Historical climate variation and migration*

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Abstract

We study how variability in precipitation and temperature over the period 1500-1750 influenced both today's 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 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 the results are stronger 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. Our work has important implications not only for studies linking environmental factors to societal and economic outcomes, but also for migration policy.

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1 Introduction

The current literature has explored extensively the role of economic push and pull factors and social networks in shaping international migration flows.[1] However, we know little about how and why historical factors affected migration patterns, both in the past and today. This paper fills this gap by focusing on the long-run impact of climate on contemporary migration. While most of the existing literature explores how climate in the origin country affects outmigration, in this paper we focus on the impact of climate in the destination country. More precisely, to investigate the relationship between current (and past) migration and historical climate variation, we use local-level data (with cells of about 56 square kilometres, equivalent to about 0.5 degree grids) in seven EU member states (France, Germany, Ireland, Italy, Netherlands, Portugal, Spain) and the UK.

Variation in climate in pre-industrial times had an important influence on crop yields, the demand for agricultural workers and the availability of food [Campbell, 2010]. The resulting changes in labor supply and demand may affect both the demand for migrants (when there are shortages of agricultural workers), and the supply of migration (when climate variation creates higher costs through uncertainty, thus reducing the destination's attractiveness for migrants) [Hanson, 2006]. The impact of climate variation on migration could also have a number of indirect effects. For instance, more volatile climate conditions may create a culture of cooperation (see Buggle and Durante [2017]) and potentially more accepting attitudes towards foreigners, both in the short and long term. In addition, more open attitudes and higher levels of social capital and trust could create migrant-friendly institutions and policies which persist throughout history. Today's migration patterns are also driven by past migration through network effects. Today's migrants are attracted to locations where their ancestors or their ancestors' peers located, thus reinforcing the direct impact of climate variation and land suitability. While this paper does not investigate the exact mechanisms, it provides evidence on the long-run link between climate variation and migration.

Our work examines the impact of historical climate variation on *inward* migration. In order to do so, we exploit two migration datasets. The first dataset provides information on current migration patterns in destination locations. Our main empirical specification with this data regresses 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 1500-1750. 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

[1] The economic determinants of migration have been studied in the literature focusing on both domestic and international migration, mostly by considering employment, wages, social security, inequality, and the size of the labour market as potential push and pull factors. See, for example Ortega and Peri [2009]; Hatton and Williamson [2002]; Hatton and Williamson [2002]; and Mayda [2010] for 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.

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 either use population density or light intensity 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, such as past colonial ties), we also include region (i.e., NUTS-1) fixed effects.

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 stronger 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. We also find evidence of a non-linear relationship between migration and precipitation variability, indicating a U-shaped relationship between historical climate variation and today's migration. While at lower levels of historical precipitation variation there are fewer migrants today, as this variability in historical precipitation increases, more migrants can be found.

Our second migration data set captures historical genealogy-based bilateral migration flows and covers the same period (1500-1750). 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, it allows us to control for origin cell-time varying factors, bilateral cell-specific factors, and destination cell-specific factors, while also exploiting the time dimension of the data. Once again, we find that there is significantly less in-migration to locations where there is more climate variation. 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.

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]. 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 at least three important contribution to the literature. First, an important innovation of this work is that it studies the drivers of *inward migration*, as opposed to *outmigration*, which is the focus of most existing studies.[2] Inward migration and outmigration are different concepts and thus may have diverging drivers and consequences. Highlighting these distinctions is important not only for academics, but also for designing appropriate policies. Second, our paper contributes to a very small but important literature on the link between climate and migration, which however has largely ignored the European context due to the lack of data. Finally, 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 suggestive mechanisms behind it.

2 Conceptual framework: Migration and climate variation

In Europe, industrialization and urbanization were not fully felt until the mid-1800s, when the industrial revolution had a real effect. Our climate variation variables cover the period 1500-1750, which means that they capture a period in European development when the vast majority of the continent was rural, most of the population depended on agriculture for subsistence, and there was limited spatial mobility and strong occupational persistence [Ladurie, 1971]. In Europe, historically most agricultural activity has focused on barley, wheat, rapeseed/canola, sugar beets, potatoes

[2]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.

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]. The growing season for these crops is generally in spring and summer. As a result, variation in climate (temperature and precipitation) - particularly during these growing months - affected yields and thus agricultural productivity [Buggle and Durante, 2017].

When there is significant variation in yields, the demand for agricultural workers and the availability of food also varies accordingly. At times of unusually good yields, the increased demand for agricultural workers likely had an impact on the demand for migrants.[3] On the other hand, climate variation, via its effect on yields and expected income, may also influence the supply side of migration. On a micro level, the individual decision to migrate will depend on evaluating the return to migration, net of any costs, relative to the return of staying in the home location.[4] 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.[5] When there is a bad season in the host country leading to *decreased* 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). Instead, when climatic conditions are favorable, and agricultural yields are good, there will be an increased demand for agricultural workers and an increased expected return for foreign migrants, thus pulling in migrants as temporary workers, leading to *inward* migration.

In pre-industrial Europe, migration was primarily agricultural [Moch, 1995]. Moves in both directions were common albeit costly, hence migration moves were mostly very short-distance, and access to land was an important factor [Dribe, 2003]. Hence, migrants are less likely to prefer locations with high climate variability, as relocating back and forth as climate varies increases the cost of migration. However, it is plausible that such an effect might be non-linear. If there are very significant swings in climate variation and therefore yields, the local population might not be able to harvest yields in good years, creating increased demand for migrant agricultural workers, thus leading to inward migration.

We also expect that the historical link between *past* variation in climate and *past* migration has persisted until today, and also explains patterns in the *contemporary* migration stock. In other words, we hypothesize that locations where there was a higher presence of agricultural migrants in the past will also have a higher share of migrants today.

There are several channels that can help explain the persistence of migration, although we are unable to distinguish the precise mechanisms at work. The existing literature offers some clues on what these may be. For instance, Buggle and Durante

[3]See, for example, [Hanson and Spilimbergo, 2001] on how changes in sectoral prices affected demand for illegal migrants in the US and hence border controls.

[4]See, for example, [Roy, 1951], [Borjas, 1987], and [Grogger and Hanson, 2011], among others.

[5]One example where climate is integrated into this framework as a factor influencing the individual decision to migrate is [Beine and Parsons, 2015].

[2017] 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 climatic risk. These norms persisted over time, even after climate had become largely unimportant for economic activity. It is also plausible that pro-migrant attitudes coexisted along with norms of trust, thus making communities that historically attracted migrants welcome destinations for migrants today. Other possible mechanisms could have included exposure to trade networks and the adoption of inclusive political institutions early on, with these (formal) institutions persisting until today. Such inclusive institutions may have interacted with the pro-migrant norms to once again encourage 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. Once again, religious communities - via their emphasis on cooperation and assistance - may have been particularly well-suited for migrant arrivals. Furthermore, past migration patterns could also have had an impact on current migration patterns through network effects whereby today's migrants are attracted to locations where their ancestors or their ancestors' peers are located, thus reinforcing the direct impact of climate variation and land suitability.

3 Data

Our analysis exploits several high-resolution datasets, which allows 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 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. [6] 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, but in our work we will use 'nationals' to describe all persons recorded as having a country of origin that is the same as the country of destination, while persons whose country of origin differs from the country of residence (as recorded in EC data) will be referred to as 'migrants'.

Our main variables of interest capturing climate variability were obtained from a historical data on precipitation and temperature [Pauling et al., 2006, Luterbacher et al., 2004]. While precipitation and temperature both have important consequences

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

for agricultural activities, they are also correlated with other important weather related factors (for example, humidity, cloud coverage, and sunshine). 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 (equivalent to about 56 kms). 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. While our main variables of interests 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 impact on economic development over time, as well as on agricultural activities and methods.

Given the differences in resolution between 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. [7] During aggregation of the EC data we used the latitude /longitude coordinates of each population cell centroid provided by EC.

Our dataset also has information on various geographical characteristics, which have been identified in the previous literature as important for agricultural activities. Our source for this data is Henderson et al. [2017]. We include elevation (in meters) and latitude. Furthermore, we include variables to capture access to water transport, which has importance for trade and economic activity in a region. In particular, 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 we use night light intensity (again obtained from Henderson et al. [2017]) or population density (from the EC data). Finally, we also control for land suitability (from Henderson et al. [2017]).

We also control for locations which experienced different types of conflicts in the past, with the dataset originating from Dincecco and Onorato [2018]. The conflict dummy variable takes the value of 1 if at least one conflict took place in the cell, regardless of its type and duration. Furthermore, we control for cities, and use a dummy variable in case the location was historically in a city with population larger than 10.000 inhabitants (source for the dataset is Bosker et al. [2008]).

In our empirical analysis, we also use an alternative dataset for migration. The dataset contains information on births and deaths of individuals taken from Kaplanis

[7]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.

Table 1: Descriptive statistics for the main variables.

	mean	sd	p50	p25	p75
Share of migrants	0.07	0.07	0.06	0.03	0.10
Mean temperature	12.99	2.88	12.24	11.40	14.69
Temperature variability	4.44	0.66	4.59	3.95	4.90
Mean Precipitation	190.72	82.13	180.51	149.44	210.41
Precipitation variability	56.22	19.15	53.75	43.30	63.69
Temperature variability, NGS	4.07	0.75	4.20	3.56	4.60
Precipitation variability, NGS	43.46	16.61	40.10	31.66	50.36
Squared precipitation variability	3527.15	2744.32	2888.97	1874.73	4056.19
Squared temperature variability	20.12	5.70	21.04	15.57	24.03
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	332019.47	132521.99	348570.00	241930.00	348570.00
Total population	36537.61	98223.18	9401.08	1230.22	34304.08
Total light intensity	18843.09	27796.31	10726.35	5277.16	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	7892				

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, we only have information about the location and year of birth and death. Hence we use the year of death for migration time. In addition, instead of using the yearly data, we use 50 year intervals as we collapse the data to 50 year intervals.

4 Empirical specification and results

Based on the outlined conceptual framework, 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. The regressor of interest is $V_{c,r}$ which is the climate variation, measured by the standard deviation in precipitation and temperature over the period 1500-1750. 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 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 control for economic activity in the cell, we use either total population or light intensity in the cell. Finally, we include a dummy variable for whether the cell is a (historical) city or rural area. All specifications also include a NUTS-specific fixed effect (v_r). The fixed effects capture region specific factors influencing the number of migrants, such as economic conditions, as well as cultural and historical factors (for example, past colonial ties).

4.1 Main results

Table 2 presents three versions of Equation 2, 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. Concerning other control variables, we find that there is a higher share of migrants in locations which are at lower altitudes or on a river. Larger population density and cities also attract more migrants, compared to rural areas or less populated places.

An important question concerns whether variation in temperature and variation in precipitation were equally important for agricultural yields in Europe. 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]. Hence, while overall there is variation to which type of crop is more sensitive to variation in precipitation or temperature, we expect that overall variation in precipitation likely had a bigger impact on crops in our regions of interest.

One reason for no significant relationship between temperature variation and migration 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 for certain crops. Indeed, when we interact temperature with precipitation in the second column, the interaction effect is significant and negative.

The non-linear effects of climate variability on migration are explored in the last column, where quadratic terms are included for both. We find a significant non-linear relationship between precipitation variation and migration, and again, insignificant results for temperature. These results indicate a U-shaped relationship. While lower levels of variation in precipitation reduce the share of migrants, higher levels of variation 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 as a result of harvesting crops. Migrants are less likely to choose such locations due to the lower expected returns to migrating. On the other hand, as climate variation increases, there is a higher probability of labor market shortages, due to the insufficient availability of domestic agricultural worker. This results 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]), which is also consistent with agriculture being the channel driving the migration impact of climate variation.

4.2 Robustness checks

Next, we undertake additional regressions aiming 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 hence labor demand in agriculture, climate variation should matter 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

Table 2: Main table

Dependent var : Migrants	(1)	(2)	(3)
Precipitation variability	-0.040	0.212	-0.089
	(0.020)**	(0.072)***	(0.040)**
Temperature variability	-0.096	2.738	-0.738
	(0.849)	(1.022)***	(4.155)
Mean Precipitation	0.005	-0.255	0.005
	(0.003)	(0.126)**	(0.003)
Mean Temperature	-0.188	-0.000	-0.183
	(0.127)	(0.003)	(0.118)
Land suitability	-0.048	-0.067	-0.060
	(0.755)	(0.794)	(0.734)
Coastal region	-0.232	-0.254	-0.251
	(0.432)	(0.439)	(0.437)
Distance to coast	3.464	2.707	3.725
	(3.430)	(3.849)	(3.311)
Altitude	-2.086	-1.845	-2.129
	(0.656)***	(0.646)***	(0.640)***
On a river	1.780	1.769	1.768
	(0.600)***	(0.602)***	(0.597)***
Area size	-0.277	-0.334	-0.273
	(0.372)	(0.373)	(0.372)
Total population	0.000	0.000	0.000
	(0.000)**	(0.000)**	(0.000)**
City	0.687	0.680	0.697
	(0.332)**		(0.330)**
Longitude	0.240	(0.326)**	0.226
	(0.170)	0.274	(0.163)
Latitude	-0.475	(0.157)*	-0.463
	(0.288)	-0.431	(0.268)*
precipitation*temperature variability		-0.054	
		(0.017)***	
		(0.281)	
Squared precipitation variability			0.000
			(0.000)*
Squared temperature variability			0.069
			(0.459)
R^2	0.02	0.03	0.02
N	7,902	7,902	7,902
Nuts 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 1500-1750. Standard errors are clustered at the NUTS level. All specifications include NUTS fixed effects.

is historical migration (which was predominantly driven by agricultural workers), 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, use light intensity at the cell level to proxy the intensity of economic activity in a given cell (see for example Henderson et al. [2017]), drop those cells from the sample which are at country borders where non-natives might not represent actual migrants, and include as an additional explanatory variable conflict, which controls for historical conflicts in the cell. Our results remain similar to those in our main specification.

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 and hence allows us to investigate the contemporaneous effects of climate variation. In addition, we also exploit the bilateral dimension of the data. Given the bilateral nature of this data, our empirical specification from equation 2 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.[8] Therefore, our empirical specification changes to:

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

Where M_{odt} is the share of migrants from origin cell o to destination cell d at time t (share is calculated as the share of origin cell population). V_{ot} is the climate variation in the origin 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 ($\emptyset_{ot}$), 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). Since our main variable of interest is climate variation in the destination cell, we are unable to include time varying destination cell fixed effects. In order to control for changing economic activity in the destination cell over time, we include population density in the destination (P_{ot}).

Following our earlier results, Table 4 show linear effects in the first column followed by interactions and non-linear effects. We find that variability in temperature has a negative impact on bilateral migration flows, with people less likely to move to a destination where climate is more variable. More specifically, we find that the

[8] 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.

Table 3: Robustness checks

Dependent var : Migrants	Non growing seasons (4)	Only city (5)	Only rural (6)
Precipitation variability	-0.035	0.003	-0.044
	(0.019)*	(0.034)	(0.020)**
Temperature variability	-0.979	-1.558	0.156
	(1.170)	(1.355)	(0.980)
Mean Precipitation	0.011	-0.011	0.007
	(0.006)*	(0.010)	(0.003)**
Mean Temperature	-0.200	-1.012	-0.131
	(0.122)	(0.294)***	(0.131)
Land suitability	-0.262	-1.599	-0.325
	(0.767)	(1.525)	(0.811)
Coastal region	-0.142	-1.348	-0.064
	(0.433)	(0.650)**	(0.473)
Distance to coast	2.110	14.462	1.649
	(3.270)	(5.911)**	(3.661)
Altitude	-2.084	-3.047	-1.980
	(0.698)***	(1.729)*	(0.740)***
On a river	1.864	1.713	1.633
	(0.588)***	(1.640)	(0.829)*
Area size	-0.332	-0.397	-0.280
	(0.366)	(0.295)	(0.501)
Total population	0.000	0.000	0.000
	(0.000)**	(0.000)**	(0.000)**
City	0.696		
	(0.323)**		
Precipitation variability, NGS	-0.037		
	(0.024)		
Temperature variability, NGS	1.814		
	(1.264)		
Longitude	0.137	0.110	0.244
	(0.178)	(0.284)	(0.180)
Latitude	-0.558	-0.542	-0.441
	(0.300)*	(0.362)	(0.311)
R^2	0.02	0.03	0.02
N	7,902	1,087	6,815
Nuts 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 1500-1750. 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.

variation in temperature in a destination cell reduces migration inflows, while in the linear specification we do not find a significant effect of precipitation variability. On the other hand, we find a significant effect for precipitation variation on inward migration in the non-linear specification.

Table 4: Genealogy-based bilateral migration flows

	Bilateral migration flows		
Precipitation variability	-0.000	-0.000	-0.001
	(0.000)	(0.000)	(0.000)***
Temperature variability	-0.075	-0.079	-0.052
	(0.038)**	(0.040)*	(0.061)
Mean precipitation	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Mean temperature	0.028	0.027	0.030
	(0.023)	(0.024)	(0.024)
Log of destination pop	0.002	0.002	0.002
	(0.001)	(0.001)	(0.001)
precipitation*temperature variability		0.000	
		(0.000)	
Squared precipitation variability			0.000
			(0.000)***
Squared temperature variability			-0.019
			(0.038)
R^2	0.83	0.83	0.83
N	7,580	7,580	7,580
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 bythe 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 4 presents a placebo test where instead of recent climate variation, we regress bilateral migration flows on *future* climate variation (for the period 100 years later). As expected, we do not find any significant relationship between future climate variation and current migration. This is makes us confident that the results we uncover are likely to be causal, rather than driven by omitted variable bias or reverse causality.

Table 5: Genealogy-based migration flows - placebo test

	Bilateral migration flows		
Precipitation variability	-0.000	0.001	0.000
	(0.000)	(0.001)	(0.000)
Temperature variability	-0.016	0.015	-0.052
	(0.025)	(0.031)	(0.140)
Mean precipitation	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Mean temperature	-0.020	-0.022	-0.019
	(0.017)	(0.017)	(0.017)
Log of destination pop	0.002	0.002	0.002
	(0.001)	(0.001)	(0.001)
precipitation*temperature variability		-0.001	
		(0.001)	
Squared precipitation variability			-0.000
			(0.000)
Squared temperature variability			0.025
			(0.076)
R^2	0.83	0.83	0.83
N	7,580	7,580	7,580
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 bythe standard deviation of precipitation and temperature for growing seasons 100 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.

5 Conclusion

Using two novel datasets, we examine the impact of historical climate variation 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 stronger 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. We also find evidence of a non-linear relationship between migration and precipitation variability, indicating a U-shaped relationship between historical climate variation and today's migration. While at lower levels of historical precipitation variation there are fewer migrants today, as this variability in historical precipitation increases, more migrants can be found. Our historical bilateral migration flow data confirms the finding that climate variability significantly reduces inward migration.

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 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.

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6 Appendix

6.1 Additional robustness checks

Table 6: Further robustness

Dependent var : Migrants	Lights	Without border cells	Conflicts
Precipitation variability	-0.037 (0.019)*	-0.045 (0.021)**	-0.040 (0.020)**
Temperature variability	-0.014 (0.833)	-0.005 (0.849)	-0.111 (0.848)
Mean Precipitation	0.005 (0.003)	0.006 (0.003)**	0.006 (0.003)*
Mean Temperature	-0.159 (0.130)	-0.234 (0.126)*	-0.183 (0.127)
Land suitability	-0.230 (0.744)	0.276 (0.600)	-0.112 (0.759)
Coastal region	-0.083 (0.409)	-0.193 (0.450)	-0.206 (0.427)
Distance to coast	2.967 (3.396)	2.818 (3.322)	3.467 (3.400)
Altitude	-1.849 (0.656)***	-2.347 (0.547)***	-2.025 (0.657)***
On a river	1.505 (0.606)**	2.252 (0.474)***	1.667 (0.600)***
Area size	-0.292 (0.369)	-0.140 (0.290)	-0.277 (0.372)
Total light intensity	0.000 (0.000)***		
City	0.157 (0.374)	0.505 (0.335)	0.589 (0.332)*
Longitude	0.249 (0.166)	0.292 (0.165)*	0.242 (0.170)
Latitude	-0.434 (0.282)	-0.495 (0.278)*	-0.477 (0.287)
Total population		0.000 (0.000)**	0.000 (0.000)**
Conflict			0.588 (0.283)**
R^2	0.03	0.03	0.02
N	7,902	7,313	7,902
Nuts 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 1500-1750. Standard errors are clustered at the NUTS level. All specifications include NUTS fixed effects. The first column presents results using light intensity as an explanatory variable instead of total population. The second column is based on a sample excluding border cells, while the last column includes conflicts as an additional explanatory variable.

Table 8: Correlation of climate variables across different scenarios.

(a) Average precipitation.

	main	nongrow	a	b	c	d	e	f
main	1.00	0.62	0.82	0.91	0.73	0.47	1.00	0.99
nongrow	0.62	1.00	0.84	0.33	0.95	0.96	0.64	0.64
a	0.82	0.84	1.00	0.51	0.83	0.79	0.83	0.82
b	0.91	0.33	0.51	1.00	0.50	0.14	0.90	0.90
c	0.73	0.95	0.83	0.50	1.00	0.83	0.74	0.74
d	0.47	0.96	0.79	0.14	0.83	1.00	0.48	0.49
e	1.00	0.64	0.83	0.90	0.74	0.48	1.00	0.99
f	0.99	0.64	0.82	0.90	0.74	0.49	0.99	1.00

(b) Average temperature.

	main	nongrow	a	b	c	d	e	f
main	1.00	0.90	0.98	0.97	0.96	0.81	1.00	1.00
nongrow	0.90	1.00	0.95	0.78	0.98	0.99	0.89	0.89
a	0.98	0.95	1.00	0.90	0.98	0.90	0.98	0.98
b	0.97	0.78	0.90	1.00	0.89	0.67	0.97	0.97
c	0.96	0.98	0.98	0.89	1.00	0.93	0.96	0.96
d	0.81	0.99	0.90	0.67	0.93	1.00	0.81	0.81
e	1.00	0.89	0.98	0.97	0.96	0.81	1.00	1.00
f	1.00	0.89	0.98	0.97	0.96	0.81	1.00	1.00

(c) Std. dev. of precipitation.

	main	nongrow	a	b	c	d	e	f
main	1.00	0.43	0.43	0.51	0.40	0.26	0.94	0.79
nongrow	0.43	1.00	0.57	0.31	0.63	0.69	0.46	0.55
a	0.43	0.57	1.00	0.60	0.77	0.76	0.37	0.53
b	0.51	0.31	0.60	1.00	0.70	0.43	0.36	0.41
c	0.40	0.63	0.77	0.70	1.00	0.80	0.33	0.46
d	0.26	0.69	0.76	0.43	0.80	1.00	0.27	0.45
e	0.94	0.46	0.37	0.36	0.33	0.27	1.00	0.87
f	0.79	0.55	0.53	0.41	0.46	0.45	0.87	1.00

(d) Std. dev. of temperature.

	main	nongrow	a	b	c	d	e	f
main	1.00	0.84	0.37	-0.28	-0.22	0.57	0.99	1.00
nongrow	0.84	1.00	0.38	-0.27	-0.22	0.67	0.85	0.85
a	0.37	0.38	1.00	0.56	0.47	0.60	0.36	0.32
b	-0.28	-0.27	0.56	1.00	0.77	0.32	-0.29	-0.34
c	-0.22	-0.22	0.47	0.77	1.00	0.24	-0.24	-0.27
d	0.57	0.67	0.60	0.32	0.24	1.00	0.61	0.54
e	0.99	0.85	0.36	-0.29	-0.24	0.61	1.00	0.99
f	1.00	0.85	0.32	-0.34	-0.27	0.54	0.99	1.00

Note: see Table **??** for the scenario definitions.

Table 9: 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

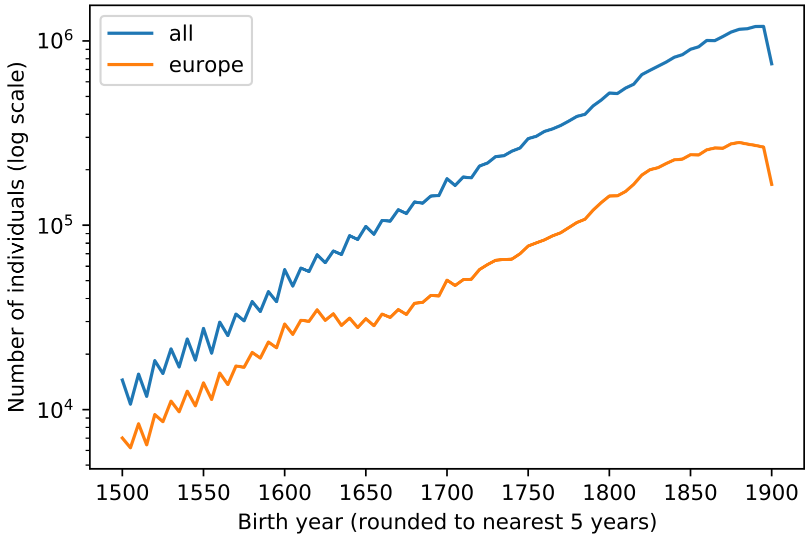
death year	death location	n observations	share
No	No	63197954	73.5
No	Yes	800686	0.9
Yes	No	12182256	14.2
Yes	Yes	9943748	11.6

(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 8: 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 4.

equal to 1.3% for all geographies and to 0.9% for the European region of interest (refer to Fig 4). 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 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).