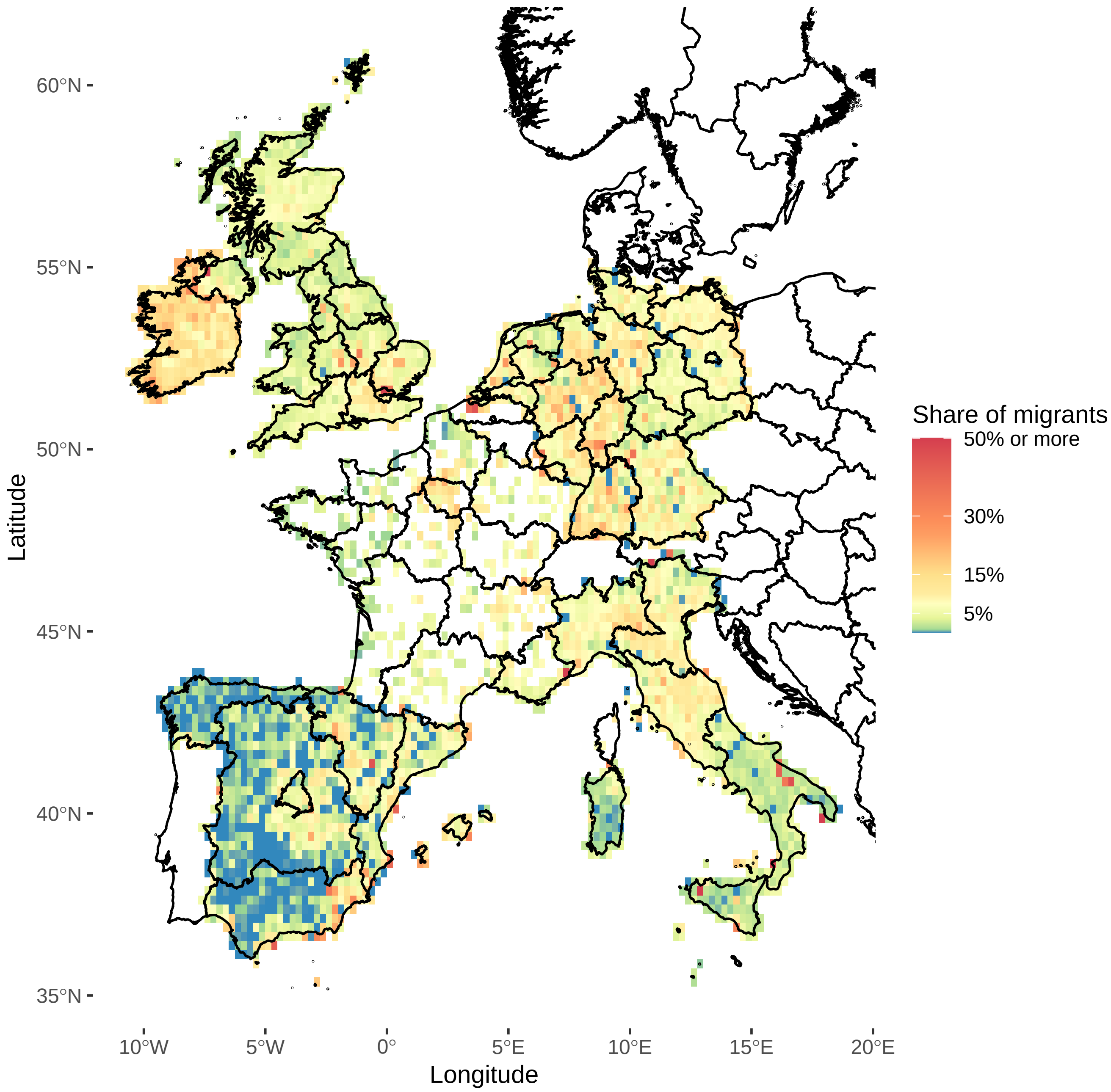
Note:.

Figure 2: Variation in temperature



Note:.

Figure 3: Share of migrants



Note:.

Table 1: Descriptive statistics for the main variables.

	mean	sd	p50	p25	p75
Share of migrants	7.47	7.63	5.75	2.87	9.97
Mean temperature	13.05	2.88	12.33	11.46	14.72
Temperature variability	4.43	0.66	4.59	3.93	4.91
Mean Precipitation	190.57	81.99	180.11	149.15	209.93
Precipitation variability	55.69	18.97	53.19	42.92	63.28
Temperature variability, NGS	4.07	0.75	4.19	3.56	4.61
Precipitation variability, NGS	46.15	17.59	42.33	33.99	53.30
Land suitability	0.61	0.29	0.67	0.38	0.86
Coastal region	0.19	0.39	0.00	0.00	0.00
Distance to coast	0.12	0.12	0.07	0.02	0.19
Altitude	0.34	0.37	0.21	0.07	0.48
On a river	0.03	0.18	0.00	0.00	0.00
Area size	331900.22	132568.11	348570.00	241930.00	348570.00
Total population	36491.38	98169.60	9357.02	1213.15	34201.43
Light intensity	18843.96	27780.93	10728.16	5277.42	20117.84
City	0.14	0.34	0.00	0.00	0.00
Conflict	0.12	0.32	0.00	0.00	0.00
Observations	7902				

4 Empirical specification and results

Based on the outlined conceptual framework, using current migration stocks, we estimate the following empirical specification:

$$M_{c,r} = \beta_0 + \beta_1 V_{c,r} + \beta_2 X_{c,r} + v_r + e_{c,r} \tag{1}$$

where the outcome variable $M_{c,r}$ is the share of migrants in a given cell c and region r.[21] The variable of interest is $V_{c,r}$, which is our proxy of climate risk, captured by the standard deviation in precipitation and temperature over the period 1500-1800. In addition, we control for other factors specific to the same location $X_{c,r}$, which include other climate and geographical controls. More specifically, other climate controls are mean precipitation and mean temperature over the same period, while geographical controls include land suitability for agricultural activities, whether the cell is located in a coastal region, on a river, its (log) distance to coast, its altitude, its (log) area size, and its latitude and longitude. In order to control for economic activity and population density in the cell, we use light intensity and (log) total population in the cell. Finally, we include a dummy variable for whether the cell is a (historical) city or rural area. All specifications also include region-specific fixed effects (v_r) at the NUTS1 level. The fixed effects capture time-invariant region-specific factors influencing the number of migrants, such as economic conditions, as well as cultural and historical factors (for example, past colonial ties).

[21] As a robustness test we also use the (log) of number of migrants in a given cell.

4.1 Main results

Table 2 presents three versions of Equation 1, with all specifications including fixed effects at the regional (NUTS) level, and standard errors clustered at the same level. In the first column, we show results from a linear specification, where both variability in precipitation and temperature enter linearly. We find that while historical temperature variation is not significant, variability in precipitation has a negative impact on the share of migrants at 5% significance. A one-unit increase in the standard deviation of historical precipitation decreases the share of migrants in a given cell by 0.04 percentage points (with the mean share of migrants in the sample being 7%, and the standard deviation of precipitation 56.22). Regarding other control variables, we find that there is a higher share of migrants in locations which are at lower altitudes, on a river and in cities.

We find no significant relationship between temperature variation and migration, only when included in an interaction form with precipitation (in column 2). An important question is whether, throughout history, temperature and precipitation risks were equally important for agricultural yields in Europe. Indeed, Schumann et al. [2013] finds that in seasonal variation in precipitation was a stronger predictor for mortality than temperature in Sweden, due to the impact through crop yields. In addition, temperature is mostly relevant for winter crops with freezing/not freezing cycles, and for some perennial crops if they need a freezing or cold period before flowering or to induce germination. Lower temperature in the summer will delay harvest, but may have a limited effect on output. Higher temperatures may only be an issue if they are accompanied with a lack of rain. By contrast, drought will also prevent growth, but can also prevent planting if the soil is hard. In addition, excess water may make it difficult to access fields and prevent the removal of pests and weeds, and then harvest. Cereals and some fruits and vegetables will be less likely to store well if they are collected in humid conditions (they will rot instead of drying). In addition, they will be smaller if rain has been insufficient. Similarly, an increase in summer rainfall leads to more leaching processes of soil nutrients (nitrogen, phosphorus and potassium), alters the acidity of soils, and increases pest infestation of crops [Tello et al., 2017, Camenisch et al., 2016]. Therefore, while some crops may be more sensitive to precipitation or temperature variation, we expect that, on average, variation in precipitation had a bigger impact on crops in our regions of interest. Indeed, a meta-analysis by [Rivington and Koo, 2010] looking at crop modeling for climate finds that precipitation variation has the greatest influence on crop yields.[22].

Other reasons for this insignificant result in temperature variation could be that precipitation has higher spatial variability (see Burke et al. [2009]), or that what matters is the combination of precipitation and temperature variations. For example, at higher temperatures, lower than average precipitation could have an important impact on crops, while at lower temperatures, precipitation might be less important

[22]It is also instructive that God tells people in the Old Testament, 'If you carefully observe the commands that I'm giving you [...] then I will send rain on the land in its season [...] and you'll gather grain, wine and oil. I will provide grass in the fields for your livestock, and you'll eat and be satisfied' (as cited in Harari [2016]

Table 2: Main table

Dependent var : Migrants	(1)	(2)	(3)
Precipitation variability	-0.045	0.250	-0.098
	(0.019)**	(0.086)***	(0.041)**
Temperature variability	-0.218	3.004	-3.802
	(0.964)	(1.188)**	(4.800)
Mean Precipitation	0.007	0.000	0.006
	(0.003)*	(0.004)	(0.003)*
Mean Temperature	-0.107	-0.178	-0.108
	(0.115)	(0.112)	(0.105)
Land suitability	-0.010	0.044	-0.022
	(0.774)	(0.815)	(0.743)
Coastal region	0.573	0.524	0.540
	(0.431)	(0.441)	(0.439)
Distance to coast	0.431	0.427	0.452
	(0.244)*	(0.252)*	(0.252)*
Altitude	-1.743	-1.546	-1.804
	(0.624)***	(0.615)**	(0.604)***
On a river	1.811	1.774	1.790
	(0.611)***	(0.611)***	(0.607)***
Area size	-0.408	-0.502	-0.406
	(0.489)	(0.494)	(0.488)
Total population	0.054	0.057	0.051
	(0.135)	(0.135)	(0.135)
City	1.073	1.091	1.094
	(0.356)***		
Longitude	0.274	(0.347)***	(0.354)***
	(0.186)	0.306	0.269
Latitude	-0.397	(0.169)*	(0.174)
	(0.274)	-0.359	-0.382
precipitation*temperature variability		-0.063	
		(0.019)***	
		(0.263)	
Precipitation variability Sq.			0.000
			(0.000)*
Temperature variability Sq.			0.375
			(0.530)
			(0.260)
R^2	0.02	0.02	0.02
N	7,332	7,332	7,332
Regional FE	Yes	Yes	Yes

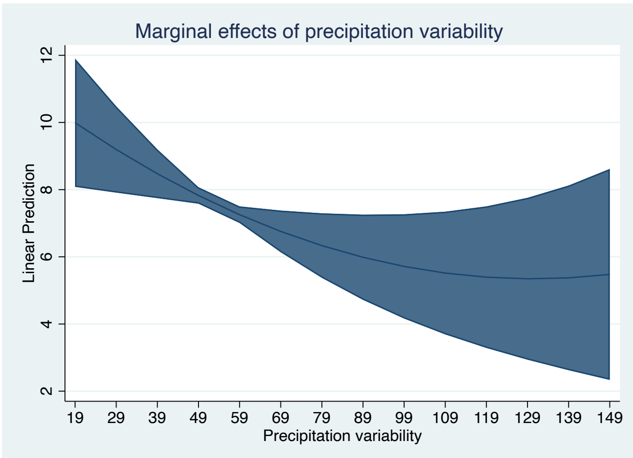
* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: The dependent variable is the share of migrants in the total population. Precipitation variability and temperature variability are measured by the standard deviation of precipitation and temperature for growing seasons between 1500-1800. Standard errors are clustered at the NUTS level. All specifications include NUTS fixed effects.

for certain crops. Indeed, when we interact temperature with precipitation in the second column, the interaction effect is significant and negative, with the marginal effects for both precipitation and temperature remaining negative, indicating a joint relationship.[23]

The non-linear effects of climate variability on migration are explored in the last column, where quadratic terms are included for both precipitation and temperature variability. We find a significant non-linear relationship between precipitation variation and migration, and again, insignificant results for temperature. The marginal effects are plotted in Figure 4, showing a slightly U-shaped relationship. While variation in precipitation in most ranges reduces the share of migrants, the very highest levels of variation slightly increase the share of migrants. One possible explanation for this finding is that lower levels of climate variation do not create sufficient labor market shortages due to crop harvesting. Migrants are less likely to choose such locations due to the lower expected returns to migrating. On the other hand, as climate variation becomes extreme, there is a higher probability of labor market shortages, resulting in a (fluctuating) demand for migrant workers, leading to higher migrant shares in those locations today. Similarly to our results, Cai et al. [2016] find that current temperature variation has a non-linear impact on international outmigration in agriculture-dependent countries. A non-linear relationship between yield in agricultural crops and climate has also been documented in other literature (see Schlenker and Roberts [2009] and Auffhammer and Schlenker [2014]), which is also consistent with agriculture being the channel driving the migration impact of climate variation.

Figure 4: Marginal effects of precipitation



Note:.

[23]In the interaction specification, we are interested in exploring whether the combination of precipitation and temperature variations has a joint effect, and not in a substantive interpretation of the interaction term.

4.2 Robustness checks

Next, we probe the robustness of our results by running additional regressions. First, we run a specification to test if the link between climate variation is indeed driven by agricultural activity. In Table 3, the first column presents specifications, where, in addition to climate variation during the growing season (as shown in Table 2), we also include the climate variation during the non-growing season. If the climate variables matter for agricultural activity and labor demand in agriculture, climate variation should matter only during growing seasons when crop yields can be affected. Indeed, we do not find a significant impact of the non-growing season variation of precipitation and temperature.

We also look at differences between rural and city areas. Again, if what we capture is impact of climate risk on migration through agricultural activities, we would expect the impact of climate variation to be smaller or negligible in historical cities, and higher in rural areas. Results presented in column 2 and 3 are based on split-sample estimates, with column 2 using a sample which is restricted to historical cities, while column 3 includes only historical rural areas. Our results are in line with the expectations, with a negative relationship between climate variation and migration only observed in the rural sample.

We undertake further robustness checks for which results are presented in the Appendix. More specifically, we drop cells which are at country borders, as in such cases non-natives might not represent actual migrants. We also use light intensity as a measure of economic activity instead of population density. Moreover, we re-estimate our main specification using climate variation calculated with alternative periods (i.e., 1500-1700, 1500-1750, 1500-1850). In addition, we replicate our main results presented in Table 2 using a fractional logit estimation. While several historian argue that local population did not emigrate as a result of weather /yield fluctuations in pre-industrial times (see for example Deschacht and Winter [2015a],Jacquemyns [1928], Vandenbroeke [1979], Dribe [2003]), if climate variation affected also native emigration, our immigration rate measure could be capturing part of local population movements. Hence a robustness check in Table 10, we use the total number of migrants (in logs) as dependent variable instead of using shares (which might be affected by changes in local population numbers). Our main results hold, with the sign and significance of our main variable of interests remaining the same. Finally, in Table 11 we present results with an alternative measure of climate variation, absolute mean deviation, and also using principal components to create a joint precipitation and temperature variability measure. The joint measure based on standard deviations is negative, and significant at 10% . Using the alternative absolute mean deviation, only the joint measure is significant, and negative. [24]

[24] As a further robustness check we exclude population from the explanatory variables which lead to almost the same coefficients/significance for our variable of interest.

Table 3: Robustness checks

Dependent var : Migrants	Non growing seasons	Only city	Only rural
Precipitation variability	-0.042	-0.011	-0.047
	(0.018)**	(0.031)	(0.020)**
Temperature variability	-0.781	-2.012	-0.023
	(1.288)	(1.265)	(1.070)
Mean Precipitation	0.013	-0.016	0.009
	(0.007)*	(0.009)*	(0.004)**
Mean Temperature	-0.094	-0.823	-0.067
	(0.115)	(0.272)***	(0.118)
Land suitability	-0.167	-1.340	-0.118
	(0.778)	(1.495)	(0.850)
Coastal region	0.517	0.788	0.526
	(0.428)	(0.820)	(0.501)
Distance to coast	0.352	1.376	0.305
	(0.241)	(0.467)***	(0.239)
Altitude	-1.786	-2.811	-1.860
	(0.662)***	(1.981)	(0.684)***
On a river	1.867	1.433	1.760
	(0.601)***	(1.669)	(0.834)**
Area size	-0.452	-0.831	-0.338
	(0.487)	(0.686)	(0.529)
Total population	0.053	-0.040	0.079
	(0.135)	(0.236)	(0.131)
City	1.079		
	(0.351)***		
Precipitation variability, NGS	-0.037		
	(0.023)		
Temperature variability, NGS	1.207		
	(1.332)		
Longitude	0.166	0.228	0.291
	(0.196)	(0.266)	(0.198)
Latitude	-0.481	-0.574	-0.366
	(0.291)	(0.384)	(0.296)
R^2	0.02	0.03	0.01
N	7,332	1,035	6,297
Regional FE	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: The dependent variable is the share of migrants in the total population. Precipitation variability and temperature variability are measured by the standard deviation of precipitation and temperature for growing seasons between 1500-1800. Standard errors are clustered at the NUTS level. All specifications include NUTS fixed effects. The first column includes non-growing season variation in climate, the second column uses a sample restricted to historical cities, while the last column uses a sample with cells only in rural areas.

4.3 Historical migration flows

In this section, we present results using our genealogy based dataset. The main advantage of this dataset is that it has a time dimension, which allows us to investigate the contemporaneous effects of climate variation. In addition, we exploit the bilateral dimension of the data, which means that our empirical specification from equation 1 modifies and maps into the gravity model. While the gravity model has been extensively used to empirically estimate trade flows since Tinbergen [1962], and the theoretical foundations have been linked to different trade models (see an overview in Head and Mayer [2014]), it has also been applied to other types of flows between countries, including migration flows.[25] Therefore, our empirical specification changes to:

$$M_{odt} = \beta_0 + \beta_1 V_{dt} + \beta_2 P_{dt} + \o_{ot} + \rho_{od} + \delta_d + e_{odt} \tag{2}$$

Where M_{odt} is the share of migrants from origin cell o to destination cell d at time t (calculated as the share of origin cell population).[26] with migration being limited to international migration.[27]V_{dt} is the climate variation in the destination cell, calculated as the average climate variation in the past 25 years. In addition, we control for origin cell-time specific factors with origin-time fixed effects ($\o_{ot}$), for origin-destination pair cell specific factors with pair fixed effects (ρ_{od}), and for destination cell specific factors with destination fixed effects (δ_d). In order to control for changing economic activity in the destination cell over time, we include population density in the destination (P_{dt}).

Following our earlier results, Table 4 show linear effects in the first column, followed by interactions and non-linear effects. Similarly to our previous results, we find that variability in precipitation has a negative impact on bilateral migration flows. More specifically, we find that the variation in precipitation in a destination cell reduces migration inflows, and again we find that also non-linear effects are significant. On the other hand, we do not find significant effect for joint effects or precipitation and temperature variation on inward migration.

Table 4 presents a placebo test where instead of recent climate variation, we regress bilateral migration flows on *future* climate variation (for the period 150 years later). As expected, we do not find any significant relationship between future climate variation and current migration. This makes us confident that the results we uncover are likely to be causal, rather than driven by omitted variable bias or reverse causality.

[25] Beine et al. [2016] provide a good overview of the gravity model's application to international migration flows and lay out also its theoretical basis.

[26] As a robustness check, we also run regressions with flows in levels, and we find that climate risk influences migration flows negatively, with the temperature variable being significant and negative. Results are available in the Annex.

[27] To distinguish international from national migration, we use the current borders as a proxy for country borders. While this might not be exactly accurate for some historical border cells, we also include cell-time specific fixed effects for origin cells. In addition, when we run regressions with all migrants (including domestic migration), our results hold.

Table 4: Genealogy-based bilateral migration flows

	Bilateral migration flows		
Precipitation variability	-0.014	0.002	-0.037
	(0.007)*	(0.017)	(0.009)***
Temperature variability	-2.246	-1.777	-7.941
	(1.815)	(1.953)	(5.648)
Mean precipitation	-0.000	-0.001	-0.002
	(0.004)	(0.004)	(0.005)
Mean temperature	0.605	0.561	0.424
	(0.574)	(0.577)	(0.516)
Log of destination pop	-0.059	-0.059	-0.049
	(0.057)	(0.057)	(0.055)
precipitation*temperature variability		-0.026	
		(0.020)	
Squared precipitation variability			0.000
			(0.000)***
Squared temperature variability			3.603
			(2.611)
R^2	0.88	0.88	0.88
N	16,247	16,247	16,247
FE	Yr x orig, dest, pair	Yr x orig, dest, pair	Yr x orig, dest, pair

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: The dependent variable is the share of migrants from an origin cell to a destination cell over 25-year periods. Precipitation variability and temperature variability are measured by the standard deviation of precipitation and temperature for growing seasons with a lag of 25 years. Standard errors are clustered at the level of destination cells. All specifications include origin cell-year, origin-destination cell, and destination cell fixed effects.

Table 5: Genealogy-based migration flows - placebo test

	Bilateral migration flows		
Precipitation variability	-0.006	0.014	-0.004
	(0.007)	(0.023)	(0.012)
Temperature variability	-1.558	-0.663	-3.083
	(1.168)	(1.538)	(2.804)
Mean precipitation	0.004	0.004	0.004
	(0.004)	(0.004)	(0.004)
Mean temperature	-0.307	-0.265	-0.307
	(0.299)	(0.300)	(0.302)
Log of destination pop	-0.064	-0.064	-0.064
	(0.060)	(0.059)	(0.060)
precipitation*temperature variability		-0.027	
		(0.027)	
Squared precipitation variability			-0.000
			(0.000)
Squared temperature variability			0.940
			(1.849)
R^2	0.88	0.88	0.88
N	16,247	16,247	16,247
FE	Yr x orig, dest, pair	Yr x orig, dest, pair	Yr x orig, dest, pair

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: The dependent variable is the share of migrants from an origin cell to a destination cell over 25-year periods. Precipitation variability and temperature variability are measured by the standard deviation of precipitation and temperature for growing seasons 150 years ahead. Standard errors are clustered at the level of destination cells. All specifications include origin cell-year, origin-destination cell, and destination cell fixed effects.

4.4 Mechanisms

Thus far, we have shown that historical climate risk likely affected migration through agriculture. However, it is still unclear how these effects persisted and influenced today's migration patterns. In this section, we explore four main potential mechanisms.

One possibility is that past migrants could have attracted more migrants to locations with lower climate risk through network effects, [Cattaneo, 2019]. In order to test this potential mechanism, we calculated the stock of international migrants in each location (using our genealogy dataset) in the year 1800 as a proxy for historical migrant networks. Column 1 in Table 6 includes this measure of past international migrants as an additional control variable. Indeed, as this variable is included, precipitation and temperature variation become insignificant indicating that the effect of past climate variation is likely to go through these past migrant networks. Thus we conclude that historical social networks likely reinforce and channel the impact of historical climate risk.

Table 6: Testing potential mechanisms

Dep. var: Migrants	Past migrants	Conflict	Trade	GDPperCap	Pop.Density	Attitudes	Institutions
Precipitation var.	-0.040	-0.045	-0.036	-0.019	-0.019	-0.054	-0.053
	(0.016)**	(0.019)**	(0.007)***	(0.007)***	(0.014)	(0.008)***	(0.008)***
Temperature var.	-0.071	-0.233	-0.492	0.001	-0.391	-0.570	-1.379
	(1.028)	(0.969)	(0.312)	(0.323)	(1.179)	(0.313)*	(0.324)***
Mechanism var.	0.004	0.581	-0.437	5.835	0.708	2.976	3.282
	(0.001)***	(0.294)*	(0.086)***	(0.565)***	(0.298)**	(0.282)***	(0.266)***
R^2	0.29	0.29	0.16	0.16	0.31	0.17	0.18
N	6,626	7,332	7,241	6,980	5,073	7,270	7,270
Regional FE	Yes	Yes	No	No	Yes	No	No
Country FE	No	No	Yes	Yes	No	Yes	Yes
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: The dependent variable is the share of migrants in the total population. Precipitation variability and temperature variability are measured by the standard deviation of precipitation and temperature for growing seasons between 1500-1800. All specifications include country fixed effects, and robust standard errors. The full list of control variables (as in Table 2) are included, but not presented in the table.

Columns 2 we test the hypothesis that locations with past conflicts drove away migrants still having an impact on today's migration patterns. While we find a marginally significant effect of past conflicts on today migration patterns, the impact of climate variation remains unchanged.

The next two columns in the table tests the importance of two additional channels. First, it could be that past climate variation led to to more welcoming attitudes towards migrants, as well as more migrant-friendly institutions, which persisted until today. In column 3, we include current attitudes towards migrants, and in column 4, current trust in parliament (as a proxy for more open institutions). While these variables measure today's attitudes and institutions (at regional level) and not past attitudes, we expect that these factors are highly persistent over time (see [Buggle and Durante, 2021] and Voigtländer and Voth [2012] on long-term persistence of similar attitudes). When including either attitudes towards migrants or trust in parliament, climate variability remains significant and negative.[28] In other words, even though we find that the correlation between attitudes towards migrants and trust in parliament is positive for current migrants, the impact of climate variation remains the same, indicating that its impact is not going through these factors.

Buggle and Durante [2021] provide an argument consistent with our findings: in locations with higher historical climate variation, people have higher trust, which is likely correlated with trust towards foreigners, and more welcoming institutions. Indeed, when we regress attitudes towards migrants, or trust in parliament, on climate variation and other geographical controls, we find a positive relationship further indicating that these are also potential reinforcing mechanisms (these regression results are presented in the Annex in Table 9).

5 Conclusion

Using two novel datasets, we examine the impact of historical climate risk on inward migration in eight European countries. We find a negative relationship between the historical variability in precipitation and the share of migrants in 2011 measured at the locality level. A one-unit increase in the standard deviation of historical precipitation decreases the share of migrants in a given cell by 0.04 percentage points (with the mean share of migrants in the sample being 7%, and the standard deviation of precipitation 56.22). In addition, the combination of historical temperature and precipitation variability has a joint negative effect on today's migration stocks. We find that these results are only present in localities that were historically rural and during periods corresponding to the growing season of major crops, suggesting that the identified long-run relationships are driven by agriculture. Our historical bilateral migration flow data confirms the finding that climate variability significantly reduces inward migration. We find evidence that past social networks, more welcoming attitudes and more open institutions are likely mechanisms through which historical climate risk still influences today's migration patterns. While our results are unable to pinpoint the exact sequence of mechanisms at play, we hypothesize that historical climate risk affected migration networks and historical income levels, which, through persistence, affected today's migration patterns.

Our results have important implications for the academic and policy debate on European migration. On the academic front, we use novel data to study the determinants of in-migration, which, despite being conceptually different from out-migration, has been understudied. Our work highlights the importance of historical climate variation for today's migration flows. This is a novel insight that has not been explored before, since highly detailed European data on the topic is scarce. On the policy front, international migration flows have reached unprecedented levels over the past decades, shaping an increasingly ethnically diverse and socially connected world. The economic and political consequences of these migration flows are at the heart of fierce

[28] As these variables vary at regions NUTS1 or 2 level depending on the country, instead of regional fixed effects country fixed effects are included in the regressions.

debates on immigration policy. Our work illuminates how present-day policies for increasing or decreasing skilled or unskilled migration are mediated by long-term historical factors such as climate and geography. We thus identify migration drivers which are less amenable to policy interventions, thus paving the way for policymakers to focus on policies - such as migration programs for high-skilled workers - which may in fact have a palpable impact on migration.

References

Daron Acemoglu, Giuseppe De Feo, and Giacomo Davide De Luca. Weak states: Causes and consequences of the sicilian mafia. *The Review of Economic Studies*, 87(2):537–581, 2020.

Philipp Ager and Antonio Ciccone. Agricultural risk and the spread of religious communities. *Journal of the European Economic Association*, 16(4):1021–1068, 2018.

Alberto Alesina, Paola Giuliano, and Nathan Nunn. On the origins of gender roles: Women and the plough. *The Quarterly Journal of Economics*, 128(2):469–530, 2013.

A Alessandrini, F Natale, F Sermi, and M Vespe. High resolution map of migrants in the eu. Technical report, JRC Technical Reports EUR 28770 EN, doi: 10.2760, 2017.

Robert Warren Anderson, Noel D Johnson, and Mark Koyama. Jewish persecutions and weather shocks: 1100–1800. *The Economic Journal*, 127(602):924–958, 2017.

Maximilian Auffhammer and Wolfram Schlenker. Empirical studies on agricultural impacts and adaptation. *Energy Economics*, 46:555–561, 2014.

Klaus J Bade. *L'Europe en mouvement: la migration de la fin du XVIIIe siècle à nos jours*. Seuil, 2002.

Paul Bairoch, Jean Batou, and Chevre Pierre. *Population des villes européennes de 800 à 1850: banque de données et analyse sommaire des résultats (la)*. Librairie Droz, 1988.

Michel Beine and Christopher Parsons. Climatic factors as determinants of international migration. *The Scandinavian Journal of Economics*, 117(2):723–767, 2015.

Michel Beine, Frederic Docquier, and Caglar Ozden. Diasporas. *Journal of Development Economics*, 95(1):30–41, 2011. doi: http://dx.doi.org/10.1016/j.jdeveco.2009.11.004. Symposium on Globalization and Brain Drain.

Michel Beine, Simone Bertoli, and Jesús Fernández-Huertas Moraga. A practitioners? guide to gravity models of international migration. *The World Economy*, 39(4):496–512, 2016.

Michel AR Beine and Lionel Jeusette. A meta-analysis of the literature on climate change and migration. *Journal of Demographic Economics*, pages 1–52, 2021.

Michael Berlemann and Max Friedrich Steinhardt. Climate change, natural disasters, and migration—a survey of the empirical evidence. *CESifo Economic Studies*, 63 (4):353–385, 2017.

George J Borjas. Self-selection and the earnings of immigrants. Technical report, National Bureau of Economic Research, 1987.

Erik Maarten Bosker, Eltjo Buringh, and Jan Luiten van Zanden. From baghdad to london: The dynamics of urban growth in europe and the arab world, 800-1800. *Vol*, 2008.

Maarten Bosker, Eltjo Buringh, and Jan Luiten Van Zanden. From baghdad to london: Unraveling urban development in europe, the middle east, and north africa, 800–1800. *Review of Economics and Statistics*, 95(4):1418–1437, 2013.

Leah Platt Boustan, Matthew E Kahn, and Paul W Rhode. Moving to higher ground: Migration response to natural disasters in the early twentieth century. *American Economic Review*, 102(3):238–44, 2012.

Johannes Christoph Buggle and Ruben Durante. Climate risk, cooperation, and the co-evolution of culture and institutions. *The Economic Journal*, 2021.

Marshall Burke, Solomon M Hsiang, and Edward Miguel. Climate and conflict. *Annu. Rev. Econ*, 7:577–617, 2015.

Marshall B Burke, Edward Miguel, Shanker Satyanath, John A Dykema, and David B Lobell. Warming increases the risk of civil war in africa. *Proceedings of the national Academy of sciences*, 106(49):20670–20674, 2009.

Ruohong Cai, Shuaizhang Feng, Michael Oppenheimer, and Mariola Pytlikova. Climate variability and international migration: The importance of the agricultural linkage. *Journal of Environmental Economics and Management*, 79:135–151, 2016.

Chantal Camenisch, Kathrin M Keller, Melanie Salvisberg, Benjamin Amann, Martin Bauch, Sandro Blumer, Rudolf Brázdil, Stefan Brönnimann, Ulf Büntgen, Bruce Campbell, et al. The 1430s: a cold period of extraordinary internal climate variability during the early spörer minimum with social and economic impacts in northwestern and central europe. *Climate of the Past*, 12(11):2107–2126, 2016.

Bruce MS Campbell. Nature as historical protagonist: environment and society in pre-industrial england. *The Economic History Review*, 63(2):281–314, 2010.

Cristina Cattaneo. Migrant networks and adaptation. *Nature Climate Change*, 9(12): 907–908, 2019.

Cristina Cattaneo, Michel Beine, Christiane J Fröhlich, Dominic Kniveton, Inmaculada Martinez-Zarzoso, Marina Mastrorillo, Katrin Millock, Etienne Piguet, and Benjamin Schraven. Human migration in the era of climate change. *Review of Environmental Economics and Policy*, 13(2):189–206, 2019.

E. J. T. Collins. Migrant labour in british agriculture in the nineteenth century. *The Economic History Review*, 29(1):38–59, 1976. ISSN 00130117, 14680289. URL http://www.jstor.org/stable/2594506.

Jonathan Colmer. Temperature, labor reallocation, and industrial production: Evidence from india. *American Economic Journal: Applied Economics*, 13(4):101–24, 2021.

Nicola D Coniglio and Giovanni Pesce. Climate variability and international migration: an empirical analysis. *Environment and Development Economics*, 20(4): 434–468, 2015.

Richard Damania. The economics of water scarcity and variability. *Oxford Review of Economic Policy*, 36(1):24–44, 2020.

Richard Damania, Sebastien Desbureaux, and Esha Zaveri. Does rainfall matter for economic growth? evidence from global sub-national data (1990–2014). *Journal of Environmental Economics and Management*, 102:102335, 2020.

Ralph Davis. *The Rise of the Atlantic Economies*. Cornell University Press, 1973.

Melissa Dell, Benjamin F Jones, and Benjamin Olken. Temperature shocks and economic growth: Evidence from the last half centur. *American Economic Journal: Macroeconomics*, 4(3):66–95, 2012.

Melissa Dell, Benjamin F Jones, and Benjamin A Olken. What do we learn from the weather? the new climate-economy literature. *Journal of Economic Literature*, 52 (3):740–98, 2014.

Nick Deschacht and Anne Winter. Rural crisis and rural exodus? local migration dynamics during the crisis of the 1840s in flanders (belgium). *Explorations in Economic History*, 56:32–52, 2015a. ISSN 0014-4983. doi: https://doi.org/10.1016/j.eeh.2014.11.001. URL https://www.sciencedirect.com/science/article/pii/S0014498314000424.

Nick Deschacht and Anne Winter. Rural crisis and rural exodus? local migration dynamics during the crisis of the 1840s in flanders (belgium). *Explorations in Economic History*, 56:32–52, 2015b.

TM Devine. Women workers, 1850-1914. *Farm servants and labour in lowland Scotland, 1770-1914/edited by TM Devine*, 1984.

Mark Dincecco and Massimiliano Gaetano Onorato. *From Warfare to Wealth*. Cambridge University Press, 2018.

Martin Dribe. Migration of rural families in 19th century southern sweden. a longitudinal analysis of local migration patterns. *The History of the Family*, 8(2):247–265, 2003.

William Easterly. Inequality does cause underdevelopment: Insights from a new instrument. *Journal of development economics*, 84(2):755–776, 2007.

Patrick R. Galloway. Long-term fluctuations in climate and population in the preindustrial era. *Population and Development Review*, 12(1):1–24, 1986. ISSN 00987921, 17284457. URL `http://www.jstor.org/stable/1973349`.

Oded Galor and Ömer Özak. The agricultural origins of time preference. *American Economic Review*, 106(10):3064–3103, 2016.

Paola Giuliano and Nathan Nunn. Understanding cultural persistence and change. Technical report, National Bureau of Economic Research, 2017.

George W Grantham. Divisions of labour: agricultural productivity and occupational specialization in pre-industrial france 1. *The economic history review*, 46(3):478–502, 1993.

Avner Greif and Guido Tabellini. Cultural and institutional bifurcation: China and europe compared. *American economic review*, 100(2):135–40, 2010.

Jeffrey Grogger and Gordon H Hanson. Income maximization and the selection and sorting of international migrants. *Journal of Development Economics*, 95(1):42–57, 2011.

Luigi Guiso, Paola Sapienza, and Luigi Zingales. Long-term persistence. *Journal of the European Economic Association*, 14(6):1401–1436, 2016.

Sylvia Hahn. Inclusion and exclusion of migrants in the multicultural realm of the habsburg" state of many peoples". *Histoire sociale/Social History*, 2000.

Yuval Noah Harari. *Homo Deus*. Random House, 2016.

Timothy J. Hatton and Jeffrey G. Williamson. What fundamentals drive world migration? `http://www.nber.org/papers/w9159`, 2002.

Keith Head and Thierry Mayer. Gravity equations: Workhorse, toolkit, and cookbook. In *Handbook of international economics*, volume 4, pages 131–195. Elsevier, 2014.

J Vernon Henderson, Tim Squires, Adam Storeygard, and David Weil. The global distribution of economic activity: nature, history, and the role of trade. *The Quarterly Journal of Economics*, 133(1):357–406, 2017.

Steve Hochstadt. Migration in preindustrial germany. *Central European History*, 16 (3):195?224, 1983. doi: 10.1017/S0008938900013935.

Steve Hochstadt. *Mobility and modernity: migration in Germany, 1820-1989*. University of Michigan Press, 1999.

Roman Hoffmann, Anna Dimitrova, Raya Muttarak, Jesus Crespo Cuaresma, and Jonas Peisker. A meta-analysis of country-level studies on environmental change and migration. *Nature Climate Change*, 10(10):904–912, 2020.

Richard Hornbeck. The enduring impact of the american dust bowl: Short-and long-run adjustments to environmental catastrophe. *American Economic Review*, 102 (4):1477–1507, 2012.

Solomon M Hsiang, Marshall Burke, and Edward Miguel. Quantifying the influence of climate on human conflict. *Science*, 341(6151):1235367, 2013.

Murat Iyigun, Nathan Nunn, and Nancy Qian. The long-run effects of agricultural productivity on conflict, 1400-1900. Technical report, National Bureau of Economic Research, 2017.

Gauillaume Jacquemyns. Histoire de la crise économique des flandres (1845-1850): Mémoires de la classe des lettres/académie royale de belgique: Collection in-8. 1928.

Matthew E Kahn, Kamiar Mohaddes, Ryan NC Ng, M Hashem Pesaran, Mehdi Raissi, and Jui-Chun Yang. Long-term macroeconomic effects of climate change: A cross-country analysis. *Energy Economics*, 104:105624, 2021.

Joanna Kaplanis, Assaf Gordon, Tal Shor, Omer Weissbrod, Dan Geiger, Mary Wahl, Michael Gershovits, Barak Markus, Mona Sheikh, Melissa Gymrek, et al. Quantitative analysis of population-scale family trees with millions of relatives. *Science*, 360(6385):171–175, 2018.

Alexander Klein and Jelle Van Lottum. The determinants of international migration in early modern europe: Evidence from the maritime sector, c. 1700–1800. *Social Science History*, 44(1):143–167, 2020.

Maximilian Kotz, Anders Levermann, and Leonie Wenz. The effect of rainfall changes on economic productio. *Nature*, 601(7892):223–227, 2022.

EL Ladurie. Times of feast, times of famine: A history of climate since the year 1000.(transl. b. bray.) doubleday. *Garden City, New York*, pages 1–426, 1971.

Billie Leff, Navin Ramankutty, and Jonathan A Foley. Geographic distribution of major crops across the world. *Global biogeochemical cycles*, 18(1), 2004.

Anastasia Litina. Natural land productivity, cooperation and comparative development. *Journal of Economic Growth*, 21(4):351–408, 2016.

Jan Lucassen and Leo Lucassen. The mobility transition revisited, 1500?1900: what the case of europe can offer to global history. *Journal of Global History*, 4(3): 347?377, 2009. doi: 10.1017/S174002280999012X.

Jürg Luterbacher, Daniel Dietrich, Elena Xoplaki, Martin Grosjean, and Heinz Wanner. European seasonal and annual temperature variability, trends, and extremes since 1500. *Science*, 303(5663):1499–1503, 2004.

Miriam Manchin and Sultan Orazbayev. Social networks and the intention to migrate. *World Development*, 109:360–374, 2018.

Marina Mastrorillo, Rachel Licker, Pratikshya Bohra-Mishra, Giorgio Fagiolo, Lyndon D Estes, and Michael Oppenheimer. The influence of climate variability on internal migration flows in south africa. *Global Environmental Change*, 39:155–169, 2016.

Anna Maria Mayda. International migration: a panel data analysis of the determinants of bilateral flows. *Journal of Population Economics*, 23(4):1249–1274, 2010.

David McKenzie and Hillel Rapoport. Network effects and the dynamics of migration and inequality: theory and evidence from Mexico. *Journal of Development Economics*, 84(1):1–24, 2007.

Katrin Millock. Migration and environment. *Annu. Rev. Resour. Econ.*, 7(1):35–60, 2015.

Leslie Moch. *Moving Europeans: migration in Western Europe since 1650*. Indiana University Press, 2003.

Leslie Page Moch. Moving europeans: Historical migration practices in western europe. *The Cambridge survey of world migration*, pages 126–130, 1995.

Valerie Mueller, Glenn Sheriff, Xiaoya Dou, and Clark Gray. Temporary migration and climate variation in eastern africa. *World Development*, 126:104704, 2020. ISSN 0305-750X. doi: https://doi.org/10.1016/j.worlddev.2019.104704. URL `https://www.sciencedirect.com/science/article/pii/S0305750X19303523`.

Tommaso Nannicini, Andrea Stella, Guido Tabellini, and Ugo Troiano. Social capital and political accountability. *American Economic Journal: Economic Policy*, 5(2): 222–50, 2013.

Nathan Nunn and Nancy Qian. The potato's contribution to population and urbanization: evidence from a historical experiment. *The Quarterly Journal of Economics*, 126(2):593–650, 2011.

Michel Oris. The history of migration as a chapter in the history of the european rural family: An overview. *The history of the family*, 8(2):187–215, 2003.

Francesc Ortega and Giovanni Peri. The causes and effects of international migrations: Evidence from OECD countries 1980-2005. Working paper, `http://www.nber.org/papers/w14833`, 2009.

Geoffrey Parker. *Europe in Crisis: 1598-1648, 2nd Edition*. Wiley, 2001.

Andreas Pauling, Jürg Luterbacher, Carlo Casty, and Heinz Wanner. Five hundred years of gridded high-resolution precipitation reconstructions over europe and the connection to large-scale circulation. *Climate dynamics*, 26(4):387–405, 2006.

Qing Pei, Yingqi Long, and Xiaolin Lin. Climate change in historical perspective: Violence, conflict, and migration. *Handbook of Labor, Human Resources, and Population Economics*, 2022.

Mike Rivington and Jawoo Koo. Report on the meta-analysis of crop modelling for climate change and food security survey. 2010.

Andrew Donald Roy. Some thoughts on the distribution of earnings. *Oxford economic papers*, 3(2):135–146, 1951.

Wolfram Schlenker and Michael J Roberts. Nonlinear temperature effects indicate severe damages to us crop yields under climate change. *Proceedings of the National Academy of sciences*, 106(37):15594–15598, 2009.

Barbara Schumann, Sören Edvinsson, Birgitta Evengård, and Joacim Rocklöv. The influence of seasonal climate variability on mortality in pre-industrial sweden. *Global Health Action*, 6(1):20153, 2013. doi: 10.3402/gha.v6i0.20153. URL `https://doi.org/10.3402/gha.v6i0.20153`. PMID: 28140999.

Guido Tabellini. The scope of cooperation: Values and incentives. *The Quarterly Journal of Economics*, 123(3):905–950, 2008.

Guido Tabellini. Culture and institutions: economic development in the regions of europe. *Journal of the European Economic association*, 8(4):677–716, 2010.

Enric Tello, José Luis Martínez, Gabriel Jover-Avellà, José Ramón Olarieta, Roberto García-Ruiz, Manuel González de Molina, Marc Badia-Miró, Verena Winiwarter, and Nikola Koepke. The onset of the english agricultural revolution: climate factors and soil nutrients. *Journal of Interdisciplinary History*, 47(4):445–474, 2017.

Jan Tinbergen. Shaping the world economy; suggestions for an international economic policy. 1962.

BH Slicher van Bath. The yields of different crops (mainly cereal) in relation to the seed c. 810–1820. *Acta Hist. Neederlandica*, 2:26–106, 1963.

Jelle Van Lottum. *Across the North Sea: the impact of the Dutch Republic on international labour migration, c. 1550-1850*, volume 1. Amsterdam University Press, 2007.

Christian Vandenbroeke. *Sociale en konjunkturele facetten van de linnennijverheid in Vlaanderen (late 14e-midden 19e eeuw)*. Maatschappij voor Geschiedenis en Oudheidkunde te Gent, 1979.

Nico Voigtländer and Hans-Joachim Voth. Persecution perpetuated: the medieval origins of anti-semitic violence in nazi germany. *The Quarterly Journal of Economics*, 127(3):1339–1392, 2012.

Elena Xoplaki, Jürg Luterbacher, Heiko Paeth, Daniel Dietrich, Niklaus Steiner, Martin Grosjean, and Heinz Wanner. European spring and autumn temperature variability and change of extremes over the last half millennium. *Geophysical Research Letters*, 32(15), 2005.

6 Appendix

6.1 Additional robustness checks and results

Table 7: Further robustness, No border cells, different periods

Dependent var : Migrants	Without border cells	Light intensity	1500-1700	1500-1750	1500-1850
Precipitation variability	-0.049	-0.041	-0.041	-0.044	-0.046
	(0.020)**	(0.019)**	(0.019)**	(0.019)**	(0.020)**
Temperature variability	-0.037	-0.084	-0.171	-0.204	-0.226
	(0.960)	(0.963)	(0.988)	(0.972)	(0.962)
Mean Precipitation	0.008	0.006	0.006	0.007	0.007
	(0.003)**	(0.004)*	(0.003)*	(0.003)*	(0.003)*
Mean Temperature	-0.155	-0.085	-0.109	-0.105	-0.104
	(0.118)	(0.121)	(0.115)	(0.114)	(0.115)
Land suitability	0.361	-0.171	-0.069	-0.015	-0.022
	(0.618)	(0.777)	(0.772)	(0.768)	(0.778)
Coastal region	0.275	0.454	0.606	0.577	0.568
	(0.405)	(0.394)	(0.431)	(0.430)	(0.432)
Distance to coast	0.313	0.367	0.443	0.432	0.428
	(0.233)	(0.233)	(0.242)*	(0.244)*	(0.244)*
Altitude	-1.798	-1.440	-1.710	-1.748	-1.739
	(0.595)***	(0.589)**	(0.621)***	(0.623)***	(0.624)***
On a river	2.363	1.494	1.805	1.818	1.808
	(0.434)***	(0.612)**	(0.609)***	(0.612)***	(0.611)***
Area size	-0.361	-0.399	-0.429	-0.408	-0.407
	(0.585)	(0.467)	(0.490)	(0.489)	(0.490)
Total population	0.191		0.055	0.054	0.054
	(0.142)		(0.135)	(0.135)	(0.135)
City	0.868	0.256	1.077	1.075	1.071
	(0.350)**	(0.379)	(0.355)***	(0.356)***	(0.356)***
Longitude	0.313	0.278	0.275	0.274	0.270
	(0.181)*	(0.180)	(0.184)	(0.187)	(0.185)
Latitude	-0.391	-0.355	-0.398	-0.394	-0.400
	(0.254)	(0.269)	(0.288)	(0.279)	(0.274)
Light intensity		0.000			
		(0.000)***			
R^2	0.03	0.03	0.02	0.02	0.02
N	6,755	7,332	7,332	7,332	7,332
Regional FE	Yes	Yes	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: The dependent variable is the share of migrants in the total population. Precipitation variability and temperature variability are measured by the standard deviation of precipitation and temperature for growing seasons between 1500-1800. Standard errors are clustered at the NUTS level. All specifications include NUTS fixed effects.

Table 8: Fractional logit regressions

Dependent var : Migrants	(1)	(2)	(3)
Precipitation variability	-0.007	0.053	-0.018
	(0.004)*	(0.020)***	(0.009)**
Temperature variability	0.002	0.621	-0.795
	(0.261)	(0.305)**	(1.387)
Mean Precipitation	0.001	0.000	0.001
	(0.001)	(0.001)	(0.001)
Mean Temperature	-0.020	-0.032	-0.020
	(0.020)	(0.020)	(0.018)
Land suitability	-0.030	-0.011	-0.029
	(0.124)	(0.129)	(0.119)
Coastal region	0.091	0.080	0.090
	(0.072)	(0.075)	(0.073)
Distance to coast	0.062	0.063	0.067
	(0.042)	(0.044)	(0.043)
Altitude	-0.315	-0.279	-0.319
	(0.119)***	(0.118)**	(0.113)***
On a river	0.174	0.164	0.171
	(0.065)***	(0.065)**	(0.064)***
Area size	-0.054	-0.072	-0.052
	(0.061)	(0.063)	(0.060)
Total population	0.008	0.009	0.008
	(0.021)	(0.021)	(0.021)
City	0.145	0.148	0.150
	(0.046)***		
Longitude	0.053	(0.046)***	(0.046)***
	(0.040)	0.062	0.054
Latitude	-0.076	(0.039)	(0.038)
	(0.047)	-0.069	-0.069
precipitation*temperature variability		-0.013	
		(0.005)***	
		(0.045)	
Precipitation variability Sq.			0.000
			(0.000)*
Temperature variability Sq.			0.082
			(0.155)
			(0.043)
N	7,332	7,332	7,332
Regional FE	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: The dependent variable is the share of migrants in the total population. Precipitation variability and temperature variability are measured by the standard deviation of precipitation and temperature for growing seasons between 1500-1800. Standard errors are clustered at the NUTS level. All specifications include NUTS fixed effects.

Table 9: Mechanisms/channels as outcomes

Dependent var :	Past migrants	Conflict	Distance to trade routes	GDP per Capita	Population Density	Trust in parliament	Attitudes towards migrants
Precipitation var.	0.010	0.013	0.002	-0.003	-0.000	0.005	0.006
	(0.013)	(0.004)***	(0.002)	(0.000)***	(0.001)	(0.001)***	(0.001)***
Temperature var.	-1.234	-0.160	-0.095	-0.087	-0.044	0.282	0.071
	(1.223)	(0.194)	(0.053)*	(0.013)***	(0.024)*	(0.020)***	(0.021)***
Mean Precipitation	-0.004	-0.002	-0.001	0.001	-0.000	-0.000	-0.000
	(0.003)	(0.001)*	(0.000)***	(0.000)***	(0.000)	(0.000)**	(0.000)
Mean Temperature	0.190	-0.048	0.118	0.021	-0.001	-0.002	0.036
	(0.199)	(0.042)	(0.020)***	(0.003)***	(0.005)	(0.008)	(0.008)***
Land suitability	-0.363	1.351	-0.894	0.126	-0.009	0.031	0.083
	(0.521)	(0.161)***	(0.063)***	(0.010)***	(0.025)	(0.023)	(0.026)***
Coastal region	0.714	0.167	-0.282	-0.019	0.056	-0.063	-0.074
	(0.418)*	(0.130)	(0.063)***	(0.010)*	(0.076)	(0.021)***	(0.022)***
Distance to coast	0.022	0.230	-0.393	0.004	0.009	-0.011	-0.022
	(0.099)	(0.047)***	(0.022)***	(0.003)	(0.011)	(0.006)*	(0.006)***
Altitude	-2.948	-1.147	0.520	0.090	-0.005	-0.023	0.096
	(1.153)**	(0.254)***	(0.103)***	(0.019)***	(0.036)	(0.043)	(0.047)**
On a river	-0.004	0.617	0.265	0.118	-0.003	0.202	0.146
	(0.160)	(0.105)***	(0.095)***	(0.015)***	(0.039)	(0.025)***	(0.022)***
Area size	-0.245	-0.044	-0.131	0.002	-0.032	0.071	0.152
	(0.250)	(0.078)	(0.041)***	(0.005)	(0.015)**	(0.020)***	(0.025)***
City	1.419	0.926	-0.185	0.042	0.085	0.049	0.028
	(0.179)***	(0.064)***	(0.043)***	(0.006)***	(0.035)**	(0.015)***	(0.016)*
Longitude	0.073	-0.047	0.017	0.016	-0.009	-0.071	-0.043
	(0.147)	(0.021)**	(0.008)**	(0.002)***	(0.005)**	(0.003)***	(0.003)***
Latitude	0.010	0.115	-0.060	0.023	0.012	-0.011	0.047
	(0.264)	(0.029)***	(0.015)***	(0.002)***	(0.010)	(0.005)**	(0.006)***
R^2	0.42		0.37	0.81	0.25	0.75	0.54
N	6,907	7,670	7,579	7,318	5,210	7,608	7,608
Region FE	Yes				Yes		
Country FE		Yes	Yes	Yes		Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: Precipitation variability and temperature variability are measured by the standard deviation of precipitation and temperature for growing seasons between 1500-1800. Standard errors are robust. All specifications include country fixed effects.

Table 10: Total migrants in levels as dependent variable

Dependent var : # of Migrants	(1)	(2)	(3)
Precipitation variability	-0.010	0.072	-0.026
	(0.005)*	(0.031)**	(0.011)**
Temperature variability	0.325	1.196	-0.391
	(0.340)	(0.426)***	(1.471)
Mean Precipitation	0.002	0.000	0.002
	(0.001)**	(0.001)	(0.001)*
Mean Temperature	-0.011	-0.034	-0.010
	(0.030)	(0.029)	(0.028)
Land suitability	-0.045	-0.025	-0.049
	(0.104)	(0.120)	(0.097)
Coastal region	0.065	0.051	0.059
	(0.073)	(0.077)	(0.072)
Distance to coast	0.033	0.031	0.037
	(0.033)	(0.035)	(0.036)
Altitude	-0.261	-0.212	-0.273
	(0.193)	(0.190)	(0.178)
On a river	0.202	0.192	0.197
	(0.073)***	(0.072)***	(0.070)***
Area size	-0.092	-0.120	-0.091
	(0.053)*	(0.055)**	(0.053)*
Total population	1.035	1.037	1.034
	(0.013)***	(0.012)***	(0.013)***
City	0.128	0.133	0.134
	(0.038)***		
Longitude	0.057	(0.036)***	(0.039)***
	(0.047)	0.069	0.055
Latitude	-0.062	(0.045)	(0.043)
	(0.054)	-0.051	-0.056
precipitation*temperature variability		-0.017	
		(0.007)**	
		(0.051)	
Precipitation variability Sq.			0.000
			(0.000)**
Temperature variability Sq.			0.075
			(0.179)
			(0.049)
R^2	0.89	0.89	0.89
N	6,792	6,792	6,792
Regional FE	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: The dependent variable is the log of the total number of migrants in levels instead of shares. Precipitation variability and temperature variability are measured by the standard deviation of precipitation and temperature for growing seasons between 1500-1800. Standard errors are clustered at the NUTS level. All specifications include NUTS fixed effects.

Table 11: Alternative measures of climate variation

Dependent var : Migrants	(1)	(2)	(3)
Precipitation-temperature var.	-0.926		
	(1.78)*		
Mean Precipitation	0.004	0.004	0.004
	(1.05)	(0.72)	(0.85)
Mean Temperature	-0.083	-0.141	-0.124
	(0.68)	(1.09)	(0.83)
Land suitability	0.133	0.041	0.062
	(0.18)	(0.05)	(0.08)
Coastal region	0.617	0.508	0.508
	(1.43)	(1.22)	(1.22)
Distance to coast	0.499	0.352	0.366
	(2.06)**	(1.35)	(1.36)
Altitude	-1.542	-2.050	-2.045
	(2.41)**	(2.80)***	(2.76)***
On a river	1.764	1.729	1.715
	(2.90)***	(2.91)***	(2.88)***
Area size	-0.415	-0.471	-0.473
	(0.85)	(0.96)	(0.96)
Total population	0.051	0.049	0.049
	(0.38)	(0.36)	(0.36)
City	1.076	1.111	1.112
	(3.03)***	(3.15)***	(3.15)***
Longitude	0.344	0.200	0.212
	(1.80)*	(0.88)	(1.07)
Latitude	-0.373	-0.239	-0.241
	(1.43)	(1.08)	(1.12)
Temperature variability, abs. mean dev.		1.021	
		(0.96)	
Precipitation variability, abs. mean dev.		-0.036	
		(1.47)	
Precipitation-temperature var., abs. mean dev.			-0.817
			(1.89)*
R^2	0.02	0.02	0.02
N	7,332	7,332	7,332
Regional FE	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: The first column uses a joint precipitation and temperature variability measure calculated with principal component analysis, based on the standard deviation of precipitation and temperature for growing seasons between 1500-1800. The second column shows results with an alternative measure, absolute mean deviation, while the third column uses the joint measure of precipitation and temperature absolute mean deviation constructed by principal component analysis. Curled brackets show the standard errors, while squared brackets show the p-values.

Table 12: Genealogy-based bilateral migration flows

	Bilateral migration flows		
Precipitation variability	0.004	0.018	-0.005
	(0.004)	(0.009)**	(0.013)
Temperature variability	-2.820	-2.484	-6.800
	(0.846)***	(0.899)***	(2.353)***
Mean precipitation	-0.001	-0.002	-0.003
	(0.004)	(0.004)	(0.004)
Mean temperature	-0.020	-0.084	-0.173
	(0.283)	(0.275)	(0.304)
Log of destination pop	0.530	0.525	0.543
	(0.080)***	(0.081)***	(0.082)***
precipitation*temperature variability		-0.026	
		(0.015)*	
Squared precipitation variability			0.000
			(0.000)
Squared temperature variability			2.391
			(1.184)**
N	3,675	3,675	3,675
FE	Yr x orig, dest, pair	Yr x orig, dest, pair	Yr x orig, dest, pair

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: In this specification the dependent variable is flows in levels instead of shares.

6.2 Data description

The final dataset combines information from several datasets, described below. Table 13 lists key sources and Figure 5 summarizes the geography of the data.

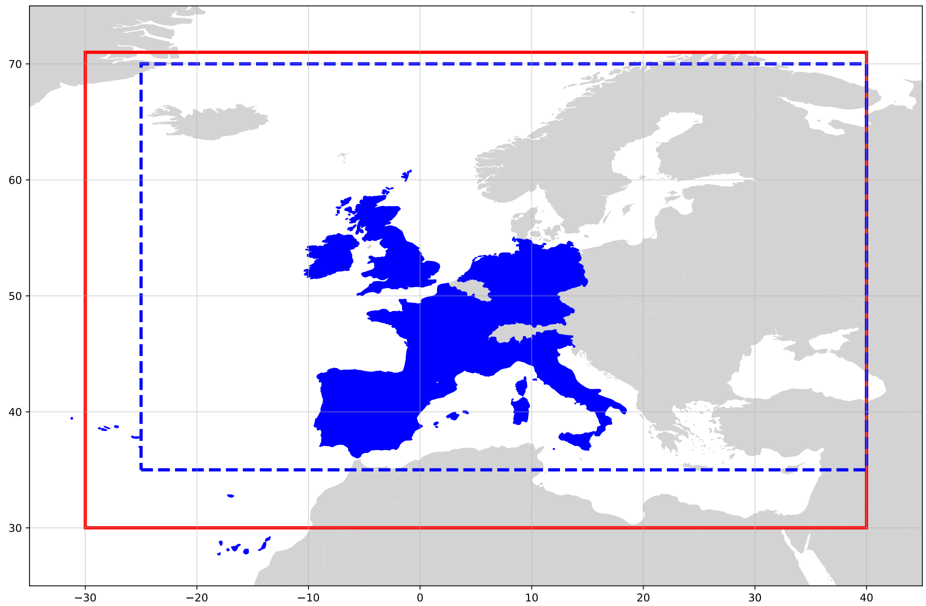
Table 13: An overview of the data used.

Source	Description	Format
Pauling et al. [2006]	Precipitation, 1500–2000	0.5 degree grid
Luterbacher et al. [2004]	Temperature, 1500–2000	0.5 degree grid
Henderson et al. [2017]	Geographic measures, nightlights	0.25 degree grid
Dincecco and Onorato [2018]	Historical battle indicator	point
Bosker et al. [2008]	Historical city indicator	point
Kaplanis et al. [2018]	Genealogical information, 1500–1900	point

6.2.1 EC micro data

Data from the European Commission contains information on country of origin (birth or citizenship) of population at 100m by 100m resolution, with accompanying latitude and longitude coordinates. Alessandrini et al. [2017] describe the construction of the dataset. The definition of country of origin varies between the countries in the sample, but in our work we will use ‘nationals’ to describe all persons recorded as having country of origin that is the same as country of destination, while persons

Figure 5: Geographic coverage of the data



Note: the red (solid line) rectangle denotes the area for which precipitation data is available, the blue (dashed line) rectangle covers the area for which temperature data is available, the countries shaded in blue (dark) color have high-resolution migrant data.

whose country of origin differs from the country of residence (as recorded in EC data) will be referred to as 'migrants'.

6.2.2 Climate data

The two historical climate datasets used in this paper are Pauling et al. [2006] for precipitation and Luterbacher et al. [2004] for temperature. The datasets were downloaded from `https://crudata.uea.ac.uk/cru/projects/soap/data/recon/`, please check the comments accompanying each dataset for data-specific details.

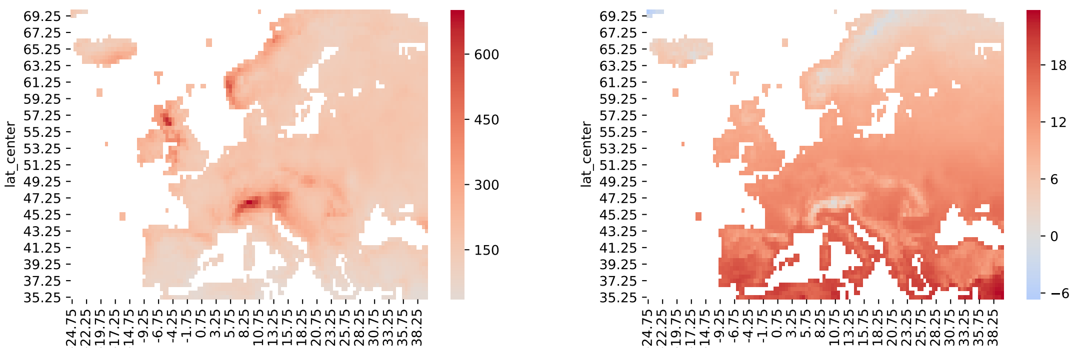
Pauling et al. [2006] reconstruct historical precipitation data using various proxies (tree-ring chronologies, ice cores, etc.) and a range of regression techniques. They are able to reconstruct the data over a long time span, from 1500 to 1983, with distinction for four seasons (spring, summer, fall, winter). The data is gridded with coordinates of a centre of a 0.5 x 0.5 degrees grid for the latitude range from 30.25N to 70.75N and longitude range from 29.75W to 39.75E.

Luterbacher et al. [2004], Xoplaki et al. [2005] develop a proxy-based spatial dataset of historical temperature. The dataset also covers a long time span, from 1500 to 2002 (with the caveat that data after 1901 is based on observational estimates, while all other values are reconstructed). The grid dimensions are the same as those in the precipitation data, but the grid ranges from 35.25N to 69.75N (latitude) and from 24.75W to 39.75E (longitude).

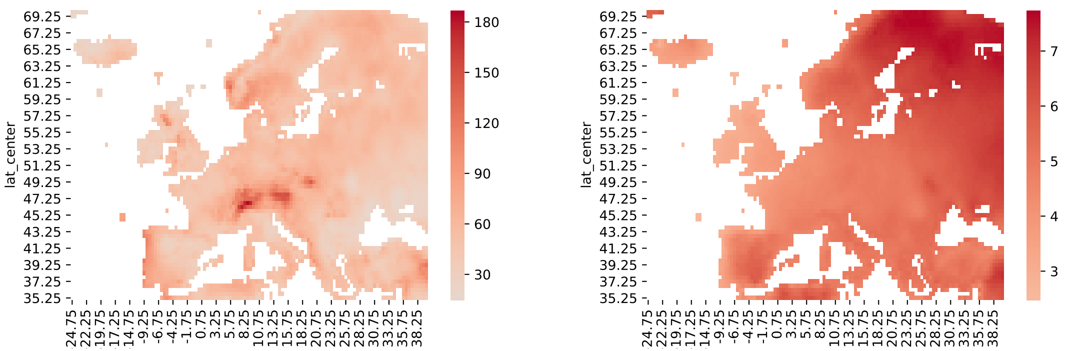
In line with Buggle and Durante [2021], we take the values of temperature and precipitation in summer and autumn of each year from 1500 to 1800 and calculate the mean and the standard deviation of temperature and precipitation. Figure 6 shows the values of these variables.

Figure 6: Climate variables for the growing seasons of 1500–1750.

(a) Average precipitation. (b) Average temperature.



(c) Std. dev. of precipitation. (d) Std. dev. of temperature.

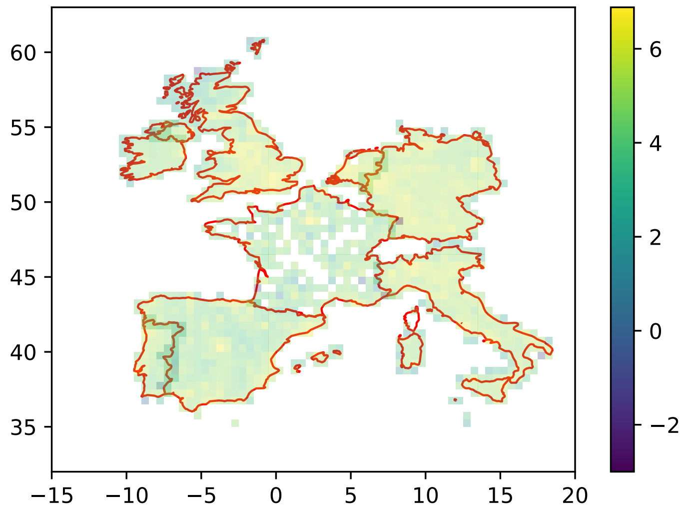


Note: the red (solid line) rectangle denotes the area for which precipitation data is available, the blue (dashed line) rectangle covers the area for which temperature data is available, the countries shaded in blue (dark) color have high-resolution migrant data.

6.2.3 Merging the EC and climate data

Given the differences in resolutions of the EC and climate data, the information was aggregated to the resolution of the climate data. The first step was to aggregate the high-resolution EC population data to the same 0.5 degree by 0.5 degree resolution of the climate data. This was done by assigning each of the EC population cells to a corresponding climate cell based on whether the EC cell centroid is within the boundaries of a climate cell. Note that the conversion between physical distance and lat/lon coordinates differs depending on the latitude, for example at latitude of 40 degrees north, one degree of longitude is about 85 km, while at latitude of 80 degrees north, one degree of longitude is about 19 km. During the aggregation of EC data

Figure 7: Total population per cell ($\log_{10}$)



Note: Population was aggregated to the climate cell resolution and added across all categories (own nationals, EU 27 nationals, non-EU nationals and others). Given the coarse resolution, some cells at the border may be assigned to two countries. The displayed colours correspond to log_{10} of the population, numbers below 0 imply less than 1 person which is due to the disaggregation procedure used by EC, see Alessandrini et al. [2017].

we used the latitude /longitude coordinates of each population cell centroid provided by the EC.

Figure 7 shows the spatial distribution of total population across the grid. Total population includes population of all categories recorded in the EC data (own-country nationals, EU nationals, non-EU nationals and others). Figure 8 shows the relative share of migrants in a given cell.

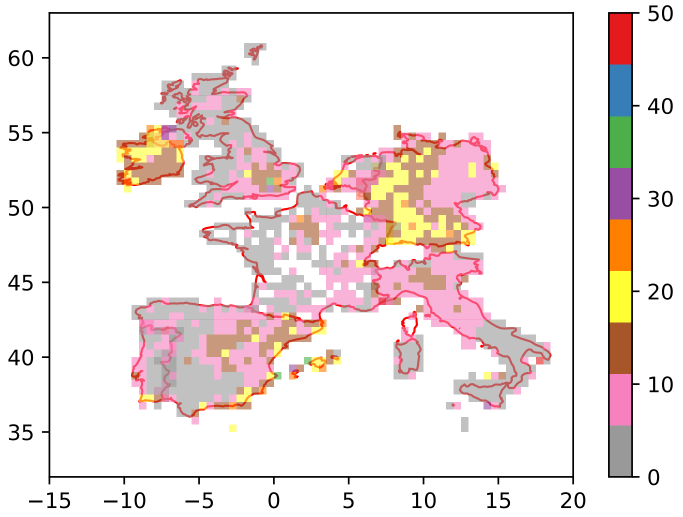
6.2.4 City data

The dataset originates from Bosker et al. [2013], The data indicates the name and location of cities with more than ten thousand inhabitants that existed between 800 and 1800 covering Europe, the Middle East, and North Africa. The City10K dummy variable created is time invariant and takes the value of 1 if at least one city with more than ten thousand inhabitants was located in the cell during the time period considered above.

6.2.5 Conflict data

The dataset originates from Dincecco and Onorato [2018] and gives us the locations of different types of conflicts that took place in Europe from 1000 to 1900. These conflicts are divided into different types and durations. The conflict dummy variable takes the value of 1 if at least one conflict took place in the cell, regardless of its type

Figure 8: Share of migrants per cell



Note: The map shows the share of total population (own nationals, EU27 nationals, non-EU nationals and others) which is due to migrants (i.e. non-own nationals).

and duration.

6.2.6 Genealogical data

Information on births and deaths of individuals is taken from Kaplanis et al. [2018], who compile the data for 86 mln individuals from genealogical records maintained by an online genealogy website. Most of the genealogical profiles are incomplete, with information on birth/death year and locations missing, Table 14 shows the patterns of data availability.

Figure 9 shows the number of individuals born per 5-year interval as recorded in the dataset. The average annual growth of births over the 1600–1900 time period is equal to 1.3% for all geographies and to 0.9% for the European region of interest (refer to Fig 5). In our calculations, we use information on 7.1 mln individuals who are born within the region of interest and have information on birth/death year and locations. We use the geolocated places of birth and death to assign individuals to specific cells that match the 0.5 degree resolution of the climate data and the birth/death year to assign to a corresponding 25/50/100-year intervals. Specifically, we compute the following measures:

- Number of individuals born within a given time period (e.g. from 1750 to 1850) in a specific 0.5 degree cell.
- Number of individuals that died within a given time period in a specific 0.5 degree cell.
- Share of individuals that are born within a given time period within a specific

Table 14: Availability of data on individual birth/death year and location.

(a) Birth information

birth year	birth location	n observations	share
No	No	50818127	59.0
No	Yes	1025894	1.2
Yes	No	18870736	22.0
Yes	Yes	15409887	18.0

(b) Death information

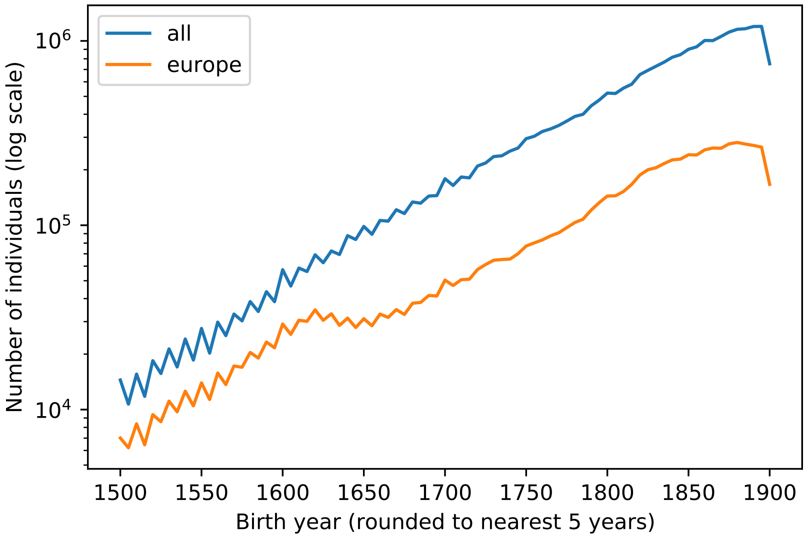
death year	death location	n observations	share
No	No	63197954	73.5
No	Yes	800686	0.9
Yes	No	12182256	14.2
Yes	Yes	9943748	11.6

(c) Combined information

birth year	birth location	death year	death location	n observations	share
No	No	No	No	49416256	57.4
No	No	No	Yes	191196	0.2
No	No	Yes	No	903507	1.0
No	No	Yes	Yes	307168	0.4
No	Yes	No	No	674720	0.8
No	Yes	No	Yes	179029	0.2
No	Yes	Yes	No	58087	0.1
No	Yes	Yes	Yes	114058	0.1
Yes	No	No	No	8150135	9.5
Yes	No	No	Yes	103079	0.1
Yes	No	Yes	No	8580782	10.0
Yes	No	Yes	Yes	2036740	2.4
Yes	Yes	No	No	4956843	5.8
Yes	Yes	No	Yes	327382	0.4
Yes	Yes	Yes	No	2639880	3.1
Yes	Yes	Yes	Yes	7485782	8.7

Note: this table is based on all observations, regardless of the time period and geographic boundaries.

Figure 9: People born in a 5-year interval across all geographies and within Europe



Note: in the early years covered by the data, birth years are reported with rounding to the nearest 5- or 10-year intervals, thus for this graph all birth years were rounded to the nearest 5-year interval; Europe is defined by the borders of our main region of interest, see Fig 5.

cell, but pass away in a different cell. This is considered as a proxy of the share of emigrants from this cell.

- Share of individuals that die within a given time period in a specific cell, but were born in a different cell. This is considered to be a proxy of the share of immigrants in this cell.
- Number of individuals imputed to move between cells based on information on the birth and death locations. The data does not identify the year (or path) of migration, so calculations using year of birth or death as the migration year are performed (this assumption becomes less relevant when looking at 50- or 100-year intervals).

7 Supplementary Annex

Table 15: Main specification with winsorized dependent variable

Dependent var : Migrants	(1)	(2)	(3)
Precipitation variability	-0.032	0.250	-0.072
	(0.015)**	(0.083)***	(0.029)**
Temperature variability	0.592	3.669	-1.081
	(0.890)	(0.954)***	(3.727)
Mean Precipitation	0.006	0.000	0.006
	(0.003)*	(0.003)	(0.003)*
Mean Temperature	0.013	-0.054	0.015
	(0.084)	(0.082)	(0.078)
Land suitability	0.094	0.138	0.077
	(0.418)	(0.459)	(0.391)
Coastal region	-0.063	-0.116	-0.084
	(0.264)	(0.275)	(0.270)
Distance to coast	0.204	0.197	0.213
	(0.153)	(0.159)	(0.160)
Altitude	-0.805	-0.601	-0.841
	(0.465)*	(0.456)	(0.448)*
On a river	1.193	1.144	1.182
	(0.430)***	(0.433)**	(0.428)***
Area size	-0.330	-0.419	-0.326
	(0.291)	(0.289)	(0.291)
Total population	0.275	0.276	0.273
	(0.076)***	(0.076)***	(0.076)***
Light intensity	0.000	0.000	0.000
	(0.000)**	(0.000)***	(0.000)**
City	0.121	0.098	0.136
	(0.236)		
Longitude	0.162	(0.226)	(0.232)
	(0.155)	0.193	0.155
Latitude	-0.168	(0.136)	(0.145)
	(0.221)	-0.130	-0.155
precipitation*temperature variability		-0.060	
		(0.018)***	
		(0.208)	
Precipitation variability Sq.			0.000
			(0.000)*
Temperature variability Sq.			0.175
			(0.416)
			(0.211)
R^2	0.09	0.10	0.09
N	7,332	7,332	7,332
Regional FE	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: In this specification the dependent variable is winsorized (at 10%) to limit the effect of possible spurious outliers

Table 16: Genealogy-based bilateral migration flows

	Bilateral migration flows		
Precipitation variability	0.004	0.018	-0.005
	(0.004)	(0.009)**	(0.013)
Temperature variability	-2.820	-2.484	-6.800
	(0.846)***	(0.899)***	(2.353)***
Mean precipitation	-0.001	-0.002	-0.003
	(0.004)	(0.004)	(0.004)
Mean temperature	-0.020	-0.084	-0.173
	(0.283)	(0.275)	(0.304)
Log of destination pop	0.530	0.525	0.543
	(0.080)***	(0.081)***	(0.082)***
precipitation*temperature variability		-0.026	
		(0.015)*	
Squared precipitation variability			0.000
			(0.000)
Squared temperature variability			2.391
			(1.184)**
N	3,675	3,675	3,675
FE	Yr x orig, dest, pair	Yr x orig, dest, pair	Yr x orig, dest, pair

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: In this specification the dependent variable is flows in levels instead of shares.