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Research Paper

Paving the way to modern growth: The Spanish Bourbon roads[☆]

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ABSTRACT

This paper analyses the impact that Spanish road construction had on local population growth between 1787 and 1857. We find that the increase in market potential associated to road accessibility had a significant effect on local population growth. The impact was substantially higher on the municipalities that had a more diversified occupational structure. By contrast, the effect of the new network on population growth was negative in municipalities close but without direct access to the roads. We interpret these findings as evidence of a process of rural-to-rural migration due to the new roads.

1. Introduction

In the central decades of the 19th century, railways brought about an unprecedented productivity boost in the European countries' inland transport sector. The railway represented the first massive application of the new technologies of the Industrial Revolution to transportation, with groundbreaking consequences in all areas, from the scale of infrastructure investment to the volumes of freight and passenger traffic. The contrast between this revolutionary change and the much less sophisticated preindustrial transport technologies explains the widespread belief that inland transport was stagnant before the arrival of the railway. Leaving aside the "canal revolution", which was limited to a small number of countries, this interpretation would describe early 19th century domestic freight and passenger trade as burdened by the high cost and lack of technological change in the inland transport sector. This widespread view was only challenged for England, where the combination of canal investment, a geography quite adapted to coastal navigation and a growing network of turnpike roads allowed the English domestic markets to be close to full integration already in the mid-18th century (Smith, 1776; Granger and Elliott, 1967; Shiue and Keller, 2007; Jacks, 2011; Uebele, 2013; Brunt and Cannon, 2014; Bateman, 2015; Bogart et al., 2022).[1]

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[1] The Netherlands was another case of early domestic market integration, although not as advanced as England in the 18th century (Bateman 2015).

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The contrast between railway dynamism and earlier stagnation, however, has been questioned by recent research, and is currently being replaced by an alternative picture of slow but gradual long-term improvements in the productivity of domestic transport, including road transport, which started well before the arrival of the railway. Early experiences of Smithian economic growth, starting before the 19th century, were by definition linked to the growth of *"the extent of the market"* (Smith, 1776), which was in turn associated to gradual improvements in transport technology, including roads. Such improvements have been clearly illustrated by Yrjö Kaukiainen, who provided evidence on the remarkable increase in the speed of information transmission in Europe well before the railway and the electric telegraph. He estimated that dispatch times decreased by two thirds between ca. 1820 and the 1850s and that the reduction in the time that information took to move was much larger before than after the introduction of the telegraph. At least in part, those early gains were the result of the increase in the speed of overland transport. While by 1820, road transport could not cover more than 100 km per day, except for Britain, northern France and, maybe, the Low Countries and part of Germany, by 1840 speed was higher than 200 km per day on many roads out of those areas, thanks to the better quality of infrastructure, better carriages and more efficient organization of coach lines (Kaukiainen, 2001). The effects of improvement in road transport before the railway era are also illustrated by the substantial increase in domestic market integration that took place across Europe before the mid-19th century (Federico and Persson, 2010; Chilosi et al., 2013; Uebele, 2013).

This paper aims at contributing to the debate on the impact of pre-railway transport by analysing the case of Spanish roads before the first wave of massive railway construction in 1855–65. The Spanish road network before the railways has been the object of quite contradictory assessments. Some researchers have described Spanish pre-railway inland transport as rather inefficient and costly, and one of the structural obstacles preventing economic development (Gómez Mendoza, 1989; Ringrose, 1970). This pessimism, however, is not consistent with the abundant evidence on the gradual reduction in transport costs starting at least in the last decades of the Ancien Régime, which would be reflected, for instance, in the significant decrease in travel times through the road network, as observed by Madrazo (1991), Grafe (2012) and Nogués-Marco et al. (2019), or with the substantial progress in Spain's market integration since early modern times and, specially, in the decades before 1850 (Barquín Gil, 1997; Martinez Vara, 1999; Reher, 2001; Llopis and Sotoca, 2005; Grafe, 2012; Nogués-Marco et al., 2019). The available evidence on the gradual development of the transport sector in pre-railway Spain has driven Frax Rosales and Madrazo (2001) to drastically reject the long standing view of a stagnant traditional transport sector which had reached its limits in the 18th century.

In this context, this paper approaches the impact of the improvements in pre-railway inland transport by analysing their effects on the demographic dynamism of those places that benefitted from better infrastructure. More specifically, we focus on the population growth impact of road construction between the late 18th and the mid-19th centuries. Starting in the late 1740s, the Spanish monarchy launched a program of construction of new, high-quality paved roads. Construction was extremely slow for some decades but accelerated since the late 18th century, and by 1855 a network of 8324 km. had been built (Uriol Salcedo, 1992). The construction of paved roads went hand-in-hand with the reduction of travel times and increasing market integration during the early 19th century, being arguably one of their explanatory factors. In order to study the potential growth effects of these new roads, in this paper we study to what extent the increase in market potential associated to the new network that took place between 1787 and 1855 translated into higher demographic dynamism at the local level. This analysis is based on the authors' construction of a new georeferenced database of the evolution of paved roads during the period under study.

Our work is related to previous research on the local impact of increasing accessibility through transport networks. This type of analysis has been carried out for several countries both for railway infrastructure in the 19th and early 20th century (Atack et al., 2010; Hornung, 2015; Jedwab et al., 2015; Donaldson and Hornbeck, 2016; Berger and Enflo, 2017; Bogart et al., 2022; Berger, 2019; Banerjee et al., 2020; Büchel and Kyburz, 2020) and for motorways in more recent times (Chandra and Thompson, 2000; Baum-Snow, 2007; Michaels, 2008; Duranton and Turner, 2012; Garcia-López et al., 2015; Jaworski and Kitchens, 2019; Baum-Snow et al., 2020; Bird and Straub, 2020; Jedwab and Storeygard, 2022; Herzog, 2021).

However, this paper is one of the first applications of this approach to measuring the effects of pre-railway road infrastructure. The main precedent to our research is Bogart et al. (2020), which study the impact of multi-modal transport on local growth in England and Wales between 1680 and 1830. In addition, a number of recent papers analyse the impact of Roman roads on historical or present-day development levels and current infrastructure location (Wahl, 2017; Dalgaard et al., 2022; De Benedictis et al., 2018; Flückiger et al., 2022), although they differ from our study because they focus on very long-term persistence, while we analyse the short/medium-run effects of the new infrastructure.

One of the main challenges of this type of analysis is endogeneity. Generally, transport infrastructures are not randomly assigned across territories but are often correlated to specific local characteristics related to potential economic growth. Therefore, the assignment of infrastructures to territorial units is potentially non-random. In order to retrieve causality, an exogenous selection of municipalities which got access to roads is required. The advantage of the Spanish road network is that it did not seek specifically for routes with high potential trade, but was instead explicitly designed to directly connect Madrid to the main cities of the country. Therefore, our case study would be an ideal natural experiment for this type of analysis, in which the underlying hypothesis (no economic criteria behind network design and exogenous selection of the treated areas) would hold. However, to reinforce our case, we also adopt an inconsequential-unit approach, removing from the analysis the termini and other cities targeted in the network design, and considering only the municipalities which got accessibility due to their random location in the middle of two important cities. As a robustness check, we also adopt an instrumental variable strategy based on a geographical instrument (least cost paths between targeted nodes) and an historical instrument (Roman roads).

Our results provide evidence of a significant positive effect of road accessibility on the population growth of the treated municipalities. The size of the effect was substantially higher in municipalities that had a higher presence of manufacturing and commercial activities in their occupational structure. By contrast, the construction of the new roads decreased population growth in those municipalities close but without direct access to the network. These findings would be consistent with the new network of paved road provoking significant population displacement effects between municipalities well before the arrival of the railway. Given the average size of the municipalities in our sample, those movements were predominantly of a rural-to-rural character. Our results therefore confirm that the Spanish transport sector was far from stagnant before the mid 19th century. Road infrastructure investment was transforming the territory before the railway era and, together with other improvements in the transport sector, would to some extent account for the slow but gradual process of Smithian growth that was taking place in the Spanish economy at the time (Álvarez-Nogal et al., 2022).

2. Road transport and the Spanish economy before the railways

The Spanish inland transport system of the early 18th century was largely based on roads. The massive shape of the country limited the reach of coastal navigation, and its rough geography reduced waterways to just ca. 300 km of canals and some stretches of rivers Ebro and Guadalquivir. Under those circumstances, most traffic within the country relied on a dense but very low quality network of traditional roads and paths. Lack of investment in medieval and early modern times meant that part of that network, specially the entrances to cities, bridges, and mountain passes, was still based on ancient Roman infrastructure (Pablo-Martí et al., 2020) and that many roads were not well adapted to wheeled traffic or were only passable in certain seasons, due to the low quality of their surface, the absence of bridges and other shortcomings (Dirección General de Obras Públicas, 1856; Alzola y Minondo, 1899; Madrazo, 1984). Municipalities were in charge of the construction and maintenance of the roads that crossed their territory, mainly through taxes on entrance and exit (*portazgos*). Limited trade and the resulting scarcity of municipal fiscal resources largely explain the state of disrepair of the network. Low quality seems to have been a characteristic shared by the whole road system, even the most important routes, such as those included in the main itineraries published during the period (Pablo-Martí et al., 2020).

The consolidation of the new Bourbon dynasty after the War of Succession (1701–1713) brought with it a project of administrative modernization of the country, which included significant changes in transport and communication policies. Already in 1716, the government nationalized and centralized the postal service and, four years later, completely reorganized it with a new regulation which included a catalogue of "post roads" of predominantly radial character. These post routes were probably better maintained than the rest of the network, given their specific interest for the Crown, and the presence of postal stops and frequent lodges would likely increase their safety and traffic. However, these improvements did not involve any significant infrastructure investment yet, and post roads remained largely unpaved and of relatively low quality (Pablo-Martí et al., 2020).

This started to change in 1747, when the Spanish government, aware of the insufficiency of municipal budgets, entrusted the construction and maintenance of roads to the Director of the postal services, and established a regular funding mechanism by the Royal Treasury for the development and conservation of the main road network (Pablo-Martí et al., 2020). Construction achievements during Fernando VI's reign (1746–1759), however, were just limited to the Santander - Reinosa road in the North and the Guadarrama pass near Madrid. A systematic construction policy was only adopted in 1761, when a royal decree passed by Carlos III approved the construction of a new road network. This construction plan should start with the roads that connected the Court with the provinces, following the model of the "post roads". As in the case of the postal system, this illustrates the administrative objectives of the road construction plans, clearly aimed at a better communication between Madrid and the rest of the territory in order to ease the administration and control of the country.

The new roads were characterized by its good quality, fully adapted to the requirements of high-speed wheeled transport. They had modern roadbeds, were equipped with bridges (a total of 1074 had been built by 1868), had moderate gradients (ideally under 6%, although this limit was not always respected) and often allowed the crossing of mountain passes throughout the year (Madrazo, 1984; Uriol Salcedo, 1992). The first finished route, from Reinosa to Santander, was a modern paved road 7.8 m wide, and the highways built thereafter were generally between 7 and 12 m, although some of them reached even 20 m (Madrazo, 1984). The progress of construction was rather slow until 1799, due to the shortage of adequately trained technicians, insufficient funding and organizational weaknesses. As a result, only ca. 2000 km. of roads had been finished by the end of the century. In fact, this figure included a few hundred km that had not been built by the central government but by the Basque provincial institutions, which enjoyed a substantial fiscal autonomy at the time (Alzola y Minondo, 1899). Thanks to organizational changes and additional training efforts, road construction accelerated in the first years of the 19th century, and the network reached 3409 km in 1808. The Napoleonic Wars interrupted construction and provoked the abandonment and deterioration of some of the new roads, but works were slowly resumed since 1816, and the resources invested in the network gradually increased during the following decades. Funds for road construction rose from 7.2 million reales per year between 1816 to 1833 to 8.3 million in 1834–40, 11.5 million in 1841–46 and 45.5 million in 1847–55. As a result, the length of the network reached 8324 km in 1855, and by that year Madrid was already connected with the main cities of the country with high quality paved roads (Dirección General de Obras Públicas, 1856; Uriol Salcedo, 1992). Although this was a small network, compared, for instance, with the 45,000 km of French roads at the time, it completely changed the conditions of transport in the main routes of the country.

The new roads, combined with the improvement in the organization of the postal system and the development of regular passenger transport services during the first half of the 19th century, had far-reaching effects. Organized passenger stagecoach services, limited before 1808 to the route Madrid-Cadiz and some short-distance lines around the capital, were established in 1816 between Madrid, Barcelona and Valencia and expanded to many other routes thereafter, gradually increasing their reliability, safety and speed and reducing their price. These advances represented a revolutionary change in the movement of people (Alzola y Minondo, 1899; Madrazo, 1984). Between 1822 and 1854 the price of stagecoach services decreased by 57 percent (Madrazo, 1991) and this was accompanied by a dramatic reduction in travel times. For instance, in the routes from Madrid to Barcelona, Cadiz or

Santander, the speed of the movement of passengers and information increased from ca. 50 km per day in the 1820s to between 150 and 200 km per day in the 1850s, a figure that was close to the best standards in the most developed European economies. The core of the railway network, which would be built between 1855 and 1865 and gave service to a large extent to the same routes as the new paved road system, would obviously increase this figure significantly. However, the time saved thanks to the improvement in road transport between the 1820s and the 1850s (from ca. 13 to 3–4 days between Madrid and Barcelona, for instance) would be much higher than the additional 1–2 days savings provided by the railways (Nogués-Marco et al., 2019). In the case of freight, although the available information is much less abundant than for passengers, Madrazo (1984) provides some scattered data on the impressive traffic growth that took place in the century before 1850, such as the almost 20-fold increase in the number of vehicles using the Reinosa road between 1750 and 1850. The high efficiency of freight road transport in the mid 19th century has also been stressed by Barquín Gil (1997).

These transformations in the road transport sector took place in an economy that was far from stagnant before the arrival of the railways. The most recent long-term estimates of Spanish economic growth (Prados de la Escosura, 2017; Álvarez-Nogal et al., 2022) show an increase of ca. 60% in both population and GDP per capita in the century before 1856, when massive railway construction started. The potential progress in market integration and traffic that was partly associated to the new road transport infrastructure would be consistent with a slow but sustained process of economic growth of Smithian character which, despite the series of catastrophic events that affected the Spanish economy (the Napoleonic invasion, the loss of the empire and the civil war of 1833–40), brought about significant changes in all aspects of economic life. The railways, therefore, did not arrive to a stagnant economy or replace a lethargic road sector, but would represent the continuation of a long-lasting dynamic trend.

To illustrate such economic dynamism and the role of the transport sector, in this paper we aim at estimating the potential impact that the improvements in accessibility associated to the construction of the new road network had on the population growth of Spanish municipalities. The next section describes the data on which our estimation is based.

3. Data

In order to estimate the impact of road accessibility on local population growth between the late 18th and the mid-19th century, we have retrieved indicators of the development of the road network and population size at the municipal level, as well as a number of control variables.[2]

As is usual in this type of research, and given the lack of alternative economic indicators at the municipal level, population is the outcome variable which we use to proxy local growth. Population data for the late 18th century come from the so-called “Floridablanca Census”. Published in 1787 and then expanded in 1789, it is the first Spanish census carried out with modern statistical techniques and allows, for all the municipalities at the time, to disaggregate population figures by sex, civil status, age and occupation.

In the case of the mid-19th century, we use the historical population data provided by the Spanish Statistical Institute (INE) website.[3] The period covered by this source starts in 1842. Figures for 1842, though, were not collected with homogeneous techniques all over the territory, and this population head count (usually known as the *“Censo de la Matrícula Catastral”* – Census of the Cadastre Register) is not considered as reliable or precise as the following ones. Thus, in our analysis we focus on data from the first modern census, carried out in 1857, discarding also later censuses due to the quick development of the railroad network after that date.

The administrative units employed for the analysis (municipalities) changed over time due to mergers and divisions. Since we do not have a map of municipality boundaries for the period under study, we had to rely on present-day maps and match the historical municipalities to the current ones using different sources. For those changes that took place after 1842, the INE website provides a complete catalogue (Ministerio de Administraciones Públicas, 2008). By contrast, the match between some of the municipalities included in the Floridablanca Census and the current ones is more complicated and not always possible, and a small share of the Spanish population (amounting to 1.13% in 1787 and 3.26% in 1857) could not be matched.[4]

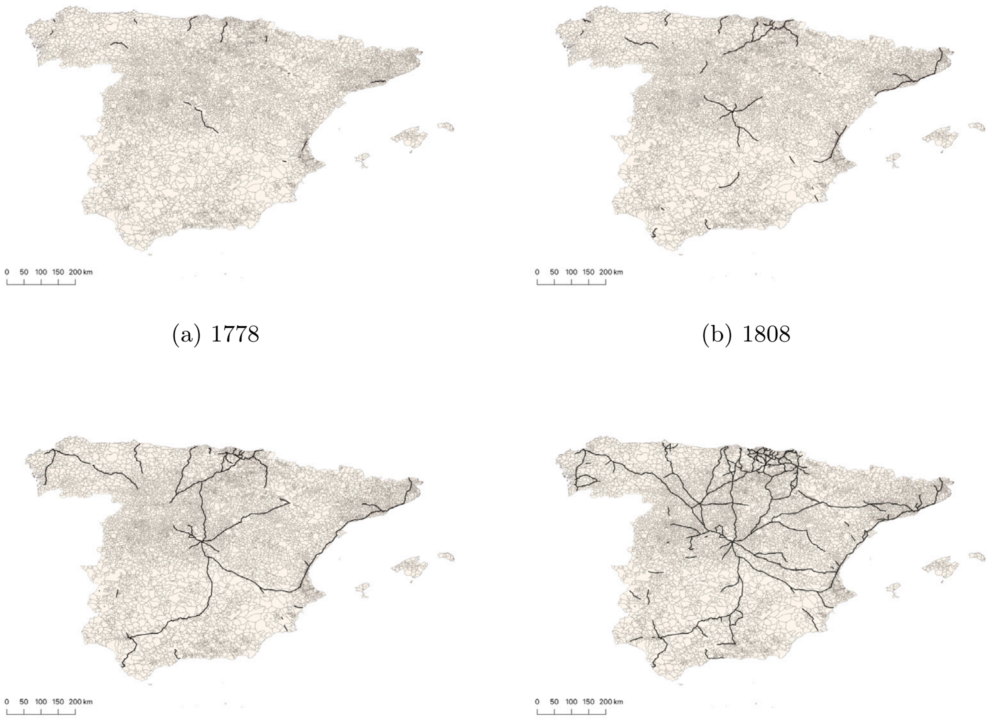
As for road development, one of the strengths of our paper is represented by the quality and precision of the digitization of the new paved road network. Applying GIS techniques to information provided in Madrazo (1984) and Dirección General de Obras Públicas (1856), we have digitized the map of the network for four different years along the period under study. First, we digitized the map of roads in 1855 that is included in Dirección General de Obras Públicas (1856) and is our baseline map.[5] It reports the names of more than 500 municipalities crossed by the paved roads, which helped us to correct for the effects of the spatial distortions of the map on the specific location of each route. We then used information included in a series of hand-drawn maps in Madrazo (1984) to obtain digitized maps of the network in 1778, 1808 and 1840 by removing from our baseline map the road stretches that were still unfinished in those dates. Those maps (see Fig. 1) have been used to compute the municipal accessibility measures we use in our analysis: a binary accessibility dummy and a market potential indicator. As is described in detail below, the latter

[2] Please refer to Garcia-López et al. (2023) for data and replication codes.

[3] http://www.ine.es/intercensal/

[4] This only refers to peninsular municipalities; the islands and the North African cities of Ceuta and Melilla are not included in the analysis. We thank David Reher for providing us with the digitized version of the 1787 census, and Alfonso Díez-Minguela and Julio Martínez-Galarraga for their invaluable help for the matching process.

[5] We also check for the more precise 1861 map (Dirección General de Obras Públicas, 1861) to correct for some road segments which are not correctly classified in the 1856 map.



(a) 1778 (b) 1808

(c) 1840 (d) 1855

Fig. 1. The Spanish paved road network, 1778, 1808, 1840 and 1855.

has been calculated on the basis of the least cost path, which has required the use of travel time parameters obtained from the careful analysis of several sources that report average speeds for passenger transport for different years in km per day in the main routes (Madrazo, 1984; Grafe, 2012; Nogués-Marco et al., 2019).[6] In order to approach the changes in market potential associated to new roads, we employ the digitalized map of the early 18th century network of old, low quality roads, which has been kindly provided by Federico Pablo-Martí(Fig. 2).[7] Finally, we also use the digitalized map of the main Roman roads in Spain (McCormick et al., 2013) as an instrument in our IV strategy.

Our analysis also includes a full set of controls to identify potential confounding factors. We account, first, for access to railroads in each municipality. The first Spanish railroad, opened in 1848, was a short (28 km) line between Barcelona and Mataró. By the end of our period of analysis (1857) the network had reached a length of 635 km. We have digitized those early railway lines, starting from the shapefile of current railways and following the chronological description of the construction process provided by García Raya (2006). We specifically control for the exact location of railways' stations operating by the end of the year 1857.[8] We also account for the presence of the two navigable canals that were constructed in the 18th century: the Canal de Castilla and the Canal Imperial de Aragon, which have been digitized using information in Google Maps. Finally, we account for the 104 main Spanish ports at the time, selected on the basis of data at Dirección General de Aduanas (1857). Railway stations, canals and the main ports are represented in Fig. 3. We have also gathered information on distance to the coast, presence of rivers and closeness to the Portuguese and French borders for each municipality using the shapefile of rivers and coastlines from Instituto Geografico Nacional (IGN). Finally, using the data provided by the Floridablanca Census, we have collected information on the population employed in a number of non-agrarian occupations (merchants, blacksmiths, craftsmen, lawyers and notaries) in each municipality

[6] For later years (1860–1930), Martinez-Galarraga et al. (2015) also use a market potential indicator to approach the impact of infrastructure construction and trade policy on regional growth in Spain. Unlike that study, in our case, due to the absence of systematic alternative cost data, we had to use passenger transport speed figures as indicators of both freight and passenger transport costs (see Appendix C.4). We consider speed figures to be a reasonable reflection of the quality of road infrastructure; in addition, travel times would be correlated with labour costs in the transport sector, which would constitute a substantial part of total transport costs. However, we should assume that there were some differences between the structures of travel times and transport costs, which might introduce some biases of unknown sign and magnitude in our results.

[7] The map is based on the analysis of several maps of Spain made in other countries, often for military reasons, in the early 18th century; see Pablo-Martí et al. (2020). Given the absence of significant investment in the old roads during the 18th century, we assume this network to be representative of the road system by 1787.

[8] We thank Guillermo Esteban for providing us the precise location of those stations.

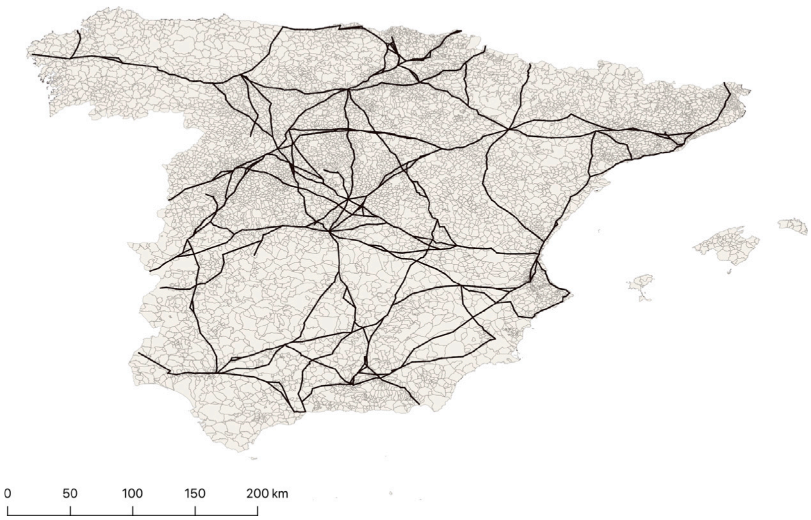


Fig. 2. The Spanish main road network before the construction of the paved roads.

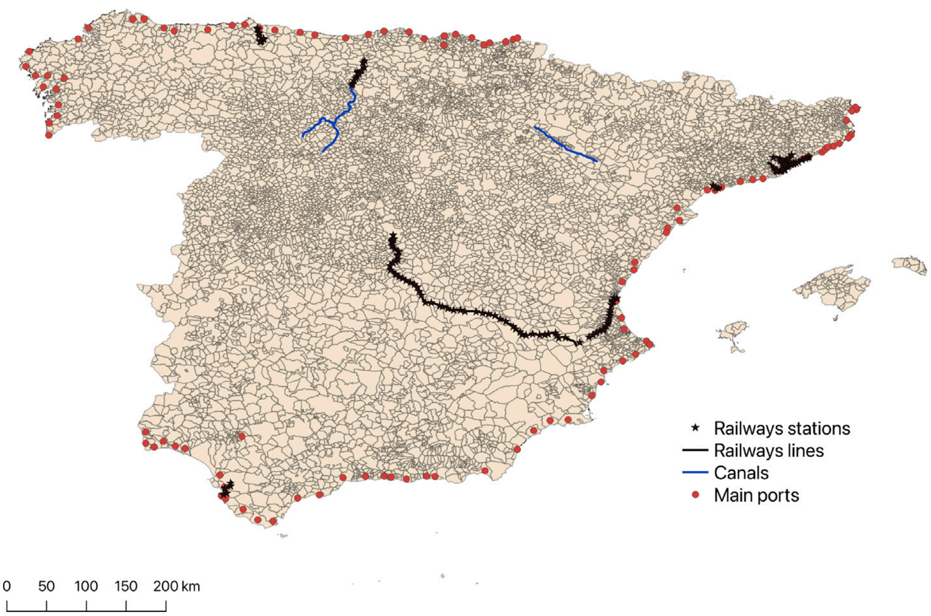


Fig. 3. Railways, canals and main ports in 1857.

at the end of the 18th century, and we have also gathered information on the main post offices in the late 18th century, taken from de Ita (1789).

4. Empirical framework

As already mentioned, endogeneity is one of the main concerns when it comes to analyse the effects of transport infrastructure. Often, transport infrastructure investment is not randomly assigned across territories, but is correlated to specific local characteristics related to potential economic growth.[9] In order to retrieve causality, an exogenous selection of municipalities which got access to roads is required. To deal with this, we exploit a historical quasi-natural experiment and we combine this with an inconsequential unit approach.

[9] Redding and Turner (2015) provide an exhaustive review of the current literature dealing with the endogenous placement of transport infrastructure.

In this regard, the advantage of the Spanish road network is that it did not seek specifically for routes with high potential trade, but it was instead explicitly designed to connect Madrid to the borders and main cities and ports of continental Spain. However, to further reinforce our case against endogeneity, we complement this with an inconsequential unit approach. This strategy, firstly adopted by Chandra and Thompson (2000), is based on the idea that the municipalities lying between two important cities (main nodes) might have got exogenous access to a new road because of their random location on the path between the two targeted cities. The idea behind this approach is to identify all the cities targeted by the infrastructure investment planner and remove them from the analysis. The underlying hypothesis is that all the remaining municipalities got access to the network only due to their geographical position. In order to define the targeted nodes that are excluded from the analysis for the inconsequential unit approach, we collect information from the 1720 general regulation of post services, whose main routes largely inspired the priorities in road construction as defined in the 1761 Royal Decree. As a result, we get a list of 57 targeted nodes, which are the cities and junctions mentioned in the description of those main post routes.[10]

A second crucial issue is the definition and measurement of road accessibility. We start by applying a binary definition of accessibility, which has often been used in the literature (Chandra and Thompson, 2000; Michaels, 2008) and differentiates between those municipalities that were crossed by a road and the rest. Binary accessibility indicators allow estimating the average impact of roads on local growth, but ignore the fact that the effect of the new infrastructure might have been very different depending on the location of each municipality and its distance to other population centres through the network. Towns close to big cities, for example, might have benefited more from increasing accessibility than more remote places that were located far from the most developed and diversified areas, and this difference would not be captured by an analysis based on a mere binary accessibility variable. Binary indicators also ignore the fact that some crossed municipalities might have had better accessibility than others before the construction of the new infrastructure, which would affect the size of the benefits received from the latter. Thus, in order to take these aspects into account, we complement a basic analysis based on a binary definition of accessibility with an analysis that uses a market potential indicator as representative of local market access.

Market potential measures have been widely applied in the more recent literature on the impact of infrastructure (Bogart et al., 2020; Donaldson and Hornbeck, 2016; Gibbons et al., 2019; Jaworski and Kitchens, 2019; Jedwab and Storeygard, 2022; Herzog, 2021). They capture the increase in local accessibility associated to all changes in the road network, and not just the average effect of the mere presence of a road. Here we use as indicator of the improvement in local accessibility the variation in market potential between 1787 and 1855 associated to new road investment.

We compute market potential as the weighted sum of inverted travel times (used as a proxy of transportation costs) to all other connected municipalities through the road network, using as weights the initial population at destination, which we take as indicator of economic activity.[11] In the calculation for 1787, we use the previous system of low quality roads (see Fig. 2 above), while market potential at the end of the period (1855) is based on the integration of the new high-quality network with those preexisting roads, deleting the old segments over which some new roads had been built (see Fig. 4).[12] In the case of those municipalities that were only crossed by the new network we added, for the 1787 calculation, the shortest straight segment between the existing network and the centroid of those locations. The municipalities included in the calculation are 2221, which accounted for ca. 50% of the Spanish population both in 1787 and 1857 and between 81% and 86% of the urban population of the country (defined as people living in cities with more than 10,000 inhabitants).

Travel times are computed with a least coast path algorithm, imputing different speeds to each type of road segment depending on its quality (i.e. new paved roads, old low-quality roads and artificially created straight segments). Our measure of market potential is given by the following equation:

$$MP_o^t = \sum_{d}^{M-1} (t_{o,d}^t)^{-\theta} * W_d \tag{1}$$

Where MP_o^t is the market potential measure for municipality o in year t; $t_{o,d}^t$ is the travel time between the municipality of origin o and each municipality of destination d in year t; θ is the elasticity to travel times; and W_d are weights to capture the size of economic activity at destinations (usually measured at *t-1* to avoid endogeneity). In our case, we set $\theta = 1$ and $W_d = pop_{d,1787}$, and the market potential indicator for each municipality is therefore calculated as:

$$MP_o^t = \sum_{d=1}^{M-1} \frac{pop_{d,1787}}{t_{o,d}^t} \tag{2}$$

[10] See de Grimaldo (1720). The targeted nodes are: Corunna, Alcalá de Henares, Alcántara, Alicante, Aranjuez, Arévalo, Badajoz, Barcelona, Baztán, Benavente, Burgos, Cadiz, Carmona, Cartagena, Ciudad Real, Ciudad Rodrigo, Córdoba, Denia, San Sebastián, Écija, El Escorial, El Puerto de Santa María, Fraga, Getafe, Guadalajara, Irún, La Junquera, Lleida, Madrid, Medina del Campo, Medinaceli, Mérida, Molinaseca, Murcia, Ourense, Pamplona, Pontevedra, Salamanca, San Clemente, Santiago de Compostela, Seville, Soria, Talavera de la Reina, Tarancón, Tarragona, Teruel, Toledo, Torrelodones, Tortosa, Trujillo, Tudela, Valencia, Valladolid, Vitoria, Zafra, Zamora and Zaragoza.

[11] We keep population constant at its initial level to capture exclusively the changes in market potential associated to the improvement in road infrastructure, excluding in this way those variations generated by differential population growth.

[12] Therefore, all municipalities connected to the old network in 1787 are included in the 1855 network, even if they did not have access to the new paved roads. In addition, the new paved road network had some isolated segments that could be connected to the rest of the network through traditional roads.

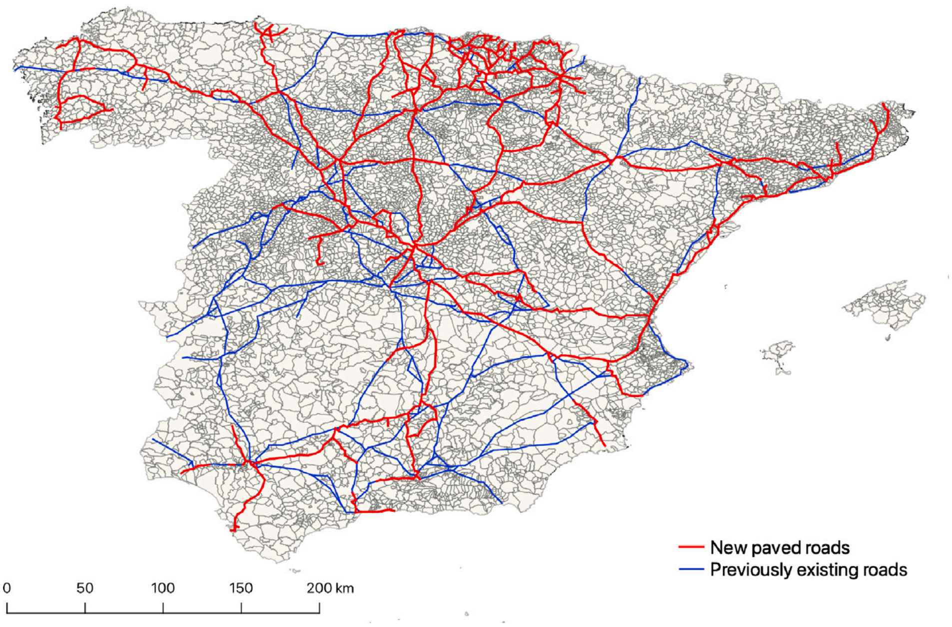


Fig. 4. Network employed for the 1855 market potential computation.

Detailed information on the construction of those networks and the speed parameters imputed for the market potential computations are provided in Appendix C. In addition, Figs. 10 and 11 in Appendix B show the value of the market potential indicator in the sample municipalities in both years of the analysis.

Our historical context, combined with the removal of the main nodes, should ensure the exogeneity of local accessibility variables. However, it is possible that the planner, while designing the road network, deliberately established detours from the most direct line connecting two targeted cities, for example to connect a third municipality with high growth potential. Those detours might induce selection effects and violate the underlying hypothesis. Thus, in our analysis we also adopt an instrumental variable approach, following the so-called inconsequential unit IV approach (Banerjee et al., 2020; Büchel and Kyburz, 2020). We employ two different instruments in order to ensure the random allocation of local access to transport infrastructure. More precisely, we use both a historical and a geographical variable to instrument for our two accessibility variables (the binary dummy and the market potential indicator). The former is based on accessibility computed through the old Roman roads in Spain (Garcia-López et al., 2015), while the latter is constructed with least-cost paths between the targeted nodes. We compute our geographical instrument based on least cost paths considering the roughness of the terrain, calculated through GIS techniques on the basis of the elevation raster of the Spanish geographical institute (IGN). Specifically, the algorithm calculates the optimal path to minimize the connection cost between the selected targeted nodes. We then use this cost-minimizing network as instrument for the real one. Fig. 5 shows the 1855 paved road network, the least-cost paths used to construct the geographical instrument and the targeted nodes. In the case of the historical IV we employ directly the digitalized network of the main important Roman roads constructed in Spain (McCormick et al., 2013). This second instrument is presented in Fig. 6.

As described above, we start by presenting a simple specification using a binary indicator of accessibility, in which we regress the long-run difference (1857–1787) log population (equivalent to population growth) on a dummy indicating if the municipality had access to the new road network in 1855, the logarithm of initial population as parameter of convergence,[13] a list of controls and historical judicial district fixed effects.[14] We exclude from the analysis the 57 targeted nodes and we instrument the access to actual roads using both the access to the network of least cost paths between nodes (geographical instrument) or the old network of Roman roads (historical instrument). We end up with a sample of 7216 municipalities, including all the non-targeted ones with information on population in both periods. The model we estimate is:

$$ln(pop_{m,1857}) - ln(pop_{m,1787}) = \alpha_0 + \beta_1 Accessibility_m + \beta_2 ln(pop_{m,1787}) + \beta_3 X_m + \theta_p + \epsilon_m \tag{3}$$

Where $Accessibility_m$ is a binary indicator for the presence of new paved roads in municipality m in 1855, $ln(pop_{m,1787})$ is the log of population in municipality m in year 1787; X_m is a vector of control variables, and θ_p are fixed effects for the 459 historical judicial districts.

[13] See Duranton and Puga (2014).

[14] Judicial districts were the smaller supramunicipal territorial divisions at the time. We thank Francisco Beltrán-Tapia for sharing with us the shapefile of the Spanish judicial districts in 1860. Fig. 8 in Appendix B shows those administrative units.

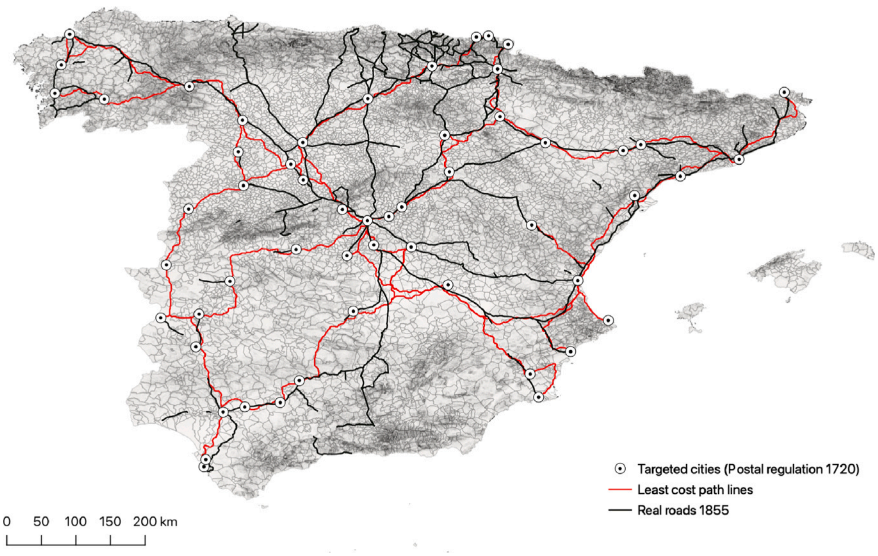


Fig. 5. Geographical instrument: digitized roads and least cost path lines.

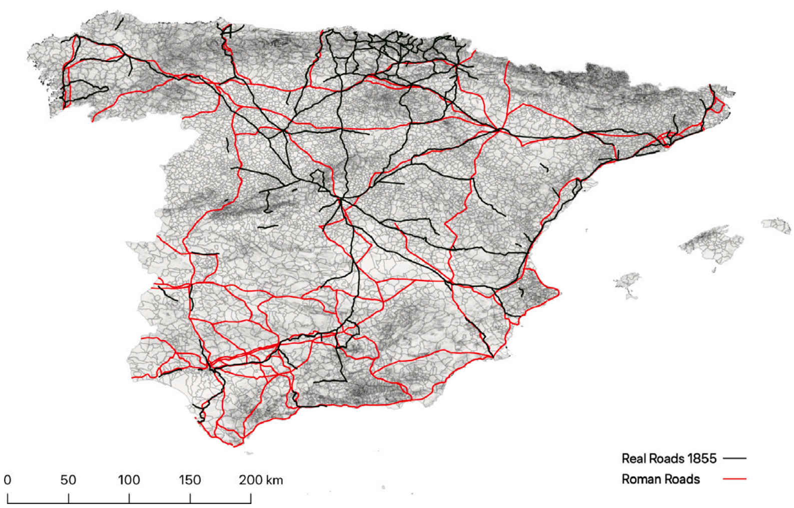


Fig. 6. Historical instrument: digitized roads and old Roman network.

In a second step, we regress the logarithm of municipal population on the logarithm of market potential, a list of controls and historical judicial district fixed effects. We cluster the standard error at the judicial district level and, consistently with the inconsequential unit approach we remove the 57 targeted nodes. Our analysis is restricted in this case to the 2164 municipalities which were connected to at least one of networks in one of the two periods. The model we estimate is as follow:

$$ln(pop_{m,t}) = \alpha_0 + \beta_1 ln(1 + MarketPotential_{m,t}) + \beta_2 X_m + \theta_p + \epsilon_{m,t} \tag{4}$$

Where $pop_{m,t}$ is the population for municipality m in year t (1787 and 1857 respectively); $MarketPotential_{m,t}$ is the market potential indicator for municipality m and year t X_m is a vector of time-invariant control variables; and θ_p are fixed effects for the 459 historical judicial districts. In this case, the market potential variable is instrumented either with the market potential computed through the network of least-cost paths between nodes or with the network of Roman roads. With data representing a panel of municipalities, we are able to partition $\epsilon_{m,t}$ into permanent and time-varying components. In fact, after estimating the model in a pooled OLS framework, we can remove the time-invariant municipal effects by estimating Eq. (4) in a panel or first-difference version.

Table 1 presents summary statistics of each variable.

Table 1
Summary statistics.

	count	mean	sd	min	max	p25	p50	p75
Population 1787	7,216	1,165.33	2,002.02	10.00	52,375.00	298.00	574.00	1,261.00
Population 1857	7,216	1,700.59	2,957.26	89.00	97,777.00	456.00	839.00	1,761.00
Binary accessibility old network	7,216	0.22	0.42	0.00	1.00	0.00	0.00	0.00
Binary accessibility 1855	7,216	0.17	0.38	0.00	1.00	0.00	0.00	0.00
Market potential old network	2,164	27,635.03	7,341.39	12,262.74	102,862.43	23,259.37	27,628.38	31,036.12
Log market potential old net.	2,164	10.19	0.25	9.41	11.54	10.05	10.23	10.34
Market potential 1855	2,164	81,723.67	30,431.95	26,606.62	567,789.49	65,358.95	81,343.60	95,060.53
Log market potential 1855	2,164	11.26	0.33	10.19	13.25	11.09	11.31	11.46
Distance to coast (km)	7,216	132.01	92.76	0.08	357.87	46.80	123.16	205.31
River accessibility (0/1)	7,216	0.06	0.24	0.00	1.00	0.00	0.00	0.00
Port (0/1)	7,216	0.01	0.11	0.00	1.00	0.00	0.00	0.00
Canal (0/1)	7,216	0.01	0.09	0.00	1.00	0.00	0.00	0.00
Railway stations 1857 (0/1)	7,216	0.01	0.10	0.00	1.00	0.00	0.00	0.00
5 km from Portuguese border	7,216	0.02	0.13	0.00	1.00	0.00	0.00	0.00
5 km from French border	7,216	0.01	0.10	0.00	1.00	0.00	0.00	0.00
Main post station (0/1)	7,216	0.03	0.16	0.00	1.00	0.00	0.00	0.00
Pop. share in secondary sector	7,216	2.00	2.92	0.00	86.49	0.26	1.20	2.64

Notes: The municipalities included are the sample employed for regressions. Specifically, we exclude those with missing population in at least one period, and the targeted nodes. For the market potential indicators, the sample is restricted to the 2164 Spanish municipalities connected by at least one of the two road networks.

Table 2
Paved roads and population growth: binary accessibility indicator.

	OLS			IV - LCP			IV - Roman		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Road accessibility (0/1)	0.051**	0.109***	0.088***	0.420***	0.391***	0.359***	0.623***	0.346***	0.314***
	(0.020)	(0.016)	(0.015)	(0.104)	(0.101)	(0.122)	(0.128)	(0.097)	(0.109)
Log population 1787	−0.130***	−0.231***	−0.248***	−0.150***	−0.249***	−0.261***	−0.162***	−0.246***	−0.259***
	(0.010)	(0.010)	(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.012)	(0.012)
Controls			✓			✓			✓
Fixed effects		✓	✓		✓	✓		✓	✓
First-Stage F-Statistic				79.91	46.15	29.60	58.32	47.45	37.07
R2	0.10	0.46	0.47						
N	7,216	7,216	7,216	7,216	7,216	7,216	7,216	7,216	7,216

Notes: The dependent variable is the long-run difference (1857–1787) in log municipal population. Fixed effects are taken at the historical judicial district level. Standard errors are clustered by historical judicial districts and are in parenthesis. *, ** and *** indicate significant at 1, 5, and 10 percent level, respectively.

5. Results

The results of our baseline estimation, in which we measure accessibility by means of a binary indicator and which include the whole sample of 7216 municipalities, are shown in Table 2. Columns 1–3 present the results of the OLS estimates, while in columns 4–6 road accessibility is instrumented with accessibility to the least-cost paths connecting targeted nodes, and in columns 7–9 we use the network of Roman roads as instrument. Specifications 1, 4 and 7 do not add any control or fixed effects; columns 2, 5 and 8 add historical judicial district fixed effects and columns 3, 6 and 9 also add controls. The standard errors are clustered at the judicial district level.[15],[16] The small differences between the estimates reported in columns 5 and 6, or 8 and 9, suggest that the results are not driven by the controls. Furthermore, adding the controls group by group (geographic variables, alternative transport means and other controls), we do not see any relevant discrepancy in the estimated coefficients. The difference in the main estimated coefficient between column 3 and columns 6 and 9 might suggest an endogenous road placement and a potential downward bias of the OLS estimates. This might indicate that the new roads tended to cross through areas with relatively low growth potential, maybe because they aimed at connecting Madrid with the periphery, rather than at following the most active trade routes. However, since we cannot exclude the presence of measurement errors, we do not put much weight on those differences.

Columns 3, 6 and 9 are our preferred specifications. We find negative and strongly significant coefficients for the parameter of convergence (log of initial population), meaning that population tended to grow faster in small municipalities than in large ones. As for our main coefficient of interest, it is positive and statistically significant in all cases, suggesting, in the case of the IV results, a 35.9/31.4% effect on population long-run (70-years) growth rate caused by road accessibility. To have an idea of the absolute magnitude of that impact, we should keep in mind that the average population growth in the Spanish municipalities between 1787

[15] As indicated above, we use judicial districts because they are the smallest supramunicipal administrative unit, allowing for the highest degree of variability. Results, however, hold if we use provinces instead, both in this regression and the following ones.

[16] In order to account for possible spatial autocorrelation we have used Conley standard errors with different distances and the results remain the same.

Table 3
Market potential and local population growth.

	(1) POLS	(2) POLS	(3) POLS	(4) POLS	(5) POLS	(6) Panel OLS
Log Market Potential	0.408***	0.403***	0.409***	0.413***	0.397***	0.343***
	[0.164]	[0.163]	[0.164]	[0.168]	[0.169]	[0.187]
	(0.087)	(0.072)	(0.086)	(0.084)	(0.061)	(0.018)
Geographical controls		✓			✓	
Accessibility controls			✓		✓	
Other controls				✓	✓	
Judicial district FE	✓	✓	✓	✓	✓	
R2	0.99	0.99	0.99	0.99	0.99	0.43

Notes: 4328 observations (2164 municipalities ×2 years (1787–1857)) in each regression. The dependent variable is the log of municipal population. Fixed effects are taken at the historical judicial district level. Standard errors are clustered by historical judicial districts and are in parenthesis, and the standardized beta coefficients are within square brackets. *, ** and *** indicate significant at 1, 5, and 10 percent level, respectively.

and 1857 was 47.2%. The first stage results and the F tests reported in the table would be consistent with the validity of the chosen instruments.

Then, in Table 3 we present the results of our OLS estimation of Eq. (4), which uses market potential as explanatory variable. As already mentioned, this second analysis is restricted to the 2164 municipalities connected to the network employed for the market potential computation. In columns 1 to 5 we follow a pooled strategy, while column 6 presents panel results. Specifications 1–5 include historical judicial district fixed effects and distinguish themselves by the gradual inclusion of controls: geographical controls in column 2, accessibility controls in column 3, other controls in column 4, and all together in column 5. The small differences between the estimates reported in all columns suggest that the results are not driven by the controls. In column 6, we remove the time-invariant municipal effects by considering a panel framework that uses municipal fixed-effects. Since our historical judicial district dummies and controls are time-invariant we cannot include any of them in this specification. The standard errors are clustered at the historical judicial district fixed effects. The panel results can now be interpreted in terms of growth and are consistent with the pooled ones. Analogously, we also estimated a first differences equation (without time-invariant variables and municipal fixed effects) and, as expected, we found similar results, which are available upon request.

Column 5 is our preferred specification. We find a positive and statistically significant coefficient, suggesting a positive effect of the increase in market potential associated to the new roads on city growth. According to the estimate, a 1% increase in market potential translated into 0.397 additional percentage points of local population growth between 1787 and 1857. In other words, doubling the market potential led to an average increase in municipal population of 39.7%. The table also provides the standardized (beta) coefficient of the market potential variable which indicates, in our preferred specification, that one standard deviation increase in market potential was associated to around one sixth (0.16) of a standard deviation increase in population growth.

In order to provide an idea of the importance of those effects, Fig. 7 presents the average changes in market potential in three different types of municipalities: i) those that were connected to both the old network in 1787 and the new roads in 1855; ii) those that were connected to the old network in 1787 but did not have access to the new roads in 1855; iii) those that were not connected to the old network in 1787 and had gained access to the new one by 1855.

As may be seen in the figure, the municipalities that enjoyed a larger average increase in market potential and, therefore, an arguably higher impact on population growth, were those that were not connected to the old network of roads in the 18th century and gained access to the new paved roads during the first half of the 19th century. At quite a distance we have those that were connected to both networks and, finally, the lowest increase in market potential was experienced, as should be expected, by those municipalities that, having been connected to the old network, did not gain access to the new one. As can be seen in the table, the average increases in market potential would arguably account for a sizeable percentage of population growth during the period under analysis, which for the Spanish municipalities was on average, as indicated before, of 47.2% between 1787 and 1857.

The previous results are robust to the implementation of different elasticities to travel times in the market potential computation: using values from 0.5 to 4 we always obtain positive and statistically significant coefficients, although of decreasing magnitude (see Table 8 in Appendix A). Higher elasticities give more weight to closer municipalities, while lower values give increasing importance to more distant destinations. An elasticity of 1 would give equal importance to all travel distances. We use the Akaike's and Bayesian information criterions to decide between the different elasticities. As shown in the table, the lowest values are reported for the elasticities of 0.5 and 1, which should then be preferred. Since the standardized coefficients of those regressions are not different, we choose an elasticity of 1 as reference value, to avoid the weights of travel costs between origins and destinations to follow a quadratic process.

The IV results of our market potential analysis are presented in Table 4. Specifically, we instrument our accessibility indicator with market potential computed through different networks. In Panel A, we present results for our historical instrument: market potential computed through the ancient Spanish Roman roads. Differently, in Panel B we use the market potential of an artificially network generated with least cost paths between the targeted nodes (geographical instrument). As the first-stage statistics above the critical values suggest, both instruments are good. In line with specifications 1–5 of Table 3, we run pooled IV models where we gradually include the different groups of controls. Again, the inclusion of the controls do not change the results. In our preferred

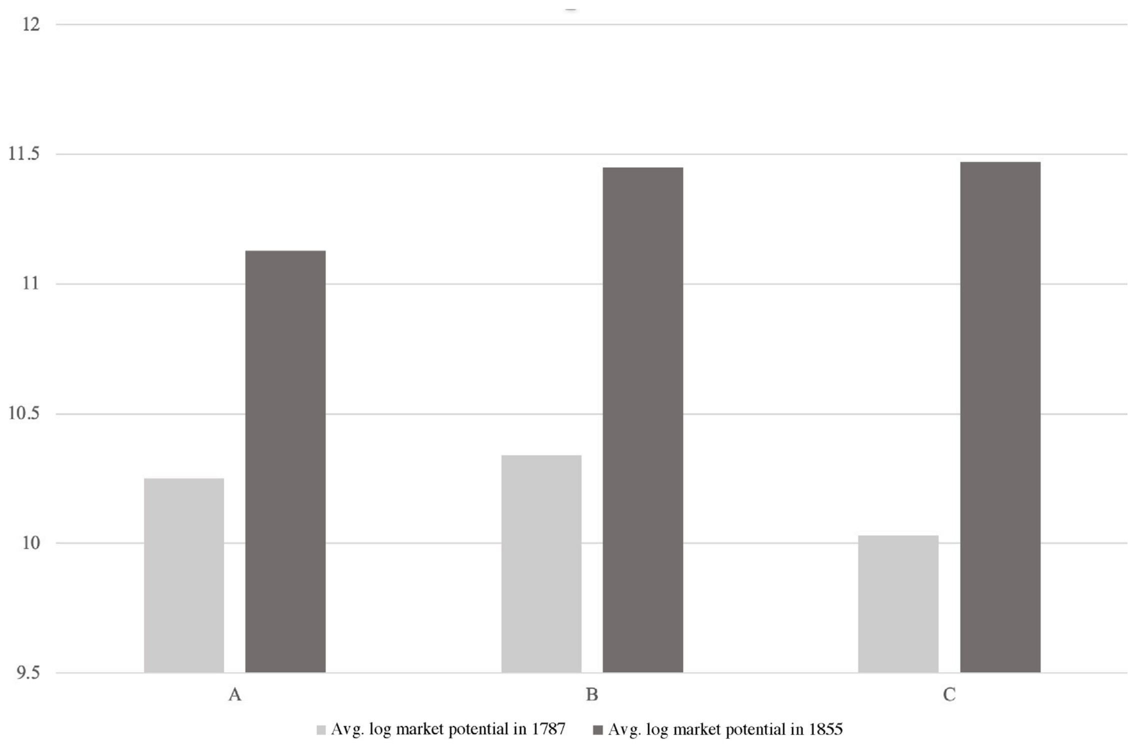


Fig. 7. Average changes in market potential in different groups of municipalities.
Notes: (A): Municipalities with access to the old network in 1787 and with no access to the new network in 1855; (B): Municipalities with access to the old network in 1787 and to the new network in 1855; (C): Municipalities with no access to the old network in 1787 and with access to the new network in 1855.

specification (column 5), the two models provide similar results which, as in the case of the binary accessibility analysis, show an even stronger impact of the construction of roads. According to those estimates, a 1% increase in market potential translated into 0.670 (panel A) or 0.647 (panel B) additional percentage points of local population growth between 1787 and 1857. Alternatively, doubling the market potential would have led to an increase in municipal population of 64.7%/67.0%.

The previous results may be hiding a significant heterogeneity of effects across different municipalities. For instance, cities which got access to the road network at the beginning of the period might have grown more than those connected in the latter years. Alternatively, the growth effect might have been different for those municipalities whose new roads were not finished yet in 1855 and thus remained unconnected to the main network by the new paved roads (see Fig. 9 in Appendix B). And, finally, the demographic impact of increasing market access might have changed depending on the occupational structure of the population.

In order to test these hypotheses, we successively add to the model of Panel A in Table 4 different interaction terms composed by the market potential indicator and a variable that captures the effect we want to analyse. In addition, we incorporate in the regression the specific variable we want to test for and we add a second instrument (the interaction between the Roman roads market potential indicator and the variable of interest). We present the results in Table 5.

In column 1 we test for the effect of early versus late accessibility, adding an interaction term that indicates whether the municipality got access to the road before or after 1808, based on information reported in Madrazo (1984). Our results suggest that the average effect presented above is not different between the municipalities connected in earlier or later years. This would indicate that the impact of road accessibility improvement on local growth materialized quite soon after the connection to a new paved road. However, the first stage statistics suggest that the two instruments might be weak, which indicates that the estimates must be taken with some caution.

In column 2 we account for the fact that some of the roads built in 1855 were not finished yet and remained unconnected to the main network (Fig. 9). Again, the coefficient of the interacted parameter is not statistically significant, which would indicate that the municipalities crossed by the new roads started benefiting from them even before the completion of the routes. However, albeit the instrument seems to be good, those results might be affected by the small number of municipalities that were crossed by those unfinished roads.

Table 4
Instrumental variable approach.

	Panel A - Roman roads instrument				
	(1)	(2)	(3)	(4)	(5)
Log Market Potential	0.672***	0.706***	0.674***	0.681***	0.670***
	(0.060)	(0.063)	(0.058)	(0.045)	(0.043)
Geographical controls		✓			✓
Accessibility controls			✓		✓
Other controls				✓	✓
Judicial district FE	✓	✓	✓	✓	✓
First-Stage F-Statistic	36.39	38.38	36.32	36.23	38.76
	Panel B - Least cost path instrument				
	(1)	(2)	(3)	(4)	(5)
Log Market Potential	0.662***	0.693***	0.663***	0.668***	0.647***
	(0.068)	(0.073)	(0.067)	(0.055)	(0.058)
Geographical controls		✓			✓
Accessibility controls			✓		✓
Other controls				✓	✓
Judicial district FE	✓	✓	✓	✓	✓
First-Stage F-Statistic	1526.68	1465.77	1478.88	1503.76	1415.08

Notes: 4328 observations (2164 municipalities ×2 years (1787-1857)) in each regression. Pooled IV regressions. The dependent variable is the log of municipal population. Log market potential is instrumented in Panel A with the market potential of Roman roads and in Panel B with the market potential computed through the least cost path networks. Fixed effects are taken at the historical judicial district level. Standard errors are clustered by historical judicial districts and are in parenthesis. *, ** and *** indicate significant at 1, 5, and 10 percent level, respectively.

Additionally, in column 3 we analyse whether the positive effect of the market potential increase on growth was higher in municipalities with a larger percentage of the total population working in manufacturing and commerce-related occupations in 1787, including merchants, blacksmiths, craftsmen, lawyers and notaries. The positive and statistically significant coefficient for the interaction term in Column (3) suggests that, within the crossed municipalities, the higher the share of population working in manufacturing and commerce, the higher the growth impact of increasing market potential. Accordingly, the new roads benefited relatively more those municipalities with a more diversified economic structure and higher presence of secondary and tertiary activities, compared to those in which the primary sector was predominant.

Finally, in column 4 we study if, among the municipalities with access to the paved road network in 1855, the impact of market potential increase on population growth was different between those municipalities that had access to the traditional network of roads in 1787 (i.e. group B in Fig. 7) and those that were not connected to that network (i.e. group C in Fig. 7). In this case we exclude the places that were not connected to the new network in 1855 and the sample is therefore limited to 1239 municipalities. We define a dummy ("old accessibility") which takes value 1 for the former and 0 for the latter. In line with the results in Fig. 7, the coefficient of the interaction in column (4) is negative, clearly indicating that the impact of the increase in market potential was higher for those municipalities that moved from having no road to being served by the new roads than for those whose road access was upgraded from an old, low quality infrastructure to a new, high quality one.

6. Mechanisms: growth vs. relocation

Our results indicate that the increase in market potential provided by the new high quality Spanish roads had a positive impact on municipal population growth. Such higher population growth might have been the result of either higher natural growth through fertility increases and mortality reductions or migrant attraction. In the context of the late 18th and early 19th centuries, when the demographic transition had not started in Spain,[17] the second mechanism is much more likely than the first one. In addition, it is also consistent with predictions by theoretical models from regional and urban economics -see a summary in Redding and Turner (2015)-, which show that better transport infrastructure generates a new population equilibrium through differential changes in market access. This new equilibrium is associated to the relocation of labour towards those places that benefit from larger reductions in trade costs.

The context of our research, though, is very different from the usual one to which those models are applied. Before 1857 Spain was still a predominantly rural country, and the extent of structural change and agglomeration economies was very limited. Given the low average size of the municipalities in our sample,[18] our results would probably be reflecting rural-to-rural movements, rather than rural–urban migration. In addition, although, as indicated in the previous section, the impact of roads was higher in those municipalities with more presence of secondary and tertiary activities, even those places with higher capacity of attraction were

[17] In Spain, both mortality and fertility remained at very high levels during the period under study. Still in the third quarter of the 19th century, Spanish life expectancy at birth was lower than 30, and the reduction of fertility remained at typical pre-industrial levels, except for some regions (Nicolau, 2005).

[18] The population of the median municipality in our sample was 778 inhabitants in 1787 and 1187 in 1857.

Table 5
Market potential and local population growth. Heterogeneity analyses.

	Pooled IV			
	(1) Time 1808	(2) Unlinked roads	(3) Secondary sector	(4) Older accessibility
Log Market Potential	0.674***	0.666***	0.652***	0.679***
	(0.034)	(0.043)	(0.059)	(0.035)
Log MP * Post1808	−0.911			
	(0.570)			
Log MP * IsolatedNew		−2.324		
		(1.663)		
Log MP * Secondary sector share			0.270*	
			(0.144)	
Log MP * Old Accessibility				−1.283*
				(0.721)
Controls	✓	✓	✓	✓
Fixed effects	✓	✓	✓	✓
First-Stage F-Statistic	5.02	38.59	4.18	3.72

Notes: 4328 observations (2164 municipalities ×2 years (1787-1857)) in regressions of columns 1 to 3. 2478 observations (1239 municipalities) in regression of column 4. Pooled IV regressions. The dependent variable is the log of municipal population. Log market potential (and its relative interactions) is instrumented with the market potential of Roman roads (and its relative interactions). We include in the regressions the second terms of the interactions, even if we omit them from the table. Fixed effects are taken at the historical judicial district level. Standard errors are clustered by historical judicial districts and are in parenthesis. *, ** and *** indicate significant at 1, 5, and 10 percent level, respectively.

still, on average, relatively small and predominantly agrarian. This differentiates our study from most analyses for the railway era (Atack et al., 2010; Berger and Enflo, 2017; Bogart et al., 2022), with the main exception of Büchel and Kyburz (2020), which also largely captures movements from rural to rural municipalities associated to railway construction in Switzerland. However, even in this case the context was much more industrialized than our own.

How likely were such rural-to-rural migration flows in the Spanish economy before 1857? The literature has often stressed that preindustrial societies could be highly mobile, although most movements were temporary (Silvestre, 2002). In addition, in the case of the rural-to-urban flows, they hardly increased urban centres' population due to their comparatively high mortality rates. However, in Spain, as in other European economies, this situation was changing since the late 18th century, with an acceleration of urban growth, based on short-to-medium distance immigration in the most industrialized regions (Cura, 1993), and a widespread increase of long-distance movements in the 1850s (Santiago-Caballero, 2021). Thus, population mobility of an increasingly permanent character seems to have been growing substantially in Spain during the period under study. On the other hand, although the available evidence for Spain is mainly associated to rural–urban migrations, some studies on other countries have reported the increasing scope of rural-to-rural permanent movements. In addition to Büchel and Kyburz (2020), who show that the railways acted as a pull factor for migrants in rural Switzerland, Dribe (2003) has also shown the importance of short-distance permanent rural-to-rural mobility in mid-19th century Sweden. This author insists on the need to consider migration patterns that cannot be accounted for by the most traditional explanations of rural–urban movements, like wage differentials, and shows that those migrants stayed close to their place of origin and tended mostly to remain in typically rural activities.

Our results would indicate that changes in trade costs associated to the construction of the new network of paved roads might have fostered short-distance, largely permanent, rural-to-rural movements in Spain. The new roads increased certain municipalities' market access and offered as a consequence, specially to the most diversified populations, new opportunities for the growth of traditional sectors or the development of new specializations. Given the paucity of statistical information at the local level for the period under study, it is difficult to find evidence on these changes and their association with improvements in the transport network. Nevertheless, for the case of the medium sized town of Monforte, for instance, Dubert (1998) has explicitly linked the arrival of the road network to an increasing ability to attract migrants, despite the extremely slow transformation of the town's socioeconomic structure. From a different perspective, Madrazo (1984) has illustrated the way in which the expansion of passenger travel that followed the construction of paved roads could have transformed the economy of many municipalities that gained access to the new network. This author estimated that the yearly amount of travellers using regular stagecoach services in Spain increased from 2000 in 1818 to 825,000 in 1850 (p. 534). Such a huge rise translated into new demands of lodging and catering services along the route as well as into the growing presence of certain jobs associated to the road: *"together with the staging post and the inn, resources at the service of traffic include the helper, ready to cover the hoofs of the horses, the blacksmith and wagoner to mend the cart axles, rods and wheels; the leather craftsman that sells or fixes harnesses, whips, collars and other tack..".* (p. 563). According to Madrazo (1984) these effects were not confined to passenger traffic. As has been pointed out, the increase in freight transport during the period under study, although much more difficult to estimate, would have also been impressive and, for instance, in the case of the Reinosa road, the aforementioned 20-fold increase in freight traffic would have stimulate the establishment of new industries along the route (pp. 689–90).

In order to capture the potential relocation effects associated with rural-to-rural migration, we analyse the average impact of the new road network, not only on those municipalities crossed by a road but also on those located at certain distance. Thus, we regress

Table 6
Access to roads and population growth: distance to the roads.

	(1) All	(2) <20 km	(3) <15 km	(4) <10 km	(5) <5 km
	Panel A				
Distance to roads (km)	−0.004***	−0.006***	−0.007***	−0.009***	−0.010***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Controls	✓	✓	✓	✓	✓
Fixed effects	✓	✓	✓	✓	✓
R2	0.9877	0.9875	0.9877	0.9877	0.9889
N	14432	11054	9810	7848	4906
	Panel B				
Distance to roads (km)	−0.002	−0.007***	−0.012***	−0.027***	−0.079***
	(0.001)	(0.002)	(0.003)	(0.004)	(0.008)
Controls	✓	✓	✓	✓	✓
Fixed effects	✓	✓	✓	✓	✓
R2	0.9877	0.9874	0.9877	0.9878	0.9891
N	14432	11054	9810	7848	4906

Notes: POLS regressions. The log of population is regressed on the linear distance (km) to the closest road. In columns (1) we present the baseline results including all the Spanish municipalities for which we have population data in both periods. In the other columns, we restrict the sample to municipalities whose centroids are within a specific distance from the 1855 network, including old and new roads. In Panel A, distance to the closest road is defined as distance to the pre-existing network for period one, and distance to the final network for period two. Differently, in Panel B we use the final network to define distance to the network in both periods. Fixed effects correspond to the historical judicial districts. Standard errors are clustered by historical judicial districts and are in parenthesis. *, ** and *** indicate significant at 1, 5, and 10 percent level, respectively.

in a pooled OLS framework the log population of all Spanish municipalities on the shortest linear distance from each municipality to the network, a list of controls, and historical judicial district fixed effects. The model we estimate is:

$$ln(pop_{m,t}) = \alpha_0 + \beta_1 Distance_{m,t} + \beta_2 X_m + \theta_p + \epsilon_m \tag{5}$$

where $Distance_{m,t}$ is, for each municipality m, the straight line distance in kilometers from its centroid to the closest road in year t; X_m is a vector of control variables and θ_p are fixed effects for the 459 historical judicial districts. As in previous analyses, we cluster the standard errors at the historical judicial district level and exclude the 57 targeted cities, in line with the inconsequential-units approach. We compute the distance in two different ways. In a first analysis the distance to the closest road is defined as the distance to the network available at each point of time, i.e. the old network of low quality roads for 1787 and the network combining old and new -paved- roads for 1855. In a second analysis we use the 1855 network (including old and new roads) to define the distance to the network in both periods. We compute distances through GIS techniques considering all roads, even those partially constructed (not connected to the main network). In addition, to account for the fact that the centroid of the geometrical borders of each municipality did not always coincide with the exact economic and social centre of the town, in the case of the municipalities crossed by a road we set the distance at 0, and accept a small bias for all the others. Table 6 presents the results for both the first (Panel A) and second (Panel B) approaches. In both panels, column 1 shows the average effect of distance for the full sample of 7216 municipalities. The coefficient for the distance variable is negative (although non-significant in Panel B), suggesting that local population growth decreased with distance from the network. However, the reduction in population growth might not have been linear with distance. To test for this, in columns 2–5, we gradually restrict the sample to municipalities within a specific distance from the network (20 km, 15 km, 10 km, 5 km). This reduces the sample size to 4905, 3924 and 2453 municipalities, respectively. The coefficients reported in those columns indicate that the effect of road infrastructure on long-term population growth tended to fade away with distance. Thus, while in the closer vicinity to the roads (column 5) the impact of each additional kilometre of distance from the roads was sizeable, this effect decreased substantially (eventually losing significance in Panel B) in more distant areas. Given the different definition of distance, the two panels provide us with three pieces of information. First, as mentioned above, both panels describe a geographical feature: population growth decreased with distance to the road network. Second, since the distance variable is time-variant in Panel A, their negative estimated coefficient suggests that municipalities that decreased their distance to the road network, grew more. Third, since the (absolute value of the) estimated coefficient is higher for the final 1855 network, Panel B shows that the growth mainly took place on those municipalities that eventually ended up close to the final road network.

Next, in Table 7, we compare the impact of road access on the municipalities crossed by the new paved roads with its effects on the neighbouring towns. In line with the methodology proposed by Büchel and Kyburz (2020), we modify our baseline equation above by replacing the distance indicator with a series of mutually exclusive binary distance bin dummies, defined by how far the centroid of each municipality was from the closest new paved road. As before, distances are calculated through GIS techniques considering all the new paved roads. In the case of the municipalities crossed by a new road we set the distance to 0. This way we ensure that all the municipalities crossed by a road are included in the first distance bin. As in previous regressions, we add the same controls and historical judicial district fixed effects. We cluster the standard errors at the historical judicial districts level and include the whole sample of 7126 municipalities (after removing the main nodes). We perform four regressions, with 1, 2, 3 and 4 km bins respectively. In each specification, the coefficient of the first dummy bin is positive and statistically different from

Table 7
Access to roads and population growth: distance to the roads.

	(1) bins = 1 km	(2) bins = 2 km	(3) bins = 3 km	(4) bins = 4 km
1st distance bin	0.250***	0.182***	0.124***	0.068*
	(0.030)	(0.031)	(0.035)	(0.036)
2nd distance bin	−0.452***	−0.279***	−0.223***	−0.139***
	(0.133)	(0.041)	(0.036)	(0.037)
3rd distance bin	−0.305***	−0.204***	−0.053	−0.051
	(0.055)	(0.034)	(0.036)	(0.033)
Controls	✓	✓	✓	✓
Fixed effects	✓	✓	✓	✓
R2	0.51	0.51	0.50	0.50
N	14432	14432	14432	14432

Notes: POLS regressions. The log of population is regressed on a series of mutually exclusive distance bins indicating the distance between the muncipality's centroid and the closest new paved road. For the municipalities crossed by a road we replace the distance from the centroid to the road by 0, so that they are all included in the first bin. The bins are defined as follow: Column (1) 0–1 km, 1–2 km, 2–3 km; Column (2) 0–2 km, 2–4 km, 4–6 km; Column (3) 0–3 km, 3–6 km, 6–9 km; Column (4) 0–4 km, 4–8 km, 8–12 km. Fixed effects correspond to the historical judicial districts. Standard errors are clustered by historical judicial districts and are in parenthesis. *, ** and *** indicate significant at 1, 5, and 10 percent level, respectively.

0, reflecting the positive effect of road access on local population. Then, in all columns the coefficients for the second distance bins (and in columns 1 and 2 also the third) are negative and significant. These results suggest that the growth of the crossed municipalities came partially at the expense of the neighbouring areas, since the construction of paved roads negatively affected the demographic growth of those municipalities located at a small distance from the network. This was arguably the outcome of short distance, largely rural-to-rural migration movements, and would be consistent with the idea of the new road network fostering a demographic relocation process. So, to sum up, rather than being part of a stagnant transport sector, by transforming the economies of the small rural municipalities they crossed and their neighbouring areas the new roads might have brought about a significant spatial reorganization of rural Spain.

7. Conclusions

This paper analyses the effects of the construction of a new network of paved roads in Spain before the first wave of massive railway construction of 1856–66. Previous research was split between those scholars that stressed the stagnation and inefficiency of the Spanish pre-railway transport system and a number of works that highlighted the progress in market integration that took place in the century before 1855. Here we adopt a different approach. Our research is inspired by a large body of recent literature that estimates the impact of new transport infrastructure on local growth using GIS techniques. Following this type of analysis, we generate a new georeferenced database of the paved road network and its evolution over time, and estimate the impact of the accessibility improvement associated to those new roads on the population growth of a large sample of Spanish municipalities between 1787 and 1857. To deal with potential endogeneity, we take advantage of the fact that the initial network design was largely inspired by administrative reasons, rather than economic ones. In addition, we adopt an inconsequential unit strategy in order to remove further endogeneity concerns. Finally, we also present IV results based on a geographical instrument (least-cost paths between the targeted nodes) and an historical one (Roman roads).

Our estimation results show that the improvement in accessibility associated to the construction of the new paved roads translated into a significantly higher population growth along the 70 years of the period under study. We also observe that the benefits of the new roads were higher in those municipalities whose occupational structure was more diversified and included a higher share of manufacturing and commerce-related activities in 1787. These results indicate that the new infrastructure had a substantial transformative capacity of local economies. Although road transport was indeed much more costly than railway transport, the investment effort carried out in the Spanish road system in the century before 1855 had persistent effects on the demographic dynamism of those locations which enjoyed a higher increase in accessibility. Those effects are consistent with the available evidence on the growth in transport flows and market integration that took place in the decades before the mid-19th century and do not give support to the idea of a stagnant economy constrained by stationary transport costs before the railways.

In fact, the changes introduced by the new paved roads in the structure of transport costs were sufficient to provoke a new population equilibrium, in line with the predictions of the Urban Economics literature. Municipalities with higher market potential were able to draw population from neighbouring areas, probably attracted by the capacity of the roads to stimulate the development of new activities along the route. Such attraction would be consistent with the results of a regression analysis in which we divide municipalities among different bins, defined by their distance to the roads. While those locations that were crossed by a road enjoyed significant positive effects, the impact of road construction was negative on the adjacent bins. This would indicate that roads triggered a process of spatial reorganization of population, with short-distance movements of population towards the vicinity of the new roads. Given the short distances involved and the low average size of the municipalities in the sample, such movements would have had a predominantly rural-to-rural character, in contrast with the rural-to-urban exodus that would characterize later periods.

In a country like Spain, with very small possibilities to use water transport for domestic trade, the railways represented a revolutionary change with long lasting effects on the integration and spatial reorganization of the economy. However, our results provide evidence on the relevance of earlier progress in the transport sector. Although the potential impact of the new paved roads would never be comparable to the effects of the railway system, their transformative capacity is an additional illustration of the dynamism of the Spanish economy in the century before 1855. Rather than awakening a dormant economy, the railways reinforced a process of change that, despite the difficulties associated to a difficult geography and recurrent political conflict, was well under way in the mid-19th century.

Data availability

Data and replication files are available at the Open-ICPSR Repository.

Appendix A. Additional tables

See Table 8.

Appendix B. Additional figures

See Figs. 8–11.

Appendix C. Methodological note

In this section, we present a detailed description of all the procedures we followed for cleaning and preparing the data, together with the information on the construction of the instrument and the market potential indicator.

C.1. Administrative units (municipalities) and population data

One of the biggest challenges while cleaning and preparing the data for the analysis has been the fact that the administrative units (municipalities) that we use changed over time due to mergers and divisions. This would already be a challenging issue for the changes occurred between the 18th and 19th centuries, within the 70-years of analysis. Furthermore, things get even more complicated since a historical map of municipality boundaries for the period under study is not available, and thus we had to rely on the maps of current municipalities.[19] To deal with these issues, we match the historical municipalities to the present ones using different sources. Specifically, after dropping non-peninsular municipalities, we observe 18,151 entries in the 1787 Floridablanca census, 10,146 in the first census carried whose data are reported by the Spanish Statistical Institute (the 1842 *Censo de la Matrícula Catastral*) and the current 7676 municipal administrative units. For those changes that took place after 1842, the INE website provides a complete catalogue (Ministerio de Administraciones Públicas, 2008) and following those information we can assign the population data to the right municipalities and correct most of the bias. By contrast, the match between some of the municipalities included in the Floridablanca Census and the current ones is more complicated and not always possible due to the lack of information.[20] Besides aggregating the population to the right administrative units, we also needed to make a few changes

[19] The shapefile of the Spanish municipalities is available on the website of the Centro Nacional de Informacion Geografica (CNIG).

[20] We thank Alfonso Díez-Minguela and Julio Martínez-Galarraga for their invaluable help for this matching process.

Table 8
Market potential and local population growth. Pooled OLS. Different elasticities.

	(1) e = 1	(2) e = 0.50	(3) e = 1.50	(4) e = 2	(5) e = 4
Log Market Potential	0.397***	0.638***	0.168***	0.068***	0.014***
	[0.169]	[0.180]	[0.130]	[0.090]	[0.049]
	(0.061)	(0.026)	(0.035)	(0.015)	(0.004)
Controls	✓	✓	✓	✓	✓
Fixed effects	✓	✓	✓	✓	✓
R2	0.9899	0.9902	0.9893	0.9889	0.9887
AIC	9256.66	9114.63	9527.63	9671.06	9751.59
BIC	9320.39	9178.36	9591.35	9734.79	9815.32

Notes: 4328 observations (2164 municipalities ×2 years (1787–1857)) in each regression. Pooled OLS regressions. The dependent variable is the log of municipal population. *e* is the elasticity to travel distances employed in the market potential computation. AIC and BIC are the Akaike's Information Criterion and Bayesian information criterion respectively. Fixed effects are taken at the historical judicial district level. Standard errors are clustered by historical judicial districts and are in parenthesis, and the standardized beta coefficients are within square brackets. *, ** and *** indicate significant at 1, 5, and 10 percent level, respectively.

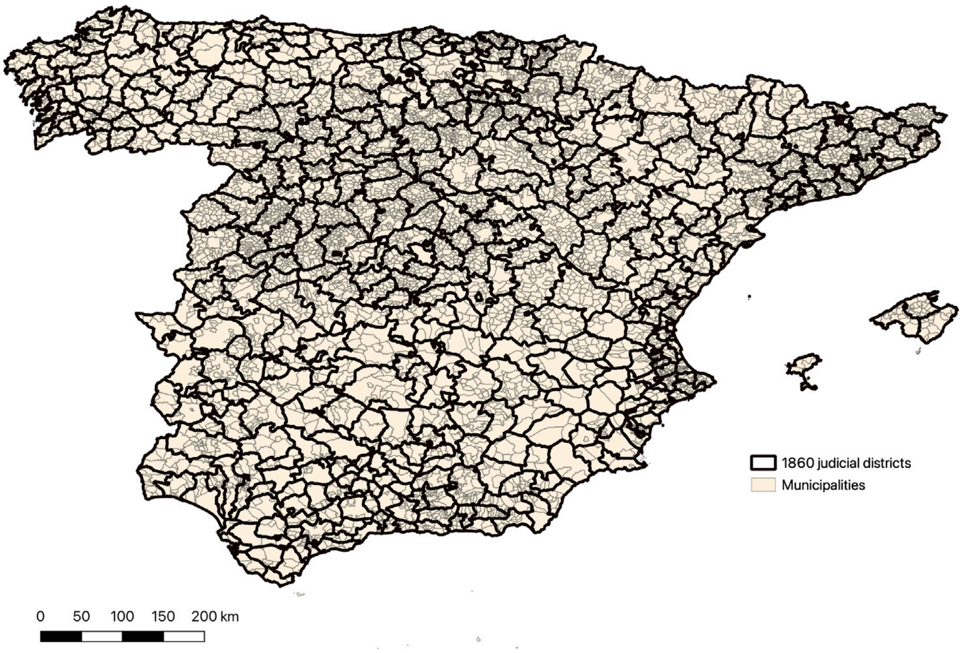


Fig. 8. Spanish judicial districts in 1860.

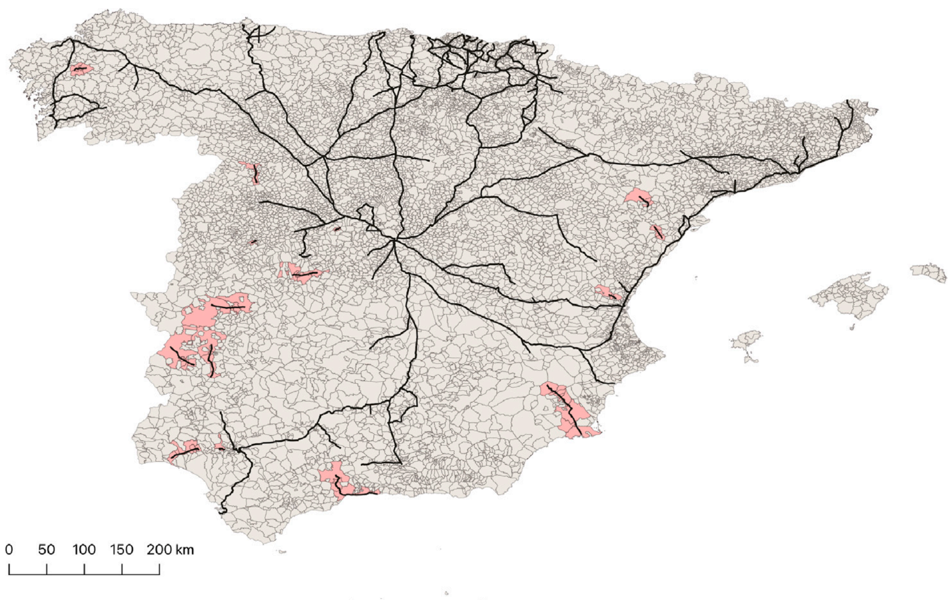


Fig. 9. Municipalities crossed by a new paved road but not connected to the main network.

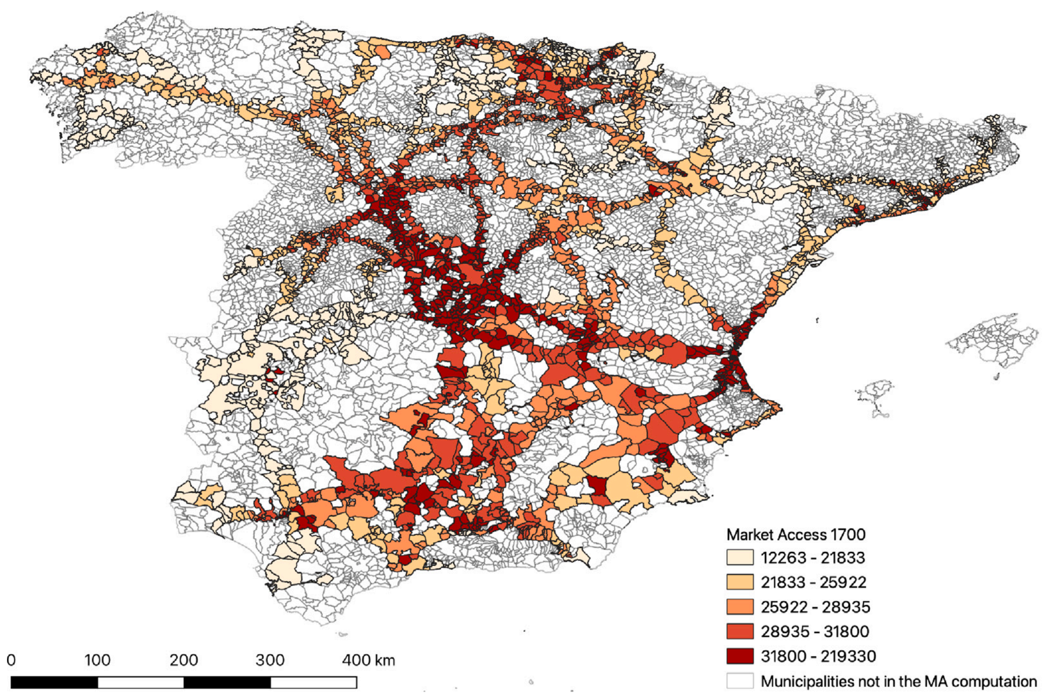


Fig. 10. Municipal market potential computed through the old network.

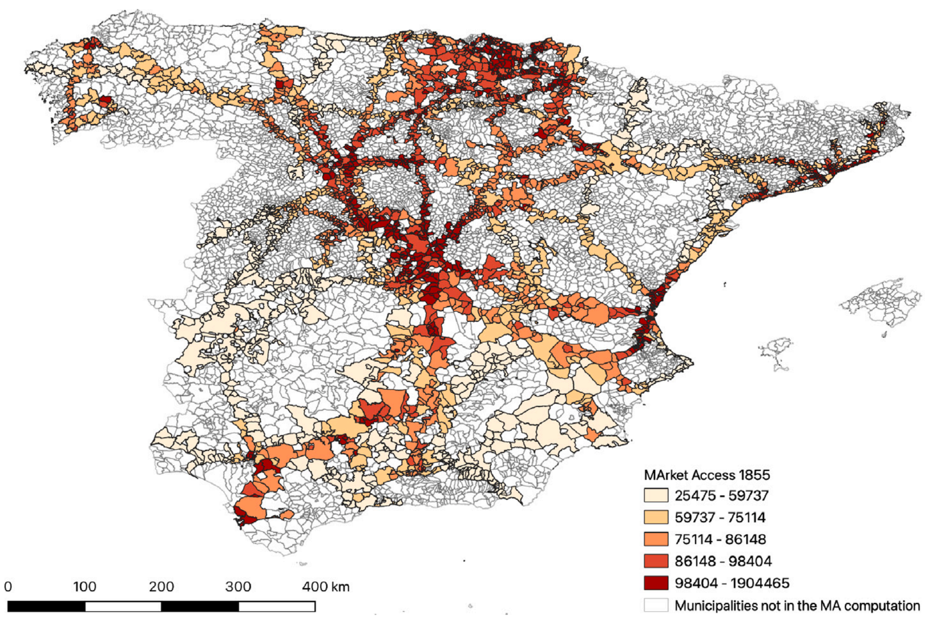


Fig. 11. 1855 municipal market potential computed through the new paved network.

- i.e. merging two or more municipalities - in the current shapepefile. The reason is that the administrative geographical borders refer to a more recent period than the last population census (2011). We make some changes to take into account those units which have been created after 2011. In particular, Dehesas Viejas, Iznalloz and Domingo Pérez de Granada have been merged in a single administrative unit; the municipality of Balanegra has been incorporated into Berja; Jatar into Arenas del Rey; Montecorto and Serrato into Ronda; Pueblonuevo de Miramontes into Talayuela; and Valderrubio into Pinos Puente.

C.2. Historical roads digitalization

One of the strengths of our paper is the quality and precision of the digitization of the new paved road network. Applying GIS techniques to information provided in Madrazo (1984) and Dirección General de Obras Públicas (1856), we have digitized the map of the network for four different years along the period under study (see Fig. 1). The digitization process has been quite complicated since the original maps were hand-drawn and not always precise. Thus, the usual method of geo-referencing scanned maps could not be used. As a consequence, we also employ the shapefile of current Spanish roads as reference. We started with the map of roads in 1855 that is included in Dirección General de Obras Públicas (1856). This map reports the names of more than 500 municipalities crossed by the paved roads, which helped us to correct for the effects of the spatial distortions of the map on the specific location of each route. Thanks to this process we obtained the shapefile of our baseline map for the year 1855. We conclude the digitalization process by checking the more precise 1861 map (Dirección General de Obras Públicas, 1861) and by correcting for some road segments which are not correctly classified in the 1856 map. We then used information included in a series of less precise hand-drawn maps in Madrazo (1984) to obtain digitized shapefiles of the network in 1778, 1808 and 1840 by removing from our baseline map the road stretches that were still unfinished in those dates.

C.3. Least cost path network

As already mentioned, we instrument accessibility to the new paved roads with accessibility to an ideal cost-minimizing network within a group of municipalities intentionally connected by the designer of the new network. In order to define the targeted nodes we collect information from the 1720 general regulation of post services, whose main routes largely inspired the priorities in road construction as defined in the 1761 Royal Decree. The targeted nodes are: Corunna, Alcalá de Henares, Alcántara, Alicante, Aranjuez, Arévalo, Badajoz, Barcelona, Baztán, Benavente, Burgos, Cadiz, Carmona, Cartagena, Ciudad Real, Ciudad Rodrigo, Córdoba, Denia, San Sebastián, Écija, El Escorial, El Puerto de Santa María, Fraga, Getafe, Guadalajara, Irún, La Junquera, Lleida, Madrid, Medina del Campo, Medinaceli, Mérida, Molinaseca, Murcia, Ourense, Pamplona, Pontevedra, Salamanca, San Clemente, Santiago de Compostela, Seville, Soria, Talavera de la Reina, Tarancón, Tarragona, Teruel, Toledo, Torrelodones, Tortosa, Trujillo, Tudela, Valencia, Valladolid, Vitoria, Zafra, Zamora and Zaragoza (de Grimaldo, 1720). We then generate an hypothetical least cost path network connecting those municipalities by considering the roughness of the terrain. Specifically, we take two of those municipalities - having in mind the design of the network - at the time and we use QGIS to run the Dijkstra's algorithm to get optimal paths between their centroids. Based on the costs derived from the elevation raster of the Spanish geographical institute (IGN), the algorithm selects pixel by pixel the cost-minimizing route between them. We repeat the process for all the couple of nodes we are interested in according to the design of the network. We then use accessibility measured through this cost-minimizing network as instrument for accessibility computed through the new paved network. Fig. 5 shows the 1855 paved road network, the least-cost paths and the targeted nodes.

C.4. Market potential computation

We want the market potential indicator to vary over time to capture the changes in the network caused by the development of new and better quality roads. To do so, we keep in our sample all the municipalities connected by at least one of the two networks employed in the analysis (the new paved network and the pre-existing low quality roads). Some of those municipalities are crossed by both networks, while others are crossed only by one. To deal with this, we impute different travel times to each segment of the network, depending on the specific case.

We compute for each municipality of this sample an indicator of market potential as the weighted sum of inverted travel times (as a proxy of transportation costs) to all other municipalities through the road network, using as weights the initial population at destination. Travel times are computed with a least coast path algorithm, assuming different speeds throughout the network. Specifically, we employ the old network to compute the market potential for the year 1787. In addition, we add to the existing roads the shortest straight segments connecting to this network the centroids of the municipalities crossed by the 1855 paved network but not previously connected. Based on different historical sources we impute to the roads of the pre-existing network a speed of 2 km/h (travel time parameter of 0.5). Differently, for the artificially added segments connecting the municipalities not crossed by the old roads we impute half of the speed (travel time parameter of 1). Although the difference between the speeds of 1 and 2 km/h may look small, it is important to remember that the old network of roads was very low quality and sometimes impassable. In addition, the segments for which we assume a speed of 1 km/h might be at least in part coincident with some second-order paths that were not included in the main 1787 network. As indicated by Pablo-Martí et al. (2020), this second-order network in the 18th century was characterized by its density, its homogeneous distribution over the territory and its general low quality. To compute the 1855 market potential, we integrate the two networks. The resulting network for the 1855 computation is composed by the pre-existing low quality roads and the new paved roads. We delete the old segments for which the path coincided with the new ones, with the idea that the new roads have been built on the old ones. To consider the fact that the two networks had different quality, we impute different travel time parameters. Specifically, we impute a speed of 6.66 km/h (travel time parameter of 0.15) based on different historical sources to the newly constructed paved roads. Differently, we keep the speed of 2 km/h (travel time parameter of 0.5) for the pre-existing network.

The resulting sample size of crossed municipalities for the computation of the 1855 market potential is 2164 (excluding the targeted nodes removed from the empirical analysis). Due to this high number, the computational task to recover all the travel times is really demanding. To deal with this, we employed the software GRASS GIS.[21] which has the advantage of calculating those travel distances without building new topologies. Specifically, after importing the shapefiles of roads and the centroids of the connected municipalities (with the command *v.import*), we prepare the network by connecting the two topologies with the command *v.net* (option connect). In this way, we are able to split the different segments at each centroid intersection. After this, we employ the command *v.net.allpairs* to compute for each municipality the travel time value to reach all other municipalities through the network that we then employ in the market potential formula. We import those parameters in STATA and we run a code to compute the market potential index for each single municipality based on Eq. (2)

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