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Abstract

We exploit the GEOSTAT 2011 population grid with a very high 1-km^2 resolution to document that Spain presents the lowest density of settlements among European countries. We uncover that this anomaly cannot be accounted for by adverse geographic and climatic conditions. Using techniques from spatial econometrics, we identify the clusters that exhibit the lowest densities within Spain after controlling for geo-climatic factors: these areas mainly belong to Teruel, Zaragoza, Ciudad Real, Albacete, Sevilla and Asturias. We also explore the attributes that characterize the municipalities located in these low-density areas: larger population losses during the 1950-1991 rural exodus, higher shares of local-born inhabitants, longer distances to the province capital, higher shares of population employed in agriculture, and larger increases in regionalist vote after the Great Recession.

Keywords: economic geography, Spain.

JEL classification: R10.

Resumen

Utilizando información sobre la distribución de la población por cada kilómetro cuadrado de Europa (GEOSTAT 2011), este artículo documenta que España es el país con un mayor porcentaje de territorio deshabitado y una mayor concentración de la población en determinadas zonas geográficas. Esta anomalía en la distribución de la población a lo largo del territorio no puede explicarse por condiciones geográficas y climáticas adversas. Asimismo, utilizando técnicas de la econometría espacial, se identifican las zonas que exhiben las densidades más bajas dentro de España al tener en cuenta los factores geoclimáticos: estas áreas pertenecen principalmente a Teruel, Zaragoza, Ciudad Real, Albacete, Sevilla y Asturias. Finalmente, se exploran las características de los municipios ubicados en estas áreas de baja densidad: mayores pérdidas de población durante el éxodo rural de 1950-1991, mayor proporción de habitantes nacidos en el municipio, mayores distancias a la capital de la provincia, mayor proporción de población empleada en la agricultura y mayores aumentos en el porcentaje de voto regionalista después de la crisis financiera global.

Palabras clave: geografía económica, España.

Códigos JEL: R10.

1 Introduction

How human settlements are distributed across space shapes economic interactions and influences economic development (see e.g. Krugman 1991).[1] This article explores the spatial distribution of population in Spain compared to that of other European countries. Using the GEOSTAT 2011 population grid, we uncover an anomaly in Spanish settlement patterns. We find that Spain presents a much lower share of inhabited areas than its European neighbors. Moreover, this pattern cannot be accounted for by geographic and climatic factors. The remaining of this introduction provides a detailed advance of the different parts and findings of the paper, which should enable a reader to grasp in advance the essence of our contribution.

In Section 2, we describe the different datasets we exploit throughout the paper. The GEOSTAT 2011 population grid is the main data source that allows us to analyze the distribution of population and settlements at a very granular level. In particular, it provides the figures of population living in each squared kilometer within Europe. This information is crucial to properly measure the distribution of population across space as opposed to the traditional density indicators (based on the ratio of population to surface of administrative areas) that do not appropriately reflect the density actually faced by individuals and firms (see Duranton and Puga, 2020).[2] We thus consider three alternative indicators to compare the actual density experienced across European countries: (i) the ratio of population to surface within each 250-km^2 grid cell; (ii) the so-called settlement density given by the percentage of 10-km^2 cells that are inhabited within each 250-km^2 grid cell; (iii) an indicator of population concentration given by the percentage of the population living in the most populated one percent of the territory within each 250-km^2 grid cell. Section 2 also describes the very granular information considered in our analysis on geo-climatic factors such as temperature, rainfall, altitude, ruggedness or soil quality for the different European countries at the grid-cell level. The municipality-level database exploited in the last section of the paper to characterize underpopulated areas within Spain is also presented in Section 2.

Section 3 uncovers an anomaly of Spanish settlement patterns in European perspective that cannot be accounted for by geo-climatic conditions. In particular, the regions with the lowest amount of settlements relative to its surface within Europe are located in Spain, Iceland, Finland, Norway and Sweden. However, while the low settlement density is fully explained by adverse geographic and climatic factors in Scandinavian countries, this is not the case in Spain, which remains the only outlier in terms of low settlement density after accounting for geo-climatic conditions. Using the alternative measures of spatial distribution of the population, we conclude that Spain is characterized by a very low settlement density and a very high concentration of the population in a small share of the

[1]Allen and Arkolakis (2014) show that geographic location alone can explain at least 20% of the spatial variation in income across the United States.

[2]According to Duranton and Turner (2018), most daily activities take place within an area of 10-km^2 that does not necessarily coincide with administrative areas. In addition, other dimensions beyond administrative units such as the number of centers within an area or the compactness of development might be relevant in determining urban outcomes (Harari 2020).

territory. These two characteristics render traditional population density indicators somehow in line with other European countries, albeit relatively low. According to Oto-Peralías (2020), insecurity characterizing the Reconquest period may explain the anomalous spatial distribution of Spanish population. Continuous warfare and insecurity heavily conditioned the nature of the colonization process, characterized by the leading role of the military orders as colonizer agents, scarcity of population, and a livestock-oriented economy (González-Jiménez 1992). This determined a spatial distribution of the population characterized by a low density of settlements and an economy based on ranching, as mobile assets were favored by military conditions (see Bishko, 1975).

In Section 4, we characterize underpopulated areas within Spain along two dimensions. First, we use spatial econometric techniques to identify clusters of underpopulated areas once we account for geography and climate. Our results indicate that these areas are mainly located in the provinces of Teruel, Zaragoza, Ciudad Real, Albacete, Sevilla and Asturias.[3] Second, we exploit density measures at the municipality level together with socio-economic characteristics of each municipality in order to characterize the underpopulated areas. Our findings suggest that low-density areas belong to municipalities characterized by higher shares of local-born inhabitants that experienced large population losses during the 1950-1991 rural exodus, longer distances to the province capital, higher shares of population employed in agriculture, and larger increases in regionalist vote after the Great Recession. Finally, underpopulated municipalities tend to present lower income per capita in nominal terms but, interestingly enough, higher income per capita if we use a PPP-adjustment based on municipality-level housing prices taken from *Registro de la Propiedad*.

2 Data

2.1 GEOSTAT 2011 population grid

The GEOSTAT population grid provides data on population distribution in space at a very high 1-km^2 resolution (Eurostat 2016). The sample consists of the territory covered by GEOSTAT 2011 after excluding the overseas regions (see Figure 1), an area slightly larger than 5 million km^2 with approximately 2.08 million populated 1-km^2 grid cells.[4]

We construct three indicators measuring different dimensions of the spatial distribution of population in the different countries. First, a settlement density indicator that measures the distribution of settlements along the territory. More specifically, it refers to the percentage of 10-km^2 grid cells

[3]On the contrary, Madrid, Málaga and Barcelona stand out as the provinces with higher settlement density within Spain.

[4]The 35 European countries included are Albania (AL), Austria (AT), Belgium (BE), Bosnia and Herzegovina (BI), Bulgaria (BG), Croatia (HR), Czechia (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (EL), Hungary (HU), Iceland (IS), Ireland (IE), Italy (IT), Kosovo (KO), Latvia (LV), Liechtenstein (LI), Lithuania (LT), Luxembourg (LU), Montenegro (ME), Netherlands (NL), Norway (NO), Poland (PL), Portugal (PT), Romania (RO), Serbia (SR), Slovakia (SK), Slovenia (SI), Spain (ES), Sweden (SE), Switzerland (CH) and the United Kingdom (UK).

that are inhabited in each 250-km^2 cell. A 10-km^2 grid cell is considered to be populated if it contains at least one 1-km^2 populated cell within it. We choose 10-km^2 as cell area because it is a meaningful size from an economic point of view. For instance, Duranton and Turner (2018) conclude that most daily activities take place within an area of 10-km^2. Also, the average size of a commune in France is 15-km^2 and, typically, each commune has more than one settlement. It is worth noting that, according to this indicator, settlements are identified through the presence of populated 1-km^2 cells. An important advantage of this way of identifying settlements is its homogeneity across countries. Other alternatives such as data on municipalities or on local administrative units cannot be used for comparative purposes since they are heterogeneous across countries.

Second, we compute an indicator of population concentration that measures the percentage of the population living in the most populated one percent of the territory within each 250-km^2 grid cell. It is worth stressing that the level of spatial aggregation used is important to this indicator. Population concentration may be high at the country level but moderate or low at the sub-national level. However, there is in practice a strong correlation (0.86) between the country level value and the average of grid-cell level values.

Third, we also consider a traditional indicator of population density given by the ratio of population to surface in each 250-km^2 grid cell. Regarding the correlation among these indicators, settlement density is negatively correlated with population concentration (-0.75) and positively with the logarithm of population density (0.77), while population concentration and population density are negatively correlated (-0.58). Table A.1 provides some descriptive statistics of the three indicators at the grid-cell level.

2.2 Geographic and climatic factors

We construct several geographic and climatic variables at the grid cell level, including temperature, rainfall, altitude, ruggedness, distance from the coast and soil quality (see Table A.1 for descriptive statistics).

Temperature and rainfall refer to annual average temperature and annual precipitation in hundred of milliliters, respectively. They are both sourced from the WorldClim database (Hijmans et al., 2005). Altitude refers to average altitude of the surface area of the observation unit while ruggedness corresponds to the standard deviation of the altitude of the territory corresponding to the observation unit, both are constructed using data from GTOPO30 (Data available from the U.S. Geological Survey). Distance to the coast refers to the geodesic distance between the centroid of the observation units and the nearest point of the coast (in km). Soil quality, taken from from Fischer et al. (2008), corresponds to the average of seven key soil dimensions important for crop production: nutrient availability, nutrient retention capacity, rooting conditions, oxygen availability to roots, excess salts, toxicities, and workability (the average value for each component is calculated for the surface area corresponding to the observation unit). Finally, we also consider latitude and longitude, the geographic coordinates of the grid cell centroids in decimal degrees.

2.3 Municipality-level variables for Spain

We also conduct part of the analysis at the municipality level within Spain. We thus collect several demographic, political, fiscal and economic variables.

Demographic variables include the dependency ratio and the share of citizens born in the municipality, which are extracted from the 2011 Census. The former refers to the share of citizens older than 65 over the population aged 15-64. We also consider the share of citizens born in the municipality as an indicator of the attraction of the area with an average of almost 50% of citizens living where they were born. We also explore how migration flows during the so-called rural exodus from 1950 to 1991 can explain current disparities in population density across municipalities.[5]

With respect to political variables, we use the share of discontent vote in 2019 general elections and the increase of regionalist votes between 2007 and 2019. These municipal variables derive from the Spanish Ministry of Home Office. While extreme political parties surged after the crisis reaching 18% of the vote on average in 2019, the share of regionalist votes increased by around 3pp over the same period.

Lastly, we measure fiscal characteristics of municipalities with public spending and public revenues per capita;[6] and socio-economic conditions with the share population employed in agriculture from the 2011 Census and the income per capita in 2015 published by INE. Average public spending is around 1,222 euros per capita, slightly below average revenue per capita. The average share of population employed in agriculture is around 7% and income per capita in the (unweighted) average municipality is around 10,000 euros. Descriptive statistics at the municipality level are available in Table A.2.

3 The Spanish anomaly in settlement patterns

This section documents that the spatial distribution of the population in Spain represents an anomaly with respect to other European countries. In particular, it presents an abnormally low settlement density with the highest prevalence of uninhabited areas even after accounting for geographic and climatic conditions. The section also provides some heuristic discussion on the potential causes of this pattern, which seem to be rooted in historical patterns of warfare.

3.1 A first glimpse at the data

We first describe the main features of the population location in Spain in comparison with other European countries. Compared to other European Union countries, population in Spain stands out for two characteristics. First, total population is low. And second, it is highly concentrated. The

[5]Collantes and Pinilla (2011) provide a detailed description of rural-urban migrations over this period.

[6]Note that the fiscal variables only refer to the city budget and include items such as spending on garbage collection or street lighting and revenues from property taxes. However, they do not include public spending on e.g. health and education, and public revenues from income or value added taxes.

first two columns of Table 1 show that, despite being the second country by land area, Spain only ranks 5th in terms of total population. For example, the number of inhabitants is 25% lower than in the United Kingdom, despite the land area being twice as much.

The low number of people living in Spain stems from the fact that there is a very high amount of uninhabited areas. Figure 1, which plots in red (white) the inhabited (uninhabited) 1 km^2 grid cells in Europe, shows that this feature stands out in sharp contrast with other countries. Indeed, Spain appears comparable only to areas where geographical and climatological conditions deter population settlements, such as the Scandinavian Peninsula or the Alps. Column 4 of Table 1 shows that only 13% of the Spanish land area is inhabited, which is the lowest value in the European Union.

This exceptionally low settlement density makes population in Spain be very concentrated. Indeed, column 5 of Table 1 reveals that the population density in inhabited areas reaches 737 people per squared km, which is the second largest in Europe (being the largest the tiny island of Malta). If we compute Lorenz curves estimating the inequality in the spatial location of population along the

Table 1: Population Density in European Union Countries (2011).

	Surface (km^2) (1)	Population (thousands) (2)	Density (3)	Inhabited area (%) (4)	Density inhabited area (5)
France	549,060	62,765	114	67.8	168
Spain	498,504	46,816	94	12.7	737
Sweden	449,896	9,539	21	25.2	84
Germany	358,327	80,213	224	59.9	374
Finland	337,547	5,340	16	30.0	53
Poland	313,851	38,500	123	62.6	196
Italy	301,291	59,429	197	57.2	345
United Kingdom	247,763	63,154	255	51.7	493
Romania	239,068	20,122	84	29.4	287
Greece	131,912	10,634	81	19.7	409
Bulgaria	110,995	7,365	66	21.3	312
Hungary	93,013	9,938	107	29.8	358
Portugal	88,847	10,562	119	46.6	255
Austria	83,944	8,402	100	51.4	195
Czech Republic	78,874	10,437	132	56.0	236
Ireland	70,601	4,575	65	80.2	81
Latvia	65,519	2,081	32	50.5	63
Lithuania	65,412	3,029	46	54.5	85
Croatia	56,539	4,290	76	43.4	175
Slovakia	49,035	5,399	110	32.4	340
Estonia	45,347	1,294	29	45.6	63
Denkmark	43,162	5,535	128	90.4	142
Netherlands	37,824	16,651	440	81.0	544
Belgium	30,668	10,990	358	83.0	432
Slovenia	20,277	2,049	101	66.0	153
Cyprus	9,249	840	91	37.3	244
Luxembourg	2,595	513	198	65.5	302
Malta	315	417	1325	92.7	1430

Source: Eurostat.

Note however that this anomaly is somehow masked when looking at traditional population density measures at the aggregate level (inhabitants per square km) in which Spain ranks slightly below the mean (see column 3).[7]

[7] Rae (2018) shows inhabited areas density in 39 European countries to reflect that the traditional measure is not complete.

inhabited 1 km^2 grid cells, one can see that Spain is the most spatially concentrated country among the selected ones. For example, while in Germany, Poland and Portugal 15% of the most populated cells account for 80% of total population, in Spain they account for 90%. The corresponding figure for France, Italy and the United Kingdom is 85%.

All in all, Table 1 suggests that population in Spain is very concentrated in the space because there is an abnormally large number of uninhabited areas in comparison to other European countries. According to these measures, we are able to identify a Spanish anomaly in settlement patterns.

3.2 Testing for the anomaly and the role of geo-climatic factors

The evidence presented in Table 1 and Figure 1 is suggestive of a Spanish anomaly in population patterns. However, Spain is characterized by high temperatures and large mountainous lands that might account for the high prevalence of uninhabited areas. This section explores whether geographic and climatic factors may explain the differences between Spain and other European countries in the distribution of population across the territory.

Using the GEOSTAT 2011 population grid, we compute two proxies for the settlement patterns in the different countries: settlement density and population density.[8] Crucially, using the GEOSTAT 2011 population grid allows us to identify population patterns through 1-km^2 cells.

The following regression allows us to better understand the role of geography and climate in explaining the Spanish anomaly in terms of settlement density and population density:

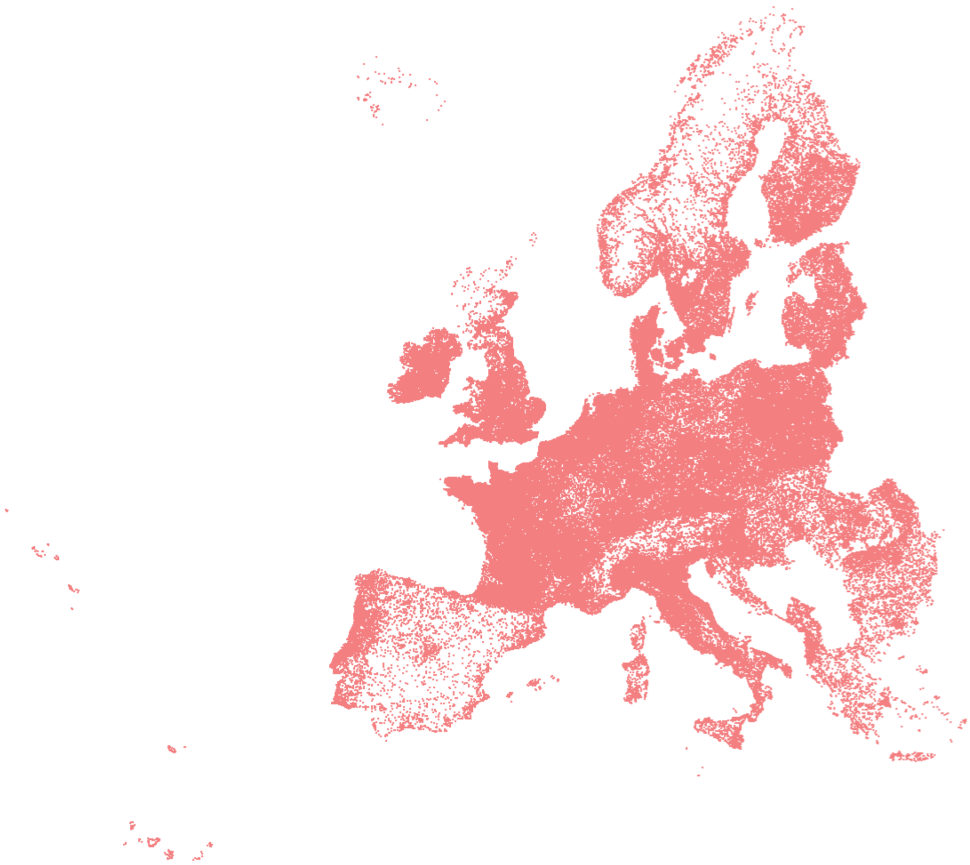
$$y_{ic} = \eta_c + x'_{ic}\beta + \epsilon_{ic} \tag{1}$$

where y_{ic} refers to either settlement density or (log) population density of 250-km^2 grid cell i belonging to country c. x_{ic} is a vector of geographic and climatic variables for each grid cell including temperature, rainfall, average altitude, ruggedness, soil quality and distance from the coast. In order to allow for non-linear effects of those variables on settlement patterns, quartile dummies are included with the omitted category being the first quartile. An island dummy and latitude and longitude coordinates are also included in the vector x_{ic}. Table A.3 in Appendix A shows the estimated coefficients for the geographic and climatic variables included in the regressions.

Finally, our main object of interest in equation (1) is the vector η_c that refers to a full set of country dummies. In order to test the significance of the Spanish anomaly after accounting for geography and climate, we analyze the estimated country dummies ($\hat{\eta}_c$) from equation (1) and their associated standard errors. France is the omitted category in all cases so that the estimated country dummies reflect the average difference in settlement density between each country and France.

[8] We also consider a third measure of population concentration. Since the findings corresponding to this measure are very similar to those of settlement density, its discussion is relegated to Appendix B.

Figure 1: Inhabited Grid Cells in Europe (2011).



Source: Eurostat.
Notes:This figure depicts in red (white) the inhabited (uninhabited) 1 km^2 grid cells in Europe.

Figure 2: The Spanish anomaly in settlement and population density.

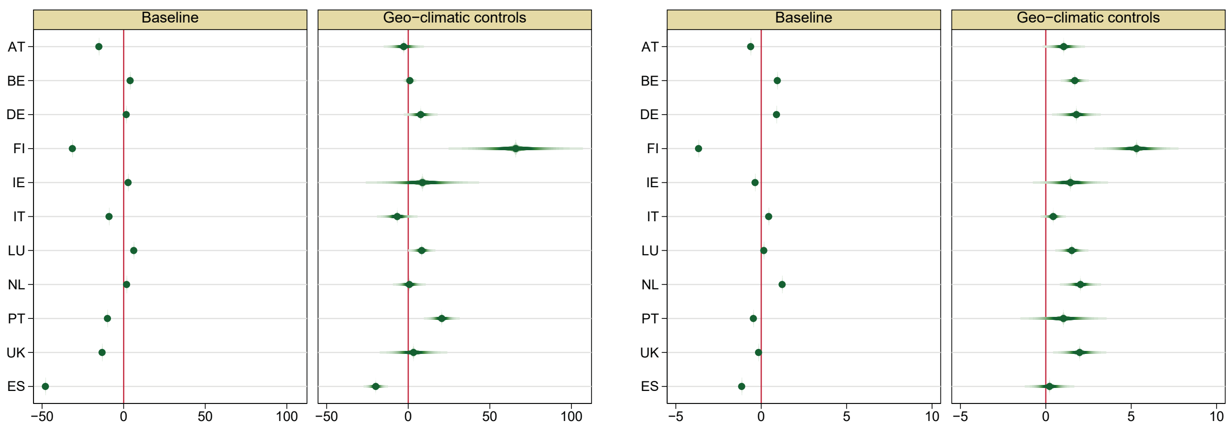


Figure 2 presents the estimated country fixed effects without controls (baseline) and with geographic and climatic controls (geo-climatic controls) for both settlement density (left panel) and population density (right panel). In the baseline panels without controls, Spain is the country with the lowest share of inhabited 10km^2 areas within each 250-km^2 grid cell as well as the second lowest population density only above Finland. For instance, the average 250-km^2 grid cell in Spain presents a settlement density 50 percentage points lower than the corresponding average cell in France, while this figure is around 30 pp. in Finland. Interestingly enough, this difference becomes positive and statistically significant in the case of Finland after accounting for geographic and climatic factors, while it remains negative and significant in Spain, albeit smaller in magnitude.

The left panel of Figure 2 clearly illustrates that geography and climate cannot fully explain the Spanish low settlement density, which is the lowest within Europe.[9] In sharp contrast, the Finnish low settlement density is fully explained by geographic and climatic factors. Indeed, after accounting for those factors, settlement density in Finland is the highest in Europe. This pattern remains unaltered if we use population concentration instead of settlement density as the dependent variable in our regressions as shown in Figure B.6 in Appendix B. Population concentration is thus the highest in Spain even after accounting for geography and climate. Indeed, both variables present a very high and negative correlation of -0.75. Turning to population density in the right panel of Figure 2, the difference between the average Spanish and French 250-km^2 grid cell is not statistically significant once we account for geo-climatic conditions.

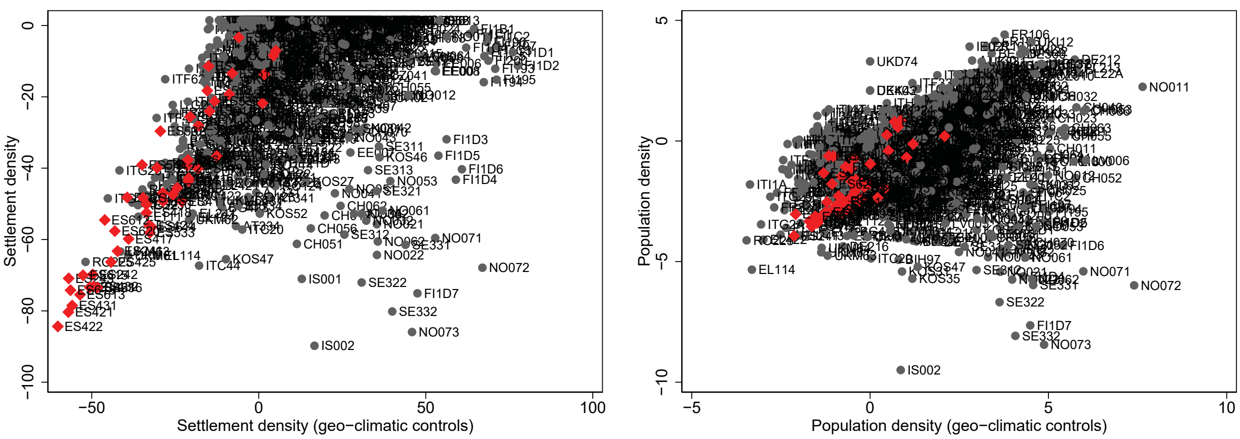
A potential concern is that we are comparing countries that are very heterogeneous in surface area. One could suspect that the singularity of Spain is perhaps conditional on the specific territorial division used in our analysis. In order to address this concern, we compare Spain to a set of virtual countries with similar surface areas. For that purpose, we randomly choose 1,000 grid cells and then create virtual countries by selecting up to 2,500 neighbors falling within 700 km from the cell's centroid (similar to Spanish land area). Then we run 1,000 regressions of settlement density on the full set of geo-climatic controls, the Spain dummy, and the virtual countries dummies (included one by one). Remarkably, in every case the coefficient on Spain for settlement density is lower than on the virtual region (see Figure A.2 in Appendix A). This figure is slightly above 70% in the case of population density, which somehow confirms the lack of statistical significance of the Spanish coefficient in the right panel of Figure 2.

In order to further explore the Spanish anomaly, we now turn to the analysis at the regional level. In particular, we estimate models analogous to equation (1) but instead of including country dummies, we now include region dummies at the NUTS3 level corresponding to Spanish provinces. The omitted category is now the Paris area (FR101) so that all estimated dummies capture the difference with respect to Paris.

The left panel of Figure 3 confirms the Spanish anomaly in settlement density by region. The y-axis plots the estimated region dummies without geographic and climatic controls while the x-axis refers to the estimated dummies with those controls. Interestingly enough, region dummies of nordic countries such as Iceland (IS), Sweden (SE), Finland (FI) and Norway (NO) present highly negative coefficients without geographic controls (much lower settlement densities than Paris) that

[9]Figure A.1 in Appendix A shows that these findings also hold in a larger sample of European countries. However, for the sake of clarity we present here the results for the Eurozone sample and the UK.

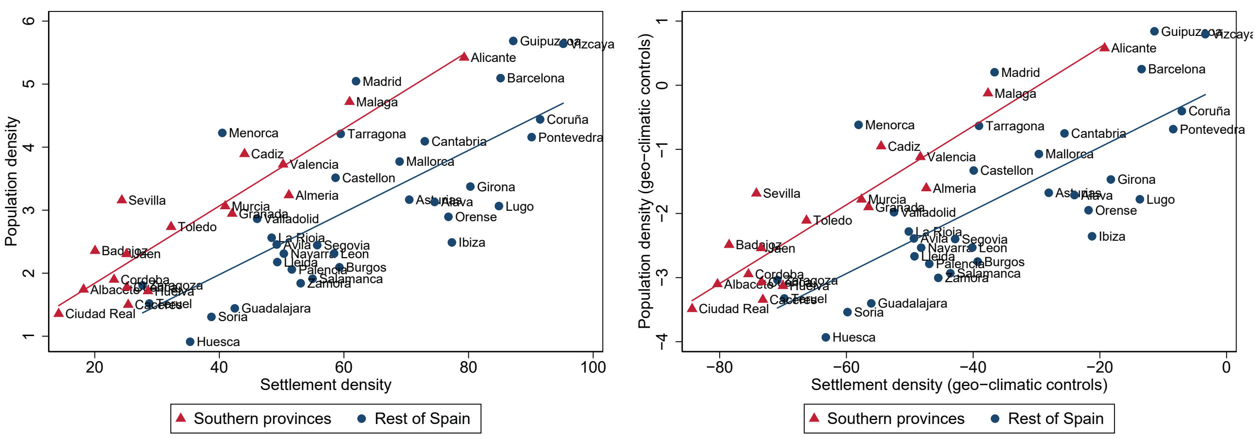
Figure 3: The Spanish anomaly by regions.



turn positive and large after including geo-climatic controls. However, Spanish regions (red dots) present in both cases the most negative coefficient estimates among all European regions. Results are revealing: the 7 regions with the lowest average settlement density are from Spain. Also, 9 out of the 10 regions with lowest settlement density (and 16 out of 20) are from Spain. The same pattern (with opposite sign) emerges if we look at population concentration (see Figure B.7 in Appendix B). In contrast, the right panel suggests that this anomaly is not so prevalent in the case of population density.

Figure 4 zooms in the differences across Spanish NUTS3 regions (provinces). In particular, Figure 4 plots the relationship between average population density (y-axis, in logs) and average settlement density (x-axis) at the province level within Spain. On top of the strong positive association between both measures, the plot shows that southern provinces (red triangles) present, for a given level of settlement density, population densities higher than the rest of Spanish provinces (blue dots). This is so even after accounting for geo-climatic factors. This pattern suggests that population is more concentrated for a given level of settlement density in the Spanish south, which might have been a limitation to economic development in the past, when the proximity to the farmland was important.

Figure 4: Settlement patterns across Spanish provinces.



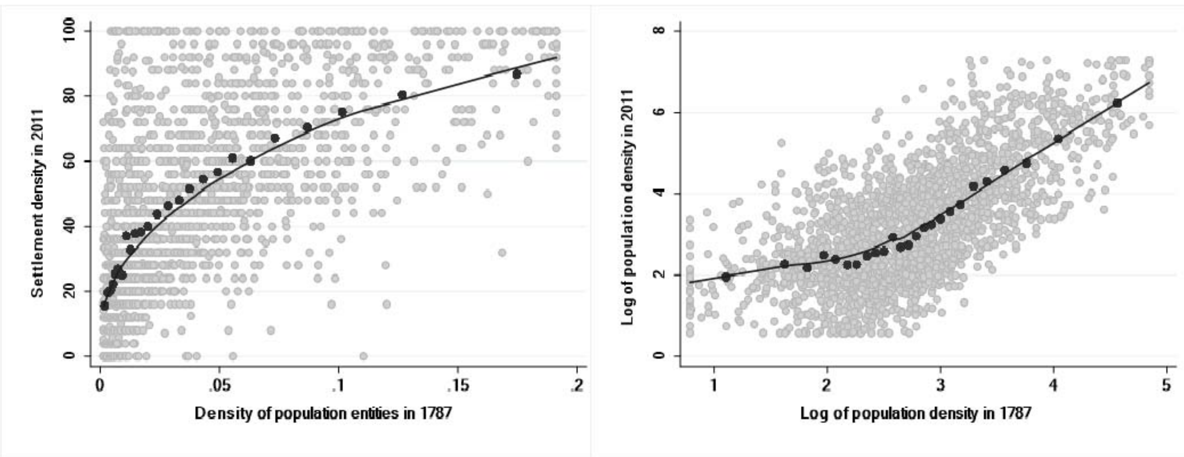
All in all, the evidence presented so far indicates that Spain has a remarkably low density of settlements, even lower than Scandinavian countries. Moreover, geographic and climatic factors fail to account for this anomaly.

3.3 History, warfare and the origins of the Spanish anomaly

Our results so far indicate that geographic and climatic factors do not satisfactorily explain Spain's population and settlement patterns, particularly in terms of settlement density and population concentration, which suggests that the peculiarities of Spanish history may be behind them together with agglomeration forces. The Spanish anomaly is not a recent phenomenon. Already in the 17th century, European travelers were impressed by the scarcity of settlements: "One can travel for days on end without passing a house or village, and the country is abandoned and uncultivated"; "Spain gives the impression of being a desert of Libya, so unpopulated it is".[10]

The left panel in Figure 5 shows that there is a high correlation between population density in 1787 and settlement density in 2011 ($p = 0.65$), while the right panel depicts an also strong correlation between (log) population density in 1787 and (log) population density in 2011 ($p = 0.69$).[11] This points to the fact that the main features of Spain's current spatial distribution of the population were already present at the end of the 18th century, well before Spain began its (late) industrialization process. Therefore, historical events taking place before this period are probably the responsible factors.

Figure 5: Persistence in settlement and population density.



[10]From the Venetian ambassadors Federico Cornaro (1678-81) and Giovanni Cornaro (1681-82), quoted in Brenan (1950: 128).

[11]To assess the magnitude of these correlations, it is important to bear in mind that the variable measuring density of population entities in 1787 is not directly comparable to settlement density in 2011. The former captures the number of population entities in 1787 divided by surface area while the latter is the percentage of populated 10-km2 cells. Similarly, population density in 1787 is not exactly comparable to the indicator in 2011 as the quality of the data sources is very different. The implication is that correlations would be actually stronger if the methodology of the indicators were more similar. See Oto-Peralías (2020) for more details.

On the theoretical side, Allen and Donaldson (2018) show that path dependence is important in determining the level of economic activity across the space and their findings open up the potential for historical accidents, such as warfare, to play an outsized role in governing where economic activity occurs. In the case of Spain, previous research stresses the Reconquest as a key historical event in this regard (Oto-Peralías and Romero-Ávila, 2016; Oto-Peralías, 2020). Two factors related to the Reconquest seem to be important here, namely, the pace or rate of the frontier expansion and military instability due to frontier warfare. Oto-Peralías and Romero-Ávila (2016) argue that a fast frontier expansion by the Christian kingdoms led to an imperfect colonization of the territory because the material and human resources available were insufficient relative to the magnitude of the colonization effort. The consequence was an occupation of the space characterized by a few settlements with large jurisdictional areas. Consistent with this, the authors find a positive relationship between the rate of Reconquest and the size of municipalities' surface areas.

Oto-Peralías (2020) emphasizes frontier warfare as a key determinant of the way the territory was colonized by the Christian kingdoms. Military insecurity favored a colonization characterized by the concentration of the population in a few well defended settlements, scarcity of population and a livestock-oriented economy. Exploiting a discontinuity in military insecurity across the River Tagus during the 11th to 13th centuries, Oto-Peralías (2020) shows that the area south of the river, more exposed to frontier warfare, has today much lower levels of settlement and population density and higher population concentration. Interestingly, the difference in settlement density across the Tagus is close to the whole difference between northern and southern Spain, suggesting that the explanatory power of historical frontier warfare is important. The evidence supports the conjecture by some historians linking the prolonged exposure to frontier warfare to population concentration and scarcity of dispersed village communities (Bishko, 1975).

4 Narrowing down underpopulated areas within Spain

This section identifies the areas within Spain with the lowest settlement and population density based on hot and cold spot analysis. It also investigates the characteristics of such areas at the municipality level.

4.1 Hot and cold spot analysis

In order to identify clusters of low-density grid cells, we apply methods from spatial analysis to the GEOSTAT 2011 population grid. In particular, we consider the hot and cold spot technique from Getis and Ord (1992). This approach overcomes the border effect problem, that is, the allocation of population in spatial units such as districts, municipalities or regions.

The so-called Getis-Ord statistic tests whether a grid cell and its neighboring grid cells form a spatial cluster. In other words, hot and cold spots are detected as spatial outliers. In particular, the hot (cold) spot is detected when a cell and its neighboring cells have similar values and higher (lower) values than the average. More formally, the statistic for variable y_i in grid cell i is given by:

$$G_i^*(d) = \frac{\sum_{j=1}^{N} \omega_{ij}(d) y_j}{\sum_{j=1}^{N} y_j} \tag{2}$$

where y_j refers to settlement or population density of grid cell j, N is the number of grid cells and ω_{ij} denotes the ijth element of the spatial weight matrix as

$$\begin{aligned} \omega_{ij}(d) &= 1 \quad \text{if} \quad d_{ij} \leq d \ \forall i, j \\ \omega_{ij}(d) &= 0 \quad \text{if} \quad d_{ij} > d \ \forall i, j \end{aligned}$$

where d is the threshold distance.

Figure 6 plots the resulting hot and cold spots within Spain for both settlement density and population density using $d = 50$km.[12] According to the upper-left map in Figure 6, most of the territory in the provinces of Badajoz, Cáceres, Ciudad Real, Albacete, Córdoba and Jaén presents the lowest settlement density within Spain (below the 10th percentile). In contrast, settlement densities in Galicia, País Vasco and Barcelona are the highest (above the 90th percentile). In the upper-right map we control for geo-climatic variables, which alters the picture. Low density areas of Extremadura and Castilla la Mancha as well as high density in Galicia and Asturias are partly explained by these geo-climatic conditions, which are better in the North that is closer to the coast and presents better soil quality and more rainfall (see Figure A.3 in Appendix A). Indeed, once we account for the role of geo-climatic conditions both the Madrid[13] and the Málaga areas appear as the highest-density zones within Spain together with Barcelona. Contrarily, the areas with the lowest settlement density belong not only to Ciudad Real and Albacete but also to Sevilla, Zaragoza, Teruel, and Asturias.

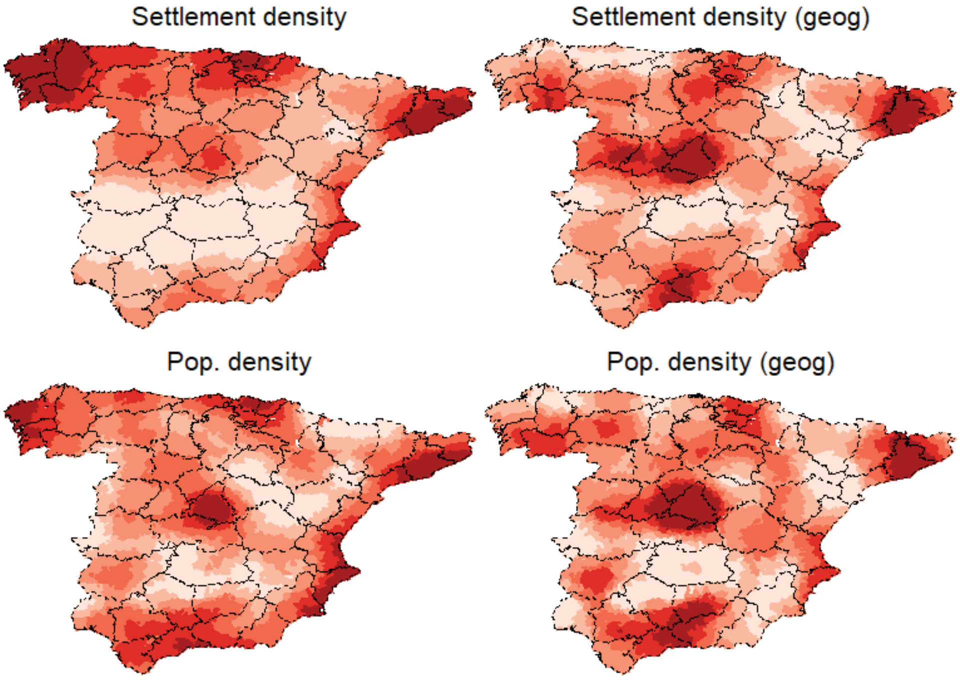
A very similar picture arises when looking at the two bottom maps of Figure 6 based on hot and cold spot analysis for (log) population density. The clusters of high population density after accounting for geo-climatic conditions belong to the provinces of Madrid, Málaga and Barcelona. The low-density areas are mainly located in Ciudad Real, Sevilla, Albacete, Zaragoza and Teruel.

The similar pictures arising from the hotspot analysis of settlement and population density are not surprising since the correlation between the resulting $G_i^*(d)$ statistics for both indicators is 0.8. We thus conclude that underpopulated areas within Spain identified from hotspot techniques are somehow the same regardless on how we measure underpopulation, either in terms of settlement or population density. Needless to say, the pattern is also the same with population concentration that presents a correlation of -0.91 with the $G_i^*(d)$ statistic from settlement density (see Figure B.8 in Appendix B).

[12] Figure A.4 in Appendix A shows the analysis based on $d = 20$km.

[13] In Appendix C, we explore the settlement of density in each Spanish region compared with Madrid.

Figure 6: Hotspot analysis.



4.2 Characterizing underpopulated municipalities

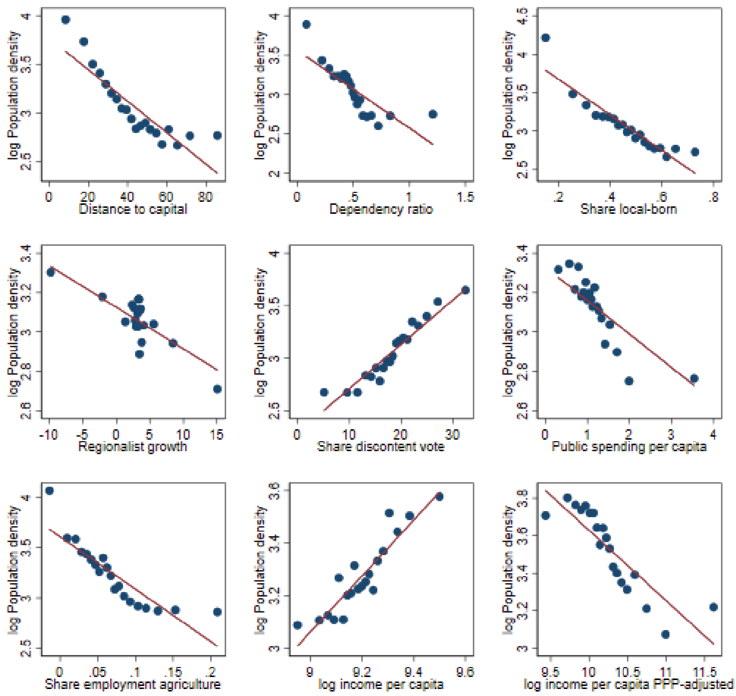
In order to characterize the identified underpopulated areas within Spain, we need to exploit data at the municipality level because economic, demographic, fiscal and political variables are only available at this level. See Section 2.3 for more details on the municipality database as well as the descriptive statistics in Table A.2 and the geographical distribution of the different characteristics in A.5.

In order to have a first glimpse at the data, we show in Figure 7 the simple bivariate correlations between *log* population density and each of the considered municipality characteristics. In particular, we group the municipality characteristics into four categories: demographic variables (dependency ratio and share of inhabitants born in the municipality), rural exodus (population growth rate between 1950 and 1991), political variables (share of discontent votes in 2019 general elections and increase in the share of votes to regionalist parties between 2007 and 2019), fiscal variables (public spending per capita and public revenues per capita) and economic variables (share of population employed in agriculture and log income per capita).

The patterns in Figure 7 suggest that low-density municipalities are characterized by longer distances to the province capital, higher dependency ratios, higher shares of local-born population, negative population growth over the 1950-1991 period, higher prevalence of regionalist vote but lower prevalence of discontent vote, higher (lower) public spending (revenues) per capita, higher employment shares in agriculture and lower income per capita in nominal terms but higher in purchasing power parity (PPP) terms.

In any case, the bivariate correlations shown in Figure 7 do not take into account partial correlations among the different characteristics and they do not allow assessing either the relative strength

Figure 7: Bivariate correlations.



Notes: This figure shows the bivariate correlation of (*log*) population density and different municipality characteristics based on a binned scatter plot. To generate the plot, we group population density into equally-sized bins, and compute the mean of each characteristic in each bin.

of the associations or the statistical significance of the correlations. In order to address these issues, we consider the following empirical specification:

$$d_{mp} = x'_{mp}\delta + w'_{mp}\gamma + \theta_p + \upsilon_{mp} \tag{3}$$

where d_{mp} refers to the (*log*) population density of municipality m in province p.[14] x_{mp} is a vector of geographic and climatic variables for each municipality including temperature, rainfall, average altitude, ruggedness, soil quality and distance to the coast. These geo-climatic controls are included non-linearly as in specification (1) above. w_{mp} is the vector of available municipality characteristics that might characterize low density areas. Finally, a set of province dummies (θ_p) is included in some specifications to exploit variation across municipalities within each province.

The vector γ includes our coefficients of interest associated to the different municipality characteristics, namely, 65+ over 16-64 dependency ratio and share of inhabitants born in the municipality (demographics), the population growth rate between 1951 and 1991 (rural exodus), the share of discontent votes in 2019 general elections and increase in the share of votes to regionalist parties between

[14] Alternatively, one can also consider as dependent variables the $G_i^*(d)$ measures computed at the 250-km^2 grid cell level using surface-based weights to compute municipality-level measures. However, these measures present stronger spatial correlation by construction and significantly reduce variation in the data. Anyhow, unreported estimates confirm that the main findings in this section remain robust to this alternative specification.

2007 and 2019 (political variables), public spending per capita and public revenues per capita (fiscal variables), and share of employment in agriculture and log income per capita (economic variables). In addition to these variables, we include in all specifications the distance in km to the capital of the province.

Table 2 shows the estimated coefficients for the model in equation (3). As expected, remoteness is associated to lower population densities. In particular, a municipality that is 100 km away from the province capital presents population densities around 1.0-1.9 log points lower. Note that we control for geo-climatic variables in all regressions but their coefficients are not reported for the sake of brevity (see Table A.3).

Table 2: Characteristics of low population density municipalities.

	(1) Baseline	(2) +Demographics	(3) +Rural Exodus	(4) +Politics	(5) +Fiscal	(6) +Economic	(7) +Fixed Effects	(8) +Prices
Distance to capital	-0.0195***	-0.0150***	-0.0123***	-0.0121***	-0.0127***	-0.0120***	-0.0103***	-0.0121***
	(0.00299)	(0.00209)	(0.00161)	(0.00166)	(0.00170)	(0.00181)	(0.00176)	(0.00199)
Dependency ratio		-0.510***	-0.0192	0.0158	0.0526	-0.0426	0.00598	-0.0619
		(0.166)	(0.106)	(0.0962)	(0.104)	(0.162)	(0.170)	(0.194)
Share born in mun.		-1.656***	-1.327***	-1.282***	-1.294***	-0.925***	-1.055***	-1.156***
		(0.426)	(0.274)	(0.265)	(0.259)	(0.245)	(0.219)	(0.224)
Pop. growth 1950-1991			0.755***	0.749***	0.741***	0.731***	0.530***	0.513***
			(0.0452)	(0.0491)	(0.0556)	(0.0506)	(0.0344)	(0.0361)
Regionalist vote growth				0.00324	0.00518	0.00394	-0.0128***	-0.0113**
				(0.00504)	(0.00473)	(0.00493)	(0.00331)	(0.00447)
Share discontent vote				0.00475	0.00724	0.00845	0.0174***	0.0177***
				(0.00631)	(0.00600)	(0.00623)	(0.00351)	(0.00445)
Public spending pc					-0.0267	-0.139*	-0.194***	-0.221**
					(0.0472)	(0.0735)	(0.0711)	(0.101)
Public revenues pc					0.00607	0.0178	0.0530	0.101
					(0.0440)	(0.0534)	(0.0411)	(0.0652)
Share agriculture						-2.187***	-1.705***	-1.923***
						(0.606)	(0.462)	(0.590)
Income pc (log)						0.608**	0.445**	
						(0.236)	(0.186)	
Income pc (PPP, log)								-0.0566
								(0.0337)
Observations	8,007	8,005	7,997	7,995	7,222	6,042	6,042	4,662
R-squared	0.551	0.597	0.664	0.665	0.670	0.664	0.726	0.718
Geo controls	YES	YES	YES	YES	YES	YES	YES	YES
Province FE	NO	NO	NO	NO	NO	NO	YES	YES

Notes: Dependent variable is (*log*) population density. Geo-climatic controls are not reported but included in all columns, namely, temperature, rainfall, average altitude, ruggedness, soil quality and distance to the coast. Standard errors clustered at the province level. *** p<0.01, ** p<0.05, * p<0.1

Regarding demographic variables added in column (2) of Table 2, we see that low density areas are associated to ageing populations in which the dependency ratio is higher, and a larger share of local-born inhabitants. As expected, these patterns indicate that underpopulated areas have received less immigrants and/or have experienced larger emigration flows in the recent past.

A relevant question related to past migration flows refers to the so-called rural exodus. While the total number of rural inhabitants in 1940 remained about the same as it had been in 1900, during the phase from 1950 to 1991 large migration flows from agricultural areas to the leading industrial regions took place in Spain (see e.g. Collantes and Pinilla, 2011). In column (3), we include population growth from 1950 to 1991 as a proxy for the rural exodus at the municipality level. The positive and strong association with population density indicates that underpopulated municipalities in 2011 are those that experienced population losses during the rural exodus. Indeed, once we account for this characteristic, the dependency ratio is not statistically significant, which suggests that young inhabitants leaving rural municipalities during the 1950-1991 period account for the current dependency ratio of those rural and underpopulated municipalities.

The inclusion of political variables in column (4) indicates that less densely populated municipalities are not associated to higher prevalence of discontent parties, namely, VOX and Podemos, which is more prevalent in high-density and urban areas. Note that the regressor is the share of discontent vote in November 2019 General Elections, which is exactly the same to the increase in discontent vote since 2007, given that the share of Podemos and VOX was zero in all municipalities in that year. The increase in the support to regionalist parties between 2007 and 2019 is not associated either to low density areas. It has increased in low density municipalities within each province (see column 7).

Turning to fiscal variables in column (5) of Table 2, the estimates suggest that low-density areas are characterized by higher spending per capita in the local budgets. Note however, that the association with public revenue per capita is much weaker. These estimates suggest that, if anything, underpopulated areas in Spain are net recipients of public funds through local budgets. In any event, note that this finding must be interpreted with a grain of salt since public expenditures and revenues here do not include the components from regional and central government transfers.

In terms of economic characteristics included in column (6), low-density areas in Spain belong to municipalities characterized by higher shares of population employed in agriculture as well as lower average income per capita (note that the number of observations is lower when including income per capita since this information from INE is only available for municipalities above 100 inhabitants). These associations are highly significant and robust to the inclusion of province fixed effects in column (7) of Table 2.

In column (8), we re-estimate the specification in (7) but substituting nominal income per capita by PPP-adjusted income per capita. In particular, we normalize nominal income by an index of housing prices available at the municipality level. In particular, we use the census micro-data on real estate transactions provided by the Spanish Ownership Registry (*Registro de la Propiedad*) to the Banco de España since 2004. Interestingly enough, the positive and significant association turns negative and significant! Despite a note of caution is in place since the purchasing power parity (PPP) adjustment considered here refers only to housing prices, this finding suggests that in PPP terms, inhabitants of low-density areas present indeed higher incomes or at least, they do not present significantly lower incomes. Finally, it is worth noting that the number of observations is lower than in column (7) because housing prices data is only available for municipalities with more than 25 mortgages in the year 2011 in order to ensure good quality of the price index. Still, if we re-estimate the specification with nominal income per capita in column (7) for the subsample in column (8) the estimates remain virtually unaltered.

In order to gauge the relative strength of the different statistical associations reported in Table 2, we also estimate the corresponding partial correlations between population density and each regressor from column (7) by standardizing the variables. These figures are -0.15 for the distance to the province capital; -0.001 and -0.11 for the dependency ratio and the share of local-born inhabitants; 0.25 for population growth during the rural exodus (1950-1991); -0.09 and 0.10 for the increase in regionalist vote and the share of discontent vote; -0.10 and 0.03 for public spending and public revenue per capita; -0.06 and 0.05 for the share of agriculture employment and nominal income per capita. We also decomposed the goodness-of-fit (R2) of the model in column (7) into contributions of individual regressor variables (see e.g. Chevan and Sutherland, 1991). After accounting for geo-climatic factors and province fixed effects, the highest contribution to the overall R2 comes from 1950-1991 population growth (32%), distance to the capital (18%), the share of local-born inhabitants (15%), the share of discontent vote (9%), and the agriculture employment share (8%). The remaining regressors jointly account for around 15% of the overall R2.

All in all, the strongest associations arise between population density and 1950-1991 population growth (+), distance to the province capital (-), the share of local-born inhabitants (-), the share of discontent vote (+), and the share of employment in agriculture (-). Needless to say, these estimates must be interpreted with caution since they refer to mere correlations. While these correlations are useful for characterizing low density areas in Spain, we acknowledge that identifying the direction of causality is beyond the scope of the present paper.

Table 3 presents specifications further exploring the voting patterns in low-density municipalities.[15] The process of urbanization and globalization have manifested political discontent in rural and low-density areas of countries such as the US or the UK, which gives rise to populism reactions in the so-called revenge of the places that don't matter (see Rodríguez-Pose 2018).

Column (1) in Table 3 refers to the baseline specification from column (6) in Table 2. Low density municipalities are associated to lower shares of discontent vote (Podemos and VOX) and higher increases in the regionalist vote between 2007 and 2019. Column (2) shows that these areas are also associated to higher prevalence of regionalism voting in levels. Interestingly enough, this bias towards regionalist parties in low density municipalities is robust to the exclusion of Catalan municipalities from the sample as shown in columns (3) and (4).

Column (5) indicates that the urban bias of discontent vote in Spain is mainly driven by left-wing parties (Podemos) while the association between right-wing discontent vote (VOX) and population density is not statistically significant. Note that both Podemos and VOX were not present in the 2007 General Election so that including their voting shares in levels is equivalent to changes from 2007 to 2019.

Finally, in columns (6) and (7) we include an index of vote fragmentation (as in Sanz, Solé-Ollé and Sorribas-Navarro 2019) both in levels and 2007-2019 changes. On the one hand, there is no

[15]Note that voting information refers to the 2019 General Election and the changes with respect to to the 2007 election.

Table 3: Characteristics of low population density municipalities — Political variables.

	(1) Baseline specification	(2) Regional vote	(3) Without Catalonia	(4) Without Catalonia	(5) Left-right discontent	(6) Fragmentation index	(7) Fragmentation increase
Distance to capital	-0.0103***	-0.0103***	-0.00948***	-0.00942***	-0.0104***	-0.0103***	-0.0103***
	(0.00176)	(0.00177)	(0.00181)	(0.00181)	(0.00175)	(0.00176)	(0.00176)
Dependency ratio	0.00598	-0.00170	0.0767	0.0732	0.0267	-0.00416	0.00673
	(0.170)	(0.168)	(0.164)	(0.167)	(0.170)	(0.168)	(0.170)
Share born in mun.	-1.055***	-1.042***	-1.109***	-1.108***	-1.098***	-1.025***	-1.058***
	(0.219)	(0.221)	(0.254)	(0.257)	(0.220)	(0.222)	(0.220)
Pop. growth 1950-1991	0.530***	0.535***	0.539***	0.538***	0.530***	0.533***	0.533***
	(0.0344)	(0.0370)	(0.0390)	(0.0408)	(0.0343)	(0.0350)	(0.0351)
Regionalist vote growth	-0.0128***		-0.0116**			-0.0119***	-0.0131***
	(0.00331)		(0.00445)			(0.00347)	(0.00351)
Share discontent vote	0.0174***	0.0173***	0.0184***	0.0186***		0.0152***	0.0179***
	(0.00351)	(0.00362)	(0.00352)	(0.00363)		(0.00324)	(0.00346)
Public spending pc	-0.194***	-0.187**	-0.237**	-0.232**	-0.199***	-0.196***	-0.194***
	(0.0711)	(0.0714)	(0.0929)	(0.0928)	(0.0701)	(0.0711)	(0.0714)
Public revenues pc	0.0530	0.0494	0.0715	0.0677	0.0549	0.0535	0.0523
	(0.0411)	(0.0411)	(0.0565)	(0.0563)	(0.0401)	(0.0413)	(0.0413)
Share agriculture	-1.705***	-1.676***	-1.984***	-1.976***	-1.565***	-1.685***	-1.721***
	(0.462)	(0.470)	(0.468)	(0.471)	(0.455)	(0.457)	(0.450)
Income pc (log)	0.445**	0.460**	0.318	0.318	0.449**	0.431**	0.445**
	(0.186)	(0.195)	(0.197)	(0.201)	(0.182)	(0.190)	(0.186)
Share regionalist vote		-0.00470		-0.00118			
		(0.00378)		(0.00235)			
Share VOX					0.00419		
					(0.00463)		
Share Podemos					0.0270***		
					(0.00373)		
Fragmentation						0.0430	
						(0.0327)	
Fragmentation growth							-0.0139
							(0.0319)
Observations	6,042	6,042	5,169	5,169	6,042	6,041	6,041
R-squared	0.726	0.725	0.690	0.689	0.728	0.726	0.726
Geo controls	YES	YES	YES	YES	YES	YES	YES
Province FE	YES	YES	YES	YES	YES	YES	YES

Notes: Dependent variable is (*log*) population density. Geo-climatic controls are not reported but included in all columns, namely, temperature, rainfall, average altitude, ruggedness, soil quality and distance to the coast. Standard errors clustered at the province level. *** p<0.01, ** p<0.05, * p<0.1, $^{+}$ <0.15.

statistical association between population density and political fragmentation in levels. On the other hand, the increase in political fragmentation is indeed lower in low-density areas, which is related to the rise of the discontent vote (VOX and Podemos) more concentrated in urban areas. All in all, there is no clear evidence on any association between low density areas and the rise of political fragmentation through discontent vote. Still, we find some evidence that the rise in regionalist vote between 2007 and 2019 might have been stronger in low-density municipalities.

Table 4 includes two additional controls: (*log*) area in km^2 as well as a rural dummy for municipalities with less than 10,000 inhabitants, which is a commonly-used threshold in Spain to label rural areas (see Collantes and Pinilla 2011). The relationship between population density and these two indicators is somehow tautological, but it may well be that some of the characteristics explored above are related to these variables rather than to (*log*) population density per se. For instance, public spending per capita or the share of employment in agriculture may be higher in low-density municipalities because they present larger areas or they are smaller in terms of population size.

According to the results in Table 4, the sign, magnitude, and statistical significance of all the estimates in our baseline Table 2 remain robust when we control for land area and population size. Also, not surprisingly, we observe that rural and larger municipalities in terms of surface generally belong to low density zones within Spain. In particular, rural municipalities with less than 10,000 inhabitants present 0.4-1.3 log points lower density on average, which represents around one standard deviation of the dependent variable (see Table A.2); also, since both variables are expressed in logs, the estimates in Table 4 indicate that a 1 percent increase in land area is associated to a reduction of around -0.4% in population density.

Table 5 shows the analogous estimates for settlement density at the municipality level as the dependent variable. All the specifications are analogous to those of Table 2 but we simply replace the dependent variable.[16]

While the statistical association with the share of local-born inhabitants remains strong and significant, the one between settlement density and the dependency ratio is positive in general.

Table 4: Characteristics of low population density municipalities — Land area and population.

	(1) Baseline	(2) +Demographics	(3) +Rural Exodus	(4) +Politics	(5) +Fiscal	(6) +Economic	(7) +Fixed Effects	(8) +Prices
Distance to capital	-0.0155***	-0.0121***	-0.0106***	-0.0103***	-0.0107***	-0.0106***	-0.00943***	-0.0110***
	(0.00225)	(0.00172)	(0.00139)	(0.00142)	(0.00144)	(0.00151)	(0.00165)	(0.00189)
Area (log)	-0.436***	-0.410***	-0.395***	-0.400***	-0.427***	-0.448***	-0.383***	-0.415***
	(0.0487)	(0.0463)	(0.0434)	(0.0436)	(0.0378)	(0.0363)	(0.0393)	(0.0388)
Rural	-1.281***	-1.155***	-0.489***	-0.476***	-0.495***	-0.421***	-0.402***	-0.390***
	(0.162)	(0.128)	(0.0847)	(0.0888)	(0.0870)	(0.0800)	(0.0734)	(0.0733)
Dependency ratio		-0.734***	-0.360***	-0.309***	-0.287***	-0.499***	-0.376**	-0.525***
		(0.148)	(0.101)	(0.0909)	(0.0930)	(0.144)	(0.148)	(0.172)
Share born in mun.		-0.879**	-0.561**	-0.519*	-0.514**	-0.0683	-0.385*	-0.357*
		(0.374)	(0.267)	(0.272)	(0.247)	(0.230)	(0.198)	(0.201)
Pop. growth 1950-1991			0.696***	0.690***	0.663***	0.633***	0.451***	0.429***
			(0.0437)	(0.0432)	(0.0475)	(0.0444)	(0.0294)	(0.0370)
Regionalist vote growth				0.00278	0.00505	0.00336	-0.0127***	-0.0117***
				(0.00486)	(0.00423)	(0.00456)	(0.00318)	(0.00398)
Share discontent vote				0.00715	0.0100*	0.0100*	0.0184***	0.0174***
				(0.00618)	(0.00545)	(0.00587)	(0.00314)	(0.00388)
Public spending pc					-0.0585	-0.152**	-0.184**	-0.205**
					(0.0452)	(0.0705)	(0.0691)	(0.0955)
Public revenues pc					-0.00610	0.0176	0.0476	0.103
					(0.0376)	(0.0514)	(0.0420)	(0.0634)
Share agriculture						-1.963***	-1.528***	-1.683***
						(0.519)	(0.448)	(0.560)
Income pc (log)						0.443**	0.350**	
						(0.213)	(0.173)	
Income pc (PPP, log)								-0.0875***
								(0.0315)
Observations	8,002	8,000	7,997	7,995	7,222	6,042	6,042	4,662
R-squared	0.627	0.657	0.704	0.705	0.714	0.712	0.756	0.753
Geo controls	YES	YES	YES	YES	YES	YES	YES	YES
Province FE	NO	NO	NO	NO	NO	NO	YES	YES

Notes: Dependent variable is (*log*) population density. Geo-climatic controls are not reported but included in all columns, namely, temperature, rainfall, average altitude, ruggedness, soil quality and distance to the coast. Standard errors clustered at the province level. *** p<0.01, ** p<0.05, * p<0.1

[16] Also, Table B.4 in Appendix B.4 shows the estimates for population concentration.

Note that the association between the dependency ratio and population density in Table 2 became insignificant once we accounted for population growth during the 1950-1991 rural exodus in Spain. Regarding the political indicators, we observe a positive (negative) relationship between settlement density and the share of discontent vote (increase in regionalist vote) once we include province dummies in columns (6) and (7).

Turning to the fiscal characteristics of areas with low settlement density, we observe the same pattern as in Table 2: once we control for socio-economic characteristics and/or province fixed effects in columns (5) and (6), low settlement density areas belong to municipalities with higher public spending per capita but not higher public revenues per capita. Indeed, the partial correlation between settlement density and public spending per capita is -0.15 and statistically significant while that of public revenues is +0.04 but insignificant.

Finally, looking at columns (6) and (7) of Table 5, we conclude that lower settlement density is also associated to higher agriculture employment and lower income per capita in nominal terms.

Table 5: Characteristics of low settlement density municipalities.

	(1) Baseline	(2) +Demographics	(3) +Rural Exodus	(4) +Politics	(5) +Fiscal	(6) +Economic	(7) +Fixed Effects	(8) +Prices
Distance to capital	-0.238***	-0.202***	-0.185***	-0.195***	-0.195***	-0.169***	-0.0821**	-0.0935**
	(0.0364)	(0.0342)	(0.0333)	(0.0341)	(0.0347)	(0.0384)	(0.0351)	(0.0389)
Dependency ratio		5.228**	8.175***	6.585***	8.182***	12.64***	7.269***	7.111**
		(2.314)	(2.469)	(2.427)	(2.435)	(3.413)	(2.543)	(3.435)
Share born in mun.		-27.60***	-25.71***	-24.48***	-25.50***	-23.16***	-26.33***	-28.64***
		(6.075)	(5.525)	(5.042)	(4.707)	(4.660)	(3.624)	(3.908)
Pop. growth 1950-1991			4.530***	4.804***	4.316***	4.489***	1.747**	1.961**
			(0.812)	(0.766)	(0.765)	(0.746)	(0.739)	(0.732)
Regionalist vote growth				0.0443	0.0883	0.0304	-0.108*	-0.0769
				(0.128)	(0.115)	(0.120)	(0.0551)	(0.0719)
Share discontent vote				-0.194	-0.155	-0.142	0.119**	0.131*
				(0.122)	(0.106)	(0.120)	(0.0539)	(0.0693)
Public spending pc					-0.520	-3.467***	-2.864***	-2.315**
					(0.889)	(1.188)	(0.924)	(1.140)
Public revenues pc					-0.898	3.29e-05	0.971	0.776
					(0.640)	(0.957)	(0.676)	(0.748)
Share agriculture						-24.12**	-11.21	-18.36**
						(10.54)	(6.757)	(8.534)
Income pc (log)						14.99***	6.815**	
						(4.225)	(2.899)	
Income pc (PPP, log)								-0.140
								(0.423)
Observations	8,007	8,005	7,997	7,995	7,222	6,042	6,042	4,662
R-squared	0.528	0.555	0.567	0.573	0.588	0.618	0.750	0.764
Geo controls	YES	YES	YES	YES	YES	YES	YES	YES
Province FE	NO	NO	NO	NO	NO	NO	YES	YES

Notes: Dependent variable is the settlement density indicator. Geo-climatic controls are not reported but included in all columns, namely, temperature, rainfall, average altitude, ruggedness, soil quality and distance to the coast. Standard errors clustered at the province level. *** p<0.01, ** p<0.05, * p<0.1

However, if we consider PPP-adjusted income per capita with the only price index available at the municipality level (i.e. housing prices), the association between settlement density and average income becomes negative but not significant.

In sum, the main characteristics of low population density municipalities identified from the analysis in Table 2 also correspond to low settlement density municipalities.

5 Concluding remarks

Using the GEOSTAT population grid with information at the 1-km^2 level, this article uncovers an anomaly in the Spanish distribution of population across the space. Compared to other European countries, Spain presents the lowest density of settlements (almost 90% of its territory is uninhabited!) together with the highest population concentration in certain areas. Interestingly enough, these patterns remain true even after accounting for geographical and climatic conditions. The article also identifies the areas with the lowest densities within Spain and characterize the municipalities that belong to these virtually uninhabited parcels of land.

Economies of agglomeration rely on increasing returns to scale and lower transportation costs, and emphasize linkages between firms and suppliers as well as between firms and consumers. The emptiness of the Spanish territory may thus influence the distribution of economic activity across firms, sectors and space. The dynamic dimension related to the interaction between internal migration flows and the process of structural change of the Spanish economy over the last decades may also shape current economic outcomes.[17] Understanding the economic consequences of the Spanish anomaly in settlement patterns represents an exciting line of open research.

[17] In related projects, Gutiérrez et al. (2020) analyze in detail the evolution over the last decades of rural-urban migrations in Spain and Budí (2020) explores the macroeconomic consequences of such migration flows.

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A Additional figures and tables

Table A.1: Descriptive statistics at the grid-cell level.

	Europe				Spain			
	(1) mean	(2) p25	(3) p50	(4) p75	(5) mean	(6) p25	(7) p50	(8) p75
Settlement density	72.34	50.00	88.00	100	45.00	24.00	44.00	68.00
Pop. concentration	38.00	20.50	31.14	49.27	61.41	44.21	60.58	79.70
Pop. density	114.6	5.545	29.05	87.65	133.3	4.920	14.12	51.68
Temperature	8.124	5.436	8.505	11.03	13.25	11.41	13.40	15.53
Rainfall	7.741	5.842	6.819	8.772	6.222	4.567	5.452	6.953
Altitude	371.0	96.75	222.1	516.9	652.7	334.6	651.2	885.0
Ruggedness	87.40	17.69	46.76	121.0	109.8	46.63	85.42	145.0
Soil quality	8.726	8.429	9	9.429	8.905	8.429	8.934	9.357
Dist. coast	134.6	20.02	89.79	205.8	119.4	40.95	109.4	183.6

Table A.2: Descriptive statistics at the municipality level.

VARIABLE	(1) N	(2) mean	(3) p10	(4) p90	(5) sd
Settlement density	8,023	55.20	24	91.67	23.85
Pop. concentration	8,024	54.37	32.63	77.72	17.26
Pop. density (log)	8,024	3.064	1.204	5.389	1.656
Regionalist vote growth	8,108	3.105	-5.051	22.74	12.04
Share discontent vote	8,131	18.26	3.823	30.22	9.420
Distance to capital	8,113	44.14	15.95	76.41	24.38
Share agriculture	7,203	0.0715	0.00786	0.155	0.0604
Dependency ratio	8,116	0.505	0.212	0.893	0.312
Share born in mun.	8,114	0.466	0.216	0.694	0.177
Population growth 1950-1991	8,104	-0.547	-1.371	0.414	0.777
Public spending pc	7,338	1.222	0.652	1.938	0.841
Public revenues pc	7,338	1.307	0.701	2.101	0.897
Income pc (PPP, log)	5,163	10.26	9.655	10.94	0.557
Income pc (log)	6,745	9.197	8.924	9.467	0.208

Table A.3: The role of geography and climate in population patterns.

	(1) Sett. density	(2) Pop. density	(3) Sett. density	(4) Pop. density
Temperature_pt2	16.27**	0.891***	18.37***	0.733
	(5.445)	(0.250)	(4.977)	(0.519)
Temperature_pt3	21.13***	1.258***	21.07***	0.644
	(5.920)	(0.193)	(5.666)	(0.661)
Temperature_pt4	18.47***	1.667***	11.18	0.0151
	(5.647)	(0.226)	(8.393)	(0.896)
Rainfall_pt2	5.312***	0.294	1.840	0.0726
	(1.666)	(0.293)	(2.424)	(0.160)
Rainfall_pt3	10.16***	0.482	4.346	0.0786
	(1.987)	(0.270)	(3.760)	(0.296)
Rainfall_pt4	9.210**	0.418	2.685	-0.502
	(2.971)	(0.250)	(4.094)	(0.329)
Elevation_pt2	-1.898	-0.443**	3.958*	-0.271**
	(1.448)	(0.144)	(1.982)	(0.130)
Elevation_pt3	-8.216***	-1.313***	-3.408	-1.120***
	(2.592)	(0.199)	(5.353)	(0.406)
Elevation_pt4	-11.81***	-1.719***	-19.41**	-3.098***
	(2.665)	(0.221)	(8.857)	(0.825)
Ruggedness_pt2	3.419**	0.318***	5.502***	0.455***
	(1.179)	(0.0437)	(1.289)	(0.0647)
Ruggedness_pt3	5.047***	0.427**	6.748**	0.694***
	(0.714)	(0.149)	(2.666)	(0.206)
Ruggedness_pt4	4.423	0.575***	7.821*	1.366**
	(2.645)	(0.154)	(4.443)	(0.545)
Soil_quality_pt2	5.256*	0.208*	7.906***	0.585***
	(2.444)	(0.0966)	(2.080)	(0.202)
Soil_quality_pt3	7.071**	0.288**	9.066***	0.566**
	(2.903)	(0.120)	(2.412)	(0.270)
Soil_quality_pt4	7.562**	0.388**	9.869***	0.667*
	(2.862)	(0.127)	(3.060)	(0.341)
Dist_coast_pt2	-2.475	-0.339*	-10.12***	-1.221***
	(2.811)	(0.183)	(1.504)	(0.193)
Dist_coast_pt3	-8.852	-0.466	-10.57***	-0.946***
	(7.091)	(0.351)	(2.735)	(0.175)
Dist_coast_pt4	-7.531	-0.114	-9.175***	-0.738***
	(5.606)	(0.273)	(3.264)	(0.226)
Island	-1.631	-0.572***	2.593	-0.289
	(2.852)	(0.140)	(2.866)	(0.265)
Latitude	26.59***	1.472***	18.39***	0.975***
	(3.055)	(0.169)	(4.973)	(0.207)
Longitude	1.475	0.111	0.152	0.111
	(2.071)	(0.164)	(1.344)	(0.109)
Latitude^2	-0.278***	-0.0163***	-0.192***	-0.0111***
	(0.0322)	(0.00161)	(0.0468)	(0.00228)
Longitude^2	-0.00970	-0.00493***	-0.0230	-0.00320*
	(0.0272)	(0.00155)	(0.0212)	(0.00168)
Latitude_longitude	-0.0143	-0.000385	0.0237	-0.000317
	(0.0465)	(0.00323)	(0.0292)	(0.00240)
Observations	10,850	10,854	21,172	21,190
R-squared	0.697	0.585	0.720	0.681
Sample	Eurozone	Eurozone	Europe	Europe

Notes: Standard errors clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1

Figure A.1: The Spanish anomaly in settlement density (Europe).

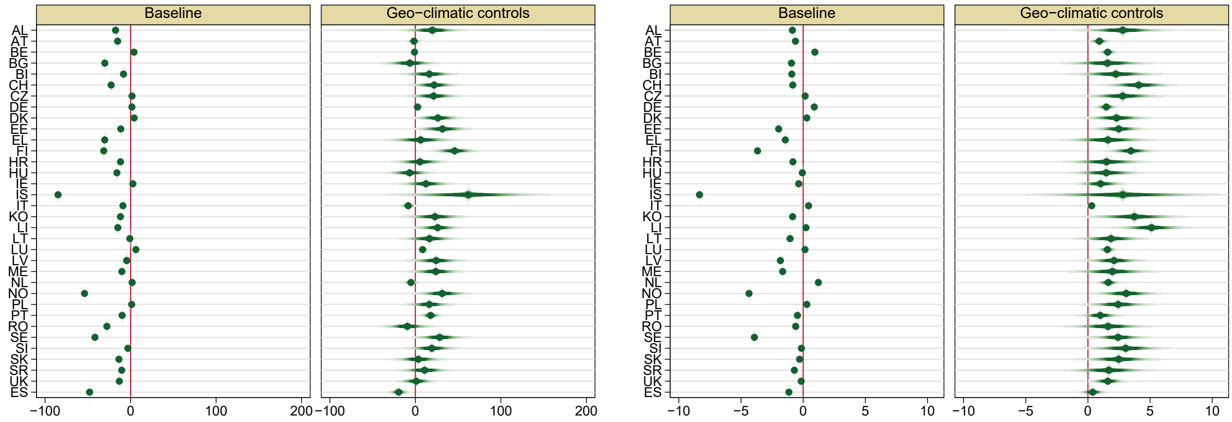


Figure A.2: Cumulative distribution of the difference between the coefficient on Spain and on each virtual country from 1,000 regressions.

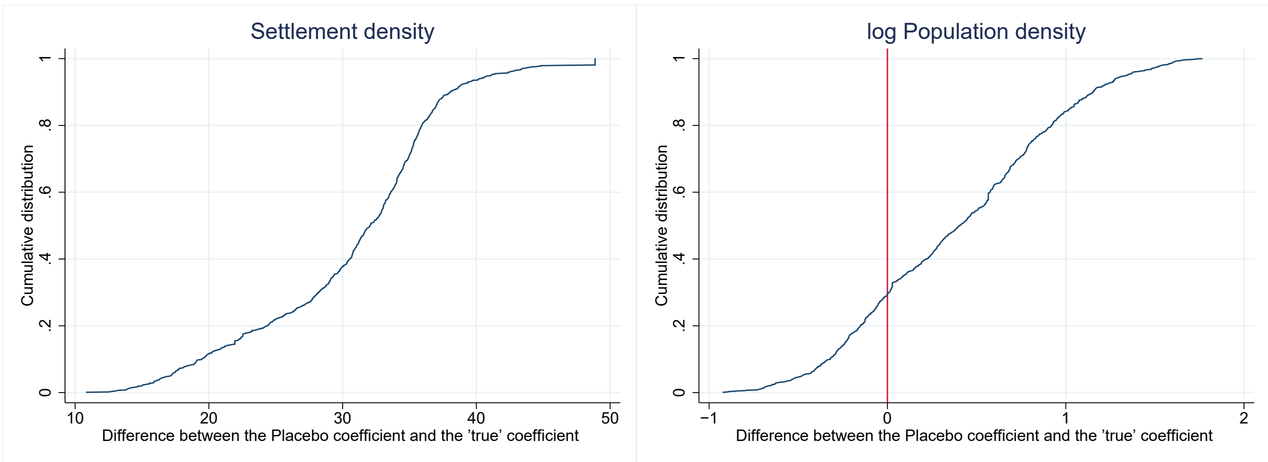


Figure A.3: Hotspot analysis for geo-climatic variables.

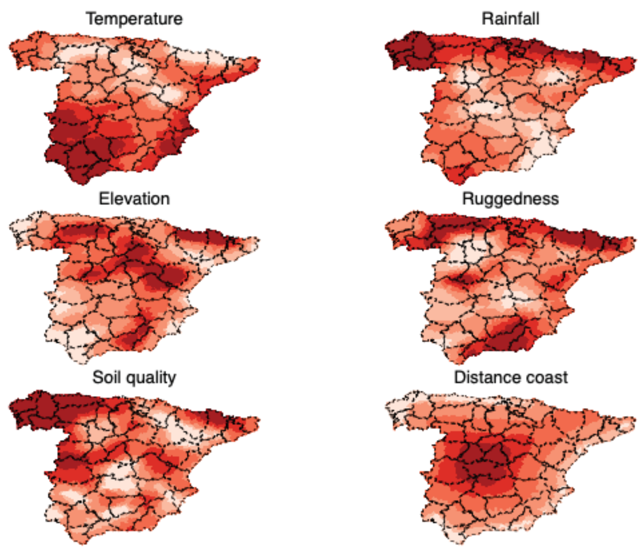


Figure A.4: Hotspot analysis (20 km).

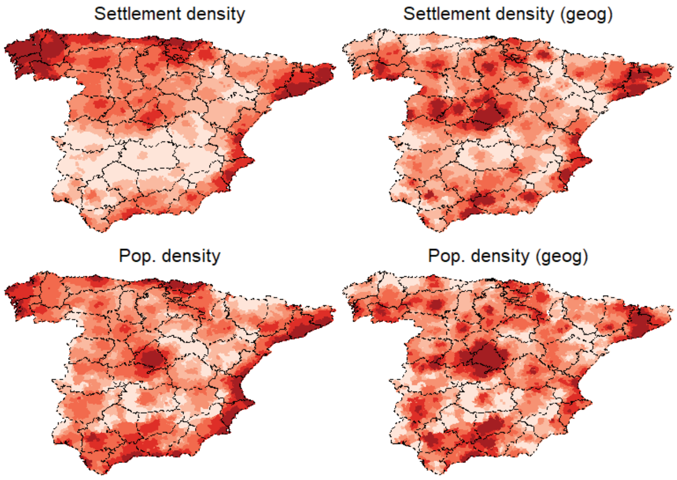
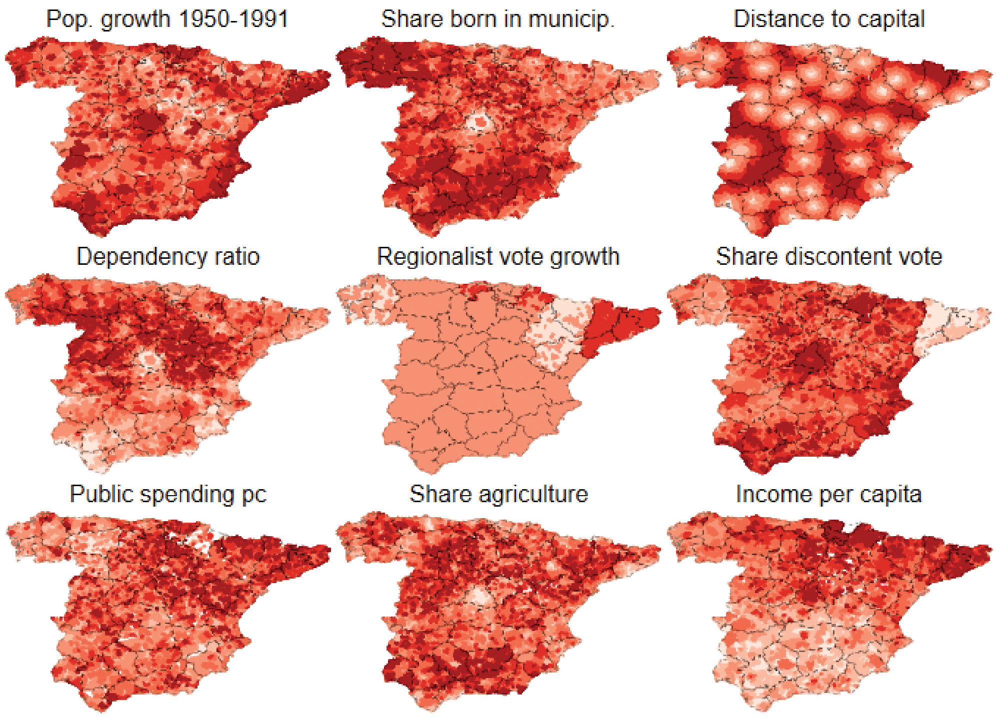


Figure A.5: Municipality characteristics.



B Population concentration results

Alternatively to settlement density and population density, we also follow Oto-Peralías (2020) and consider an indicator of population concentration that measures the percentage of the population living in the most populated one percent of the territory.

Figure B.6: The Spanish anomaly in population concentration.

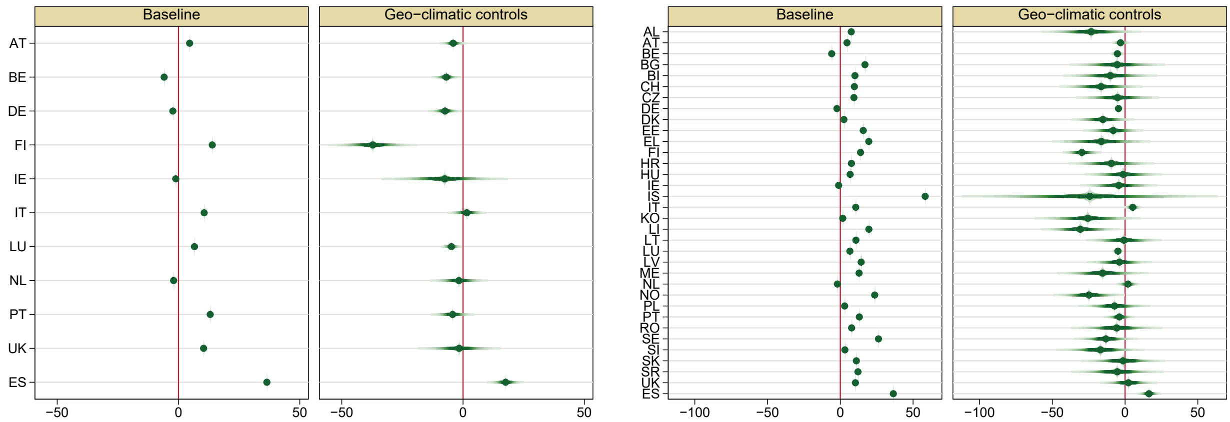


Figure B.7: The Spanish anomaly in population concentration by region.

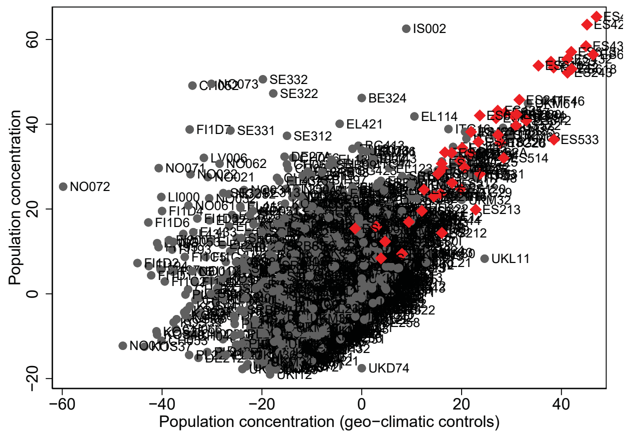
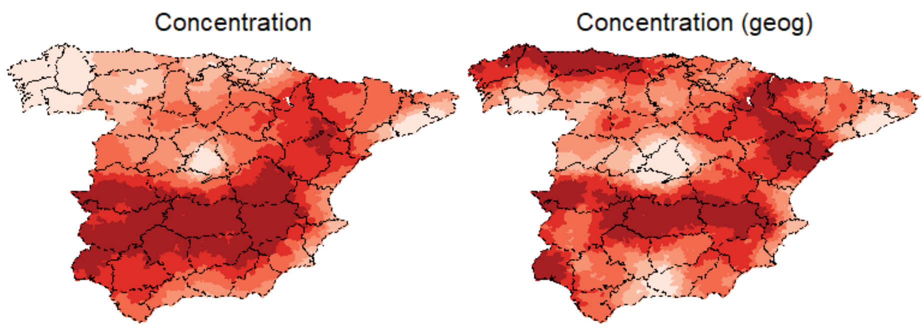


Figure B.8: Hotspot analysis for population concentration.



C The Madrid anomaly

Left panel of Figure C.9 shows that, within Spain, all regions at the NUTS2 level have a lower settlement density than Madrid (the omitted category) after accounting for geography and climate. Similar pattern at the NUTS3-province level with the exception of Barcelona and Girona that are not significantly different. Right panel of Figure C.9 shows that this excess of settlement density in the capital region is not observed in France. Contrarily, it holds for other European countries (omitted category is always the region capital for Germany, Italy, Portugal...), both using NUTS2 and NUTS3 regions (available under request).

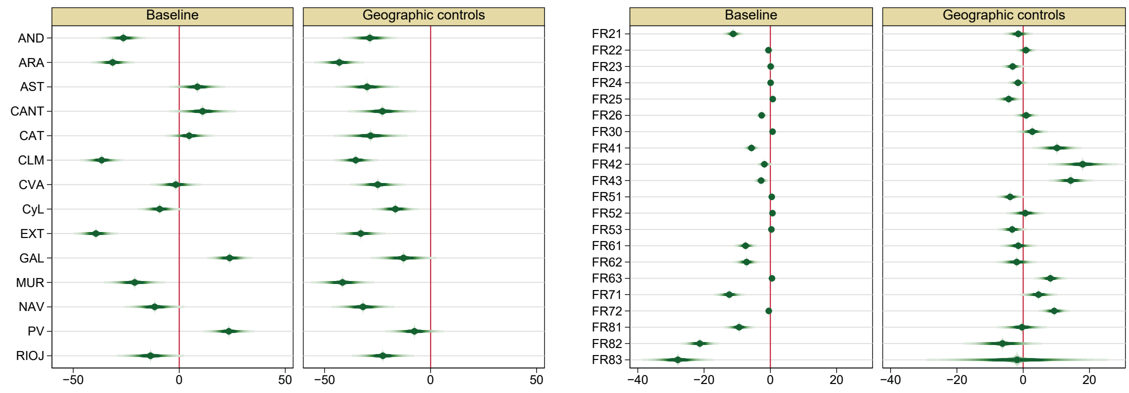
Table B.4: Characteristics of high population concentration municipalities.

	(1) Baseline	(2) +Demographics	(3) +Rural Exodus	(4) +Politics	(5) +Fiscal	(6) +Economic	(7) +Fixed Effects	(8) +Prices
Distance to capital	0.196***	0.175***	0.152***	0.152***	0.157***	0.148***	0.0778***	0.0928***
	(0.0312)	(0.0265)	(0.0240)	(0.0253)	(0.0256)	(0.0267)	(0.0240)	(0.0251)
Dependency ratio		-2.604	-6.568***	-6.548***	-8.104***	-14.08***	-9.506***	-9.829***
		(1.960)	(2.079)	(2.069)	(1.981)	(2.776)	(1.732)	(2.308)
Share born in mun.		15.37***	12.90***	12.70***	14.44***	15.10***	17.35***	19.67***
		(5.417)	(4.423)	(4.157)	(4.100)	(4.034)	(3.207)	(3.486)
Pop. growth 50-91			-6.044***	-6.049***	-5.855***	-6.523***	-4.125***	-3.891***
			(0.886)	(0.895)	(0.895)	(0.703)	(0.409)	(0.418)
Regionalist vote growth				-0.0122	-0.0197	-0.00777	0.00729	-0.0262
				(0.0746)	(0.0719)	(0.0752)	(0.0684)	(0.0796)
Share discontent vote				0.000941	-0.00516	-0.0583	-0.160***	-0.202***
				(0.0909)	(0.0925)	(0.105)	(0.0378)	(0.0399)
Public spending pc					0.590	1.804	0.751	-0.130
					(0.683)	(1.224)	(0.860)	(1.156)
Public revenues pc					0.506	0.605	-0.0852	0.708
					(0.548)	(0.858)	(0.577)	(0.692)
Share agriculture						12.02	6.948	9.974
						(8.957)	(6.906)	(7.417)
Income pc (log)						-6.560*	-3.182	
						(3.545)	(2.273)	
Income pc (PPP, log)								0.0733
								(0.454)
Observations	8,007	8,005	7,997	7,995	7,222	6,042	6,042	4,662
R-squared	0.354	0.371	0.411	0.411	0.428	0.473	0.618	0.648
Geo controls	YES	YES	YES	YES	YES	YES	YES	YES
Province FE	NO	NO	NO	NO	NO	NO	YES	YES

Notes: Dependent variable is the population concentration indicator. Geo-climatic controls are not reported but included in all columns, namely, temperature, rainfall, average altitude, ruggedness, soil quality and distance to the coast. Standard errors clustered at the province level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Indeed, we can summarize the cross-country evidence on the capital anomaly by simply doing a scatter plot with zero and different colors for each country to show that Spanish dots are always to the left of zero but this is not the case for other countries.

Figure C.9: The capital anomaly.



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