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What drives the allocation of motorways?
Evidence from Portugal's fast-expanding network

Bruno T. Rocha[1*], Nuno Afonso[2], Patrícia C. Melo[1], João de Abreu e Silva[2]

Abstract

This study investigates the factors that influenced the allocation of motorways across municipalities in mainland Portugal over the period from 1981 to 2011. Our analysis, based on Poisson Pseudo-maximum Likelihood models, suggests that population size and market potential in 1981 are important determinants of motorway density in 2011. Likewise, physical and geographical variables also help explain the spatial distribution of motorway investment, as terrain ruggedness, distance to the coast, and distance to the border with Spain are negatively associated with motorway density. In addition, we consider the influence of the proximity to historical and pre-existing transport networks on the allocation of motorways; we find that municipalities that are closer to the 1800's itineraries, the main roads of the 1945's National Road Plan, and 1981's train stations appear to have higher motorway densities in 2011, but this effect is concentrated in the vast and sparsely populated area of the country that excludes what we term the high-density Portuguese "blue banana". Interestingly, it is also only in this low-density region that partisan alignment between the municipal and the national levels of government appears to affect the allocation of transport investment, which suggests that motorways are more of a political asset in more remote or less urbanised areas.

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1. Introduction

The development of the Portuguese motorway network occurred very late for European standards, but was remarkably fast. Indeed, while in the late 1980s Portugal had less than 300 km of motorways, the network increased to around 1500 km in 2000 and to more than 3000 km in 2013 (ceasing to expand thereafter). In other words, the country moved rapidly from having a blatant lack of motorways to, quite possibly, a state of over-investment in this type of infrastructure. In fact, according to Eurostat data, in 2017 Portugal had the third highest endowment of motorways relative to GDP in the European Union (EU). As in other European countries, motorways were seen as a way to attenuate regional asymmetries and an investment to stimulate economic growth. Yet, to the best of our knowledge, there are no analyses on the factors that influenced the spatial distribution of transport infrastructure across the Portuguese territory. Given the substantial amounts of EU funding allocated to the development of the road network since the adhesion to the EU in 1986 – and particularly to the construction of motorways –, this paucity of research is surprising and in great contrast to other countries, notably Spain, which also invested heavily in its motorway network over the same period.

This study contributes to fill this gap by setting out to shed light on the main drivers of the spatial distribution of a large-scale, rapid-growing motorway network. More specifically, we use Poisson Pseudo-maximum Likelihood techniques to identify and quantify the relative importance of the factors that influenced the allocation of motorways across municipalities in mainland Portugal over the 30-year period from 1981 to 2011. Building on evidence from different literature strands, we consider an extensive set of possible determinants of the location of new motorways: topography and other physical or geographical variables (e.g. altitude range and distance of the municipality population-weighted centroid to the coast); the distance to historical and pre-existing transport networks (e.g. the road "itineraries" of more than two centuries ago); population size, population accessibility (based on an indicator of market potential), and local economic activity levels (that is, variables that are more directly related to demand for transport infrastructure); and, finally, political economy factors, measured by the extent of partisan alignment between the national and the municipal levels of government. Importantly, in this study we also explore the country's marked regional asymmetries by analysing separately, on the one hand, what we term the (high-density) "Portuguese blue banana" i.e. the coastal strip between the Metropolitan Area of Lisbon and the north of the country, and, on the other hand, the (low-density) rest of the country e.g. the interior regions.

Our results show that population size and market potential in 1981 are important determinants of motorway density in 2011. Terrain ruggedness (as measured by altitude range), distance to the coast, and distance to the border with Spain also help explain the spatial distribution of motorway investment and are all negatively associated with motorway density. Municipalities that are closer to historical or pre-existing transport networks – the 1800's itineraries, the main roads of the 1945's National Road Plan, and 1981's train stations – appear to have higher motorway densities, but this effect is concentrated in the vast and sparsely populated area of the country that excludes the Portuguese "blue banana". It is also only in this low-density region that partisan alignment between the municipal and the national levels of government appears to have an effect on the allocation of motorway investments. This suggests that this type of infrastructure is more of a political asset in more remote or less urbanised areas. In sum, while there are important similarities between these two types of regions in terms of how motorways are allocated across municipalities, there are also significant differences.

The rest of the paper is organised as follows. Section 2 summarises key findings from related studies, with an emphasis on European countries. Section 3 provides a brief historical account of the development of road networks in Portugal. Section 4 describes the dataset used in this study, while the following section explains our econometric methodology. Section 6 reports and discusses the results, and includes a series of sensitivity analyses. Section 7 concludes.

2. Related literature

A number of studies have tried to explain what drives the allocation of transport infrastructure in a given country.[1] Different types of explanatory factors have been considered. Not surprisingly, most if not almost all analyses include demand-related variables – e.g. population size, market potential, and regional GDP – as explanatory

[1] It should be noted that this body of literature is clearly not as abundant as the one that aims at identifying the causal effects of transport infrastructure on the location of population, economic activities, and on economic development more generally. See Redding and Turner (2015) for an extensive survey.

factors. Some studies also include geographical or physical variables – e.g. some indicator of altitude or terrain ruggedness – meant to capture building costs associated to more demanding topographical conditions, an important supply-related element. In addition, a growing number of studies has explored the relationship between historical or pre-existing transport networks and current infrastructure; in many cases, the former are considered as valid instrumental variables for the latter in studies whose primary objective is to estimate causal effects of transport infrastructure on population or economic outcomes.[2] A related research strand comes from the political economy literature, which, as discussed below, has investigated the links between political and ideological factors and the spatial distribution of public investments, including transport infrastructure.

As we are interested in the case of Portugal, a relevant work is Holl (2011), which looks at the factors related to the placement of new motorways in Spanish municipalities between 1983 and 2004. Spain's motorway network expanded greatly during this period, growing from 2162 to 10747 km. Using linear probability models (the dependent variable equals one if a municipality received a motorway within a circle-approximation to its area and zero otherwise), Holl finds that the placement of motorways follows to a significant extent the pre-existing trunk road network, noting that past decisions account, in part, for the influence of topography in the financial cost and feasibility of road construction projects. She also finds that motorway placement was associated with population size, population accessibility, the fact that a municipality forms part of a major urban agglomeration, and prior population growth (in this case only for 1994-2004 but not in 1983-1993).

An early study is Rietveld and Boonstra (1995), which carries out an econometric analysis for the supply of railways and highways (measured in terms of network density i.e. meters per square km) in a cross-section of 92 European NUTS2 regions in eight countries. While the authors note that caution should be exerted in interpreting their results in a causal sense, they find that regional population density and national GDP per capita are the main determinants of the supply of both types of infrastructure; population density in neighbouring regions is also a significant determinant for highways, even at this level of spatial aggregation. Costs associated to physical conditions are measured by

[2] See sections 20.4.2.1 and 20.4.2.2 in the Redding and Turner (2015) survey. As an example, the first-stage regressions of Garcia-López et al. (2015) show that Roman roads and the 1760 Bourbon roads matter for modern highway construction in Spain.

means of a dummy variable that equals one for regions where the highest altitude is at least 2000 and zero for the other regions. Altitude is found to act as a negative significant determinant for railways but not for highways – the authors recognise that this may be caused by the crude way in which these costs were measured, as more refined data (e.g. on slopes) was difficult to obtain.

Some papers attempt to explain the inter-regional allocation of investments in infrastructure (in general) in the context of the traditional efficiency-equity dilemma. De la Fuente (2004), for example, proposes a test comparing the observed distribution of the stock of infrastructure across regions in Spain with an optimal allocation derived from a planning problem based on parameters as the degree of aversion to inequality and the non-productive fraction of the population, concluding that public investment has been "too redistributive". Yamano and Ohkawara (2000) provide similar findings regarding the trade-off between economic efficiency and prefectural equity in Japan. In Castells and Solé-Ollé (2005), however, the government's motives are not confined to this trade-off. Their study of the distribution of transport infrastructure in Spain shows that governments are tactical, in the sense that they tend to invest more in the NUTS3 regions where "electoral productivity" is higher. Other papers that focus on electoral concerns include inter alia Joanis (2011) on Canada and Rodríguez-Pose et al. (2016) on Greece. Sole-Ollé (2013) extends this type of analysis by noting that, at least in Spain, political motives are not only tactical but also ideological, with both influencing the shape of the government's efficiency-equity trade-off (on the other hand, terrain ruggedness, measured in this case as the percentage of land over 1000 meters of altitude, appears to have no effect on the inter-regional allocation of infrastructure investment). Cadot et al. (2006) find that, in addition to electoral motivations, lobbying (proxied indirectly by the number of large establishments in a region) is also a significant determinant of the distribution of transport infrastructure investment in France.

Regarding Portugal, while there is some research on the local or regional economic effects of transport infrastructure (Holl, 2004; Pereira and Andraz, 2006; Melo et al., 2010; Pereira and Pereira, 2015; Audretsch et al., 2020), to the best of our knowledge there are no studies on the factors that influenced the location of infrastructure investment across the Portuguese territory. This lack of research is surprising and in great contrast to Spain, which, as seen above, has received considerable attention from scholars. There is nevertheless a loosely related body of work from the political economy literature – Veiga and Pinho (2007), Veiga and Veiga (2013), Mourão (2013) –, which looks at transfers by the central government to municipalities as pork barrel. Mourão (2013), in particular, shows that the Portuguese government tends to increase investment transfers to the municipalities that are ruled by the same political wing.

3. Roads and motorways in Portugal

Historical antecedents: from royal roads to the first highway

Roads began to be built in Portugal in a regular and systematic way from the mid-19th century onwards, although in a context in which railways (the first rail line opened in 1856) and also the more traditional inland waterways or coastal navigation were broadly seen as better options for long-distance transportation. As in many other countries, railways were a symbol of progress and considered to be the backbone upon which the rapidly expanding transport network of the country should be structured (Justino, 1988-89; Alegria, 1990).

The concept of a national road network with different categories was already present in official documents from 1835 and 1843 and was the central object of the important decrees-law of 1850 and 1862. The latter established a road classification with three categories: 1st class royal roads, 2nd class district roads, and municipal roads. Royal roads were *direct* if they connected Lisbon, or a direct railway line to Lisbon, to the district capitals or to the main border posts, and *transversal* if they connected district capitals, border posts, and ports. District roads, in turn, connected ports and important cities and towns to royal roads. In reality, the network expanded in a rather uneven way – much denser in the coastal regions between Lisbon and the north (the more populated part of the country), and, in general, with municipal roads developing slowly across the territory (Alegria, 1990; Pacheco, 2004, Chapter 3). As of June of 1896, there were 5563 km of royal roads (against around 200 km in 1850), 4214 km of district roads, and 3121 of municipal roads (Santa-Rita, 2006).

The transition to the 20th century was not without economic and political turmoil. The financial crisis of 1890-92 led Portugal to abandon the gold standard and to a partial default. Between 1892 and 1902 the government was effectively banned from raising loans in the international financial markets (Lains, 2008). The reign of King Carlos (1889-

1908) was marked by political divisions and instability; the king was assassinated in 1908 by Republican partisans and the monarchy was overthrown in 1910. Yet, the First Republic (1910-1926) was also a period of great instability: Portugal had 45 governments in 16 years. It is not surprising, then, that the military dictatorship, implemented in 1926, inherited a road network in very bad conditions, with many roads in ruins. A period of investment in roads rapidly ensued, which was consolidated and amplified until the late 60s under the Estado Novo autocratic regime (1933-1974), in tandem with the advent of the automobile and the rising relevance of road passenger and freight transportation in comparison with rail transportation; for example, between 1937 and 1957 the railway network almost did not grow, while asphalt roads expanded from 3564 km to 7495 km (Pacheco, 2004, Chapter 3). The first motorway opened in 1944 with an extension of 8 km, linking Lisbon to the National Stadium located in the nearby municipality of Oeiras. Yet, the second motorway would not be opened before 1961, connecting Lisbon to Vila Franca de Xira (25 km). This was the beginning of the A1 motorway corridor connecting Lisbon to Porto, the main motorway of Portugal, which would be completed only in 1991.

Building a large motorway network

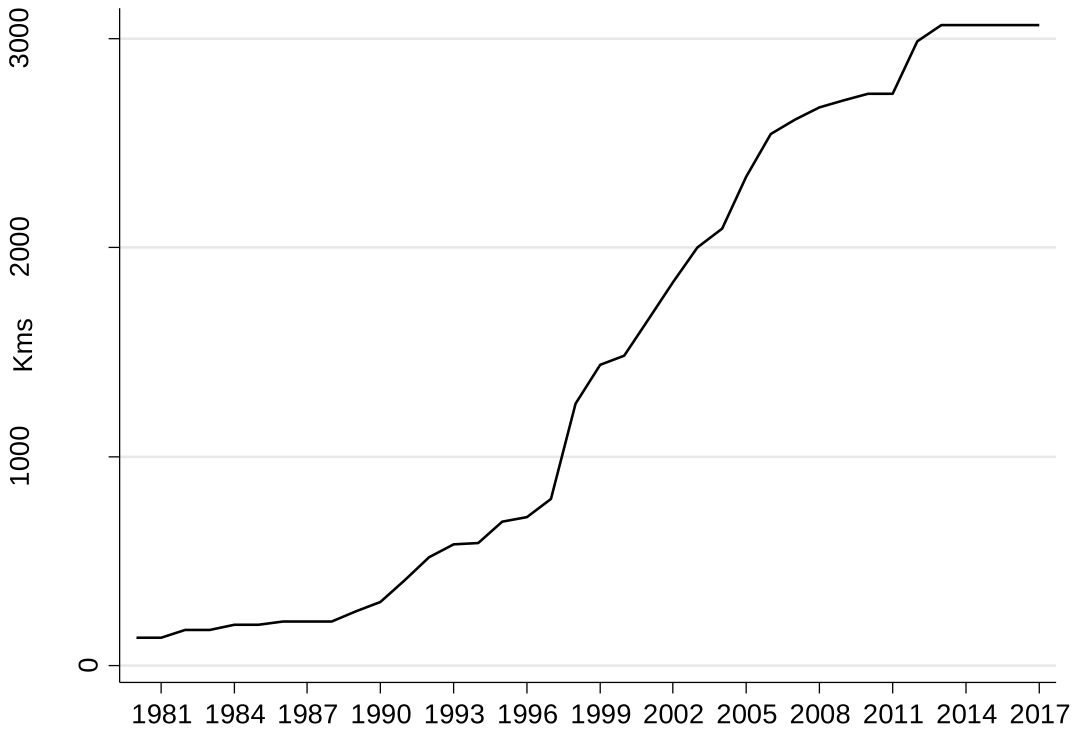
The development of the motorway network in Portugal after 1990 was remarkably fast, as seen in Figures 1 and 2. In 1986 Portugal had 196 km of motorways (i.e. 19.5 km per million inhabitants); by 2017 the network had increased to 3065 km (297.2 km per million inhabitants). For comparison, during the same time span Spain increased its motorway network from 2154 km (55.9 km per million inhabitants) to 15523 km (333.6 km per million inhabitants).[3] While in 1980-89 investment in motorways represented no more than 0.072% of GDP in Portugal, in 2000-09 this investment reached 0.586% of GDP, more than the investment in railways (0.349%), airports (0.061%), and ports (0.056%) combined (Pereira and Pereira, 2017). That is, while the case of Spain if often cited as an example of a large-scale motorway-building programme, in particular since its adhesion to the EU and the resulting access to EU funding, the case of Portugal is, in proportional terms, analogous in many respects – yet, it remains much less studied.

The geographical expansion over time of the network shown in Figure 2 is perhaps not surprising. As of 1991, existing motorways essentially served the metropolitan areas of Lisbon and Porto and the A1 corridor connected these two cities. In the following two

[3] Source: authors’ calculations using Eurostat data.

decades, the network expanded to create connections to Spain and to serve low-density regions in the interior of the country (connecting them to coastal areas), in accordance with cohesion-oriented objectives of promoting a regionally balanced development of the Portuguese territory (PRODAC, 1989; Pacheco, 2004, Chapter 3). At the same time, more kilometres of motorway were built in the metropolitan areas of Lisbon and Porto and in the coastal regions between the Lisbon area and the north, thus augmenting the density of the network in this part of the country.[4]

Figure 1. Extension of the motorway network in Portugal



Source: Pordata.

[4] For example, since 2009 it is possible to travel by highway between Lisbon and Porto without using the A1. The two cities are connected by a "parallel highway" located between the A1 and the coast formed by the A8, A17, A25 (a small section), and A29.

Figure 2. Evolution of the motorway network in Portugal

Panel A. Country (mainland) **Panel B.** Porto metropolitan area **Panel C.** Lisbon metropolitan area

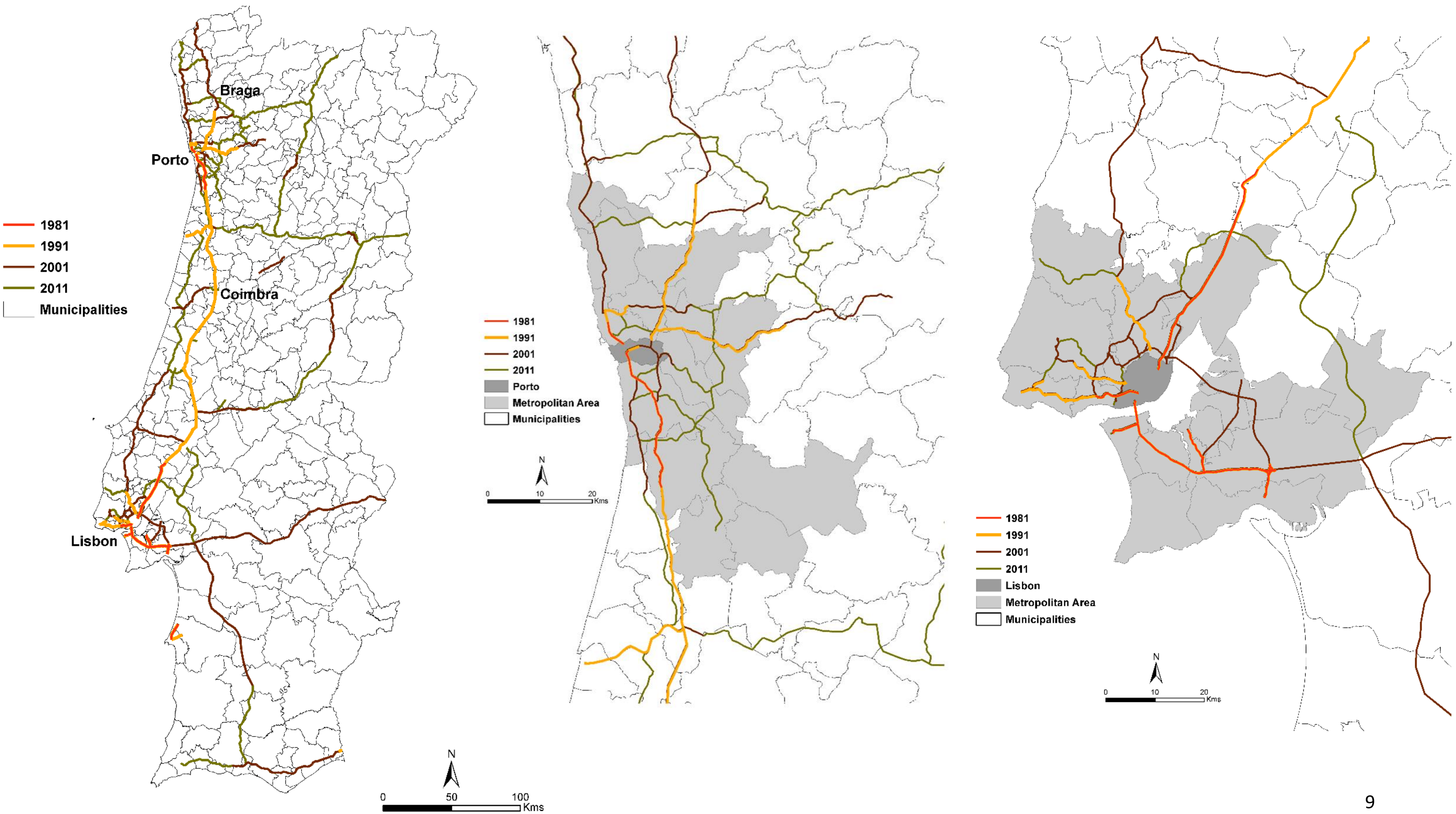
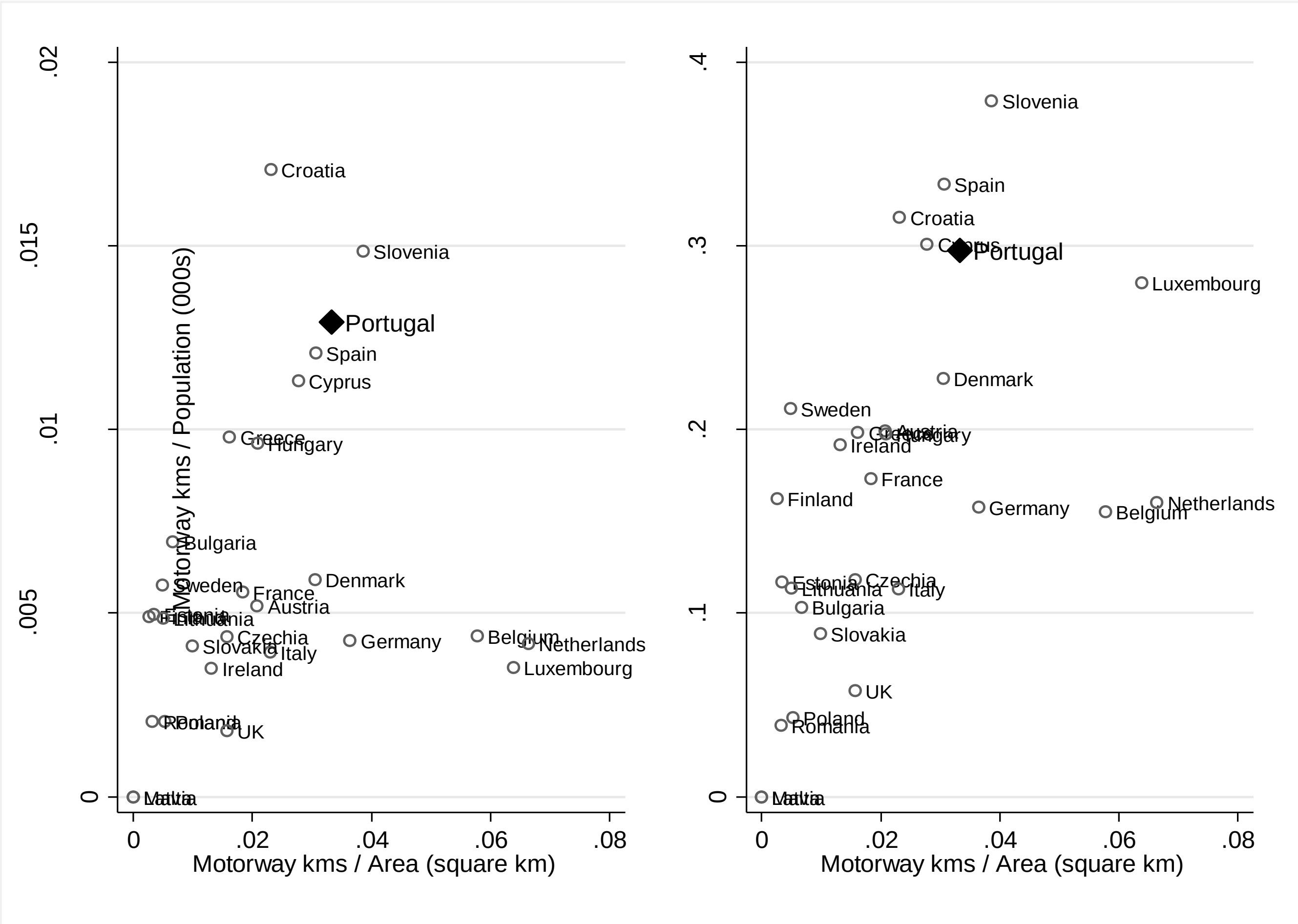


Figure 3. Motorways in the European Union, 2017



Source: authors' calculation using Eurostat data. Note: Motorway kms refer to 2017 or the most recent available year.

The result of all this investment is that, at present, Portugal has the fifth longest motorway network in absolute terms in the European Union. In 2017, only the much larger EU27 countries of Spain (15523 km), Germany (13009 km), France (11618 km), and Italy (6943 km) had more kilometres of motorways than Portugal (3065 km). In terms of the ratio between network extension and GDP (population, area), Portugal ranks third (fifth, and sixth) in the EU (see Figure 3). Also, as happens in the case of Spain – see e.g. Holl (2011: 1285) and Albalate et al. (2015) –, the fact that there are some motorways with relatively low daily traffic intensities is frequently a matter of public debate.[5] According to Pereira and Pereira (2017), the marginal product of the investment in motorways on output has decreased by around a factor of 6 between 1979-1988 and 2002-2011, leading these authors to recommend cutting back in this type of investment. Indeed, further expansions of the motorway network are not seen as an objective in the present-day political discourse. For example, the word "autoestrada" (motorway in Portuguese) does not appear a single time in the Government Program for the 2019-2023 legislative term, whereas "to give priority to railways" constitutes an explicit policy aim. After decades in which railways were regarded as secondary vis-à-vis motorways (railway lines in use decreased from 3611 km in 1981 to 70% of that in 2019),[6] the official view today is that railways should be the backbone of the transport network in the metropolitan areas of Porto and Lisbon, as well as constitute a factor of territorial cohesion at the national level (XXII Governo Constitucional, 2019: 66).

4. Data and descriptive statistics

We constructed a dataset composed of 275 municipalities in mainland Portugal.[7] The dataset contains information regarding motorway infrastructure, physical and geographical features, historical and pre-existing transport networks, socioeconomic (demand-related) indicators, and, lastly, a political variable that measures the partisan alignment between local and national governments. The main variables are described in the following paragraphs, whereas Table 1 reports basic descriptive statistics of their distribution.

[5] For example, in 2019 the A17 (117 km) and the A15 (40 km) had an approximate average daily traffic of 8477 and 5201 vehicles respectively; seven other motorways had an average daily traffic below 10000 vehicles (authors' calculation with data from IMT, 2020).

[6] Source: Pordata.

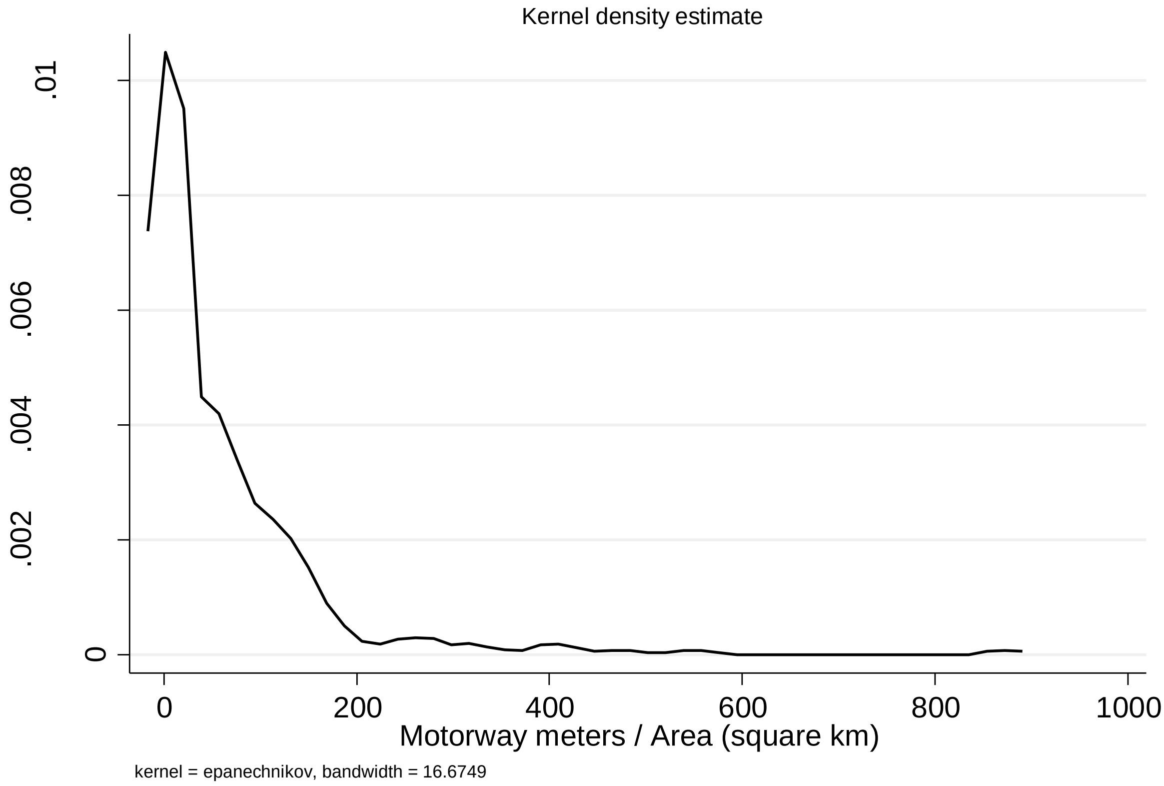
[7] Mainland Portugal has 278 municipalities since 1998; five municipalities lost part of their territory to form the three new municipalities that were created in 1998. To ensure data consistency we use the pre-1998 administrative division of 275 municipalities.

Table 1. Variable definitions, descriptive statistics, and data sources

Variable	Definition	Mean (s.d.)	Min. - Max.	Source
Motorway density, 2011	Meters of motorway per square km.	57.2 (97.0)	0 - 874.3	Authors' GIS calculations
Altitude range	Maximum altitude minus minimum altitude (meters).	555.8 (363.8)	17 - 1818	Pordata
Distance to the coast	Straight line distance from the population-weighted* municipality centroid to the coast (kms).	59.6 (46.0)	0.54 - 204.8	Authors' GIS calculations
Distance to the border	Straight line distance from the population-weighted* municipality centroid to the border with Spain (kms).	71.2 (45.2)	0.28 - 181.1	Authors' GIS calculations
Distance to an 1800 itinerary	Straight line distance from the population-weighted* municipality centroid to the road itineraries of the year 1800 (kms).	3.2 (4.7)	0.01 - 45.9	Authors' GIS calculations; 1800's itineraries from Matos (1980).
Distance to a PRN 1945 1st class road	Straight line distance from the population-weighted* municipality centroid to a 1st class road as defined in the National Road Plan of 1945 (kms).	6.0 (8.7)	0.01 - 68.8	Authors' GIS calculations
Distance to a 1981 train station	Travel distance from the population-weighted* municipality centroid to a train station active in 1981 (kms).	10.0 (10.4)	0 - 49.9	Authors' GIS calculations
Population, 1981	Resident population.	33951.8 (62562.5)	2157 - 807937	INE (Statistics Portugal), Census 1981.
Population accessibility, 1981	The index of potential population accessibility for municipality i in 1981 equals $\sum_{j \neq i} \frac{Population\ 1981_j}{distance_{ij}}$, where "distance" is the travel time in 1981 between the population-weighted* centroids of municipalities i and j.	69962.7 (28755.7)	28704.7 - 211951.5	Authors' GIS calculations
Electricity Consumption per capita, 1981	kWh / Resident population.	1191.0 (2307.7)	112.6 - 23186.5	INE (Statistics Portugal)
National-Municipal partisan alignment, 1980-2006	Proportion of alignment time between the municipal and national levels of government between January 1980 and December 2006.	0.461 (0.243)	0 - 0.898	Authors' calculations

Note: * population weights were calculated using population data from 1981.

Figure 4. Motorway density in Portuguese municipalities, 2011



The objective of this study is to help explain motorway endowment in physical terms at the municipal level. We measure this by using motorway density i.e. metres of motorways per square km as the main dependent variable in our empirical analyses, in order to account for differences in the size of municipalities.[8] [9] Figure 4 plots the kernel density estimate of motorway density in 2011, which presents a fat-tailed distribution. Note that the variable contains an important mass of zeros, as in 119 municipalities (43.3%) there are no motorways at all. At the other extreme, from the 14 municipalities

[8] Note that there is a large variation in the area of municipalities in mainland Portugal. In our dataset the mean size of municipalities is around 323 km^2, with a standard deviation of about 284 km^2. The smallest municipality has an area of 8 km^2, while the largest one has 1721 km^2.

[9] In a sensitivity analysis we use the distance from the municipality centroid to the nearest motorway access node as the dependent variable, although this has the disadvantage of not representing a direct measure of the physical stock of motorway infrastructure that exists within a given municipality.

with the highest motorway densities (i.e. the top 5% of the distribution), 5 belong to Lisbon Metropolitan Area and 6 to Porto Metropolitan Area.

Our dataset includes three geographical variables. Altitude range accounts, to an important extent, for differences in topography. As noted by inter alia Holl (2011), features such as mountains and valleys influence the structure of networks, as well as the cost and feasibility of new projects. The second variable is the distance of the municipality centroid to the coast, which may reflect both cost and demand factors. On the one hand, municipalities that are closer to the coast have, usually, a less rugged topography. On the other hand, many of them are in areas that traditionally receive important touristic flows. They also tend to be closer to transport infrastructures that are essential for transnational economic flows – ideally, these ports and airports[10] should be interconnected with a good road network in order to allow for an efficient transit of goods and people. Finally, distance to the border is included to capture (a contrario) spatial proximity to Spanish markets as well as to prospective points of connection to the Spanish road network (probably this variable also captures "border effects" that may hamper economic interactions and local economic development).

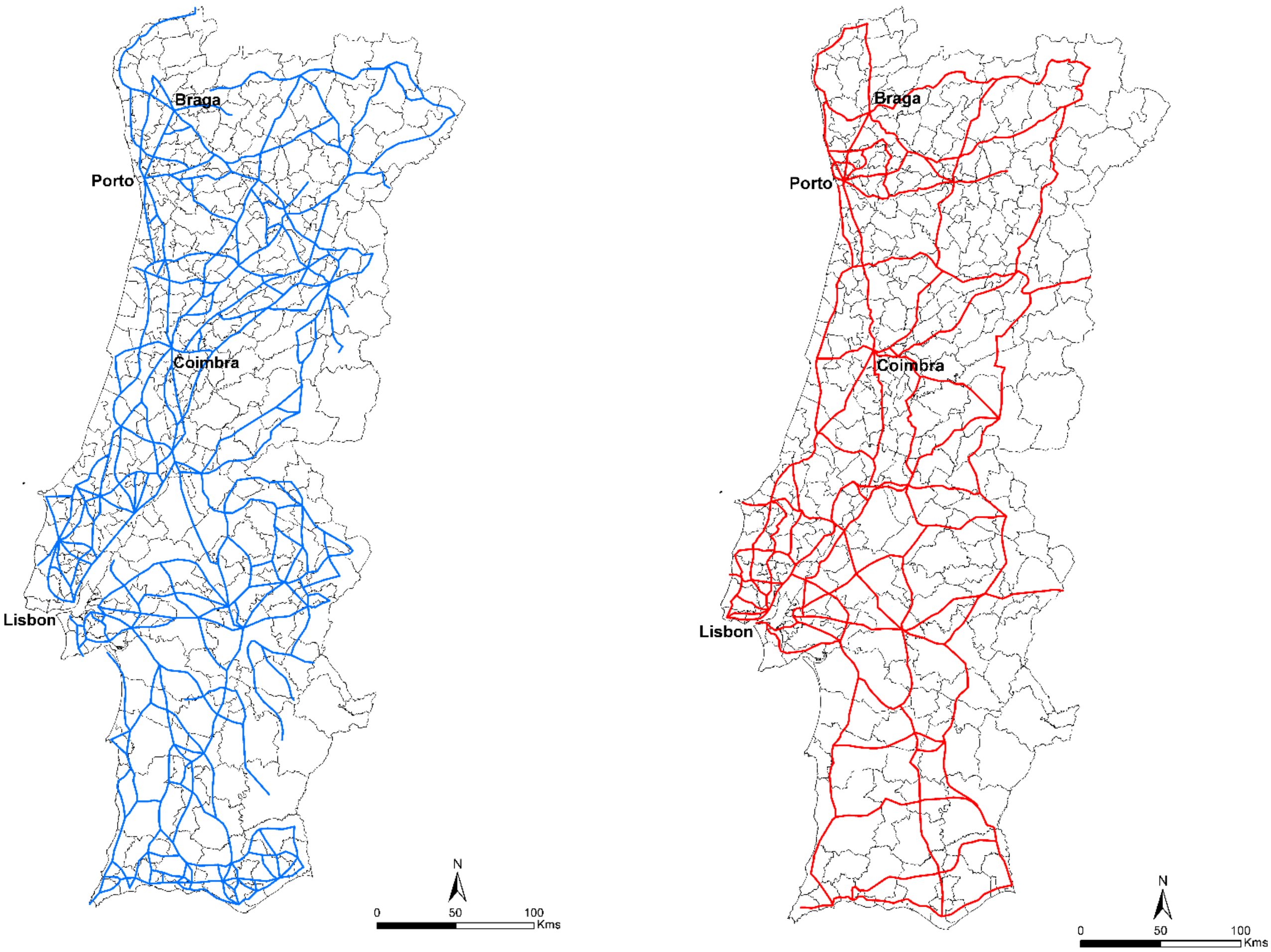
The following three variables refer to the presence of historical and pre-existing transport networks. This type of "correlation with the past", or "path-dependence" may reflect not only construction costs and feasibility (related for instance with local topographical features) but also historically persistent differences in the socioeconomic characteristics of municipalities (e.g. population size), which possibly induced the construction of transport infrastructures in similar locations in different moments in time. The first variable is the distance to the (mainly dirt) roads, or "itineraries", of the year 1800. Although roads in this period were in general in bad conditions (Matos, 1980; Pacheco, 2004, Chapter 3), Figure 5 shows a relatively dense network, as the average distance of a municipality centroid to the nearest 1800 itinerary was of no more than 3.2 km. We also include the distance to a 1st class road as defined in the National Road Plan of 1945.[11] According to the official text,[12] these roads formed the main network of the country, establishing "easy and rapid connections" between the most important centres, between these and the ports or the border with Spain, and, in addition, between district

[10] The three mainland airports are located in coastal cities: Lisbon, Porto, and Faro.
[11] See Sousa (2010) for a detailed analysis of the network topologies of both the 1800's itineraries and the 1945 National Road Plan.
[12] Decree-law 34593 of 1945.

capitals – this was the first time that the importance of easy and fast connections was explicitly mentioned in a classification of roads (Sousa, 2013).[13] The third variable is the distance to the nearest active railway station in 1981. As noted in Section 3, historically railways had been seen as the most important transport network. Our data sources allow us to identify the train stations that were operating in 1981, but, in reality, almost all of these stations were in service well before that. Indeed, in 1981 the extension of the Portuguese rail network was of 3611 km – in 1968, for example, this was of 3592 km i.e. almost identical.[14]

Figure 5. Pre-existing road networks

Panel A. 1800 itineraries **Panel B.** 1945 NRP 1st class roads



Source: adapted from Sousa (2010).

[13] The maximum speed limit in 1st class roads was of 100 or 80 km per hour. The maximum speed limit in current motorways is of 120 km per hour.
[14] Source: Pordata. In the 1930s the network already had 3423 km (Silveira et al., 2011).

Population size and population accessibility (measured by an indicator of market potential) – both in 1981 – reflect, essentially, dimensions of demand. Our measure of market potential corresponds to the distance-discounted sum of the population of the other 274 municipalities (see equation in Table 1). Additionally, we also consider electricity consumption per capita as a proxy for the local level of economic activity. We consider 1981 as our reference year for these demand-focused variables as an attempt to remove, or at least mitigate, the influence that the development of the motorway network may have had on these variables themselves (more on this below).

As discussed in Section 2, political factors may influence the allocation of motorways across municipalities. For example, it is plausible to assume that the channels through which one or more municipal leaders could exert pressure on the national government to attract investments to their municipalities are more direct and receptive if the national government is controlled by their political party. Because of this we include a variable that captures the political partisan alignment between the municipal and the national levels of government. More precisely, we measure the proportion of alignment time between January 1980 and December 2006.[15] If during a given year the municipal government was led by a political party that was in the national government our variable assumes value one; if, for example, the time of alignment was of 3 months, the variable assumes value 0.25. The yearly values were then averaged across the 27-year period. There were municipal elections in 1979, 1982, 1985, 1989, 1993, 1997, 2001, and 2005. At the national level, Portugal had centre-left governments (PS, "Partido Socialista") between October 1995 and April 2002 and between March 2005 and October 2009; between June 1983 and November 1985 the government was formed by a coalition between the two largest parties of the Portuguese political system, PS (the centre-left party) and PSD ("Partido Social Democrata", the centre-right party). In the remaining of this 27-year period Portugal had centre-right governments (either PSD alone or in coalition with smaller right-wing parties). According to Table 1, the mean period of partisan alignment in mainland municipalities was slightly below 12 years and a half i.e. 46% of 27 years.

[15] We did not consider in this variable the last five years (i.e. 2007-2011) of our period of analysis to account for the fact that there is a time span of some years between the political decision to build a motorway and its actual planning and construction.

5. Empirical methodology

As seen in the previous section, our dependent variable, motorway density, is a nonnegative variable with a skewed distribution characterised by a large proportion of zeros (see Figure 4). A log transformation of the dependent variable would result in the loss of many observations. However, "zero" is a meaningful outcome that is, clearly, fully integral to the process of allocating motorways across municipalities. Because the zeros in the dependent variable should be included in the analysis, we use Poisson Pseudo-maximum Likelihood (PPML) methods to estimate our econometric model. The simulations in Santos Silva and Tenreyro (2006, 2011) show that the PPML estimator is consistent[16] and well-behaved under different patterns of heteroscedasticity and when the proportion of zeros in the dependent variable is very large. An important advantage is that the dependent variable does not have to be an integer i.e. it can be continuous as is the case of motorway density.

The PPML technique has been employed to investigate a diversity of issues, including not only trade, capital, and migration flows between countries (e.g. Santos Silva and Tenreyro, 2006; Head and Ries, 2008; Francois and Manchin, 2013; Beine and Parsons, 2014), but also, for example, firm location decisions in Berlin (Moeller, 2018), the geography of patient admission in Italy (Fabbri and Robone, 2010), or the effects of alcohol regulation on road traffic accidents in Brazil (Nakaguma and Restrepo, 2018). To the best of our knowledge, we are the first to employ PPML to analyse the process of allocation of transport infrastructure within a country.

That is, for municipality *i* we have:

$$\ln MD_i^{2011} = \alpha + \boldsymbol{X}_i'\boldsymbol{\beta} + \varepsilon_i,$$

where MD^{2011} stands for motorway density (meters per square km) in 2011, $\boldsymbol{X}$ is a vector of explanatory variables (detailed in the previous section), and ε is the error term. As this equation is not defined for observations with zero motorways, we estimate instead the following model by PPML:

[16] Gourieroux et al. (1984) demonstrate how "pseudo-maximum likelihood estimators" of parametric models having finite variances will in general be consistent so long as conditional means are correctly parameterized.

$$MD_i^{2011} = e^{\alpha + \boldsymbol{X}_i' \boldsymbol{\beta} + \varepsilon_i}. \quad (1)$$

All inference was based on a heteroscedasticity-robust covariance matrix estimator, since the PPML estimator does not take full account of the heteroskedasticity in the model (Santos Silva and Tenreyro, 2006).

For comparison purposes, we also use OLS to estimate two other equations. The first one is:

$$\ln(1 + MD_i^{2011}) = \alpha + \boldsymbol{X}_i' \boldsymbol{\beta} + \varepsilon_i. \quad (2)$$

That is, we employ a logarithmic transformation of the dependent variable that allows us to keep in the sample the 120 cases for which MD^{2011} equals zero. However, it should be noted that estimates obtained in this way have to be regarded with caution. Although this type of transformation remains relatively common in empirical analyses, the operation is fundamentally arbitrary, and the estimated coefficients may be biased (Santos Silva and Tenreyro, 2006). In the second additional equation we consider instead a different dependent variable: the distance from the municipality centroid to the nearest motorway access node in 2011, which we denote by DN^{2011}. In this case we have:

$$\ln DN_i^{2011} = \alpha + \boldsymbol{X}_i' \boldsymbol{\beta} + \varepsilon_i. \quad (3)$$

While this variable does not reflect in a direct way the process of physical allocation of motorways across municipalities (more on this below), it has the practical advantage of being strictly positive for all observations.

6. Results and discussion

6.1. Main results

Columns 1 to 5 of Table 2 display our main PPML results using the variables detailed in Section 4. In the first column we include as explanatory variables our group of geographical variables. The second column includes instead our measures of distance to historical and pre-existing transport networks. The variables in column 3 reflect demand for transport infrastructure, while column 4 refers to the political alignment between national government and municipal power. In column 5 we combine all the variables in our preferred specification.

Table 2. Allocation of motorways across Portuguese municipalities

Dependent variable (estimation method)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Motorway density, 2011 (PPML)					Log of (1 + motorway density), 2011 (OLS)	Log of distance to the nearest motorway access node, 2011 (OLS)
Altitude range	-0.249**				-0.209**	-0.374**	0.0338
	(-2.41)				(-2.03)	(-2.16)	(0.38)
Dist. to the coast	-0.400***				-0.231***	-0.361***	0.197***
	(-6.92)				(-3.88)	(-4.15)	(2.91)
Dist. to the border	0.279***				-0.101	-0.120	-0.0345
	(2.60)				(-1.56)	(-1.05)	(-0.50)
Dist. to 1800 itinerary		-0.180**			-0.124**	-0.185**	0.162***
		(-2.17)			(-2.43)	(-2.41)	(2.98)
Dist. to 1st class 1945 road		-0.220***			-0.115**	-0.154**	0.0939**
		(-4.80)			(-2.53)	(-2.35)	(2.02)
Dist. to 1981 train station		-0.191***			-0.142***	-0.252***	0.0986**
		(-4.33)			(-3.17)	(-2.90)	(2.10)
Population, 1981			0.331***		0.286***	0.716***	-0.351***
			(3.59)		(3.12)	(5.62)	(-3.43)
Population accessibility, 1981			1.500***		1.219***	0.727**	-0.935***
			(5.05)		(4.93)	(2.05)	(-3.26)
Electricity consumption per capita, 1981			0.212**		-0.0250	0.192	-0.0251
			(2.24)		(-0.24)	(1.44)	(-0.35)
Partisan alignment with national government, 1980-2006				-0.136	0.00379	0.131	-0.264
				(-0.31)	(0.01)	(0.32)	(-0.89)
R^2	0.208	0.094	0.557	0.0004	0.637	0.573	0.473

Notes. The number of observations is 275 in all estimations. All explanatory variables in logs except partisan alignment. *t*-statistics in parentheses (based on robust standard errors); * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All estimations include a constant (not reported to save space).

The estimates suggest that altitude range, which partially reflects higher construction costs, has a negative effect on motorway density in 2011, as expected. To be more precise, if this range increases by 1%, motorway density will decrease by 0.21% ceteris paribus. Municipalities that are closer to the coast have more motorways per square kilometre – the estimated elasticity is around -0.23. While the coefficient of distance to the border is positive in the simple model of column 1, this becomes negative (but borderline statistically insignificant) after introducing the other explanatory variables in the model, namely market potential.[17] This is not surprising, as the border is located in the interior part of country, where municipalities in general are more sparsely populated and have a lower market potential.

The existence of preceding networks appears to have an effect on the spatial allocation of motorways in Portugal. The most remarkable case is, perhaps, that of the distance of the municipality centroid to the itineraries of the year 1800. Indeed, there is an effect that seems to persist even after two centuries, as a 1% increase in that distance is associated with a reduction in motorway density of 0.12%. The distance to a 1st class road of the National Road Plan of 1945 appears to form another vector of path-"dependence", with an elasticity of a similar magnitude. The proximity to an active railway station in 1981 is also a statistically significant predictor of motorways in 2011, as the elasticity of motorway density w.r.t. the distance to a 1981 train station is -0.14. These results indicate that development of the Portuguese motorway network was influenced, to a certain degree, by the shape of earlier transport networks and national-scale planning.

The third block of variables – population size, population accessibility, and electricity consumption per capita (as a proxy for the average level of economic activity) – represent, to a large extent, demand for transport infrastructure. These variables refer to the initial year 1981, as a way to ensure that the coefficients that we estimate for these variables are not contaminated by the reverse causality that could arise from the effect that the expansion of the motorway network could have had on population and economic activity. There is also, of course, a direct effect on market potential caused by the reduction of the time distance between municipalities that results from the expansion of the network between 1981 and 2011; to safeguard against this source of bias, our measure of market

[17] Indeed, the coefficient becomes negative after controlling for just market potential (-0.121, with a t-stat of -2.08). The simple correlation of the log of distance to the border with the log of market potential (1981) is 0.594 (0.0000) (see all pair-wise correlations in Table A1 in the Appendix).

potential was calculated using 1981's driving time distances between municipality centroids (which in turn were calculated using 1981-population weights). According to our estimates, population size and accessibility in 1981 appear to be important determinants of motorway density in 2011. In particular, when market potential increases by 1%, motorway density increases by 1.22%. The level of electricity consumption per capita, on the other hand, does not have an effect on motorway density – the statistical significance of this coefficient vanishes in the general specification of column 5.

Finally, we consider the political alignment between the national and municipal levels of government as a potential determinant of motorway density. Yet, this political economy variable does not display, *on average*, any statistically significant association with motorway density (see columns 4 and 5). At a first glance it appears, therefore, that political motivations were not a significant factor in the allocation of motorways across Portuguese municipalities (more on this below).

In column 6 we use a different econometric technique, i.e. we use OLS to estimate equation (2) above. While these estimates corroborate in qualitative terms our preferred results, an important caveat applies, for, as noted in Section 5, the estimated coefficients may be biased. In the last column we consider instead a different dependent variable: the distance from the municipality centroid to the nearest motorway access node.[18] While this variable does not reflect in a direct way the process of physical allocation of motorways across municipalities, it has the practical advantage of being strictly positive for all observations. That is, we can employ OLS to estimate equation (3). We confirm the same overall pattern as before; for example, if market potential increases (by 1%), the distance to the nearest node decreases (by -0.94%). The coefficient of distance to the border, as in column 6, is not statistically significant (although in column 6 the magnitude of the estimated coefficient is very similar to that in column 5). The coefficient of altitude range is also not significant, in contrast with both columns 5 and 6. In this case, however, we argue this is not surprising, as there are no reasons to believe that the *distance* of the municipality centroid to the nearest access node could be, a priori, strongly associated with our measure of local topography, a partial proxy for construction costs (in particular taking into account that in 43% of the municipalities no motorways were built as of 2011).

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[18] This is, again, the population-weighted centroid calculated with 1981-population weights. The mean distance of this centroid to a motorway access node in 2011 was 20.4 km. The largest distance was 170.1 km. There were 29 (5) municipalities for which this distance was larger than 50 (100) km. Conversely, in 84 cases this distance was smaller than 5km.

For instance, municipality A and municipality B could be 35 and 70 km away from the nearest access node respectively – in principle this difference between A and B should not be systematically associated with differences in their local topography, as in reality both of them are quite distant from the nearest motorway access node.

6.2. Sensitivity analysis

In sum, our results above suggest that motorway density is driven by different types of factors: physical and geographical, proximity to historical and pre-existing transport networks, as well as population size and population accessibility. We tested the sensitivity of our main PPML estimates to a number of changes in model specification (we report these additional estimates in Table A2 in the Appendix to save space).

First, it could be argued that the association between population in 1981 and motorway density in 2011 could be driven, to some extent, by existing public plans and/or expectations in the beginning of this long investment cycle regarding the construction of specific future highways (e.g. the A1 connecting Lisbon to Porto). Because of this we replaced population (and also electricity consumption per capita in 1981) by their corresponding values in 1970. In this year, Portugal was still ruled by a dictatorship, which would invalidate any prospects of membership in the European Community (EC) – a major funder of infrastructure projects in the Cohesion countries (Portugal submitted its membership application in 1977 and joined the EC in 1986). As seen in column 2 of Table A2, the coefficient of population remains significant, whereas the coefficient on electricity consumption continues to be statistically insignificant. Second, as in 1981 there were already some motorways in Portugal (around 172 km), for completeness we considered in the dependent variable only the motorways that opened after 1981, controlling in one of the specifications for motorway density in 1981. These estimates – see columns 3 and 4 in Table A2 – are very similar to our main results in column 5 of Table 2.

We also considered whether our findings could be driven by specific clusters or groups of municipalities, a possibility that we explore in Table 3. In column 1 we start by removing from the sample those municipalities which already had motorways in 1981: Lisbon, Porto, and 17 other nearby municipalities. This is where the long cycle of investment in motorways started, and growth in motorway density in these 19 municipalities in the following years was indeed remarkable – from, on average, 72.2

m/km^2 in 1981 to 197.1 in 2011. In the following column we remove the municipalities that constitute the Metropolitan Areas of Lisbon and Porto. These 33 municipalities had in 2011 an average motorway density that was much larger than that of the rest of mainland Portugal – 206.8 vs. 36.8 m/km^2 – and, in the same year, concentrated no less than 45.6% of the resident population (42.8% in 1981). In column 3 we eliminate instead the 18 district capitals, which are historically important political and administrative centres across the territory (for example, districts coincide with the mainland electoral constituencies for the national parliament, they have large district public hospitals, the main University and/or Polytechnic campuses, etc.). Lastly, in column 4 we remove all these three partially overlapping groups. None of the considered groups appears to exert a particular influence on our results, as the estimated coefficients are remarkably stable across the four regressions and very similar to those in column 5 of Table 2.

6.3. The "Portuguese blue banana" and the rest

The most distinctive characteristic of the spatial distribution of population and economic activities in Portugal is, perhaps, its strong concentration in the areas closer to the coast roughly comprised between Setúbal, in the south part of the Lisbon Metropolitan Area, and the Viana do Castelo district in the north. In Figure 6 we consider all the municipalities whose centroid is less than 50 km from the coast as approximating what we could call the Portuguese "blue banana" – an illustrative analogy with the well-known European "blue banana" (Brunet, 1989) i.e. the corridor of densely populated and highly urbanised regions that comprises e.g. London, Amsterdam, Brussels, Frankfurt, Zurich, and Milan. In 2011, the average motorway density per municipality was of 108.0 m/km^2 in the Portuguese blue banana area and 22.2 in the rest of the country; also, the number of municipalities with no motorways in the blue banana was of 20 (out of 112) and 99 (out of 163) in the low-density "non-banana" area.

Table 4 compares the variables considered in our econometric analysis between these two regions. The differences are clear: the average blue banana municipality has a less rugged topography, is closer to historical and pre-existing transport networks, has a much larger population size and a larger market potential, and also a higher per capita consumption of electricity. The only variable for which there is no relevant difference between the two regions is the extent of political partisan alignment with the national government.

Table 3. Allocation of motorways across Portuguese municipalities: Excluding specific groups of municipalities

Dependent variable (estimation method)	(1)	(2)	(3)	(4)
	Motorway density, 2011 (PPML)			
Altitude range	-0.225**	-0.235**	-0.262***	-0.298***
	(-2.04)	(-2.21)	(-2.67)	(-2.63)
Dist. to the coast	-0.235***	-0.258***	-0.201***	-0.268***
	(-3.90)	(-4.13)	(-3.49)	(-3.77)
Dist. to the border	-0.143**	-0.142**	-0.0904	-0.157**
	(-2.23)	(-2.18)	(-1.26)	(-2.25)
Dist. to 1800 itinerary	-0.126**	-0.125*	-0.131**	-0.210**
	(-2.24)	(-1.93)	(-2.23)	(-2.40)
Dist. to 1st class 1945 road	-0.126***	-0.154***	-0.131***	-0.121**
	(-2.64)	(-3.34)	(-2.96)	(-2.29)
Dist. to 1981 train station	-0.115**	-0.148***	-0.146***	-0.147***
	(-2.25)	(-2.99)	(-3.11)	(-2.77)
Population, 1981	0.321***	0.240***	0.410***	0.260**
	(3.49)	(2.81)	(4.00)	(2.55)
Population accessibility, 1981	1.344***	1.163***	1.020***	1.223***
	(5.58)	(4.46)	(3.95)	(4.21)
Electricity consumption per capita, 1981	0.0477	0.116	0.00988	0.148
	(0.43)	(1.25)	(0.10)	(1.40)
Partisan alignment with national government, 1980-2006	-0.164	0.246	0.0178	0.0244
	(-0.55)	(0.83)	(0.07)	(0.07)
Excluded group:	With motorways in 1981	Metropolitan Areas	District capitals	All three groups
Observations	256	242	257	223
R^2	0.663	0.466	0.676	0.468

Notes. All explanatory variables in logs except partisan alignment. *t*-statistics in parentheses (based on robust standard errors); * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All estimations include a constant (not reported to save space).

Figure 6. The “Portuguese blue banana”

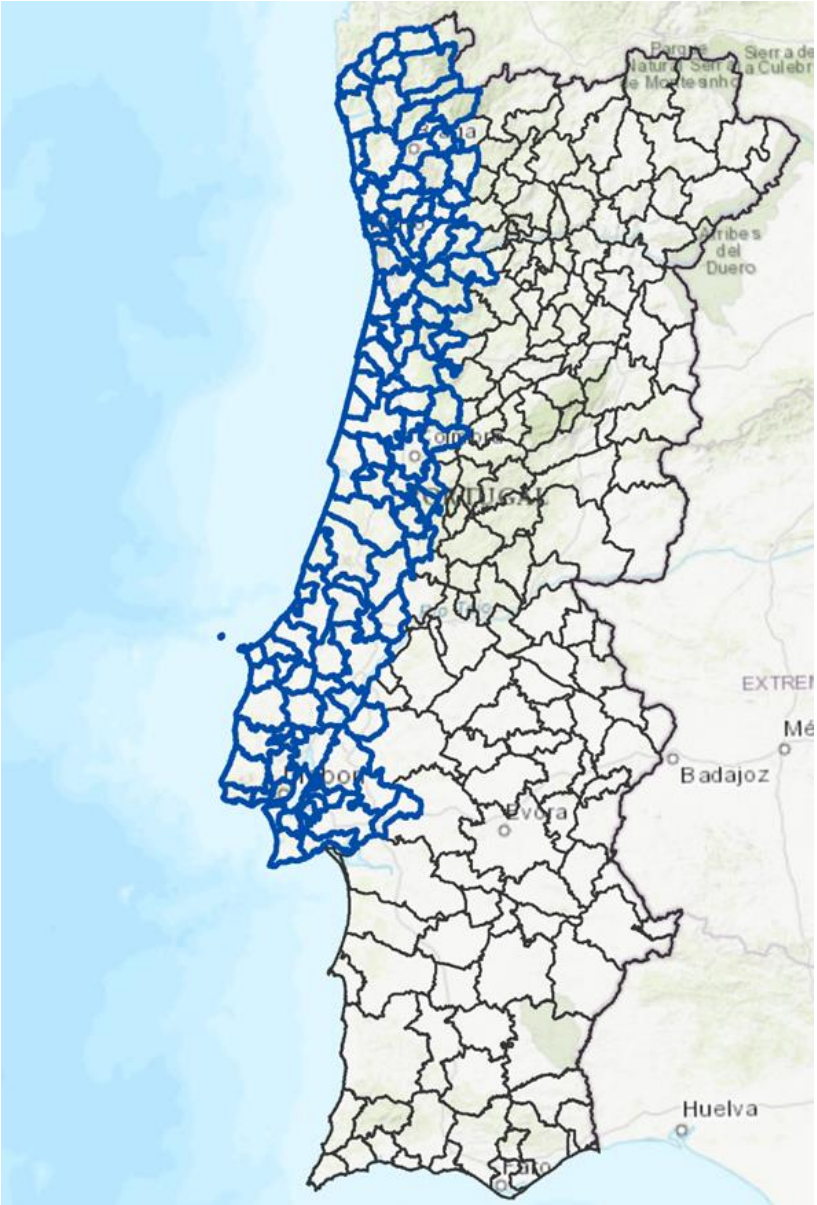

Table 4. Differences in means:
The "Portuguese blue banana" vs. the rest of the country

	(1) Blue banana	(2) The rest	(3) = (2) - (1) Difference (p-value)
Motorway density, 2011 (m/km^2)	108.02	22.25	-85.77 (0.0000)
Altitude range (m)	457.48	623.32	165.84 (0.0001)
Dist. to the coast (km)	22.93	84.77	61.84 (0.0000)
Dist. to the border (km)	100.83	50.84	-49.987 (0.0000)
Dist. to 1800 itinerary (m)	2746.9	3512.9	766.0 (0.1519)
Dist. to 1st class 1945 road (m)	3153.7	7983.8	4830.1 (0.0000)
Dist. to 1981 train station (m)	7253.4	11823.1	4569.7 (0.0001)
Population, 1981	59788.6	16199.0	-43589.7 (0.0000)
Population accessibility, 1981	94213.1	53299.8	-40913.3 (0.0000)
Electricity consumption (kWh) per capita, 1981	1449.7	1014.9	-434.9 (0.0875)
Partisan alignment with national government, 1980-2006	0.4816	0.4464	-0.0352 (0.2355)
Observations	112	163	

Table 5. Allocation of motorways across Portuguese municipalities: The "Portuguese blue banana" vs. the rest of the country

Dependent variable (estimation method)	(1)	(2)	(3)
	Motorway density, 2011 (PPML)		
Altitude range	-0.209** (-2.03)	-0.203* (-1.84)	-0.264 (-1.51)
Dist. to the coast	-0.231*** (-3.88)	-0.206*** (-2.75)	-0.306*** (-3.31)
Dist. to the border	-0.101 (-1.56)	-0.153** (-2.10)	-0.287*** (-2.81)
Dist. to 1800 itinerary	-0.124** (-2.43)	-0.0770 (-1.36)	-0.373*** (-3.53)
Dist. to 1st class 1945 road	-0.115** (-2.53)	-0.0997* (-1.81)	-0.218*** (-4.00)
Dist. to 1981 train station	-0.142*** (-3.17)	-0.0641 (-1.22)	-0.285*** (-5.32)
Population, 1981	0.286*** (3.12)	0.294*** (2.72)	0.256* (1.79)
Population accessibility, 1981	1.219*** (4.93)	1.381*** (3.61)	1.250** (2.18)
Electricity consumption per capita, 1981	-0.0250 (-0.24)	-0.109 (-0.79)	0.256** (2.11)
Partisan alignment with national government, 1980-2006	0.00379 (0.01)	-0.220 (-0.61)	1.565*** (3.82)
Sample:	All	"Portuguese blue banana"	The rest of the country
Observations	275	112	163
R^2	0.637	0.621	0.584

Notes. All explanatory variables in logs except partisan alignment. *t*-statistics in parentheses (based on robust standard errors); * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All estimations include a constant (not reported to save space).

We examine in Table 5 whether there are any substantial differences in the process of spatial allocation of motorways between these two regions. For convenience, column 1 reproduces our main results of column 5 in Table 2, while in columns 2 and 3 we estimate the same equation for the "banana" and the "non-banana" municipalities respectively.[19] Regarding our first block of explanatory variables, the three geographical determinants, we note that their coefficients are always negative but slightly larger in the case of the low-density region (the coefficient of altitude range, however, is estimated with less precision).

It is with the variables that capture path-"dependence" i.e. proximity to historical and pre-existing transport networks that a striking difference emerges. In the "non-banana" municipalities this correlation is clearly much stronger – and this is so for *all the three* variables –, whilst for the banana municipalities the estimated coefficients are always much smaller, and statistically significant (at the 10% level) only in the case of the distance to a 1945 1st class road. In other words, the transport networks that existed in a more or less distant past – e.g. around 1800 or in the early 1940s – do not appear to be, ceteris paribus, strongly associated with the shape of the motorway network of the Portuguese blue banana. A speculative interpretation of this result has to do with the important socioeconomic changes that this region has experienced since (at least) the late 1970s,[20] which may have weakened that potentially latent association. Indeed, in the blue banana, the network evolved rapidly in many directions and connected large and fast-growing urban and suburban areas, for example with or within the Metropolitan Areas of Lisbon and Porto. In general, that type of socioeconomic transformation did not happen at the same pace in the rest of the country i.e. the non-banana region, within which it is plausible to suppose that there should be a closer alignment between the shape of preceding networks and the 2011's motorway network. All of them should reflect, to a certain extent, socioeconomic spatial distribution patterns that were more persistent over time. It is also possible that this proximity to the "networks of the past" reflects construction choices induced by a more demanding and less adaptable topography.

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[19] As a sensitivity check, we delimited the "blue banana" using different distances from the municipality centroids to the coast i.e. 40 and 60 km. Results are very similar to those reported in Table 5 and are available from the authors upon request.

[20] In 2011 municipalities in the banana region had an average population of 68172.1, considerably more than the 59788.6 of 1981 (Table 4). In the non-banana municipalities average population *decreased*, from 16199.0 in 1981 to 14799.7 in 2011.

The coefficients for population size and population accessibility are similar for the two regions (both coefficients are slightly higher and estimated with more precision in the case of the high-density region). Yet, it is only within the low-density region that motorway density tends to be larger in the municipalities with more economic activity (as proxied by electricity consumption per capita). This suggests that the process of allocation of a relatively scarce asset in this vast region incorporated more dimensions that in the high-density region. Indeed, given that expected traffic flows were necessarily not very high in the low-density region, it is reasonable to assume that a way of increasing them and partially optimising this investment was to build motorways in those areas that were more developed and would, expectably, generate more traffic. The fact that, as said above, the construction of motorways in this vast region depended more on the shape of pre-existing networks than in the high-density region suggests, in addition, that construction cost considerations were also a more binding element in a more complex and challenging investment allocation process.

Finally, our analysis suggests that partisan alignment between national and municipal governments may well have played a role in the allocation of motorways across municipalities, but, again, only in the low-density region. According to our estimates, for each additional year of partisan alignment, motorway density is on average 6.0% higher in non-banana municipalities.[21] This makes sense, as motorways are much rarer outside the Portuguese blue banana (see Table 4) and generated, in many cases, huge improvements in accessibility to other parts of the country, thus representing an important political asset.

7. Conclusion

It is common knowledge that the development of national transport networks involves, more often than not, exceptionally large public investments – it is important, hence, to improve our understanding of the forces that govern their expansion. This paper focuses on the case of Portugal, which has now a remarkably modern and extensive motorway network. This is the result of a prolonged investment cycle that started in the early 1980s and was essentially concluded after about three decades. We use econometric techniques to shed light on the factors that drove the spatial placement of motorways

[21] This is equal to ($e^{0.058}$-1)x100, with 1.565/27 = 0.058.

across Portuguese municipalities during this long investment cycle. According to our analysis, there are many variables that have influenced this process. Clearly, population size and market potential in 1981 appear to be strong demand-side determinants of motorway density in 2011, even after controlling for geographical features and historical and pre-existing transport networks (since these are variables which in principle may also have an influence on population size and market potential). This suggests that a causal effect is likely and, if so, that efficiency considerations played a role in shaping the spatial development of the Portuguese motorway network. This latter conclusion is reinforced, in our view, by the fact that our main findings also indicate that geographical variables – altitude range, distance to the coast, and distance to the border – are negatively associated with motorway density at the municipal level. As discussed in the text, these variables may reflect higher construction costs and/or lower demand for transport infrastructure.

We have identified, in addition, a strong association between historical and pre-existing networks – 1800's itineraries, 1945's main roads, and 1981's train stations – and motorway density in 2011, although this is concentrated in the vast low-density part of the country that excludes what we call the "Portuguese blue banana". We see this as a possible consequence of the profound socio-economic transformations that took place over the past five decades in the small, high-density blue banana, which led to the dynamic development of a dense motorway network that is less correlated with preceding transport networks.

A particularly interesting result is that partisan alignment between the municipal and national levels of government seems to have an influence on the allocation of motorways across municipalities – but, again, only in the "non-banana" part of the country. While more research on how this difference occurs is needed, a plausible interpretation is that in low-density regions motorways represent a highly visible political asset, which may mean, in turn, that in these regions non-efficiency factors may interfere more with decisions on if and where a motorway will be built. In other words, the political economy of this type of infrastructure investment may be fundamentally different in high- and in low-density regions, probably in connection in the latter with concerns as increasing connectivity and reducing accessibility regional asymmetries (rather than responding to significant transport demand pressures). This is an interesting hypothesis, one that, in our view, could be further explored by extending the type of analysis we carried out in this paper to other countries and other types of transport networks e.g. the historical development of railway networks. As such a study is beyond the scope of the present paper, we left if for future research.

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Appendix

Table A1. Matrix of correlations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Motorway density 2011										
(2) Altitude range	-0.329									
(3) Dist. to the coast	-0.473	0.408								
(4) Dist. to the border	0.264	-0.303	-0.337							
(5) Dist. to 1800 itinerary	-0.199	0.100	0.059	-0.197						
(6) Dist. to 1st class 1945 road	-0.287	0.226	0.342	-0.377	0.229					
(7) Dist. to 1981 train station	-0.285	0.162	0.202	-0.066	0.207	0.243				
(8) Population 1981	0.569	-0.046	-0.466	0.328	-0.210	-0.345	-0.246			
(9) Population accessibility 1981	0.600	-0.337	-0.421	0.594	-0.160	-0.365	-0.221	0.566		
(10) Electricity consumption per capita 1981	0.382	-0.396	-0.425	0.352	-0.254	-0.364	-0.294	0.408	0.465	
(11) Partisan alignment with national government 1980-2006	-0.019	0.392	0.034	-0.053	0.064	0.074	0.008	0.115	0.001	-0.110

Notes: 275 observations. All variables in logs except (1) motorway density and (11) partisan alignment.

Table A2. Allocation of motorways across Portuguese municipalities: Supplementary estimates

Dependent variable (estimation method)	(1)	(2)	(3)	(4)
	Motorway density, 2011 (PPML)		Δ Motorway density between 2011 and 1981 (PPML)	
Altitude range	-0.209** (-2.03)	-0.177* (-1.73)	-0.178 (-1.62)	-0.241** (-2.32)
Dist. to the coast	-0.231*** (-3.88)	-0.248*** (-4.21)	-0.244*** (-3.81)	-0.229*** (-3.70)
Dist. to the border	-0.101 (-1.56)	-0.102 (-1.63)	-0.0899 (-1.33)	-0.129* (-1.95)
Dist. to 1800 itinerary	-0.124** (-2.43)	-0.124** (-2.42)	-0.148*** (-2.61)	-0.127** (-2.34)
Dist. to 1st class 1945 road	-0.115** (-2.53)	-0.113** (-2.42)	-0.133*** (-2.81)	-0.118** (-2.42)
Dist. to 1981 train station	-0.142*** (-3.17)	-0.136*** (-3.03)	-0.155*** (-3.34)	-0.131*** (-2.74)
Population, 1981	0.286*** (3.12)		0.233** (2.29)	0.329*** (3.29)
Population, 1970		0.236** (2.54)		
Population accessibility, 1981	1.219*** (4.93)	1.348*** (5.25)	1.160*** (3.78)	1.295*** (4.98)
Electricity consumption per capita, 1981	-0.0250 (-0.24)		-0.0837 (-0.66)	-0.0390 (-0.37)
Electricity consumption per capita, 1970		0.0116 (0.18)		
Partisan alignment with national government, 1980-2006	0.00379 (0.01)	-0.0179 (-0.06)	0.280 (0.83)	0.0966 (0.30)
Motorway density, 1981				-0.0066** (-2.08)
R^2	0.637	0.625	0.531	0.604

Notes. Column 1 reproduces column 5 of Table 2. The number of observations is 275 in all estimations. All explanatory variables are in logs except partisan alignment and motorway density in 1981. *t*-statistics in parentheses (based on robust standard errors); * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All estimations include a constant (not reported to save space).