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Transport and Biological Living Standards: Evidence from Late 19th-Century Catalonia*

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Abstract

The living standard of a population is influenced by numerous factors, which, in addition, may change over time. Transport can be one of them as it acts as a mediator for other factors: it influences the price and supply of essential foods; it affects wages and income; it has an impact on the speed of contagious disease spread; it plays a role in the time to access health services. Using Catalonia as a case study, we explore the relationship between transport linkages and well-being in the late nineteenth century. To test this relationship, we rely on two rich and new datasets; one is on individual male heights, and the other consists of municipal market and port access. We conclude that the transport linkages-height nexus was positive, statistically significant and of a non-negligible magnitude, and, contrary to other studies, we do not find evidence that rural areas were negatively affected by market integration, although urban settings appear to have benefited the most. We suggest that the primary mechanisms underlying this positive association were improved food accessibility, along with urban economies and rural development.

JEL Codes: I12, N33, O18, R41

Keywords: Height, market access, living standards, railways, southern Europe

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1. Introduction

A variety of factors influence the health and nutritional status of a population. In an early work, Richard H. Steckel and Roderick Floud (1997, p. 6) differentiated between socio-economic determinants of the physical stature, which included, income, inequality, public health, personal hygiene, disease environment, technology, labour organisation, cultural values, and food prices. Personal hygiene, and proximate determinants, which were associated with diet, disease, work intensity, maintenance and genetic. Mediating between determinants and outcomes, other factors could be added. Transportation is one of them, and it is not a negligible one. Current evidence shows that isolated areas with deficient or even lacking access to basic transport infrastructure and services experience lower levels of economic, social, and human development, including food security, maternal health, and education enrolment (United Nations, 2021, p. 3, see also e.g. Gibson and Rozelle, 2003, Stifel and Bart Minten, 2017, for case studies). Given these impacts, it is unsurprising that transportation—often framed as sustainable transport—has been incorporated as a key Sustainable Development Goal (SDG) in the United Nations' 2030 Agenda (United Nations, 2021, p. 1). Furthermore, the UN has explicitly highlighted the interconnections between transport and health (UNCTAD, 2016).

Should the same perspective be applied to historical contexts? While some historical analyses have acknowledged the positive impact of improved transport infrastructure and networks on living standards (see Section 2 for a summary), relatively few studies have explicitly examined this relationship from the perspective of biological living standards. This is somewhat surprising given the dynamism of the literature on the determinants of living standards (e.g., Steckel, 2009; Kelly & Komlos, 2016; Harris, 2021), and the extensive research on the impact of transportation on economic and social change (e.g., Atack et al., 2010; Álvarez-Palau et al., 2024). A likely explanation is that this type of analysis is very data-intensive, requiring precise information on transportation and variables that approximate living standards with high territorial granularity.

In this article, we examine the case of Catalonia, a north-eastern Iberian region, during the late nineteenth century, a period generally characterized by the development of new transport technologies, urbanisation and improvements in biological living standards. This case is particularly compelling. Thanks to the data we have compiled, the Catalan case offers a valuable opportunity to explore the relationship between transport infrastructure and biological living standards with a high degree of depth and specificity. The territorial granularity of our data enables us to capture variations at the municipal level, facilitating a detailed examination of the transport-height nexus within a well-defined historical and geographical context.

Moreover, the Catalan case presents other noteworthy characteristics that make it particularly significant. Compared to other territories in southern Europe, Catalonia was a developed region, with relatively higher industrialisation levels as measured by the share of industry and mining in total employment before World War I (Rosés & Wolf, 2018). In the first decades of the 19th century, the factory system emerged in Catalonia, bringing about the expected costs in living standards associated with modern industrialization (e.g., Ramon-Muñoz & Ramon-Muñoz, 2016, 2024). However, in contrast to this earlier period, the second half of the 19th century saw significant improvements in living standards in Catalonia, a process that unfolded alongside the expansion and modernization of its transportation system (e.g., Pascual, 1990, 1991; Esteban-Oliver & Martí-Hennenberg, 2022). Thus, Catalonia offers the possibility to examine whether and to what extent, improvements in transport infrastructure and networks played a significant role in shaping changes in living standards in industrialising regions.

There is another reason that makes the case of Catalonia particularly interesting. While Catalonia's per capita GDP in 1900 was higher than that of many other European regions, it was similar to some currently developing countries (Rosés & Wolf, 2018; Bolt & van Zanden, 2020). Thus, studying the Catalan case can contribute to a better understanding of how transportation improvements may be interacting with well-being in present contexts.

The anthropometric literature has established that diet and disease are two proximate determinants of biological living standards. These factors interact in several ways (e.g., Eveleth & Tanner, 1990; Steckel, 1995, 2008; Harris, 2021). For example, certain diseases can hinder nutrient absorption in the body, while a deficient diet can cause or accelerate certain diseases.

Improved transportation offers the potential to mitigate the negative impact of suboptimal diets and diseases in various ways, particularly by enhancing access to food. However, transportation improvements also give rise to situations that can harm health. The effect of better transport infrastructure and transport networks can also vary by population's settlement type, e. g. rural and urban, with the net effect depending on population distribution. Therefore, carefully considering both the positive and negative impacts is crucial.

While anecdotal evidence suggests a potential positive relationship between access to transportation infrastructure and biological living standards in Catalonia, there are also instances indicating the opposite. For example, it has been argued that "as a strategic zone of transit for both people and goods, with its active maritime ports, Barcelona was more susceptible to contagion than other inland or more isolated areas", which may explain "the repeated, varied epidemics that periodically affected Catalonia" (Sabaté, 2017, p. 46). Furthermore, by the late nineteenth century, higher crude mortality rates were generally observed in Catalonia's four provincial capital cities compared to the rest of the region—a pattern also evident across Spain around 1900 (Pérez Moreda, Reher & Sanz Gimeno, 2015)—precisely in the localities with the highest density of communication nodes.

To test the hypothesis that improved accessibility to transport linkages had a positive effect on biological living standards, we utilised two comprehensive datasets in our analysis. The first consists of individual male height measurements, which serve as a proxy for biological living standards. This dataset covers nearly all municipalities in Catalonia before World War I and includes all 21-year-old males residing in Catalonia in 1911. The second dataset, which is newly created, contains information on market accessibility for Catalan municipalities in 1890. This variable —Market Access, hereafter MA— is based on the theoretical framework of Donaldson and Hornbeck (2016) and measures the ease with which economic agents in a given location can reach and trade with other markets. Specifically, in this article we estimated inter-municipal trade costs for all Catalan municipalities using a multimodal transportation model within Geographical Information Systems (GIS). Additionally, we included a port access (hereafter PA) dummy to account for the effect of international and colonial markets.

We then employed an Ordinary Least Squares (OLS) cross-sectional model to examine the relationship between transport linkages (MA and PA) and height (hereafter HE). Additionally, to address potential endogeneity concerns, we complemented this approach with an instrumental variable (IV) strategy based on least-cost paths (LCPs) and lighthouses (ALGH). We suggest that the primary mechanisms underlying this positive association were improved food accessibility—making a wider variety of food, including high-protein products, more affordable and available, along with urban economies —driven by scale and agglomeration economies, and rural development —supported by strengthened agricultural specialisation and the consolidation of commercial agriculture. Other potential factors, such as urban health externalities, were also considered, but likely played a more limited role during the period under study.

These results might not be so obvious given the ongoing controversies on industrialisation, urbanisation, market integration, and their impact on living standards, as approached from different angles (e.g., Davenport, 2020, 2021; Szreter & Mooney, 2021 on mortality and urbanization in 19th-century England, see also Section 2). Therefore, we contribute to the existing literature on these topics in several ways. Firstly, we add new and rich evidence at both individual and local levels to better understand the historical determinants of biological living standards by considering a relatively overlooked mediating factor: transportation and market integration. Indeed, only a handful of studies, no more than a couple of dozen, have explicitly addressed the historical relationship between improved transportation and HE, with all of them focused on the United States of America (USA) and North-western Europe (see Section 2). Not all of these studies support the hypothesis that transport linkages positively impacted biological living standards, neither do they address the mechanisms behind this relationship. In contrast to other works, and as argued, they are associated with the positive externalities of food accessibility, on the one hand, and specialisation, scale, and agglomeration economies, on the other. When possible, we quantitatively address these mechanisms, which is not always found in the literature on the topic. By analysing the case of 19th-century Catalonia, we also shed light on the benefits of market integration in territories that were less developed by contemporary standards during the century of classical industrialisation.

Secondly, contrary to most previous works on the transportation-HE nexus, we measure domestic transport linkages through a MA variable as defined by Donaldson and Hornbeck (2016). Specifically, to the best of our knowledge, this is the first study in Europe using a MA approach to test for the influence of transport linkages on biological living standards. This is relevant because contrary to other indicators for transportation linkages—such as if a locality had access to a railway stations or proximity to a road—the MA variable considers inter-modality and network structure, and the size of markets; thus, capturing the broader economic connectivity of a municipality. Additionally, another main advantage of MA is that it considers network-wide changes in connectivity and accessibility. This helps to isolate the influence of connectivity improvements on HE, making it less likely that infrastructure development is simply a response to local economic conditions or endogenous demand for infrastructure in a specific location (Donaldson & Hornbeck, 2016; Zimran, 2020; Álvarez-Palau et al., 2024).

Our paper can be also placed among the emerging and novel literature on the historical impact of improved transportation in the economy and society (Bogart, 2024). This includes, among others, the agricultural and industrial sectors in the

United States in latter half of the 19th century (Donaldson & Hornbeck, 2016; Hornbeck & Rotemberg, 2019), population density, emigration and the agricultural sector in Ireland between the 1840s and the 1910s (Fernihough & Lyons, 2022), the fertility transition in Europe (Ciccarelli, Fenske, and Martí-Henneberg, 2023), urban growth in England and Wales during the first industrial revolution (Álvarez-Palau et al., 2024), and biological living standards in early 19th-century USA (Zimran, 2020). In fact, our paper is most closely related to this latter study. Similarly to Zimran (2020), we also use MA as a measure of domestic transport linkages, and individual-level data as a proxy for the health and nutritional status of the population to test the relationship between these variables. However, we focus on a region in Europe at the end of the 19th century, when the transport revolution led by railways was in its final stages, and we obtain different results. While Zimran (2020) found a negative relationship between MA and HE due to the impact of urban development, we find a positive relationship, partially explained by a similar mechanism that, in our context and period, proves beneficial for biological living standards.

The structure of this paper is as follows: Sections 2 and 3 provide a literature review and historical context, respectively. Section 4 describes the data employed in this study, while Section 5 outlines the empirical strategy. Sections 6, 7 and 8 present and discus our findings and the underlying mechanisms of the MA and PA-HE positive nexus. Finally, Section 9 provides the concluding remarks.

2. Literature review

The existing body of anthropometric literature has indicated that transportation infrastructure, particularly railways, influences the quality of living standards. Although some econometric and narrative analyses consider transportation as a potential factor affecting individuals' physical stature, the studies examining the relationship between transportation and body HE in deep are relatively limited. Moreover, research in this area has predominantly focused on the United States during the Antebellum years, a period characterized by economic growth but also increasing mortality rates and declining HE (e.g., Margo & Steckel, 1983; Fogel, 1986; Komlos, 1987, 1996; A'Hearn, 1998; Cuff, 2005; Floud et al., 2011).

Earlier studies by Komlos (1987) and Komlos and Coclanis (1997) suggested that this apparent paradox could be attributed to changing relative prices that negatively affected diet quality. Moreover, these authors argued that changing relative prices were associated with improvements in transportation and increased commercialisation and led to changing consumption patterns against protein-rich foods. In the context of increasing commercialisation, farmers' behaviour also contributed to a deterioration of their diet, either by moving their production into non-food crops or by exporting a larger amount of food crops, worsening in both cases rural nutrition.

Building upon these works, a series of studies conducted by M.R. Haines, L.A. Craig, and T. Weiss developed these previous hypotheses (Haines, 1998; Craig & Weiss, 1998; Haines, Craig & Weiss, 2003). These authors performed econometric tests in which the impact of transportation was measured using a dummy variable that indicated whether a county had access to a navigable waterway in 1840. Once controlling for other factors, their results showed a negative impact of transportation on living standards, as measured by death rates and HE. Specifically, access to a navigable waterway was found to "increase the death rate by about four per thousand" and "reduce adult HE by a quarter of an inch", approximately 0.64 cm (Haines, Craig & Weiss, 2003, pp. 396 and 405, respectively).

The implications of transportation access on living standards may vary depending on the population's settlement type. Based on Haines, Craig, and Weiss (2003) and using a geographically weighted regression (GWR), Yoo (2012) reevaluated previous findings on the impact of transportation on HE and crude death rates in the United States before the Civil War. Yoo's analysis revealed that access to water transportation improved nutritional status in urban areas of the Northeast, while it had a detrimental effect in rural areas of the Midwest. According to Yoo (2012), these results are consistent with historical facts and previous hypotheses proposed by Komlos (1987). The expansion of steamboats in the mid-1810s reduced transportation costs, leading to increased agricultural product exports from the rural Midwest in exchange for manufactured goods from the Northeast. While peasants' income increased, their living standards did not, as the consumption of nutrient-rich food among rural families declined. Market integration resulted in a shift in dietary patterns in rural areas, with farmers consuming less protein-rich products like meat and dairy and more carbohydrates. Conversely, in urban areas of the Northeast, the ability to import cheaper food enhanced nutritional status and improved living standards.

Recent research by Zimran (2020) confirmed the adverse effects of railways in rural areas during the period 1820-1847. Unlike previous studies, this author employed Geographic Information Systems (GIS) to determine the location and opening dates of canals, railroads, and steamboat-navigable waterways. With these data, he computed annual MA information for all counties east of the Mississippi. Importantly, Zimran could address concerns about potential spurious relationships between transportation data and physical stature. These improved data and methodology enabled estimating causal effects between transportation and health rather than mere correlations. The findings of the study were diverse. Firstly, transport, as measured by MA, harmed health, as indicated by the fact that greater MA decreased the mean physical stature by 0.14 inches (0.36 cm) in rural areas. This decline accounted for 37% of the overall observed decrease in HE during the period 1820-1847. Secondly, Zimran (2020) provided evidence for potential mechanisms explaining why greater exposure to transportation linkages resulted in a deterioration of living standards. One of the mechanisms identified was population density. In an era with poor sanitation technology, increased transportation linkages led to higher population density, which, in turn, hurt health. The author refers to this mechanism as the local development mechanism. Lastly, Zimran (2020) observed that population density grew more intensively in agriculturally suitable counties. Transportation linkages fostered agricultural productivity and promoted local development, attracting immigrants seeking new farms. Consequently, greater MA resulted in increased population density, a worsened disease environment, and health deterioration. Therefore, contrary to previous studies, the shrinking in physical stature during the Antebellum period would have been more a consequence of deteriorating epidemiological conditions rather than a decline in diet quality.

Regarding the years following the USA Civil War, the overall conclusions differ at the aggregate level but show similarities when distinguishing between rural and urban settlements. During this period, transportation improvements were primarily associated with the development of the railway network, which expanded and consolidated over the half-century following the Civil War. Guven Solakoglu (2006) approached this topic by estimating marketable surplus and converting it into daily protein per person. These data were then regressed on railroad mileage, and the resulting coefficient was multiplied by the effect of daily protein intake on average HE to derive an estimate of the impact of railroad development on average body HE. In other words, Guven Solakoglu (2006) approached the impact of railways on physical stature by considering the influence of the marketable protein surplus. She found an overall positive effect of railroads on average HE, amounting to 0.43 inches (around 1 cm) for 1867-1906. However, this positive effect was limited to the period 1867-1887, when average HEs in the USA were declining, indicating that railways and their role in providing food at lower costs could only partially counterbalance the negative impact of other factors. Conversely, during the period 1887-1906, when average HEs in the USA increased, Guven Solakoglu (2006) found the effect of railways on physical stature to be negligible.

In a study by Zehetmayer (2011), the author examined whether the decline in HE observed during the Antebellum period extended until the end of the 19th century and to what extent. The study utilised a sample of nearly 60,000 army recruits born between 1847 and 1894 and enlisted between 1898 and 1912. This dataset offered improved coverage relative to the previous ones: first, it encompassed the entire country, and second, it represented the stature of the common man, surpassing previous studies that focused on specific regions or particular populations. By applying truncated normal regressions, the author concluded that HEs continued to decline among the birth cohorts of the Civil War, decreasing by approximately 0.4 inches (1.0 cm). HE stagnation followed while the average body HE increased in the late 1880s. As a result of this latter increase, by 1890, the physical stature of the common man in the USA could reach the levels observed in 1850. Moreover, Zehetmayer (2011) noted considerable regional variability, with recruits from the South being the tallest and those from the Northeast being the shortest. One of the conclusions drawn by Zehetmayer (2011) was that proximity to protein-rich nutrients, and the availability of protein and calcium had a significant positive effect on biological living standards, similar to the findings by Haines, Craig, and Weiss (2003) for the Antebellum period. However, regarding the influence of market integration, as proxied by the length of completed railroad lines in each state by the mid-1880s, Zehetmayer (2011, p. 323) found that it was not statistically significant. According to the author, a technical issue explains this lack of statistical significance: "the high level of aggregation fails to capture the county-by-county variation in railroad access".

In a subsequent study by Zehetmayer (2013), these latter findings were qualified. The author focused on urban HE trends and their determinants compared to rural areas in the second half of the 19th century. The study considered the 100 largest metropolitan areas in the USA, using the same dataset and econometric strategy as Zehetmayer (2011). The author observed an urban HE penalty of up to 0.58 inches (1.5 cm) relative to rural areas. Nevertheless, he also found a positive and statistically significant relationship between transportation, as proxied by the number of railroad lines that connected a city, and HE, once controlled by other factors, including death rates, real wages, the share of foreign-born, and the percentage of the city population in manufacturing. The impact of transportation on HE was substantial, with a one standard deviation increase in railroad lines per 10,000 inhabitants resulting in a HE increase of 0.12 to 0.28 inches (0.31 to 0.70 cm). These outcomes indicate that railways improved urban dwellers' nutrition by enabling cheaper and more abundant food supplies. However, this positive impact was counterbalanced by the harmful effects of the disease environment, as proxied by the death rate, and the conditions of industrial work, as proxied by the percentage of the city's population employed in manufacturing.

For Europe, and other areas, the number of works testing the impact of transportation infrastructure on biological living standards is also limited, and this impact only was econometrically tested from around 2010 onwards. Previously, Komlos (1989) on the eighteenth-century Habsburg Monarchy and Baten (1999) on the German region of Bavaria in the early 19th century posed the basis for further developments. Komlos (1989, p. 106) argued that "nutritional levels depended to some extent on market integration". According to him, by the 1740s and the 1750s, recruits from the more isolated and agriculturally oriented areas of the Habsburg Monarchy were taller than their counterparts from other less remote regions, indicating that the former had a higher nutritional status despite being born in subsistence-peasant areas. However, recruits from formerly isolated areas experienced a rapid decline in HE as markets became more integrated after the 1760s and, as a result, grain exports increased. Komlos (1989) argued that this resulted from changing consumption patterns: peasants from previously isolated areas began consuming more luxury and expensive goods, providing their children with less protein-rich food products, negatively affecting biological living standards.

For the case of Bavaria, Baten (1999) also found evidence of the potential negative impact of market integration before the expansion of railways. Indeed, this author observed that in the early 1830s, males born in the areas surrounding the larger towns of Bavaria were shorter than the average and relative to other agricultural-oriented regions. This was especially true compared to milk production areas, where the tallest men were born. Part of the explanation for lower biological living in areas closer to the larger towns is that peasants sold many of the produced nutrients to the urban areas instead of consuming them. Another reason was that peasants' workload was higher in these areas to generate more output and income. Finally, the "non-agricultural goods available in the towns probably tempted the farmers to forego consuming some milk" (Baten 2009, p. 169), a very protein-rich product which positively impacted HE.

In 2009, the two first studies that applied econometric methods when considering transportation data and their direct relationship with the physical stature of individuals were published. Baten and Fertig (2009) analysed this relationship for the German county of Arnsberg, located East of the Ruhr River in North Rhine-Westphalia. Using data for the birth cohorts of 1882 and 1897, they performed two independent cross-sections, one for each year, in which they considered several determinants of HE. One was market integration, proxied by the distance of each locality or place within Arnsberg to the nearest railway station. In their regression, market integration generally interacted with agricultural production, termed by the authors as the "agricultural factor". This factor, which is informative about local protein production, included agricultural land quality, as proxied by per capita tax for land, the per capita number of cows, and the per capita number of pigs. For the cross-section of 1882, they observed that "when keeping occupations and the district-level numbers of cows constant, to bring the railroad to a non-agricultural place (one standard deviation below average) would add 0.91 cm to the HEs of the local recruits, while building a railroad close to an agricultural place (one standard deviation above average) would add only 0.64 cm" (Baten and Fertig, 2009, p. 180), suggesting that in this period market integration was more beneficial to urban dwellers. By contrast, in 1897, the interaction between rail distance and the agricultural factor was not statistically significant, and, therefore, "remoteness, in interaction with agricultural specialisation, did not play a positive role anymore" (Baten and Fertig, 2009, p. 281). These results show that proximity to nutrient production areas might have resulted in a health advantage, which vanished as the market became more integrated and railways reached these more isolated areas. In the end, this evidence suggests that, as in previous studies, market integration through railways development would have benefited urban rather than rural populations, at least regarding biological living standards.

Also, in 2009, Groote, Elhorst and Tassenaar (2009) published a study on the 19th-century Netherlands that partially confirmed it. They focused on 90 municipalities located in the northern rural provinces of Groningen and Drenthe between the first decades of the 19th century and 1890, using Geographic Information Systems (GIS) based on paved roads, canals and navigable rivers, tramways, light railways, and main railways. In turn, they proxied biological living standards by considering the percentage of the undersized conscripts, i. e. the percentage of recruits that did not meet the minimum HE at the local level at five-year periods. By running OLS regressions and advanced spatiotemporal models, they found a long-term positive impact of transportation on body HE but a negative one in the short-term. Nevertheless, the authors recognised that this negative coefficient was not statistically significant and that they could not "reject the hypothesis of the 'antebellum puzzle'" that took place in the USA in the first two-thirds of the 19th century (Groote, Elhorst and Tassenaar, 2009, p. 388).

The case of France seems otherwise. Using a sample of 81,605 conscripts at the departmental level, Heyberger (2011a; 2011b) concluded that the railway's arrival improved the country's biological living standards. He found that ceteris paribus, the effect of railways construction on males' physical stature was positive and of a non-negligible magnitude, namely 0.5 cm in a context in which HE increased by 2 cm. over the long term. Moreover, this influence was positive both in urban and rural areas, suggesting that the railways' impact in France differed relative to the USA and some regions in Germany and the Netherlands. The author provides a likely explanation for the positive effect of railways on HE: French secular transport policy unified the French microbial space before the advent of the railway, which had to result in "a gain in stature which reflects better supplies and better export possibilities, and therefore income" (Heyberger 2011a, p. 286, the translation is ours).

In a subsequent paper on mid-19th-century France, Heyberger (2014) included transportation improvements as an explanatory variable for HE differences across settlements. As a proxy for transportation, he considered whether a rail track crossed a canton. Again, the author observed a positive impact of railways on biological living standards but concluded that this was "a statistical artefact". Once controlled for the male recruit's departments of residence, "the coefficient associated with the railway lines diminishes almost to nothing, be the network that of 1868 (+2 mm) or that of 1853 (-0,1 mm)" (Heyberger, 2014, p. 133). An explanation given by the author was that railways captured socio-economic features before controlling for departments.

Büchel and Kyburz (2016) also found a positive impact of railways on well-being was also found by in late 19th-century Switzerland. In their paper, they used geo-referenced railway network information. Though their primary interest was the relationship between railways and population growth, they also considered sectoral work shares and body HE to test for the effect of railway access on regional development. The empirical strategy these authors followed consisted of using instrumental variables (IV) based on least-cost paths between nodes, namely applying an inconsequential units' IV approach. They run cross-sectional and panel data regressions and OLS and IV estimates. Regarding the impact of transportation on HE, Büchel and Kyburz (2016) performed two cross-sectional regressions at the district level (178 districts), one for the birth cohorts of 1865-1872 (examined from 1884 to 1891) and the other for those born between 1889 and 1893 (inspected in 1908-1912). Their dependent variable was the centimetres change in conscripts' average body HE within these two periods. The authors found that railways positively affected the population's biological living standard once controlled by other factors. Nevertheless, this positive effect was only statistically significant in the second period, when young males' physical stature in districts that gained full railway access in the late 19th century increased by an additional HE of 9.3 mm relative to those with no improved access. According to the authors, these were meagre improvements considering that the average increase in body HE across districts over the same period was 2.2 cm.

Positive but no significant impact is what the study of Ramon-Muñoz & Ramon-Muñoz (2024) on the urban-rural HE gap in late 19th-century Catalonia found for the role of railways and other transportation infrastructure on the physical stature of individuals. Regarding railways access, proxied by the number of railway stations per 100 sq. km in the municipality where the conscript in question resided, the coefficients these authors obtained are positive but with no statistical significance. They also found not statistical significance when measuring the distance between a municipality and a seaport. Similar to Zehetmayer (2011), as well as Heyberger (2014), the authors suggested that the lack of statistical significance might be explained by how their transport variables were proxied. In the case of railways access, they argued that the railways' impact on HE "cannot be ruled out" through the use of "a different proxy".

Instead, the study by Hatton (2014) confirms the positive impact of railways on HE. Unlike most studies, he considered 15 countries for the one hundred years following the 1870s. He estimated fixed effects regressions to account for within-country changes in HE. Among the independent variables in their regression, he included railways, considered a central factor in improving access to fresh foodstuffs. He measured the impact of transport by railway track miles per urban resident at the country level and over the period under consideration. He observed that when infant mortality, which captures the diseases environment, was excluded from the model, the coefficient on "railway miles increases in size and significance" and "its effect was largest in the prewar and early transwar years when the railway mileage increased more rapidly than the urban population" (Hatton, 2014, p. 365).

Recently, Álvarez-Palau et al. (2024) and Ciccarelli, Fenske, and Martí-Henneberg (2023) have considered the relationship between various dimensions of living standards and transportation. One of the novelties of their research is their use of a MA approach. Álvarez-Palau et al. (2024) focused on England during the first industrial revolution and observed that greater MA led to higher child mortality between 1680 and 1830, likely through the mechanism of fostering migration into towns, which resulted in urban overcrowding. By considering Europe between 1840 and 1940, Ciccarelli, Fenske, and Martí-Henneberg (2023) concluded that MA delayed the fertility transition in the Old Continent by increasing the nuptiality of young women due to income gains.

For other countries and regions outside the Western World, the historical studies dealing with railways and living standards are few, and they are mainly focused on India and, to a less extent, Japan. They use different econometric techniques and do not always apply to the same period. Moreover, they keep the relationship between railways and HE unresearched, while their main concern is mortality.

In India, railroad construction led trading costs to decline and to a more integrated market as inter-regional price gaps reduced (Donaldson 2018). In addition, agricultural prices and real incomes were less exposed to weather shocks (Burgess and Donaldson 2010). By relying upon previous findings and through new evidence, Burgess and Donaldson (2017, p. 4) argued that because of the trade openness associated with railways expansion, the incidence of famines reduced in India between the mid-19th and the early 20th centuries, mortality rates also became "less responsive to rainfall shocks as districts are penetrated by railroads".

Ahmad (2021) arrived at similar conclusions for 1881-1931. However, his findings point to pessimism regarding per capita income growth. The author observed that the arrival of railways caused, among others, mortality to fall dramatically, namely by about 9%. Yet, fertility also increased, and, in the end, railways accelerated population growth, absorbing the income gains that might result from railways and increased trade.

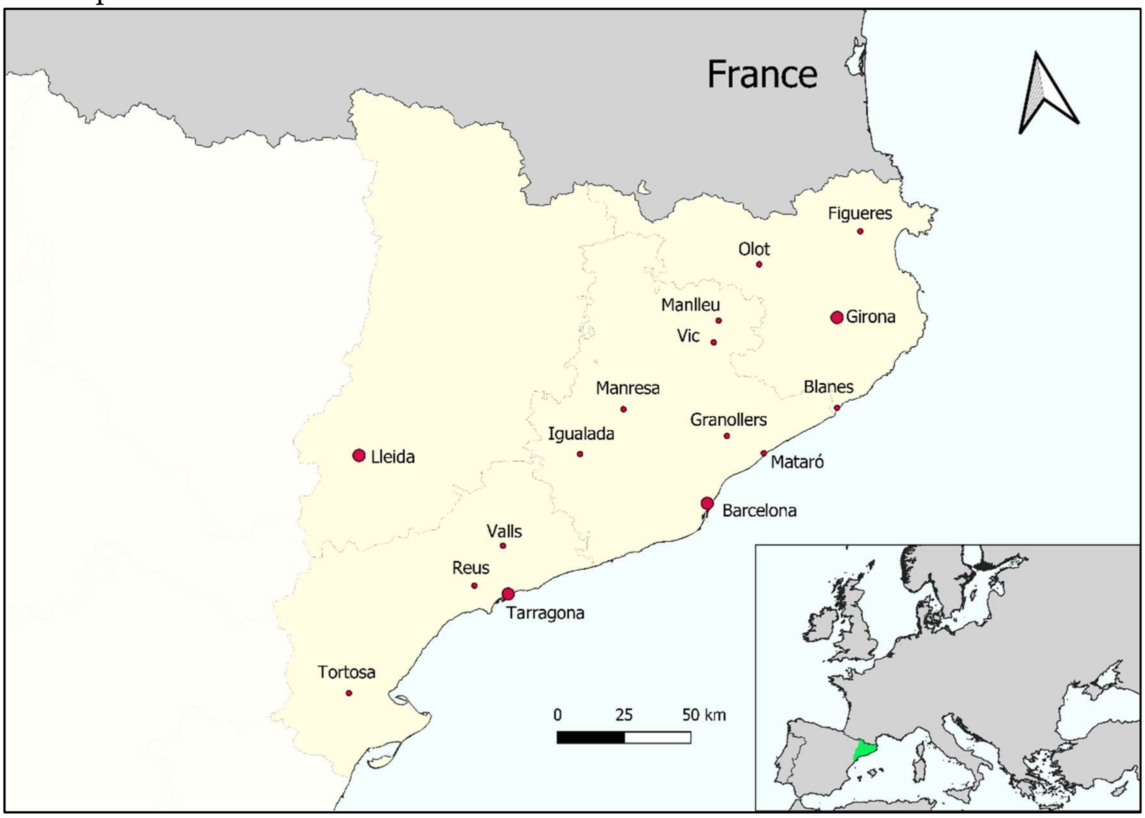
Contrary to the case of India, Tang's (2017) results for Japan over the period 1886-1893 show that gross mortality rates rose by 6% as the railways' network expanded into new regions by the late 19th century. They also indicate that the mechanism behind mortality growth is contagious disease due to more labour mobility and transmission to previously protected areas in rural Japan.

In summary, the available evidence indicates that in the Western world, the initial phases of enhanced market integration during the 19th century may have been linked to a decline in HE. However, trends could vary between rural and urban areas. It is uncertain whether developing regions followed the same pattern, and exceptions to the generally negative impact of transportation associated with market integration have also been observed in the Western world. In the long run, transportation, particularly railways, likely contributed to improved health and better nutritional status among populations. However, there are examples in which the impact of railways on HE has been considered relatively modest and found not statistically significant. Additionally, the effects of other transportation infrastructure during the latter half of the 19th century still need to be explored. Furthermore, there are numerous geographic areas where a comprehensive and in-depth analysis of transportation infrastructure as a potential determinant of biological living standards is still pending, and Catalonia is one such region.

3. Historical context

With a well-established industrial sector, Catalonia (see Figure 1) had become a relatively developed and prosperous region by late 19th-century Southwestern European standards (Rosés & Wolf, 2018). Contrary to other peripheral regions in Europe, the industrialization process started relatively earlier, in the central decades of the 18th century. The first calico printing factories were established in the city of Barcelona in the 1730s, and the industry spread to other cities, including Mataró, Olot, Vic, Manresa, Manlleu, Igualada, and Reus. Barcelona became Europe's leading calico-printing centre by the 1780s (e.g., Sánchez, 1989; Thomson, 1992). Between the 1780s and the 1820s, the cotton textile industry, the most dynamic sector at that time, adopted new machinery, and mechanization spread (e.g., Martínez Galarraga & Prat, 2016 for a summary). The introduction of steam engine and the factory system in the 1830s marked the beginning of a new phase in the industrialization process, which brought important locational transformations (e.g., Nadal 1975; Raveux 2005, for a summary).

Figure 1. Map of Catalonia: current provinces, their capital cities, and other municipalities mentioned in this text



Source: Authors' elaboration. Larger red circles indicate provincial capitals.

The available evidence shows a growing long-term trend in industrial production from then to World War I, though oscillations were far from uncommon (Carreras, 1985; Maluquer de Motes, 1994). After four decades of strong growth, industrial production stagnated in the 1860s, mainly due to the American Civil War, but recovered in the following decade. The forty years following 1880 witnessed moments of modest growth or even decline, which were the result of a series of important events, such as the impact of the so-called late-19th-century agrarian crisis in the 1880s and the Cuba Independence War in the second half of the 1890s. Yet, according to existing estimates, annual rates of growth remained above 3% between 1880 and 1900 and above 2% between 1900 and 1910.

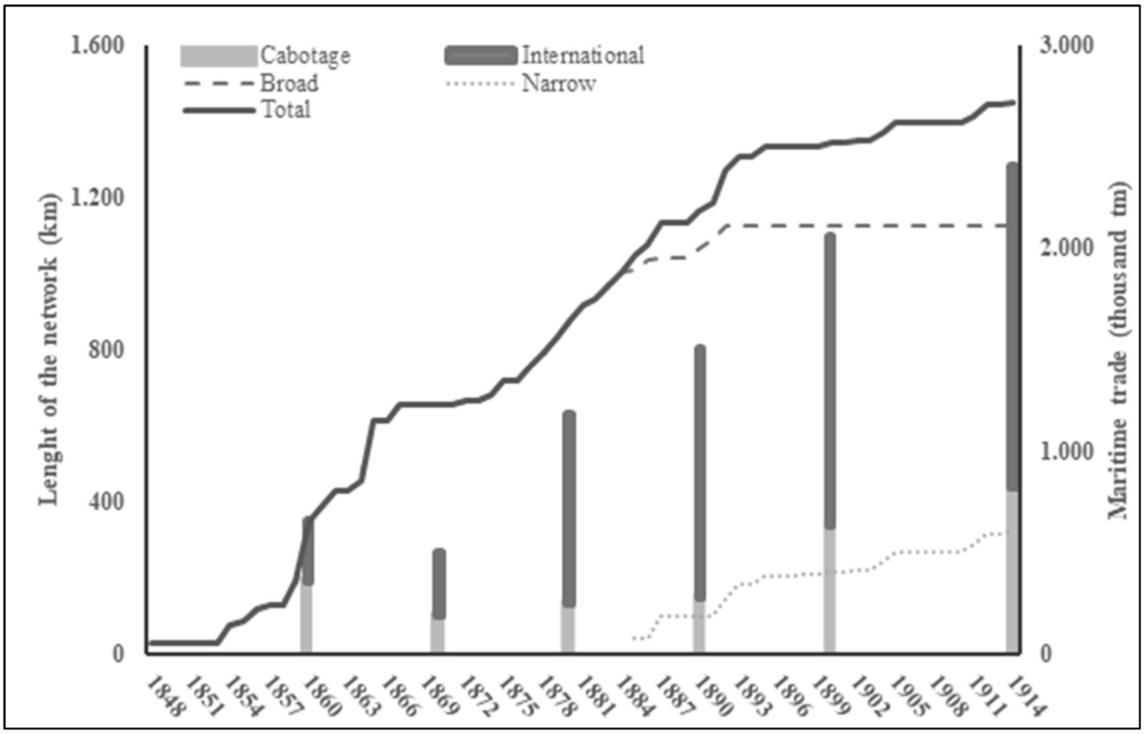
As in the rest of Western Europe, Catalonia's industrialization process was not without its costs. While crude death rates began a declining long-term trend between the 1760s and the 1840s (Ferrer-Alòs, 2021), infant and child mortality did not, at least in certain industrial towns and urban centres. The case of Igualada has been well researched. Located in the centre of Catalonia, west of the city of Barcelona, by the 1760s, Igualada was a leading wool district that, by the 1840s, had already transformed into Catalonia's leading cotton centre. In this context, infant mortality rates rose between the mid-18th century and the first decades of the 19th century as domestic and proto-industrial woollen activity expanded and remained very high over the first two-thirds of the 19th century when the factory system emerged and became predominant in the town. Infant mortality rates (1q0, children under the age of one year old) of 200 per thousand live births and even higher were far from uncommon between the 1780s and the 1860s (Marfany, 2010; Ramon-Muñoz & Ramon-Muñoz, 2015).

Not surprisingly, high levels of infant mortality rates have also been reported for mid-19th century Barcelona, by far the largest urban area in Catalonia (Sáez, 1968; Benavente, 1990), which can be explained by several factors. One of them is related to food consumption, and indeed, there is enough evidence showing deficiencies in terms of availability, variety, and quality in food consumption and, therefore, suboptimal diets among the working class in Barcelona during the decades around 1850, particularly regarding children and females (Cussó, 2016; Borderías, 2016; Borderías & Cussó, 2023). In fact, per capita meat consumption is likely to have declined in Barcelona between the late 1840s and the 1860s, as data on carcass meat from the city's slaughterhouses suggest (Nicolau & Pujol, 2005).

HE data available for other urban centres in Catalonia go in the same direction. To give some examples, in the industrial towns of Reus, Manresa, and Igualada, the physical stature of the cohorts born between the 1840s and the 1860s experienced a clear declining trend (Ramon-Muñoz, 2011; Ramon-Muñoz & Ramon-Muñoz, 2016, 2018), suggesting a deterioration of the nutritional status of the population in the years that the steam engines and the factory system were spreading. Reus, Igualada, and Manresa were certainly far away from Barcelona as far as inhabitants were concerned. Still, with 28,171, 15,264, and 14,000 inhabitants, respectively, they ranked among the ten largest towns and cities in Catalonia in 1857.

If industrial HEs fell before the 1870s, rural HEs experienced a similar decline, at least in western Catalonia, where they dropped by 1.4 centimetres from 164.8 to 163.4 between the ten-year periods of 1840-1849 and 1851-1860 (Ramon-Muñoz & Ramon-Muñoz, 2018). However, available data suggest that the decline in biological living standards was less severe in rural than in industrial areas, leading to the emergence of an urban HE penalty in mid-19th century Catalonia and, consequently, uneven health and nutritional conditions associated with the type of settlement (Ramon-Muñoz & Ramon-Muñoz, 2024).

Figure 2. The Expansion of the railway network and maritime trade in Catalonia, 1848-1914



Sources: Authors' elaboration from: Railway length: Esteban-Oliver and Martí-Henneberg (2024). Maritime trade: Álvarez-Palau, Esteban-Oliver and Martí-Henneberg (2025). Notes: Maritime trade includes cabotage and international traffic for all the ports of Catalonia.

Along with other issues related to public health, food consumption became a major concern among urban planners and social reformers in mid-19th century Catalonia (e.g., Monlau, 1847; Cerdà, 1867; Giné i Partagàs, 1872). Not surprisingly, it was also an issue that businessmen paid close attention to and invested significant efforts and resources in, although for different reasons. Indeed, while the Catalan industrial sector was very dynamic, it was not internationally competitive, in part due to facing very high energy and food prices (e.g., Nadal and Sudrià, 1993; Pascual, 1999, p. 37, Delgado, 2022).

Therefore, one of the primary concerns of economic agents for the development of transport infrastructure in Catalonia was focussed on addressing this issue. They reasoned that better connections with the agricultural and mining areas in inner Catalonia, the wheat-producing regions in central Spain and the rest of Europe would reduce the import costs of coal and grains, thus fostering the industry's competitiveness. It would also facilitate the export of commercial agricultural products, such as wine and olive oil, and manufactures to Spain and its colonies in Cuba and The Philippines.

Figure 3. Railway lines, ports, paved roads, and nodes in 1890 Catalonia

Source: Authors' elaboration using Esteban-Oliver and Martí-Henneberg (2024), Esteban-Oliver, Álvarez-Palau and Martí-Henneberg (2024) and Esteban-Oliver, Álvarez-Palau and Martí-Henneberg (Mimeo) for railways, ports and roads respectively.

Railways were the primary transport technology for this purpose, and its construction was considered a priority in the region. Proving this priority is that the first line that opened in peninsular Spain connected Barcelona with Mataró in 1848. However, it was only after the passing of the Railways General Law (*Ley General de Ferrocarriles*) of 1855 and until the financial crisis of 1866 that the network expanded fastest. A second wave of construction started in 1877, and by 1890, most of the lines were already in operation (Figure 2). Private capital mainly financed the construction of the network, which followed a radial approach, with its centre in Barcelona and, to a lesser extent, in the southern cities of Reus and Tarragona. These were central nodes, and from them, the network focused on connecting several areas, including critical municipalities on the coast with inner Catalonia, Spain's most populated areas, through the cities of Zaragoza and Valencia, and the French border along the northeastern town of Figueres (Figure 3).

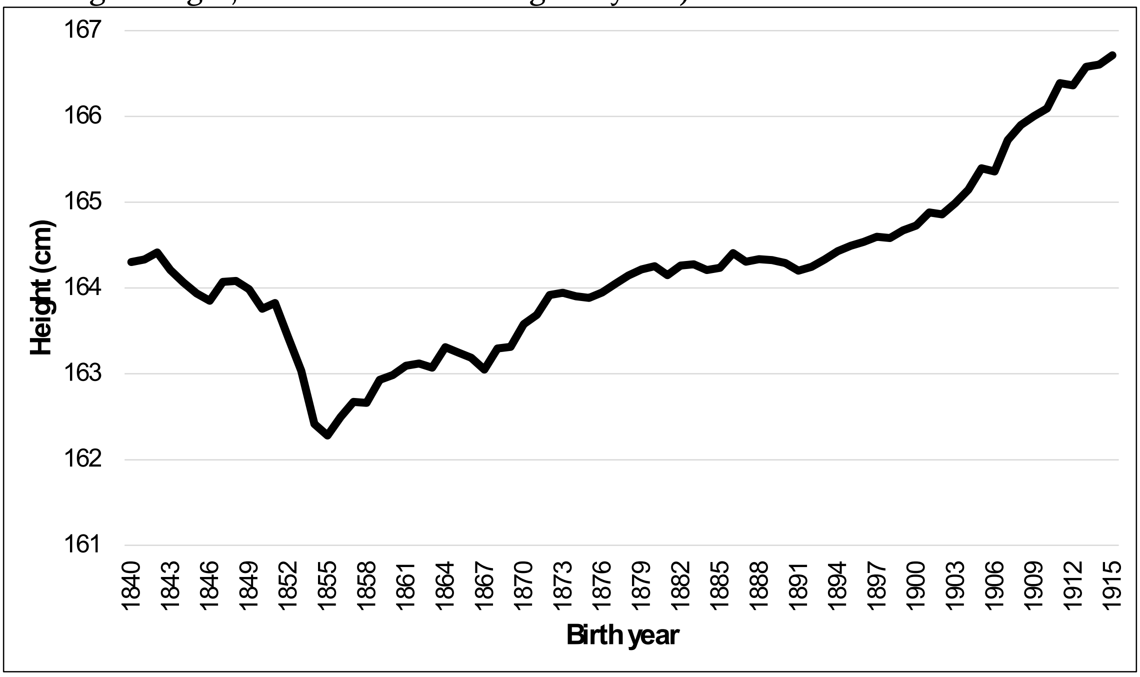
The Catalan port system also had its centre in Barcelona. Its port received several improvements, completed by 1875, and gained a direct railway connection in 1881, greatly facilitating trading activities (Alvarez-Palau, Esteban-Oliver & Martí-Henneberg, 2025). The port of Tarragona also played a significant role in Catalonia's economy. Like Barcelona's port it underwent significant improvements during the second half of the nineteenth century, and by 1856, it already had a connection to railways. Regarding the rest of the Catalan ports, they were primarily significant at the local level. In addition to improving port infrastructure and its connection with railways, the transition from sail to steamships in the 1870s was also crucial since it reduced maritime transport costs and significantly shortened shipping times worldwide (Pascali, 2017). Importantly, the ports in the region—particularly Barcelona's port—were central to Catalonia's economic expansion, facilitating major trade flows and maintaining vital links with Spanish colonies in Cuba and Puerto Rico, as well as with European countries. Indeed, Barcelona's port held a prominent position within Spain's port structure, driven by increasing exports of industrial goods and cash crops, alongside imports of primary products (Álvarez-Palau, Esteban-Oliver and Martí-Henneberg, 2025).

Concerning paved roads, authorities initially projected them to ease access from the inland areas to the region's leading ports. However, the development of paved roads acquired a new purpose after the construction of the railway: they had to facilitate the accessibility of isolated populations to the nearest stations (Pascual, 1999). Therefore, paved road development aimed to alleviate the excessive radiality of the Catalan railway network. They expanded in two waves. The first wave started in 1848, after the promulgation of the *Ley General de Carreteras* (Roads General Law); whereas the second wave developed during the 1880´s. This translated in an increase from around 970 km in 1860 to 1,500 in 1877, and 1,900 in 1890. However, by this latter year, the network's density was relatively modest, and, according to some scholars, this hampered agricultural and industrial development in Catalonia's most isolated areas (Pascual, 1999, p. 40).

Did improved transportation infrastructure enhance living standards in Catalonia? The well-being of the population clearly improved from the 1860s onwards.

Epidemics were not eradicated, and in fact, they were far from unusual in the 1850s and 1860s (cholera), the 1870s (smallpox and yellow fever), the 1880s (cholera), and over the period 1902-1914, during which the Catalan population suffered from smallpox in 1904 and 1906, dengue and typhoid fevers in 1905 and 1914 respectively, and some bouts of the plague in 1906 and 1913 and cholera in 1911 (Sabaté, 2017, p. 43). However, the general health environment of the Catalan population appears to have improved. Infant mortality rates declined, as data on both infant and child life expectancy in Catalonia for the years 1865, 1890, and 1910 clearly show (Cabré, 1999, p. 41). The same is true for industrial towns for which data are available, such as Igualada. In this latter case, infant mortality rates (1q0) almost halved between 1860 and 1890, from around 200 deaths of children under the age of one year old per thousand live births to around 100 (Ramon-Muñoz & Ramon-Muñoz, 2015, p. 31).

Figure 4. Males mean HE trends in Catalonia in the nineteenth century (five-year moving averages; standardised HE at age 21 years)



Source: Authors' elaboration from Ramon-Muñoz and Ramon-Muñoz. CATHE-9 Dataset.

HE data also capture this general improvement in health and nutritional status. After decades of decline and stagnation, the physical stature of male cohorts born in Catalonia after the 1860s began to grow (Figure 4). This time, urban HEs rose more than rural ones. As a result, the cohorts of urban males born in 1890 and residing in 1911 in settlements of more than 20,000 inhabitants were between half and three-quarters of a centimetre taller compared to those residing in rural areas of 5,000 inhabitants or less. This means that by the late 19th century, the former urban HE penalty had reversed into an urban HE premium. The point to be stressed is, nevertheless, that on average, the physical stature of the cohorts of young Catalans grew by around 4 cm between the late 1860s and the outbreak of World War I. This increase is certainly lower than in other regions in southern Europe. Yet, by the early 1910s, Catalonia was probably one of the regions in Iberia where young people were taller (Ramon-Muñoz & Ramon-Muñoz, 2024). This paper aims to assess whether transportation infrastructure explains these improvements and the cross-territorial HE differences within Catalonia.

4. Data

To examine the influence of transport infrastructures on biological living standards, we present a novel dataset that combines information on individual male HE and municipal MA. Notably, since the liberal reforms of the 19th century, municipalities have been the smallest territorial units in Catalonia. They typically consist of a single population centre and have an average area of approximately 35 km², allowing for a high level of territorial detail. Additionally, we also consider other variables that will be introduced below. Importantly, as the first years of life are critical in determining the final HE of an individual, the main explanatory and control variables will always refer to the period around the year of birth of the conscripts (Tanner, 1978; van Zanden et al., 2014; Schneider, 2020; Gao and Schneider, 2021).

4.1. Height (HE)

Information on male HEs comes from Ramon-Muñoz and Ramon-Muñoz (2024) and was originally extracted from Spanish military sources (Tables 1 and 2). This dataset refers to the cohort born in 1890 and, inspected, measured, and enlisted in 1911 (when they were 21-year-old).

First, we consider the birth cohort of 1890 because, to date, it is the only one for with data for the entire Catalan territory. Moreover, as mentioned in the previous section, the bulk of railways and other modern transportation infrastructures investments were done between the 1860s and 1880s (Figure 2). Consequently, we expect that similarly to the case of population dynamics (Esteban-Oliver, 2023), their effect on HE was especially noticeable by the latest decades of the 19th century.

Second, the dataset we use has a broad coverage. It includes 91% of the 21-year-old recruits born in 1890, who were still alive in the enlistment year of 1911 and had Catalonia as their official residence. Also, it comprises data for 99% of the total municipalities according to the 1911 municipal borders and 97% of the current municipalities. This distinction between historical and current municipalities requires further consideration. To allow for future intertemporal comparisons, and so that all variables remained consistent, we adjusted this information to Beltrán-Tapia et al.

(2023) municipal database (ESPOP), which provides homogeneous municipalities and their population size for the 1860 to 1930 period. However, the ESPOP database presents an issue. It does not provide historical borders. Consequently, we used the 2018 borders map of the Spanish National Geographic Institute (*Instituto Geográfico Nacional*, IGN), the most recent available. Unfortunately, some historical municipalities no longer exist today, meaning their borders were unavailable. In these cases, we approximated their historical boundaries by creating a 35 km² buffer area—equivalent to the average municipal size in Catalonia—around their centroids.

Table 1. Description of the variables

Variables	Description	Source
	Dependent variable	
Recruits' height, HE	Recruits' height (HE) in mm	Ramon-Muñoz and Ramon-Muñoz (2024)
	Transport variables	
Market Access, MA	*Ln* of municipal market access	Own work
Access to ports, PA	Binary indicator, equals 1 if there is a port with custom offices within the borders of a municipality	Álvarez-Palau, Esteban-Oliver and Martí-Henneberg (2025)
	Control variables	
	First-nature variables	
Municipal coordinate X	Municipal latitude in degrees	Beltrán-Tapia et al. (2023)
Municipal coordinate Y	Municipal longitude in degrees	Beltrán-Tapia et al. (2023)
Ln land suitability index for wheat, olives and citrus	Log of the municipal land suitability index for wheat in the average period 1961-1990	FAO-GAEZ https://gaez.fao.org/pages/data-viewer
	Second-nature variables	
Ln population 1860 and 1887	Log of the municipal population in 1860 and 1887	1860 and 1887 Population census (Junta General de Estadística, 1863; and Instituto Geográfico y Estadístico, 1892; respectively)
District capital dummy	Binary indicator, equals 1 if capital of the judicial district, 0 otherwise	1887 Population census (Instituto Geográfico y Estadístico, 1892)
	Territorial categorical variable	
Territorial Units	Categorical variable, 1 to 8 depending on the Territorial unit a municipality falls into	IDESCAT
	Instrumental variables for transportation	
MA (LCPs)	Modified market access indicator	Own work.
Indicator of lighthouse	Binary indicator, equals 1 if there is a lighthouse within the borders of a municipality, 0 otherwise	Esteban-Oliver, Álvarez-Palau and Martí-Henneberg (2024)

Source: Authors' elaboration. See also text.

Third, our data also avoid some of the significant shortcomings in studies using HE data from military sources. Most of the explanation for this lack of shortcomings is that military service was compulsory and universal by the cohorts born around 1890. In other words, our recruits' lists contain the HEs of all the conscripts called for recruitment and present during the inspection process, irrespective of whether they will serve (Komlos, 2004; Bodenhorn, Guinnane & Mroz, 2017, 2019; Komlos & A'Hearn, 2019; Zimran, 2019; Schneider, 2020).

Fourth, the dataset we use provides information on the place of residence of conscripts but not their place of birth. This could raise concerns about selection bias, particularly in the context of industrialisation and significant migratory flows from rural areas to industrial cities, which may have affected the biological standard of living in both urban and rural areas, either positively or negatively. However, for Catalonia, the available evidence for the cohorts born in late 19th century suggests that rural-to-urban migration did not result in an increase in the average height of the urban population. This is because rural migrants—whether from Catalonia or other regions of the Iberian Peninsula—tended to have a lower average height than those born in major industrial cities. Likewise, according to the same evidence, the average height of Catalan rural conscripts residing in urban municipalities was not significantly different from that of those who remained in rural areas (Ramon-Muñoz & Ramon-Muñoz, 2022, 2024).

4.2. Market Access (MA)

In this study, we seek to understand the effect of transport linkages on living standards. To achieve this, we followed Donaldson and Hornbeck (2016) MA framework[1]. However, we formulated the MA variable using a simplified approach as articulated in Álvarez-Palau et al. (2024). This can be defined as:

(1)

$$MA_i = \sum_{j}^{J} pop_j \, \tau_{ij}^{-\theta}$$

Where pop_j refers to the population data of municipality j, τ_{ij} are the trade costs between i and j, and θ is a parameter greater than 1, reflecting inverse variation of productivity across locations. Importantly, this "simplified" approach omits the trade resistance term $MA_j^{-(1+0)/\theta}$ included in Donaldson and Hornbeck (2016) original formulation. The main advantage of this omission is that the MA indicator can be

[1] This approach builds on several foundational works, including Redding and Venables (2004) and Eaton and Kortum (2002).

calculated more easily. On the other hand, this could bias the measures of MA_i. However, results usually remain nearly identical using both formulations in previous works. This points to the bias of omitting this term being only minor (Álvarez-Palau et al., 2024).

Regarding the trade cost term, τ_{ij}, we followed a large literature in defining it as:

(2)

$$\tau_{ij} = \frac{tc_{ij}}{Producer\ Price} + 1,$$

Where tc_{ij} is the monetary freight transport per unit and $Producer\ Price$ is the average per unit price paid to producers. To obtain this value, we first calculated the freight transport costs term between all Catalan municipalities, tc_{ij}. To do so, we utilised the multimodal transportation model of Spain for the year 1887 Esteban-Oliver, Álvarez-Palau and Martí-Henneberg (Mimeo).[2] Specifically, we integrated this transportation database and all the 911 Catalan municipal centroids in Geographical Information Systems (GIS). We then applied network analysis tools to determine the lowest-cost routes for all possible bilateral connections between these centroids using Dijkstra's algorithm. This algorithm minimizes the cost of accessing the network from the origin TC_i^o, the cost of traveling through all the different means TC_{pq}^n, the transshipment costs TC_r^t and the cost of arriving to the destination TC_j^d:

(3)

$$tc_{ij} = \min\left[tc_i^o + \sum tc_{pq}^n + \sum tc_r^t + tc_j^d\right]$$

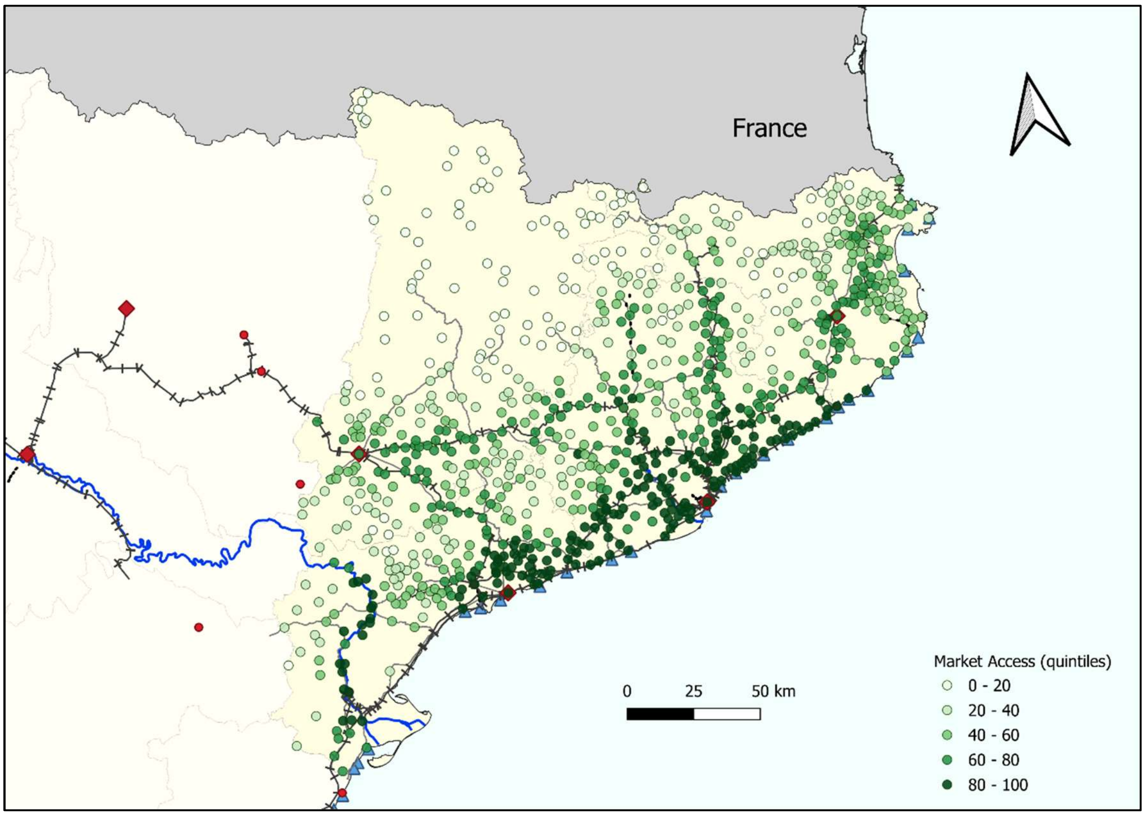
Importantly, using this same database and formulation we also calculated the transportation costs between all Catalan municipalities and the 440 Spanish district capitals. This step was necessary to account for the rest of the country when calculating the MA of Catalan municipalities (see Equation 1). While transportation and population data are available for all of Spanish municipalities, we limited the sample to the district capitals for computational feasibility. Computing a freight cost matrix for all 9,130 origin-destination pairs would have resulted in over 45 million bilateral connections, imposing an excessive computational burden on the analysis.

Although using only district capitals simplifies calculations, it could introduce bias, as these capitals did not contain the entirety of their district's population. To address this issue, we followed Donaldson and Hornbeck (2016) approach, and assigned the

[2] Between 1887 and 1890, no new railways were constructed, and road construction was minimal. Consequently, the transportation networks in 1887 and 1890 remained virtually unchanged. For further details on the reconstruction process of this database, see Esteban-Oliver, Álvarez-Palau and Martí-Henneberg (Mimeo) Appendix B.

total district population to its capital, assuming that, as administrative and commercial hubs, district capitals were usually centres for trade in 19th-century Spain.[3] This resulted in a matrix of 943,973 freight cost connections covering all municipalities included in the sample in the sample tc_{ij}.

Figure 5. Municipal level Market Access (MA) in Catalonia (1890)



Sources: Authors' elaboration.

Next, we calculated the average *Producer Price*. Firstly, we identified the share of different traded goods in late 19th-century Spain from the Memoirs of the MZA and Norte Railway companies (Anes, 1978), as well as from the *Estadística*(s) *Generales(s) del Comercio Exterior de España,, con sus provincias de ultramar y potencias extranjeras* and *Estadística(s) general(es) del comercio de cabotaje entre los puertos de la Península e Islas Baleares* (Spanish foreign trade and cabotage statistics) for the year 1890.[4] Based on this information, we selected goods that represented a significant percentage of the total traded merchandise and had reliable producer price data. The selected goods — wheat, flour, coal, olive oil and wine—accounted for a 60% of the total trade tonnage in late 19th-century Spain. These products were also representative of the trade

[3] Donaldson and Hornbeck (2016) employed the same approach, assigning the entire population of each county to its capital.
[4] By 1890 MZA and Norte managed the vast majority of the Catalan railway network (Esteban-Oliver and Martí-Henneberg, 2022).

patterns at the time: wheat exemplified mid-value goods per metric tonne, while coal and olive oil of represented low and high value goods per metric tonne respectively.

Secondly, we determined the producer price for each of product category. The producer prices for wheat, flour, olive oil and wine were extracted from the *Boletin(es) Oficial(es) de la(s) Provincia(s)* (Spanish provincial official bulletins) for the year 1890, including only prices reported by the top-producing markets to calculate it.[5] The average producer price of coal for 1890 was sourced from Coll and Sudrià (1987). To compute the overall average producer price, we multiplied each product's share — 21% (wheat), 15% (flour), 26% (coal), 5% (olive oil) and 32% (wine)— by its corresponding average producer price per metric tonne —191, 288, 11, 935 and 167 pesetas, respectively This resulted in a final weighted average producer price of 196 pesetas per metric tonne for the period.

Thirdly, we calculated the trade elasticity parameter θ, which inversely captures the log standard deviation of productivity and reflects to the scope for comparative advantage. Following Álvarez-Palau et al. (2024), we estimated various versions of Equation (1) at different values of θ. We selected a value of 2 as it yielded the highest R2 across several specifications.

Lastly, we combined this information with the municipal population data (Beltrán-Tapia et al., 2023), and solved Equation (1) to estimate MA for 911 Catalan municipalities. Figure 5 presents the spatial distribution of MA across the region, showing that, in 1890, MA was highest near the better-connected and most populated areas, such as Barcelona and Tarragona. Conversely, it was lowest in the north-western part of Catalonia, a sparsely populated, mountainous area with no easy access to modern transport infrastructure.

4.3. Port Access (PA)

As highlighted in the historical context section, international and colonial trade played a pivotal role in late 19th-century Catalonia. One limitation of our MA approach is that it does not fully account for the potential effects of accessibility to these specific markets on living standards. To address this issue, we introduce a proxy variable for accessibility to international and colonial markets, using a PA indicator.

[5] For olive oil, wine, and cereals, this information was extracted from Dirección General de Agricultura, Industria y Comercio (1891a, 1891b, 1891c) (Statistical Report(s) on the Cultivation and Production of Olive, Vine, and Wheat and Other Cereals in Spain). For flour, we used its price in Santander, the leading production area in Spain during this period.

This binary variable is defined as 1 if a municipal centroid is within 4km of a port that had customs offices during this period, and 0 otherwise. We determined the 4km threshold through a cross-sectional analysis assessing the impact of port proximity on recruits' health outcomes across different spatial units (see Table A.1, Appendix). The results indicated that the effect of proximity to ports was significantly stronger for recruits residing in municipalities located within 4km of a port, while the effect size remained consistent for other spatial units. Interestingly, this finding aligns with previous research on the geographical threshold effect of railway stations on population growth (Esteban-Oliver, 2023), further bolstering the validity of our chosen binary indicator.[6]

Importantly, we opted for this binary approach rather than using continuous variables, such as distance or as the minimum cost (in terms of time and money) of reaching Catalonia´s ports. This decision was driven by the fact that in Catalonia's case, these types of variables exhibited high correlation with the domestic MA, which lead to severe multicollinearity issues.[7]

4.3. Other data

We incorporated several other municipal-level variables sourced from various databases and sources (Table 2).[8] Firstly, we developed a new land suitability database for Catalan municipalities using the Food and Agriculture Organization (FAO) raster database, accessible at https://gaez.fao.org/pages/data-viewer, which provides information on wheat, citrus, and olive cultivation.

Secondly, we obtained municipal coordinates (latitude and longitude) from Beltrán-Tapia et al. (2023). These coordinates were originally extracted from the 2018 Map of the Instituto Geográfico Nacional (IGN, 2018).

Thirdly, data from the 1887 Population Census (Instituto Geográfico y Estadístico, 1892) was utilised to determine whether each municipality served as the capital of Judicial District in that same year, and to extract municipal literacy rates.[9]

[6] Moreover, ports are typically located around 2 km from the nearest municipal centroid, where their influence is most pronounced.
[7] This correlation exists because both population size and the stock of modern transportation infrastructure were significantly greatest in coastal areas.
[8] Unfortunately, individual-level variables for all municipalities are not available. For instance, there is no data on personal or family income, literacy levels, or the occupations of recruits' parents. Therefore, we rely on additional municipal-level variables, assigning each recruit to the municipality where they were officially residing in 1911.
[9] Judicial districts were territorial divisions for the administration of justice, comprising neighbouring municipalities within the same province. Their capitals, designated as administrative centres, could differ significantly in socioeconomic structure from other municipalities within the district

Table 2. Summary Statistics of the variables

Variable	Obs	Mean	Std. Deviation	Min	Max
Dependant variable					
Recruits' height, HE (mm)	17,968	1,642.72	62.13865	1,000	1,930
Transport variables					
Market access, MA (index)	911	101,228	64,386	17,049	556,122
Access to ports, PA (Yes=1)	911	0.03	0.1604039	0	1
Selected control variables					
Land suitability index for wheat	911	3,843.41	1,610.352	0	7,850
Land suitability index for olives	911	1,615.58	860.4987	0	4,153.53
Land suitability index for citrus	911	1,886.28	1,284.088	0	4,499.613
Population size 1887	911	2,019	13,636.27	126	405,913
Population size 1860	911	1,786	8,857	192	254,542
District capital dummy (Yes=1)	911	0.04	0.1986	0	1
Distance to a node (meters)	911	29,547.81	20,487.8	0	110,568.8
Municipal literacy rate 1887 (%)	911	25.39	9.405666	2.23	61.24
Instrumental variables for transportation					
Access to LCP (Yes=1)	911	0.313622	0.4642098	0	1
At least 1 lighthouse (Yes=1)	911	0.02	0.1366229	0	1

Source: See Table 1 and text.

Lastly, information on the Territorial Units (TUs) to which each municipality belonged was retrieved from IDESCAT, the Statistical Institute of Catalonia. Catalonia is divided, among other administrative divisions, into eight TUs, officially known as territorial planning areas (Figure A.1, Appendix). They group together counties with similar geographical and developmental characteristics, though they may differ in other aspects (Ramon-Muñoz & Ramon-Muñoz, 2024).

5. Empirical strategy

5.1. OLS approach

In this section, we outline our empirical strategy. Overall, our analysis employed several specifications of the following model to analyse the impact of market accessibility on living standards, as proxied by male HEs:

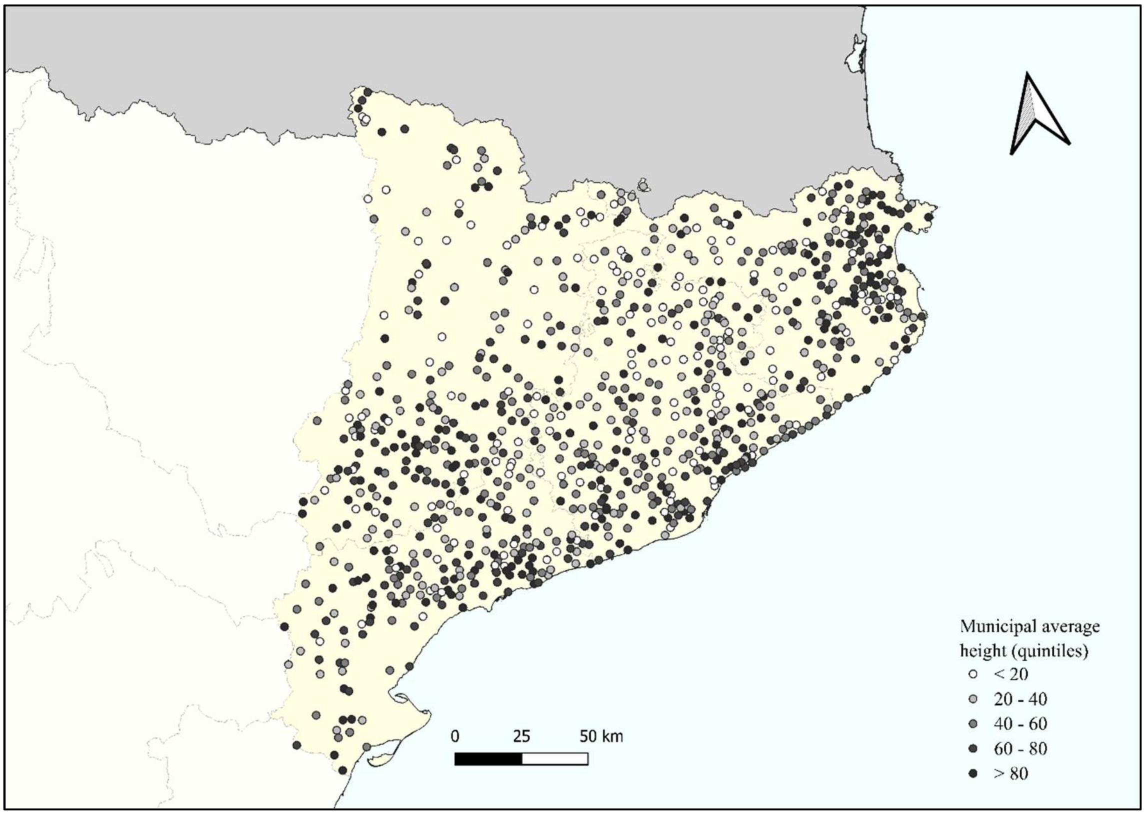
(4)

$$HE_{im,1890-1911} = \propto_2 + \beta_1 \widehat{\mathrm{MA}}_{im,1890} + \beta_2 \widehat{\mathrm{PA}}_{im,1890} + \emptyset_2 X_{im,1890} + \mathrm{TU}_{im,1890} + \eta_{im}$$

Where the outcome $HE_{im,1890-1911}$, i.e. the height of recruit i born in 1890, inspected in 1911 and resident in municipality m in 1911, is a function of municipal MA

$\widehat{\text{MA}}_{im,1890}$ and PA $\widehat{\text{PA}}_{im,1890}$ in 1890. The term $\emptyset_2 X_{im,1890}$ is a vector incorporating all control variables.

Figure 6. Municipal mean HE of recruits in 1911 in quintiles



Notes: Authors' elaboration.

Regarding first nature variables we included land suitability indices for key Mediterranean crops—wheat, olive, and citrus. These indexes account for several geographical factors such as land composition, altitude, pluviosity and ruggedness. Consequently, to avoid collinearity problems, we exclude this latter set of variables from the analysis.[10]

Spatial heterogeneity and autocorrelation can pose robustness challenges in territorial modelling. However, as illustrated in Figure 6, these concerns do not appear to be particularly significant in our case study. Nonetheless, to flexibly address potential spatial issues, we included a second order polynomial in municipal coordinates (longitude and latitude). Additionally, we included a categorical variable for Territorial Units, $\text{TU}_{\text{im},1890}$, which is expected to further account for spatial differences. Specifically, this term should help capture time-invariant territorial

[10] For example, land citrus suitability is highly correlated with municipal altitude (See Figure A.3 and A.4, Appendix).

characteristics, thereby isolating the impact of transportation on HE by controlling for local differences.

We also included several second-nature variables as controls. Firstly, we added a dummy variable indicating whether a municipality served as the capital of a Judicial District in 1887, as they may have had distinct socioeconomic characteristics compared to other municipalities (see Section 4.3). Secondly, we included municipal literacy rates to account for variations in local development. Lastly, note that although the model is estimated at the recruit level, all variables are measured at the municipal level. Therefore, standard errors are clustered at the municipal level to account for this hierarchical structure.

5.2. Endogeneity concerns

While an OLS approach is useful for establishing a correlation between transport linkages (MA and PA) and HE, this identification strategy can raise empirical concerns when attempting to stablish a causal relationship. Unobserved historical factors that influenced recruits' heights before the 19th-century transport revolution may have also shaped spatial population distribution and subsequent transport investments in Catalonia. If this were the case, our outcome variable (HE) could be explaining municipal MA and PA rather than vice versa, leading to endogeneity and biased results.

To mitigate these concerns, we implemented several strategies. First, we reduced sample selection bias by removing the observations where endogeneity concerns may be more severe. Thus, following Esteban-Oliver (2023), we eliminated the nodes from the sample.[11]

Another approach to addressing endogeneity is the inclusion of fixed effects (FE) at various territorial levels. However, given that our empirical strategy is cross-sectional, we could not include FE. Nonetheless, the TU categorical variable serves as a partial substitute, helping to control for regional unobservables. Further, the inclusion of additional control variables mitigates omitted variable bias and accounts for heterogeneity. Notably, we included municipal population size in 1860, —prior to the transport revolution— to reduce potential confounding between HE and MA.

[11] The nodes represent key cities that were deliberately selected as central points in the transportation networks because of its economic relevance. In Catalonia, these include Barcelona, Tarragona, Girona, Lleida, Blanes, Reus, Figueres, Manresa, Tortosa, and Granollers. See Figure A.2 in the Appendix.

This variable is particularly relevant as it may explain both HE (Ramon-Muñoz & Ramon-Muñoz, 2024) and MA (Equation 2) in 1890.

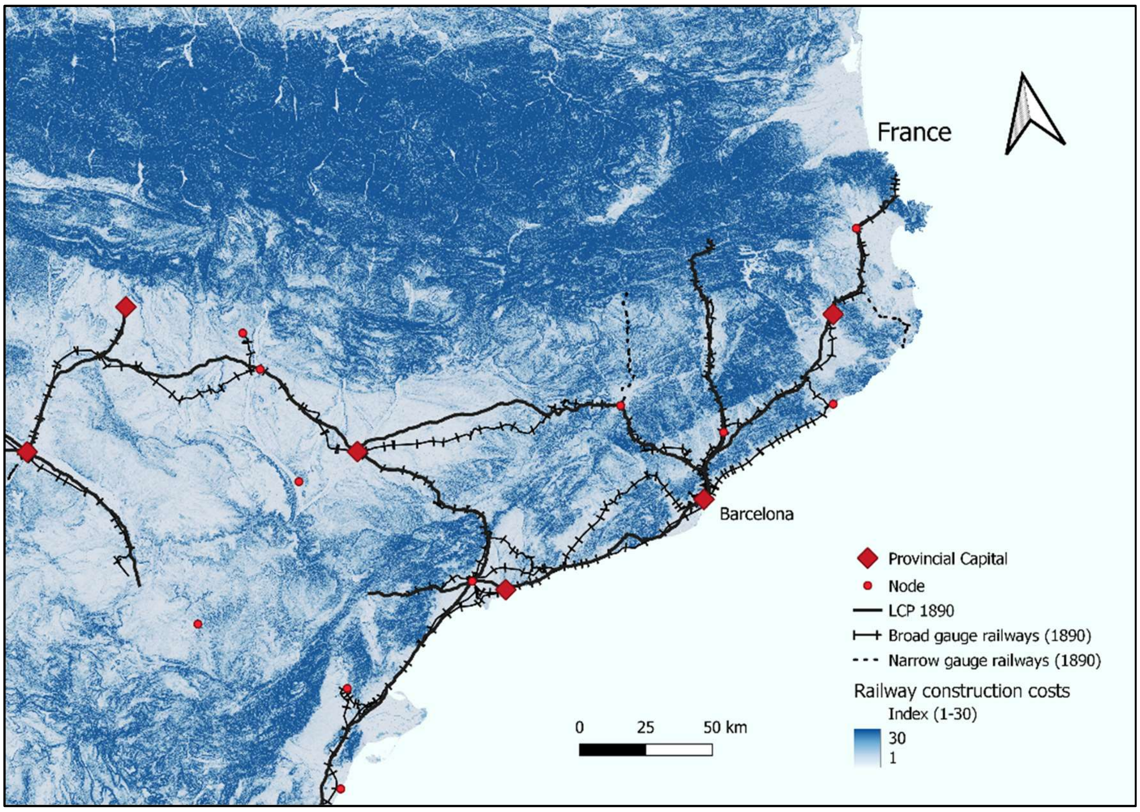
In addition to the above, and to further mitigate endogeneity concerns, we adopted an instrumental variable (IV) approach as our primary identification strategy. We employed separate instruments to address this issue for both the MA and PA variables.

5.3. Empirical strategies: Instrumental Variables (IV) approach

5.3.1. IV approach for Market Access (MA)

As discussed, Equation (3) helps establish a correlation between HE and MA, but the relationship may be biased. To address this issue, we employed an IV approach. Following Jaworski & Kitchens (2019) and Fernihough & Lyons (2022), we adopted an IV strategy based on calculating an alternative measure of MA, replacing the actual transportation networks with a non-endogenous counterpart. Specifically, we implemented the Least Cost Paths (LCPs) approach outlined by Álvarez-Palau et al. (2024).

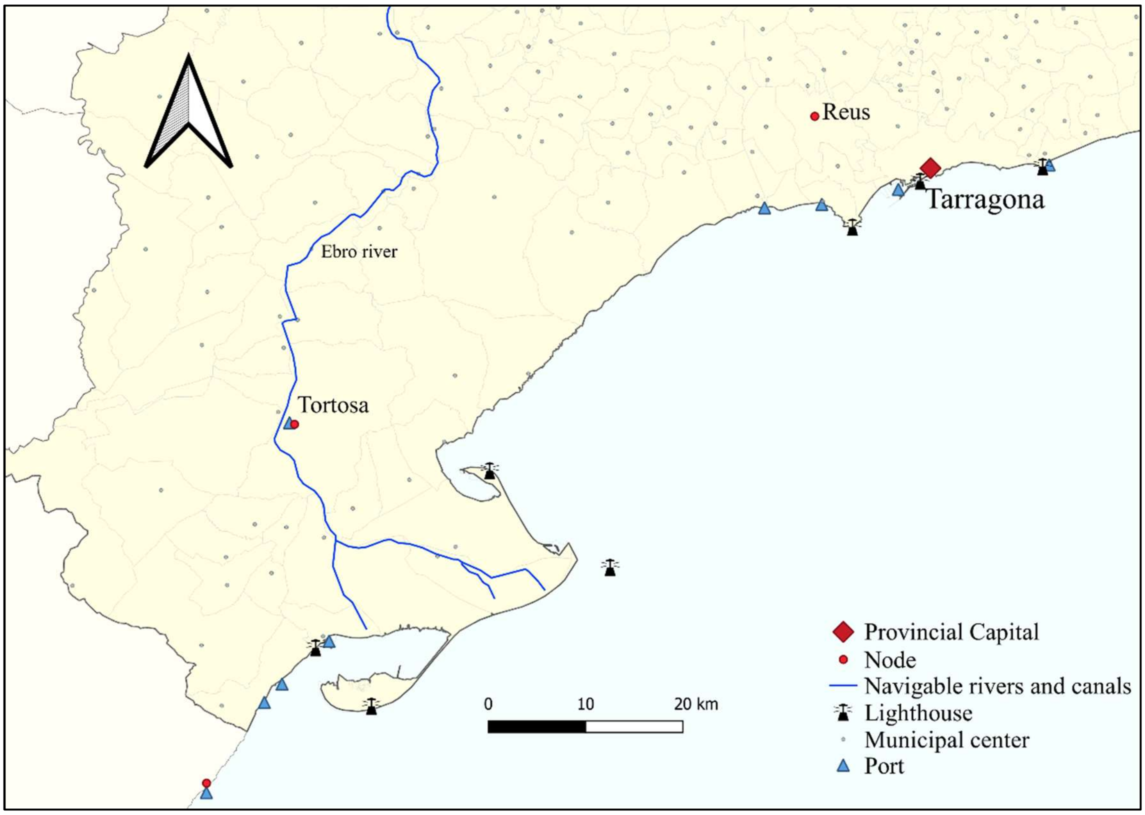
Figure 7. Least Cost Paths Railway Construction Costs and Lines in 1890



Source: Authors' elaboration.

This approach assumes that transport infrastructure development prioritised connecting major urban nodes. If infrastructure were built to link these nodes in the most cost-effective way, access would be determined solely by geographical factors rather than the socioeconomic characteristics of municipalities along the route. However, planners occasionally deviated from the most direct route, potentially introducing selection bias. To address this issue, the literature employs an IV strategy based on geographically optimal routes (LCPs), which represent the paths that would have been chosen if decisions had been based purely on physical geography and construction costs.

Figure 8. Municipalities, Lighthouses, and Ports in the Province of Tarragona (c. 1890)



Source: Authors' elaboration.

While the nodes, placed at the endpoints of these routes, were not randomly selected, the validity of the instrument depends on controlling for the likelihood that municipalities between nodes were more likely to be traversed by railways. Our instrumental variable, LCPs MA, was calculated using an inter-municipal transport cost matrix, replacing the main (inter-nodal) railway lines with the 1890s LCPs extracted from Esteban-Oliver (2023). Additionally, we excluded economic railways (narrow-gauge) and rail lines or paved roads designed primarily for local connections (Figure 7), as these were more prone to endogenous placement.

5.3.2. IV Approach for Port Access (PA)

This study also seeks to identify the causal impact of international and colonial trade on biological living standards. However, as with land transport nodes, port infrastructure may have been established in the more dynamic coastal municipalities. This was particularly true for Tarragona and Barcelona, designated as First-Class Order Ports under the 1880 Spanish Ports Law due to their economic and administrative significance. Consequently, municipalities with a port and customs office in 1890 may have had higher biological living standards well before the 19th-century transport revolution, making it difficult to isolate the causal effect of PA.

To address this issue, we propose using lighthouse locations as an instrumental variable (IV). Lighthouses were placed based on geographical features, such as capes, and should not have directly influenced recruits' HE (see Figure 8 for the province of Tarragona around 1890). However, this variable presents its own challenges. There were only 72 coastal municipalities in Catalonia, of which 25 had ports and 18 had at least one lighthouse. Thus, the sample size could affect instrument validity. This issue will be further explored in the next sub-section and in Section 6.

5.3.3. Balance Test and Estimates

For the IV strategy to be valid, two conditions must be met. First, the instrumental and explanatory variables must be correlated (i.e., ρ≠0). The second condition implies that there must be no correlation between the factors determining the recruits' HEs and the IV.

(5)

$$MA_{im,1890} = \propto_1 + \beta_1 MALCP_{im,1890} + ALGH_{im,1890} + \emptyset_1 X_{im,1890} + \mathrm{TU}_{1890} + \epsilon_{\mathrm{im}}$$

(6)

$$PA_{im,1890} = \propto_1 + \beta_1 ALGH_{im,1890} + MALCP_{im,1890} + \emptyset_1 X_{im,1890} + \mathrm{TU}_{1890} + \epsilon_{\mathrm{im}}$$

Equations 5 and 6 outline the specifications for both first stages. In these equations, $MA_{im,1890}$ and $PA_{im,1890}$ refer to MA and PA, respectively, of municipality m in 1890. $MALCP_{im,1890}$ and $ALGH_{im,1890}$ are the refers to the alternate MA indicator (LCPs), and Access to Lighthouses, respectively, of municipality m in 1890. The term $\emptyset_2 X_{im,1890}$ is again a vector that includes all control variables, listed in Table 1 above. TU_{1890} is a categorical variable that distinguished to which Territorial Unit each municipality belonged to.

Table 3. First-Stage: alternate Market Access (MA) indicator (LCPs) and lighthouses (ALGH) in 1890

	(1)	(2)	(3)
Estimator	IV	IV	IV
Dependant variable	*Ln* MA	PA	*Ln* MA and PA
Ln MA (LCPs)	0.841***		0.838***
	(0.0217)		(0.021)
Access to a lighthouse (ALGH)		0.409***	0.404***
(Yes=1)		(0.1401)	(0.14)
Additional controls	Yes	Yes	Yes
Territorial Units	Yes	Yes	Yes
Observations	12,023	12,023	12,023
R-squared	0.013	0.013	0.011
Number of groups	861	861	861

Notes: Additional controls include an indicator variable set to 1 if the municipality was a district capital, the natural logarithm of the municipal population size in 1860, the natural logarithm (ln) of the average land suitability for wheat, olive, and citrus, the municipal literacy rate in 1887, latitude and longitude, their squared terms, and the interaction between the latitude and longitude of municipal centres. Nodes were excluded from the sample. Standard errors are clustered at the municipal level. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Table 3 presents the results for the first stage of the IV regression. In Column (1), the modified *ln* of MA (LCPs) is statistically significant in explaining actual MA during the period, and in Column (2), the location of lighthouses significantly explains access to ports with customs offices. Column (3) estimates the regression with both variables instrumented together, yielding similar outcomes. Consequently, in both MA and PA, the first condition is not violated.

The second condition requires that the correlation between the factors determining the recruits' HE and both the alternative MA measure (MALCPs) and access to a lighthouse (ALIGHT) arises solely through their relationship with actual MA and access to ports (PA), respectively. However, in the case of the MA LCPs approach, this condition may be violated because the endpoints of the LCPs are the nodes—Catalonia's main cities—and the ports.

Therefore, as in the OLS approach, we exclude recruits residing in the nodes from our HE data. Notably, LCPs select routes with the lowest construction costs between nodes, avoiding river crossings or steep slopes (Figure 7). This suggests that proximity to an LCP could also correlate with distinct municipal economic structures. However, the previously introduced first- and-second nature controls should account for this issue.

Regarding access to a lighthouse, this variable is correlated with distance to the coast. In 19th-century Catalonia, coastal proximity was also associated with a distinctive agricultural and dietary orientation compared to non-coastal municipalities (Cussó & Garrabou, 2003-2004), which could, in turn, affect recruits' HE. However, this issue should be mitigated by including the previously described set of first-nature variables. Specifically, the citrus and olive suitability indexes, which are highly correlated with coastal proximity, could serve as proxies for these dietary differences (Figures A.2 and A.3, Appendix). Additionally, the inclusion of the 2nd polynomial of the latitude and longitude, the TUs variable, and the previously described second-nature variables should further address this issue.

Then, in Table A.2 of the Appendix, we tested whether this second condition was being violated, confirming that both instruments are correlated with our variable of interest, HE, exclusively through their relationship with MA and PA, respectively. [12]

(7)

$$HE_{im,1890-1911} = \propto_2 + \beta_2 \widehat{\mathrm{MA}}_{im,1890} + \beta_3 \widehat{\mathrm{PA}}_{im,1890} + \emptyset_2 X_{im,1890} + \mathrm{TU}_{1890} + \eta_{\mathrm{im}}$$

Equation 7 displays the second stage in our IV empirical strategy. As mentioned, we used the instrumental variables $MALCP_{im,1890}$ and $ALGH_{im,1890}$ to estimate the effects of MA, $MA_{im,1890}$, and PA, $\widehat{\mathrm{PA}}_{im,1890}$, on the HE of the recruit i born in 1890, inspected and residing in municipality m in 1911 ($HE_{im,1890-1911}$), alongside additional control variables ($\emptyset_2 X_{im,1890}$).

6. Results: the access to markets and height nexus

This section presents the results of our tests for the impact of access to markets on biological living standards. As mentioned in the previous section, we employed two types of approaches: Ordinary Least Squares (OLS) and Two-Stage Least Squares (2SLS) with instrumental variables.

6.1. Ordinary Least Squares (OLS)

Table 4 displays our results, for different specifications of the model. In Column (1), the results from a parsimonious specification indicate that the coefficients of the natural logarithm of MA (ln MA) and PA in 1890 are positive and highly significant in explaining the height (HE) of Catalan recruits born in 1890 and enlisted in 1911. However, these results may be biased.

[12] When MA or PA is excluded from the regression, the instrumental variables (IVs) explain HE. However, once the non-instrumented variables (MA and PA) are introduced, the instruments (MALCP and ALGH) no longer explain HE.

To address this, Column (2) of Table 4 includes the TU categorical variable. The coefficients for the ln of MA and PA remain largely unchanged, with both variables retaining high statistical significance and exhibiting a positive effect on the recruits' average municipal HE.

Table 4. OLS estimates on the impact of Market Access (MA) and Port Access (PA) in 1890 on the height (HE) of recruits born in 1890 and enlisted in 1911 (mm)

	(1)	(2)	(3)	(4)
Estimator	OLS	OLS	OLS	OLS
Dependent variable	HE (mm)	HE (mm)	HE (mm)	HE (mm)
ln of market access (MA), in 1890	4.420***	6.559***	7.624***	
	(1.030)	(1.512)	(1.765)	
MA > 50% percentile				3.429**
				(1.543)
Access to a port (PA), in 1890	10.16***	9.654***	9.342***	10.10***
	(2.621)	(2.470)	(3.045)	(3.439)
Territorial Units	No	Yes	Yes	Yes
Additional controls	No	No	Yes	Yes
Constant	1,599***	1,575***	27,028***	26,108***
	(9.277)	(14.72)	(9,716)	(9,829)
Observations	12,023	12,023	12,023	12,023
Number of municipalities	861	861	861	861
R-squared	0.006	0.010	0.013	0.012

Notes: Standard errors are clustered at the municipal level. For a comprehensive view, Appendix Table A.4 presents the full specification for Column (3), including the estimated coefficients for all control variables. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Column (3) of Table 4 presents our preferred specification, as it incorporates the full vector of control variables into the regression. Compared to Columns (1) and (2), the conclusions remain consistent: both MA and PA had a significant effect on recruits' height. Specifically, the MA coefficient indicates that a 1% rise in municipal MA corresponds to a height gain of 0.08 mm, with this effect reaching 5.3 mm for a 100% increase in MA. As for the PA dummy, the results indicate that having access to a port is associated with an average height increase of approximately 9.34 mm.

To facilitate comparison between these two variables, Column (4) of Table 4 presents an alternative specification in which the *ln* of MA is transformed into a discrete variable. Specifically, we distinguished between recruits residing in municipalities in the top 50th percentile of MA and those in the lower half. Table 4 shows that recruits in the top 50th percentile were significantly taller than the rest, with a coefficient of 3.4 mm —a figure slightly lower, but consistent, than those for the 40th (5.6 mm) and 60th percentiles (4.2 mm) (Table A.3, Appendix).

Lastly, as noted earlier, in all specifications, standard errors are clustered at the municipal level to account for the hierarchical structure of the data. For further robustness, Table A.5 in the Appendix presents results using a multilevel model, which remain highly consistent, reinforcing the reliability of our findings. Additionally, we conducted an alternative specification using district-level categorisation instead of territorial units, yielding similarly stable results (see Table A.6, Appendix). A likely explanation is that, once geographic and socioeconomic factors are controlled for, cross-municipal characteristics may not significantly influence recruits' HE. This is supported by regressions (not shown), which indicate that the municipal residual interclass correlation was just 0.014.

6.2. Instrumental Variables (IV)

Even after removing the nodes and incorporating multiple control variables, establishing causality remains challenging. Table 5 addresses this issue further using an IV approach. Column (1) presents the results of instrumenting MA with the alternative LCPs measure while including all control variables and the TU categorical variable. The results remain highly significant and closely align with the preferred OLS estimates (Table 4, Column (3)).

Columns (2) and (3) of Table 5 instrument PA using lighthouses (ALGH): Column (2) does so without instrumenting MA, while Column (3) includes the instrument for MA (LCP). Although the PA (ALGH) results remain stable, their statistical significance is now lower, having been reduced to the 10% level.

Columns (4) and (5) estimate the regression using MA and PA in their discrete forms. The results remain significant for MA but not for PA when instrumented, which has now lost statistical significance, though the sign remains positive. This may be due to the weakness of the IV, as indicated by a low F-statistic (not shown). Specifically, the small sample size of recruits from municipalities with ports and/or lighthouses may limit the IV's explanatory power, preventing precise causal estimates. Unfortunately, no better instrument for PA in this period was found.

Table 5. IV estimates on the impact of Market Access (MA) and Port Access (PA) in 1890 on the height (HE) of recruits born in 1890 and enlisted in 1911in Catalonia (mm)

	(1)	(2)	(3)	(4)	(5)
Estimator	IV	IV	IV	IV	IV
Dependent variable	HE (mm)	HE (mm)	HE (mm)	HE (mm)	HE (mm)
Ln of Market Access (MALCP) (instrumented)	7.361*** (2.023)		7.246*** (2.020)		
Ln of Market Access (MA)		7.545*** (1.767)			
MA>50% percentile				4.571** (2.289)	4.569** (2.285)
Access to a Port (ALGH) (instrumented)		12.57* (7.155)	12.42* (7.109)	10.40 (6.744)	
Access to a Port (PA)	9.360*** (3.048)				10.19*** (3.445)
Territorial Units	Yes	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes	Yes
Constant	27,037*** (9,700)	24,128** (11,544)	24,297** (11,537)	25,522** (11,451)	25,715*** (9,853)
Observations	12,023	12,023	12,023	12,023	12,023
R-squared	0.013	0.013	0.013	0.012	0.012

Notes: See Table 4.

Despite this, the consistency in effect size and direction across specifications increases confidence in the results for MA. The IV estimates confirm a strong relationship between MA and HE in Catalonia. Specifically, recruits from areas with high MA (50th percentile) are almost half a centimetre taller than those in less accessible regions, compared to 0.34 cm in the OLS estimates. When MA is defined continuously, effect sizes remain similar to the OLS coefficients. In contrast, PA loses statistical significance in some specifications when instrumented, yet its effect size remains very stable.

7. Mechanisms: food accessibility, specialisation and scale and agglomeration economies, and urban health externalities

What mechanisms could influence the strong positive link between transport linkages and HEs in late 19th-century Catalonia? Figure 9 illustrates the mechanisms through which we believe the former may have positively influenced the latter, while also considering factors that may have mitigated or offset the positive impact of MA and

PA. We classify these mechanisms as food accessibility, urban economies, urban health externalities and rural development. Unfortunately, suitable data was not always available to empirically test whether and to what extent these mechanisms were at play, though some quantitative evidence allows for an approximate assessment. By compiling this evidence and, where possible, conducting econometric tests, we conclude that transport linkages influenced biological living standards primarily through food accessibility, urban economies and rural development. In contrast, urban health externalities do not appear to have been fully operational during the period surrounding the birth of the 1890 cohort.

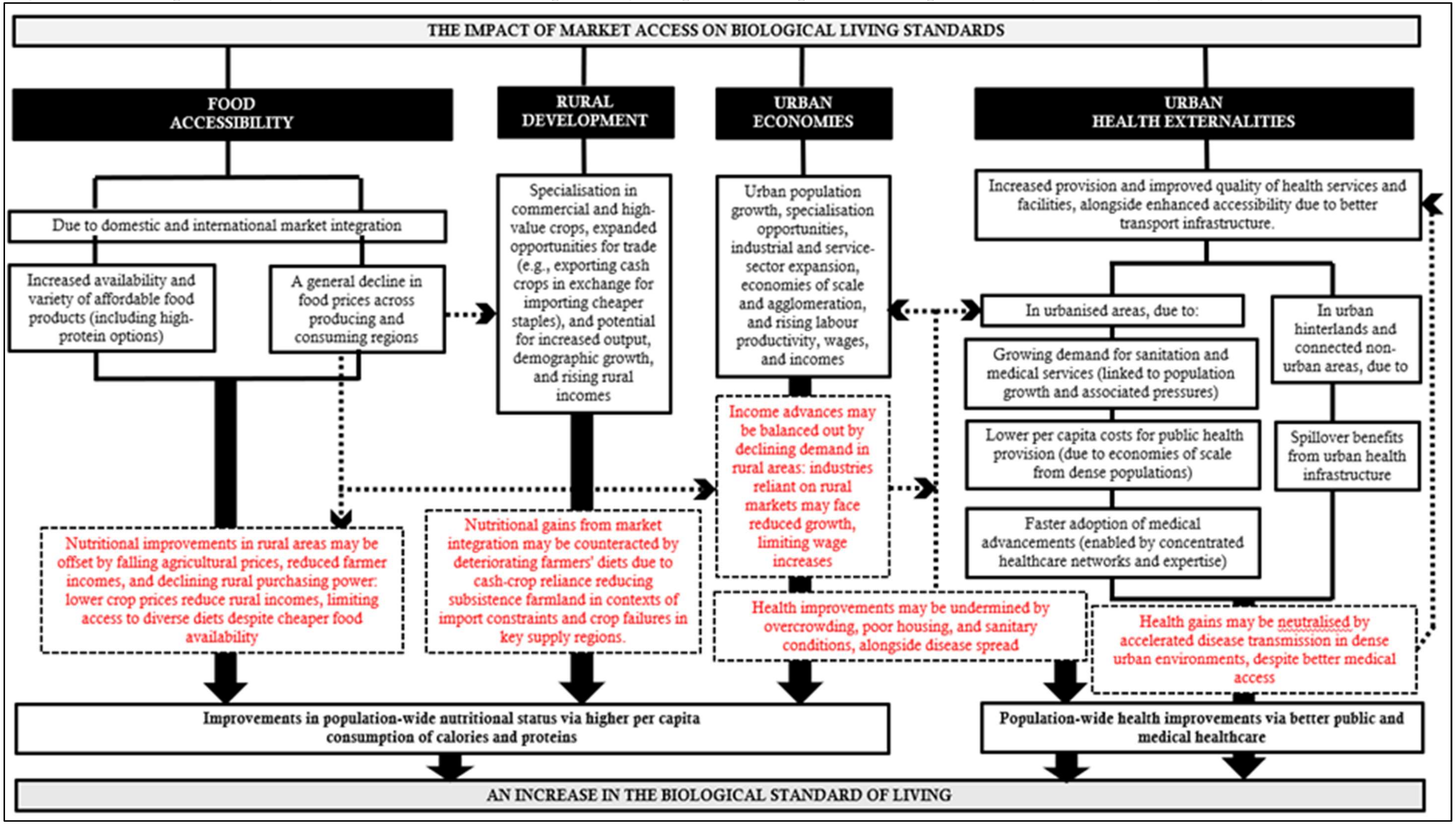
However, it is important to acknowledge that in this section, we deliberately refrain from emphasizing the effects of international market access, proxied by the Port Access (PA) variable, due to a key analytical limitation. While results revealed a significant correlation between PA and HE, we were unable to establish a robust causal relationship between the two. Correlation, as is well understood, does not imply causation, and in this case, other confounding factors—such as different dietary options due to proximity to the coast—might affect the observed link. Then, without a reliable instrument to isolate port access´s effect, any claims about causality, and particularly of effect sizes, remain tentative.

7.1. Food accessibility

An improvement in market connectivity should, in theory, provide better access to a cheaper, greater quantity and wider variety of food, including high-protein products. This is particularly true in urban areas, while in rural areas it could also lead to an oversupply of certain products alongside the initiation or acceleration of agricultural specialisation processes, as will be detailed below in Section 7.4.

One of the primary expected effects of improved connectivity is its impact on food prices. In Catalonia, the expansion of the railway network significantly reduced the transport costs of wheat—the staple cereal in the Catalan diet (Cussó & Garrabou, 2003–2004; 2006)—while the price gap between Spain's main production areas and Catalonia's key consumption centres narrowed (Garrabou & Sanz, 1985). However, this did not necessarily lead to lower wheat and cereal prices; in fact, the opposite was sometimes true (Pascual, 2016b).

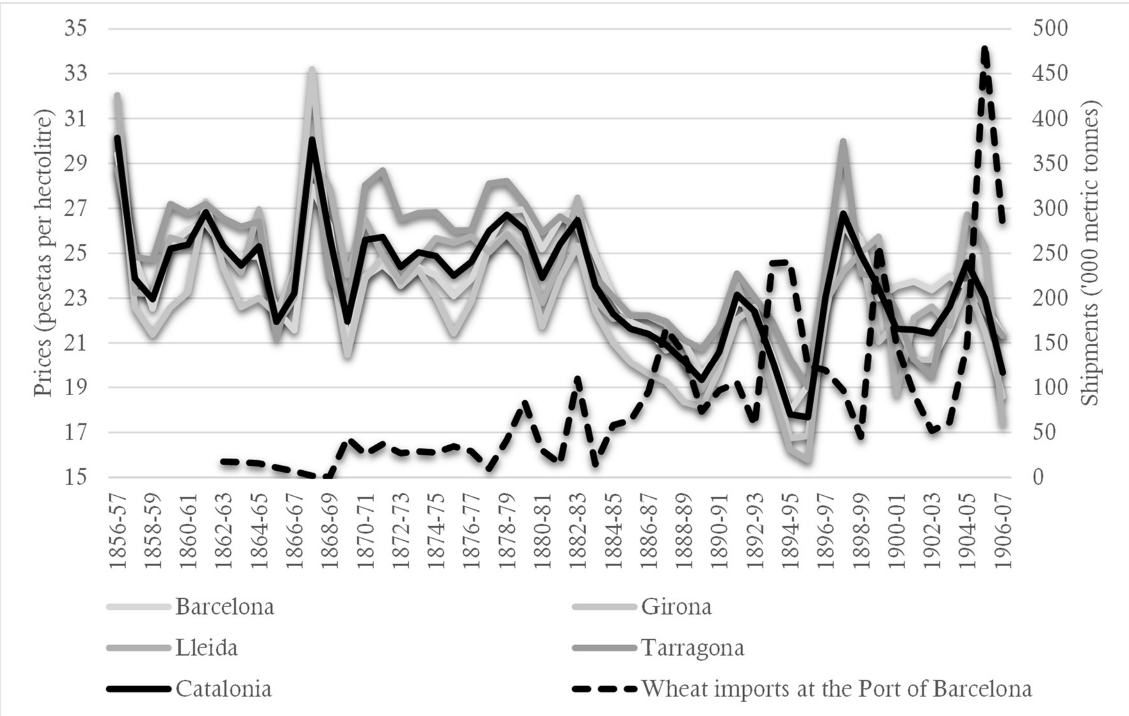
Figure 9: Conceptual diagram of the mechanisms explaining the positive impact of transport linkages on biological living standards



Source: Authors' elaboration. See text.

A reduction in wheat and agricultural prices more broadly only occurred during the 1880s and early 1890s—coinciding with the late 19th-century agrarian crisis, a consequence of globalisation and international market integration (e.g. O'Rourke & Williamson, 1999; Jacks, Meissner, and & Novy, 2008; Meissner, 2024). This process is well-documented: the decline in maritime freight and trade costs—driven by the expansion of steamships and other technological developments—allowed cheaper agricultural products to enter the Catalan market, triggering a period of price declines and crisis for the agricultural sector (e.g. Sánchez-Albornoz, 1975; Garrabou, 1975 and 1988; Sánchez-Albornoz & Carnero Arbat, 1981; Garrabou & Pujol, 1987; Simpson, 2001; Esteban-Oliver, Álvarez-Palau & Martí-Henneberg, Mimeo). Furthermore, import trade was facilitated by improvements in Catalonia's ports, particularly the port of Barcelona (Section 3).

Figure 10. Wheat prices and shipments in Catalonia by provinces, 1856-1906



Sources: Authors' elaboration based on Sánchez-Albornoz (1975) and GEHR (1980), and Spanish foreign and cabotage trade statistics. Prices are expressed in pesetas per hectolitre. Wheat imports at the Port of Barcelona include both foreign and domestic shipments and are expressed in thousands of metric tonnes.

Figure 10 presents evidence of declining wheat prices across both western (Lleida) and coastal provinces (Barcelona, Girona, and Tarragona) from the early to mid-1880s. Additionally, Table 6 further illustrates a consistent decrease in food prices by documenting key foodstuffs consumed in late 19th-century Catalonia. Unfortunately, data on vegetables, fruits, fish, and dairy products were unavailable; however, we included animal feed (straw, barley, and maize) and high-protein foods such as meat. These figures, which refer to the province of Barcelona—a highly urbanised and densely populated area—reveal a clear downward price trend from the mid-1870s to the early 1890s. Notably, the decline extended beyond staples like wheat to include meat and animal feed, highlighting the broader impact of market integration on food accessibility and dietary improvements. This trend aligns with existing evidence on the dramatic increase in food imports through seaports before the early 1890s, alongside growing coastal trade (e.g., Carreras & Yáñez, 1992; Ibarz & von Briesen, 2022, p. 204; and Álvarez-Palau, Esteban-Oliver & Martí-Henneberg, 2025, for the port of Barcelona and Catalonia).

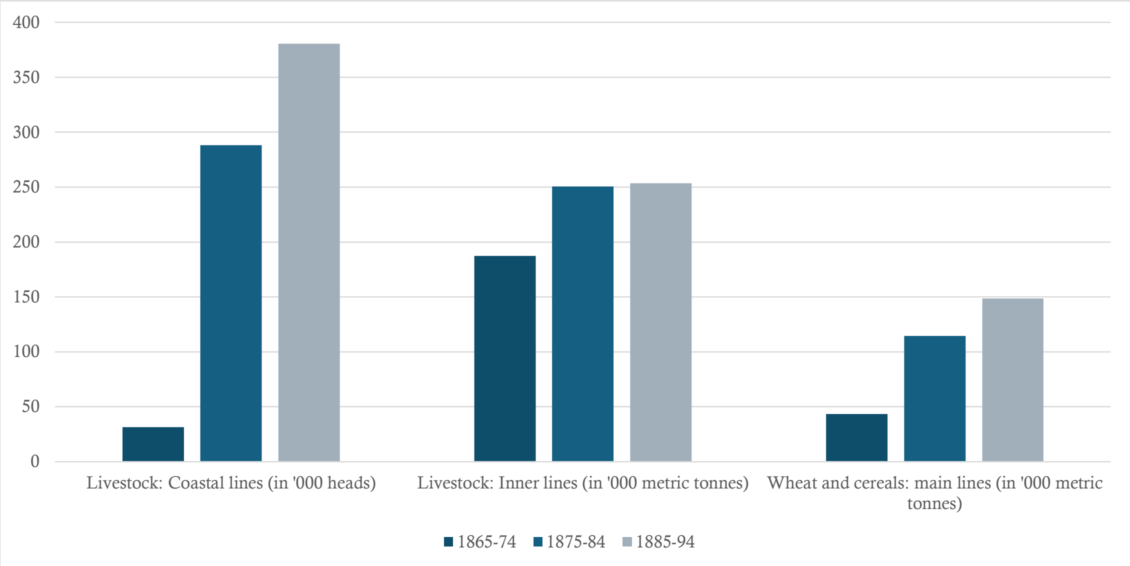
Table 6. Trends in nominal prices of human and animal foodstuffs in the province of Barcelona, 1870s –1890s (1877=100)

Product	1877	1887	1891-1895
Meat [a]			
Mutton	100	95	87
Cow	100	96	79
Pig	100	130	73
Cereals and their by-products			
Wheat	100	88	86
Barley	100	92	85
Rye	100	88	nd
Maize	100	91	91
Rice [c]	100	89	70
Straw	100	82	nd
Legumes			
Chickpeas	100	76	nd
Liquids			
Olive Oil	100	86	80
Wine [b]	100	74	50
Brandy	100	100	nd

Notes and sources: For 1877 and 1887, and if not otherwise indicated, prices are calculated as the simple mean of the average prices recorded in the localities of Arenys de Mar, Barcelona, Berga, Granollers, Igualada, Manresa, Mataró, Sabadell, Sant Feliu de Llobregat, Terrassa, Vic, Vilafranca del Penedès, and Vilanova i la Geltrú for the months of March and August, as reported in the *Boletín Oficial de la Provincia de Barcelona*, 1877 and 1887. For 1891-95, the annual average is based on the yearly prices provided by GEHR (1980, 1981) and Pujol (1988). For meat, rice and wine prices, respectively: (a): prices for the city of Barcelona, (b): prices for the area of Penedès, (c): prices for 1891-95 probably refer to the city of Barcelona; nd: no data available.

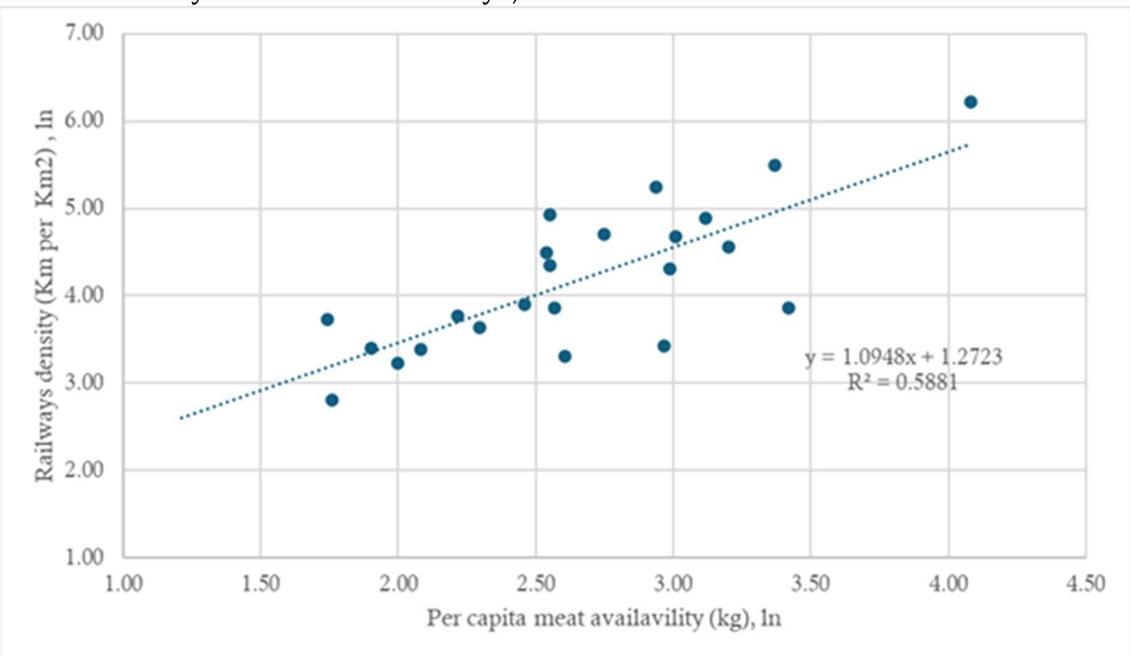
Enhanced transport infrastructure also facilitated dietary diversification, increasing the consumption of protein-rich foods such as meat and dairy products and reflecting a general improvement in nutritional standards (Cussó & Garrabou, 2003–2004, pp. 73–77; 2006, p. 453). Indeed, railway expansion significantly reduced the cost of transporting livestock from production areas to consumption centres. As Catalonia's railway network expanded and integrated with Spanish and French systems, the volume of livestock—particularly cattle—transported by rail increased considerably (Figure 11). This trend mirrored national increases in livestock imports, further boosting supply and supporting the introduction of new breeds (Gallego & Pinilla, 1996; Garrabou & Pujol, 1988, p. 109). Consequently, high-protein foods became more accessible and affordable to a broader population.

Figure 11. The transport of livestock and cereals by railways in Catalonia, 1860s-1890s (ten-year annual averages)



Sources: Authors' elaboration based on Gómez Mendoza (1984) and Pascual (2016a). For livestock (inner lines), which include those connecting Catalonia with non-coastal cities in Spain, the period 1865–74 is recorded as 1869–74. For wheat and cereals, the data for 1888-1892 have been estimated.

Figure 12. The relationship between railways density and per capita meat availability in Catalonia by districts with railways, c. 1890



Sources and notes: Authors' elaboration based on data of Dirección General de Agricultura, Industria y Comercio (1892) and Instituto Geográfico y Estadístico (1892). Estimates on per capita meat availability are based on the available data on cattle slaughtered in municipal slaughterhouses for public consumption in 1891 and the average live weight in kilograms of the cattle in 1929.

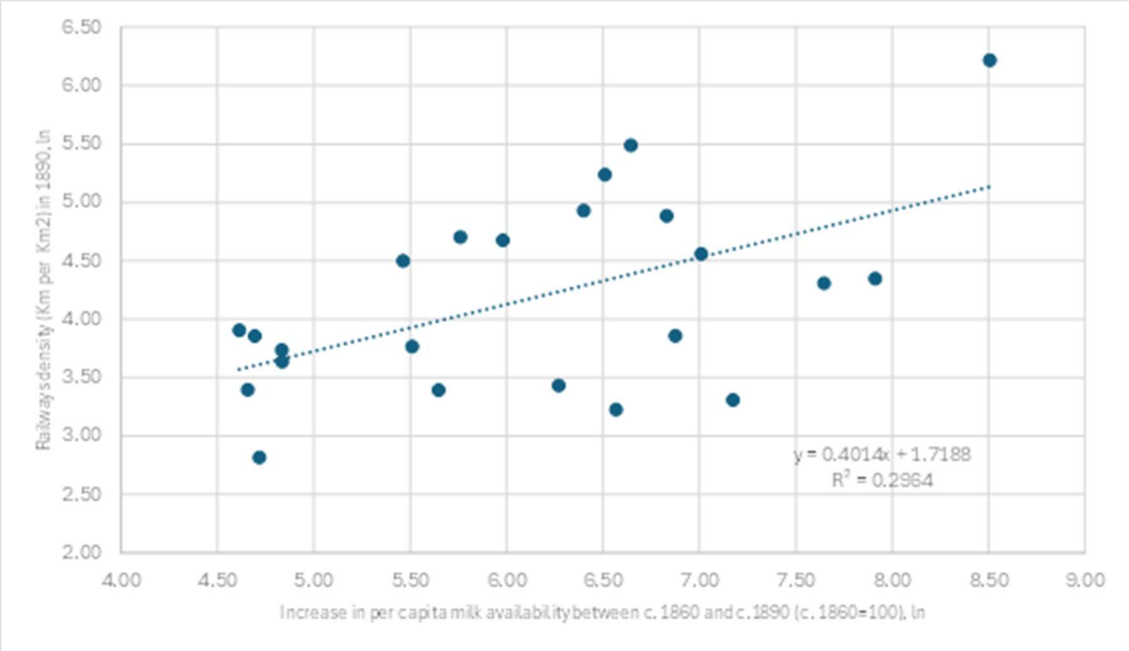
Barcelona, as the primary centre for meat demand, exemplifies this trend. Large quantities of livestock were transported to the city for slaughter, alongside substantial Catalan processed meat production (Muñoz Rubio, 2009, 2015; Pascual, 2016a; Castell & Ramon-Muñoz, 2022). Between 1881 and 1900, the number of cattle slaughtered for human consumption increased by 150% (Nicolau & Pujol, 2005, p. 109), while meat prices in 1891–1895 were 10–25% lower than in the mid-1870s (Table 6). Notably, historical estimates suggest that prior to the 1870s—when the railway network was still developing—meat consumption growth in Barcelona lagged behind population growth. Only after the railway system was fully operational did meat consumption outpace population increases (Guàrdia et al., 2018, p. 197).

Similar trends likely applied to other parts of Catalonia (Cussó & Garrabou, 2003–2004, pp. 73–75). In addition, we find a strong positive correlation between railway presence and per capita meat availability by the early 1890s. Districts without railway connections had per capita slaughtered meat availability nearly 30% lower than those with rail access. Moreover, railway density—measured as kilometres of broad-gauge lines—was significantly associated with per capita meat availability (Figure 12).

Alongside meat, dairy products, particularly milk, were a crucial source of animal protein in Catalonia (Cussó & Garrabou, 2003–2004, pp. 74–76; Nicolau & Pujol, 2005, pp. 114–115; Nicolau, Pujol & Hernández-Adell, 2010). By the 1860s, per capita milk availability remained modest—about seven litres per person annually—and was significant only in regions well-suited to cattle farming. Several factors contributed to these low figures. Catalonia's climate, more conducive to cereal, olive, and vineyard cultivation, restricted cattle farming to specific northern areas. In addition, poor milk processing standards hindered preservation, making it difficult to transport milk under sanitary conditions and limiting its consumption outside production zones. Transport infrastructure further compounded these challenges, as inadequate distribution networks prevented fresh milk from reaching urban centres efficiently (Pujol, Nicolau & Hernández-Adell, 2007; Nicolau & Pujol, 2008; Hernández-Adell & Pujol, 2017). These logistical difficulties spurred the rise of urban dairies and cowhouses, which emerged as key suppliers of fresh milk to local populations (Whetham, 1964; Atkins, 1977; Teuteberg, 1981).

The second half of the 19th century saw significant transformations in the dairy sector. The gradual adoption of pasteurisation and railway expansion helped mitigate earlier limitations on milk transport and consumption. By the late 19th century, milk transported by train accounted for a substantial share of urban consumption in major European cities—85% in London, over 75% in Paris, and 55% in Berlin (Hernández-Adell & Pujol, 2017, p. 77).

Figure 13. Relationship between railway density in 1890 and the growth of per capita milk availability in Catalonia between 1865 and 1890 by districts with railway infrastructure



Sources and notes: Authors' own calculations, based on estimates of milk availability derived from district-level cow populations for the years 1865 and 1917, as presented in Giralt (1990). These figures were converted into per capita terms using data from the Instituto Geográfico y Estadístico (1892). The values for 1890 were interpolated linearly.

A similar, albeit smaller-scale, process unfolded in Catalonia. In Barcelona, milk transported by rail increased, contributing to a rise in per capita milk consumption from approximately four litres in the 1860s to 12 litres by the late 19th century (Hernández-Adell & Pujol-Andreu, 2017, p. 89; Pujol, Nicolau-Nos & Hernández-Adell, 2007, p. 307). However, even by 1900, railway-transported milk accounted for less than 30% of total consumption. Instead, urban dairies remained the dominant suppliers, producing over 70% of the milk consumed in Barcelona (Hernández-Adell & Pujol, 2016, p. 198; 2017, pp. 76–77).

The close proximity between producers and consumers helps to explain the relatively weak correlation between railway density and per capita milk availability growth between 1860 and 1890 (Figure 13). Nonetheless, districts with railway lines experienced faster increases in milk availability compared to those without rail infrastructure, meaning that transport connectivity still had an impact on milk availability.

Indeed, in Catalonia, transport linkages facilitated two key developments that contributed to rising milk consumption outside the production areas. The importation of Swiss and Dutch cattle breeds—among the best dairy cows—helped improve local milk production (Langreo, 1995). At the same time, increased production and imports of animal feed, particularly from inner Catalonia and Aragón, provided essential support for urban dairies (Nicolau & Pujol, 2008; Ramon-Muñoz, 2008, 2013). In this way, the expansion of railways ensured a steady supply of fodder, further enabling milk production for urban populations.

7.2. Urban economies

Improved transport linkages may have positively influenced biological living standards not only by making a wider variety of food, including high-protein products, more affordable and accessible but also by fostering urbanisation and broader economic development. Throughout the 19th century, Catalonia underwent significant economic transformations, ultimately emerging as a relatively developed and prosperous region by the century's end, largely due to industrialisation and urbanisation. These processes were strongly driven by increasing market integration (Rosés, Martínez-Galarraga, & Tirado, 2010), which, in turn, was significantly facilitated by improvements in transportation (Esteban-Oliver, Álvarez-Palau, & Martí-Henneberg, Mimeo).

Increased market integration has important economic consequences. In urban areas, the expansion of non-local markets facilitates cheaper access to food and inputs, while also fostering urban, industrial, and service sector growth. More industrialised and urbanised areas typically possess larger, more specialised markets, which often focus on sectors with increasing returns to scale, leading to higher wages and incomes (Krugman, 1980, 1991; Fujita, 1988; Fujita, Krugman & Venables, 1999).

Historical research supports these patterns, at least regarding urban areas. Several studies have consistently demonstrated the connection between market integration, industrial concentration, market potential, agglomeration, scale economies, and advances in labour productivity in Catalonia between 1860 and 1900 (e.g., Tirado, Paluzie & Pons, 2002; Rosés, Martínez-Galarraga & Tirado, 2010; Martínez-Galarraga, 2012; Martínez-Galarraga, Tirado & González-Val, 2015). These and other studies have also shown that regions specialising in industry, such as Catalonia, enjoyed higher levels of per capita income. Moreover, in this region, the purchasing power of industrial workers' wages consistently exceeded that of agricultural wages (Garrabou, Pujol & Colomé, 1991, pp. 40–49; Garrabou, Tello & Roca, 1999, pp. 447–454; Camps, 1995, pp. 214–215), with the urbanised province of Barcelona experiencing the highest wage rates despite a process of real wage convergence across Catalonia in the second half of the 19th century (Rosés & Sánchez-Alonso, 2004, p. 422).

Table 7. OLS and IV Estimates of the Impact of 1890 Market Access (MA) on 1887 Municipal Population Size (POPSZ), and the Effects of the Interaction Between MA and POP, as well as 1890 Market Potential (MP), on the Height (HE) of the 1890 Male Cohort

	(1)	(2)	(3)	(4)	(5)	(6)
Estimator	OLS	IV	OLS	IV	OLS	IV
Dependent Variable	Ln POPSZ	Ln POPSZ	HE (mm)	HE (mm)	HE (mm)	HE (mm)
Ln Market Access (MA)	0.0664***	0.0953***				
	(0.0205)	(0.02391)				
Access to a port (PA)	-0.0316	0.134				
	(0.052)	(0.111)				
MA≤50%* POPSZ ≤5000			Ref.	Ref.		
MA≤50% * POPSZ >5000			2.574	3.033		
			(3.334)	(3.404)		
MA>50% * POPSZ ≤5000			3.096*	4.073*		
			(1.627)	(2.306)		
MA>50% * POPSZ >5000			8.954**	9.774**		
			(3.604)	(3.889)		
MP≤50% * POPSZ ≤5000					Ref.	Ref.
MP≤50% * POPSZ >5000					-4.055	-4.062
					(5.833)	(5.857)
MP>50% * POPSZ ≤5000					5.079***	5.132
					(1.679)	(3.411)
MP>50% * POPSZ >5000					9.993***	10.040**
					(3.421)	(4.200)
Access to a port (PA)	-	-	Yes	Yes	Yes	Yes
Territorial Units	Yes	Yes	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	14.21**	-31.22	25,682***	25,437***	25,509***	25,562***
	(107.3)	(111.3)	(9,796)	(9,794)	(9,617)	(9,616)
Observations	861	861	12,023	12,023	12,023	12,023
R-squared	0.914	0.914	0.012	0.012	0.013	0.013

Notes: Robust Standard errors are clustered at the municipal level. The interaction between the municipal coordinates (longitude and latitude) has been excluded from the regression in Columns (1) and (2) to avoid multicollinearity. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

To quantitatively assess whether this was the case, we examined this mechanism using municipal population size (POPSZ) as a proxy for urban economies, interacting it with MA. While we acknowledge that population size reflects various factors—including urban food accessibility and health externalities—previous studies in this field have employed urban data, such as population density, to analyse the role of urban development in explaining the relationship between MA and HE (Zimran, 2020, pp. 700–703). Following Zimran's (2020) approach, in Table 7, we tested the relationship between MA and POPSZ as a proxy for urban economies, namely specialisation, scale, and agglomeration economies. We applied both OLS and IV methodologies, as described earlier, using equations closely resembling Equation (4) for OLS and Equation (7) for IV (Section 5).

For this mechanism to be valid, an initial condition must be met: transport linkages must have a positive impact on POPSZ. In Spain, existing literature supports this relationship, demonstrating that municipalities located near railway stations—a primary component of MA—experienced higher population growth (Esteban-Oliver, 2023). In our case study, the bivariate correlation between MA and POPSZ is notably high at 0.5 ($p = 0.000$). Columns (1) and (2) of Table 7 test the MA-POPSZ relationship, and the results indicate a consistently positive and statistically significant correlation across all specifications. They show that around 1890, a 10% increase in MA was associated with a 0.7% to 1% increase in population size, depending on whether MA was instrumented. The effect of PA is more uncertain, as it exhibits highly unstable coefficients. As mentioned earlier, this may be due to the sample size being too small. Consequently, we will focus on understanding the mechanism using domestic MA as our main variable of interest, while PA will be used for supporting purposes only.

If MA influenced both population size and biological living standards, and if scale and agglomeration economies contributed to improved physical stature, we should expect the impact of MA to vary with municipal population size. To test this hypothesis, we introduced an interaction term between MA and POPSZ. Municipalities were categorised into two groups: those with fewer than 5,001 inhabitants (POPSZ $\leq$ 5,000) and those with more than 5,000 inhabitants (POPSZ>5,000). Similarly, MA was divided into localities at or below the 50th percentile (MA $\leq$ 50%) and those above it (MA>50%). In this particular case, we believe that using categorical variables is more meaningful than a linear regression of MA and POP. Categorisation allows us to capture potential threshold effects and non-linearities that a simple linear regression might overlook, providing a clearer interpretation of how different levels of MA and POP influence the outcome.[13]

[13] The relationship between these variables may not be strictly linear and, although positive, in its linear form the interaction between MA and POPSZ is not statistically significant. See Table A.7 in the Appendix.

Columns (3) and (4) of Table 7 confirm this expectation in both the OLS and IV specifications. The results show that, relative to males living in municipalities with fewer than 5,001 inhabitants and a MA at or below the 50th percentile, those in more populous and better-connected localities were significantly taller. Specifically, young males in municipalities with more than 5,000 inhabitants and a MA above the 50th percentile were almost 1 cm taller than the reference group at a 95% confidence level. Interestingly, they were also 0.5 cm taller than young males in municipalities within the same MA percentile but with a population of up to 5,000 inhabitants.[14]

Finally, Columns (5) and (6) of Table 7 provide further evidence supporting the urban economies mechanism. Here, instead of MA, we use Market Potential (MP) as the explanatory variable. Specifically, we incorporate municipality *i*'s own population size into our equations. As in the previous specifications, we interact MP with POP, categorising municipalities by population size and MP by percentiles, as done in Columns (3) and (4). When instrumenting IV, we follow the same procedure as with MA (Section 4), using LCPs. These adjustments and the use of MP allow us to capture the effect of a municipality's own market size as an additional proxy for urban economies. The results confirm our previous findings and as expected, slightly amplify the impact observed for localities with more than 5,000 inhabitants and a MP above the 50th percentile when interacting MA with POPSZ.

Additionally, in Table A.9 of the Appendix we show that Port Access yields very similar results when interacted with municipal population size. That is, its effect on HE is greater in larger municipalities, which reinforces our confidence in the overall results.

This body of evidence suggests that enhanced transportation connectivity, as a driver of population size and, therefore, urban economies, played a significant role in improving male heights in late 19th-century Catalonia. Moreover, in this period, the potential negative impacts of improved transportation connectivity on biological living standards do not appear to have outweighed its positive effects. On the contrary, as more abundant, richer in protein and cheaper food became accessible to a broader population, transportation connectivity helped improve health by expanding market opportunities, fostering specialisation, promoting scale and

[14] We replicated this exercise using Railway Access (RA) in 1890 instead of MA and obtained similar results: males in localities closer to a railway station with more than 5,000 inhabitants were between 0.5 and 0.9 cm taller than their counterparts. See Table A.8 in the Appendix. In this case, RA equals 1 if the distance between a municipal centre and the nearest railway station is less than 4.5 km; otherwise, it equals 0. This threshold reflects direct access to a railway station, approximately within a one-hour walking distance. We also instrumented this variable using LCPs, following the procedures described in Section 5.

agglomeration economies, and ultimately increasing incomes, particularly in urban areas, which, in the second half of the 19th century, were concentrating a higher percentage of the total Catalan population (Vidal, 1979; Nicolau, 1990, p. 28).

7.3. Urban health externalities

Urban growth can have both positive and negative effects on living standards. On the positive side, as previously discussed, market expansion, specialisation, and economies of scale and agglomeration contributed to rising incomes and improved well-being. Additionally, urban expansion facilitated the development of health infrastructure and medical services. While urban centres benefitted the most, well-connected rural and suburban areas also experienced positive spillover effects, gaining access to improved healthcare facilities and services.

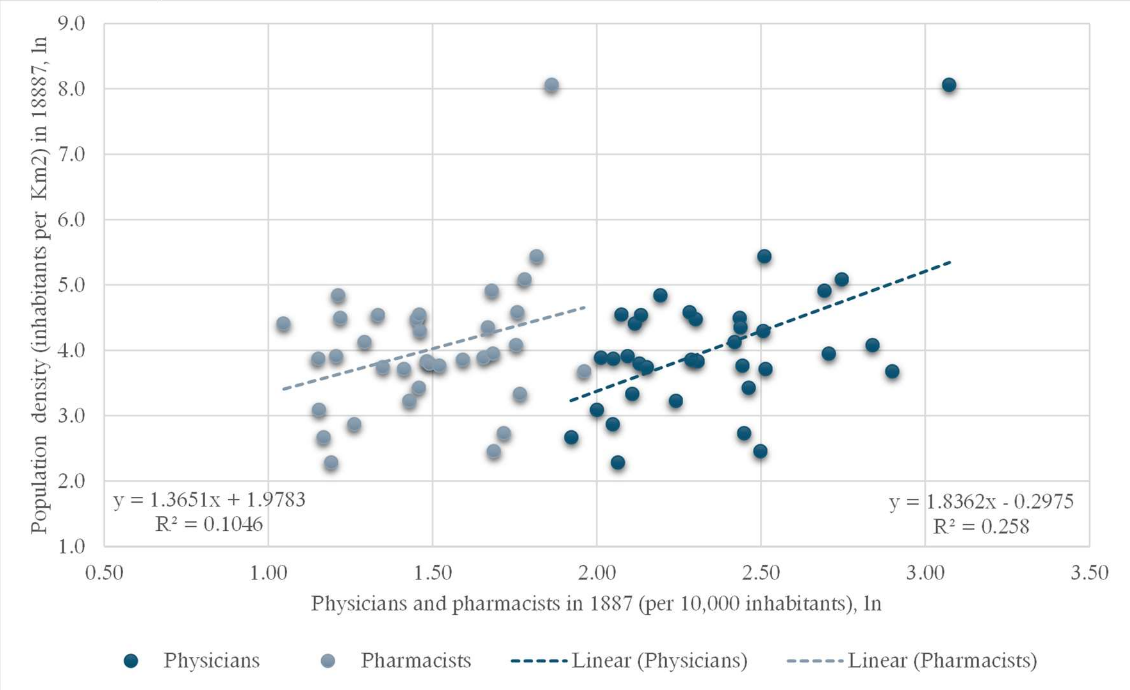
The expansion of urban health infrastructure occurred through three primary channels. The first was the increased demand for sanitation and medical services, which eventually led to their implementation (Duffy, 1993; Porter, 1999; Tulchinsky & Varavikova, 2014). In the 19th century, rapid population growth, overcrowding, and the spread of infectious diseases posed significant challenges related to housing, water supply, waste management, and healthcare. However, these challenges also spurred substantial improvements in public health and sanitation, particularly in Western Europe from the mid-19th century onwards (Szreter, 1988; Harris & Hinde, 2019). Moreover, the emergence of a growing urban middle class with greater purchasing power reinforced the demand for sanitation and medical services, further stimulating their expansion.

A second channel linked urbanisation with improved living standards through the effects of agglomeration (Gallardo-Albarrán, 2024). Larger cities typically had greater financial resources, allowing for increased investment in sanitation and public health infrastructure. Additionally, the high population density in urban areas made healthcare provision more efficient, as resources could be distributed more effectively, improving overall public health outcomes.

The third channel was the accelerated adoption of medical advancements. The late 19th century saw significant breakthroughs in medical science and healthcare infrastructure. Hospitals modernised their facilities and introduced laboratory-based medicine, improving diagnostics and surgical procedures (Cunningham & Williams, 1992; Bynum, 2008; Kisacky, 2017; Adams, 2018; Fernández-Pérez, 2021). Key medical discoveries, such as germ theory (Pasteur, 1861; Koch, 1876) and antiseptic surgery (Lister, 1867), complemented earlier advancements in anaesthesia (Simpson,

1847) (Gaynes, 2011). Urban centres were more inclined to adopt these innovations due to the presence of medical institutions and professional networks, facilitating knowledge diffusion and collaboration.

Figure 14. Relationship between population density and medical density in Catalonia by districts, c. 1890



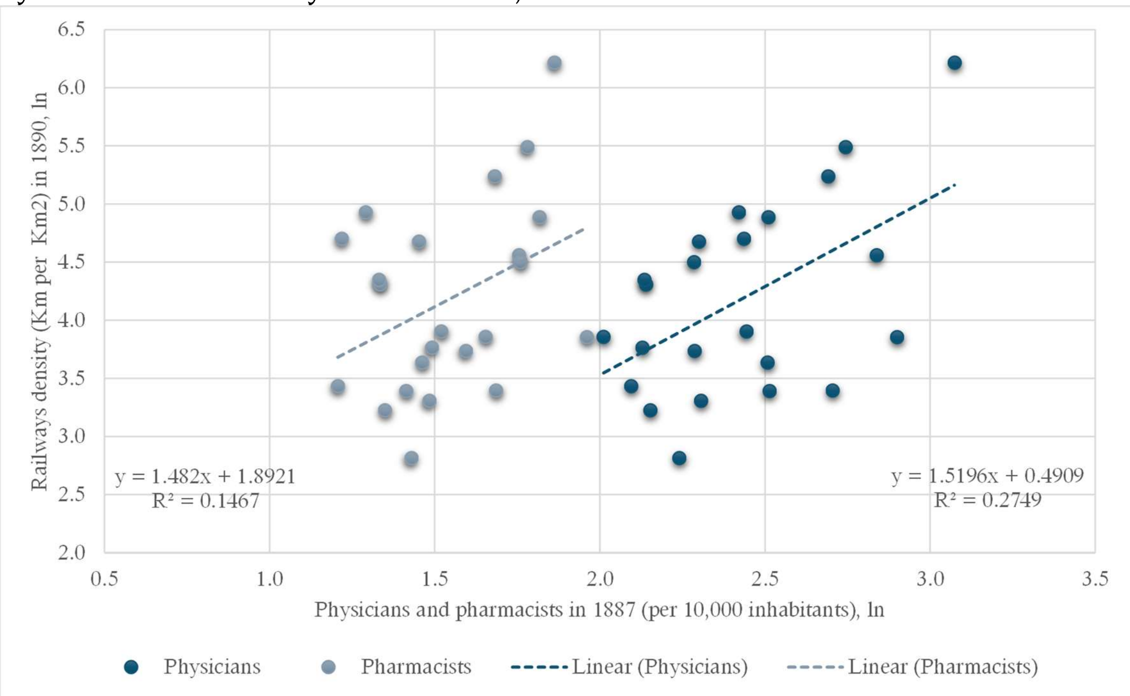
Notes and sources: Authors' own elaboration. See text and Figures 12 and 13.

In Catalonia, both qualitative and quantitative evidence suggest that medical service development closely followed urbanisation patterns. In the highly urbanised district of Barcelona, there were approximately 22 physicians per 10,000 inhabitants, compared to 11 per 10,000 in the rest of Catalonia (Instituto Geográfico y Estadístico, 1892). A positive correlation also existed between population density and the number of physicians per capita (Figure 14).

Industrial and medium-sized towns saw their hospitals reformed and expanded, while smaller rural hospitals declined. Notable examples of hospital expansion included Reus (1835, with an operating room added in 1863), Igualada (1845-1853), and Valls (1868). In the Barcelona metropolitan area, new hospitals such as Sant Joan de Déu (1861), Sagrat Cor (1879), and Sant Rafael (1889) were established (Comelles & Martín, 1996, p. 244; Pons-Pons & Vilar-Rodríguez, 2019, 2021, pp. 41–44). By 1898, Barcelona alone had 12 hospitals, of which 10 were privately operated, highlighting the significant role of private initiatives in public healthcare provision (Pons-Pons & Vilar-Rodríguez, 2019, p. 7).

In medium-to-large urban centres, private surgical clinics and medical facilities emerged, creating nascent health districts that incorporated modern medical practices, including operating rooms and advanced anaesthetic equipment (Fernández-Pérez & Sabaté, 2019, pp. 94–96; Zarzoso, 2021, pp. 76–86). Additionally, Friendly Societies played a critical role in providing medical services, particularly in industrial areas (Vilar-Rodríguez & Pons-Pons, 2019).

Figure 15. Relationship between railway density and medical density in Catalonia by districts with railway infrastructure, c. 1890



Notes and sources: Authors' own elaboration. See text and Figures 12 and 13.

Public health and sanitation also exhibited an urban bias. From the 1880s onwards, Barcelona and other urban centres implemented significant sanitation improvements. The 1885 cholera epidemic, for example, prompted the establishment and reorganisation of municipal medical corps. By 1897, these services conducted approximately 120,000 home visits annually, expanding healthcare access (Pons-Pons & Vilar-Rodríguez, 2021, p. 42). A microbiological laboratory was also established to address public health concerns (Urteaga & Nadal, 2002, pp. 181–182). Concurrently, sanitation infrastructure saw major advancements, particularly in water supply projects (Capel & Tatjer, 1991; Barceló-Prats & Comelles, 2020). Barcelona, for instance, undertook significant efforts to improve access to clean water (Martín Pascual, 2011; Tello & Ostos, 2012; Guàrdia, Rosselló & Garriga, 2014; March, 2015; Matés-Barco, 2019).

While urban areas stand to benefit the most from improved sanitation and medical services, improved accessibility to cities and towns can also positively impact populations in surrounding hinterlands and well-connected non-urban areas, allowing them to take advantage of spillover effects from enhanced healthcare facilities and services. In fact, districts with broad-gauge railways had, on average, 34% more physicians per capita than those lacking such infrastructure. Moreover, a positive correlation emerges when examining railway density (measured in kilometres per square kilometre) alongside medical density, proxied by the number of physicians and pharmacists per 10,000 inhabitants. This relationship is particularly pronounced for physicians, suggesting that improved transport infrastructure may have facilitated access to healthcare services across Catalonia (Figure 15).

Despite these improvements, significant limitations remained. Drinking water supply was often inadequate due to conflicts between municipalities and private providers (March, 2015, pp. 352–353). The renewal of Barcelona's sewer system was delayed until 1902 (Guàrdia, Rosselló & Garriga, 2014, p. 423). Additionally, hospital capacity was insufficient, particularly in Barcelona, where rapid population growth exacerbated demand (Pons-Pons & Vilar-Rodríguez, 2021, p. 40). The municipal medical corps, despite its expansion, remained inadequate for a city with over half a million inhabitants (Pons-Pons & Vilar-Rodríguez, 2021, p. 42). Thus, while medical advancements primarily benefitted urban populations, rural areas continued to rely on general practitioners with limited resources (Vilar-Rodríguez & Pons-Pons, 2019). Consequently, urban health externalities appear to have only modestly contributed to the positive impact of transport linkages on HE, at least for the years around 1890.[15]

7.4. Rural development

Instead, there was another mechanism —the last in our sequence— that may have become more relevant, which we term rural specialisation. Transport connectivity and market integration create opportunities for market expansion and increased

[15] We do not rule out—and, in fact, it might well have been the case—that improvements in health infrastructure and medical services between 1890 and 1911, the period between the birth and inspection of our male cohort, could have a positive impact on their average height, possibly supporting a healthier pubertal growth spurt. However, at this stage of research, several uncertainties remain. For example, even if health infrastructure and medical services had contributed positively to adolescent height, it is unclear whether this effect was strong enough to offset earlier deprivation and stunting. We hypothesise it was not, given that, as already argued, early-life conditions play a decisive role in shaping an individual's adult height (see Section 4). Based on a large dataset of British children, Gao and Schneider (2021) suggested that the pubertal growth spurt was substantially weaker before 1910. We therefore propose, for now, that urban health externalities likely played a relatively limited role in the relationship between transportation linkages and height for the cohort of males born in 1890.

agricultural output, allowing for specialisation in commercial and higher value-added crops, ultimately enhancing farmers' incomes and access to goods (Chan, 2022). However, transport connectivity and market integration also tend to increase competition, which may lead to declines in agricultural prices, rural wages, rents, and incomes, potentially even negatively affecting industrial and urban earnings (Betrán & Pons, 2011).

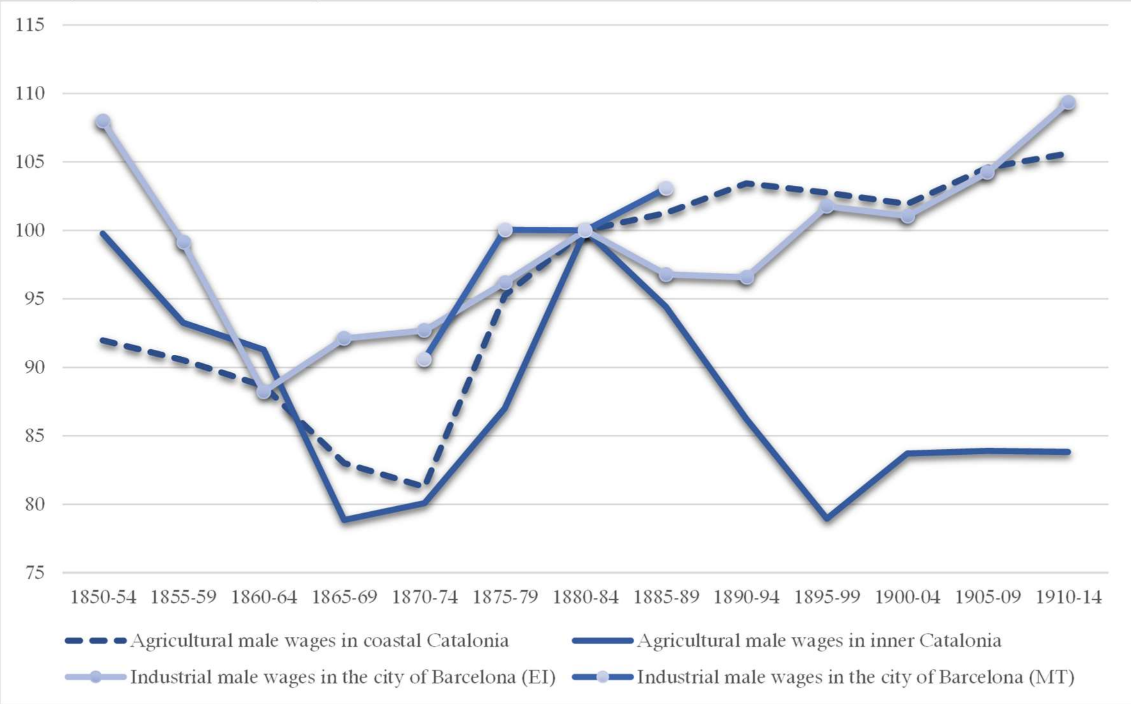
These two processes may have a complex impact on individuals' physical stature. Expanding market opportunities do not necessarily translate into improved well-being in rural areas. Likewise, rising agricultural competition is not necessarily associated with a deterioration in the health status of the rural population (see Section 3 and below).

The literature has identified two distinct cycles in Catalonia's agriculture during the last quarter of the 19th century. The first covers the 10 to 15 years leading up to the mid-1880s, a period of agricultural expansion largely driven by new vineyard plantations and the production and export of wine to France, which was suffering from the phylloxera pest. Additionally, other woody crops and commercial-intensive productions, such as olive oil and horticultural products, saw significant progress, while certain counties experienced a growing orientation towards forestry and cattle breeding (Garrabou & Pujol, 1987, pp. 73–75).

Partly driven by improved transport connectivity, the strengthening of specialisation and commercial agriculture contributed to population growth in rural municipalities. Although this growth was modest and unevenly distributed, it marked a return to a positive demographic trend after two decades of population decline. Agricultural expansion was accompanied by rising real wages and coincided with a moderate upward trend in the height of male cohorts born between the late 1870s and early 1880s (Ramon-Muñoz, Ramon-Muñoz, & Koepke, 2022, for western Catalonia).

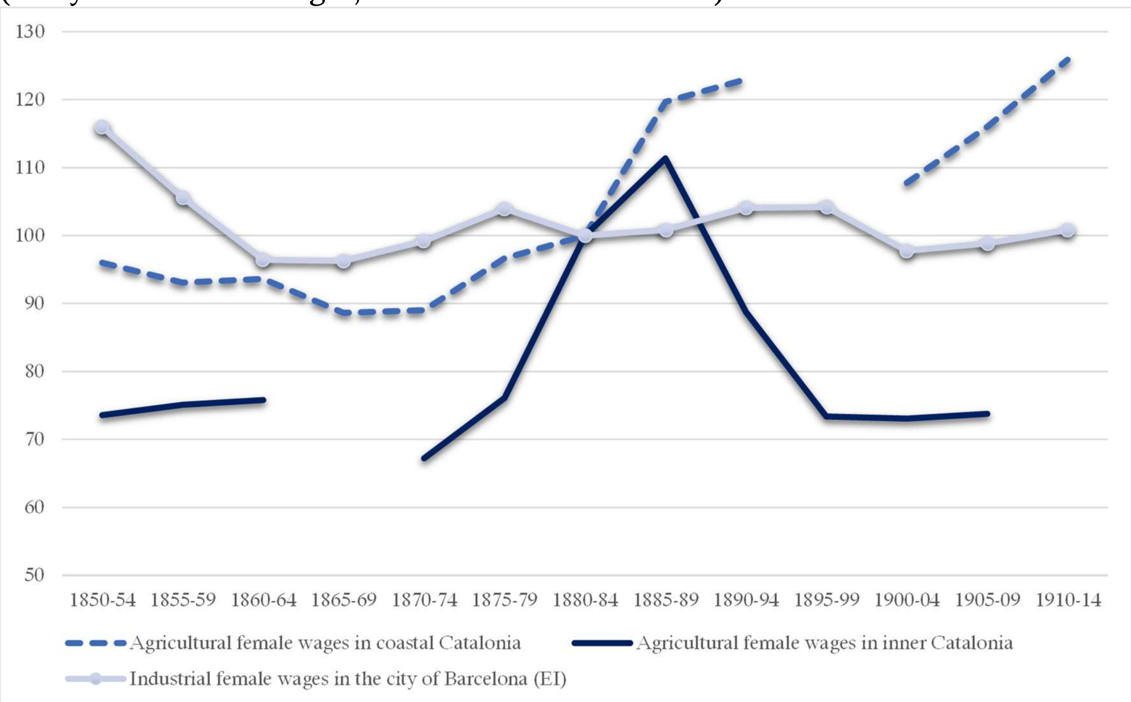
This suggests no deterioration in the nutritional status of the population and may indicate that rising rural incomes may have translated into improved health outcomes. It also makes it clear that population growth, as we will discuss below, did not damage biological well-being, while the strengthening of agricultural specialisation and commercialisation did not result in deteriorating nutritional conditions either.

Figure 16. Agricultural and industrial male real wages in Catalonia, 1850-1914 (five-year annual averages, index numbers 1880=100)



Notes and sources: Authors' elaboration based on Garrabou (1982), pp. 189-192, Garrabou, Tello and (1999), pp. 447-454, Camps (1995), pp. 214-215, and Maluquer de Motes (2013). EI and MT mean wages form the firms "La España Industrial" and "La Maquinista Terrestre", respectively.

Figure 17. Agricultural and industrial female real wages in Catalonia, 1850-1914 (five-year annual averages, index numbers 1880=100)



Notes and sources: Authors' own elaboration based on Garrabou, Pujol, and Colomé (1991), pp. 40-49, Camps (1995, pp. 214-215), and Maluquer de Motes (2013). See also Figure 14.

From the mid-1880s to the mid-1890s, Catalonia's agriculture experienced a new cycle characterised by recession —the late 19th-century agrarian crisis (see Section 7.1). To make matters worse, phylloxera reached Catalonia, leading to the decline or abandonment of vineyards in some areas. At this stage, transport connectivity and market integration were no longer driving expansion, instead, they were exacerbating difficulties in Catalan agriculture, impacting rural incomes and, in some cases, urban economies as well.

However, this process was more complex than it may initially appear. Figures 16 and 17 provide evidence on real wages in 19th-century Catalonia. While they do indicate a decline in real wages, this trend was not uniform across rural areas. In coastal territories, where agricultural specialisation and commercial production were more pronounced, the decline was far less severe than in inland and western Catalonia. Moreover, urban wages were not always negatively affected, and where declines did occur, they were relatively modest and short-lived, suggesting that the difficulties in agriculture had only a moderate, if any, impact on the urban labour market. By the early 1890s, industrial real wages in Barcelona were substantially higher than in the early 1860s, suggesting that increased domestic and international MA—which, as discussed in Section 7.3, fostered specialisation, agglomeration, and economies of scale—was positively correlated with material well-being and, arguably, biological living standards (Borderías & Cussó, 2023, Ramon-Muñoz & Ramon-Muñoz, 2024).

These trends in real wages are particularly relevant to our discussion. First, it is uncertain whether oversupply, price declines, and shrinking incomes in agricultural counties necessarily led to a deterioration in the nutritional status of the rural population. Those who did not migrate from rural areas after the mid-1880s, ultimately remained close to sources of food supply.

Furthermore, medium and small landowners predominated in late 19th-century Catalonia (Garrabou et al., 1992; Garrabou & Saguer, 2006). While many smallholders had insufficient land and worked as labourers for larger landowners (Colomé, Saguer & Vicedo, 2002; Garrabou et al. 2014), substantial declines in caloric intake have not been documented in the areas where the agrarian crisis appears to have been most severe (Ramon-Muñoz, Ramon-Muñoz, & Koepke, 2022). This may be because most rural households owned at least a small plot of land, along with poultry, rabbits, pigs, and a vegetable patch for self-consumption and family sustenance (Ferrer-Alòs, 2023).

Table 8. OLS and IV Estimates of the Impact of 1890 Market Access (MA) and Port Access (PA) on the height (HE) of male conscripts born in 1890 and enlisted in 1911 in localities of Catalonia up to 5,000 inhabitants

	(1)	(2)	(3)	(4)
Estimator	OLS	IV	OLS	IV
Dependent variable	HE	HE	HE	HE
Ln Market Access (MA)	6.961***		7.066***	
	(1.880)		(1.908)	
Ln of Market Access (MALCP) (instrumented)		7,031***		7.136***
		(2.138)		(2.169)
Access to a Port (PA)	10.560***	10.570***		
	(3.746)	(3.742)		
Access to a Port (ALGH) (instrumented)			17.200**	17.260**
			(7.601)	(7.645)
Territorial Units	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes
Constant	23,989**	23,983**	20,338*	20,304*
	(10,226)	(10,215)	(11,163)	(11,199)
Observations	10,040	10,040	10,040	10,040
R-squared	0.012	0.012	0.012	0.012

Notes: Robust Standard errors are clustered at the municipal level. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Nevertheless, a complementary explanation—one more directly related to the Transportation-HE nexus—for the lack of evidence of substantial declines during a period of crisis is possible. The fact that real wage declines in coastal areas were almost negligible compared to those in inland Catalonia suggests that agricultural specialisation and commercialisation may have contributed to improved health conditions even after the mid-1880s. The connection between these latter processes and improved transport connectivity has been highlighted in the literature. During the expansive cycle of Catalan agriculture, it has been argued that railways—by facilitating wine commercialisation, as seen in some coastal territories since the 1850s—also encouraged vineyard cultivation in the counties where this crop experienced the greatest expansion between the mid-1870s and mid-1880s (Parcerisas, 2012, pp. 514–515; Pascual, 2015, p. 309). Similarly, advances in horticultural specialisation have been closely linked to railway construction (Garrabou & Pujol, 1987, pp. 73–75). In most cases, these commercial crops were exported to international markets through Catalonia's improved seaports. During the recessionary period, it has also been suggested that, despite—or in some cases as a result of—the late 19th-century agrarian crisis, specialisation processes continued and even intensified in certain counties further reinforcing pre-existing trends (e.g. Ponce, 1995, Garrabou & Pujol, 1987, pp. 73–75).

To this literature, we add empirical evidence showing that the positive and statistically significant transport linkage-HE nexus persists even when focusing exclusively on rural municipalities rather than all localities. Using the same specifications applied in Section 6 to test the overall effect of MA and PA on HE, we find that in rural municipalities, a 1% increase in MA corresponds to a height gain of 0.07 mm (Table 8), both before and after instrumenting this variable. Although this effect is slightly lower than the 0.08 mm increase observed when considering all municipalities, the results strongly and consistently indicate the impact of transport connectivity on rural biological well-being, likely due to enhanced opportunities for rural development. Although they should be interpreted with caution, the results for PA follow a similar pattern and are even more pronounced in rural municipalities compared to all municipalities: proximity to a port increases the height of rural males by 1 to 1.7 cm—between 0.1 and 0.5 cm more than the effect observed when including non-rural localities (see Tables 4 and 5).

Considering all this evidence, we hypothesise that in rural Catalonia, agricultural specialisation and the expansion of commercial agriculture were also facilitated by enhanced transport connectivity. We refer to this mechanism as rural development. Furthermore, we propose that the interaction between these factors may have mitigated the negative effects of the agricultural crisis as well as dietary changes resulting from the commercialisation of agriculture.

To test these hypotheses, we first empirically explored the potential positive relationship between transport linkages and specialisation in commercial, high value-added crops at the municipal level. However, the lack of detailed crop and production data at the local level precludes a direct test. As a second-best approach, we analysed population trends in rural municipalities, assuming these trends reflect rural development and the characteristics of the agricultural sector—specifically, agricultural dynamism, which may lead to higher labour demand, increased economic opportunities, and, ultimately, population growth. This dynamism can plausibly be linked to commercial agriculture oriented towards higher-value-added products, facilitated by enhanced transport connectivity that enables the exchange of such goods for incoming foodstuffs.

Table 9. OLS and IV estimates of the impact of 1890 Market Access (MA), Port Access (PA) and 1890 Railways Access (RA) on municipal Population Growth (POPGR) between 1887 and 1900 in localities of Catalonia up to 5,000 inhabitants

	(1)	(2)	(3)	(4)
Estimator	OLS	IV	OLS	IV
Dependent variable	POPGR 1887-1900	POPGR 1887-1900	POPGR 1887-1900	POPGR 1887-1900
Ln Market Access	0.008***	0.006***		
(MA)	(0.001)	(0.001)		
MA>50%			0.006***	0.009***
			(0.00104)	(0.00197)
Access to a port (PA)	0.002	0.004	0.003	0.003
	(0.0034)	(0.0068)	(0.003)	(0.003)
Territorial Units	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes
Constant	6.632	6.352	5.811	5.218
	(6.278)	(6.317)	(6.332)	(6.299)
Observations	843	843	843	843
R-squared	0.169	0.167	0.160	0.154

Notes: The interaction between the latitude and longitude of the municipal centres was excluded from the regressions to avoid multicollinearity. Instead, the regression includes two additional control variables: the municipality's average population growth between 1877 and 1887, and its distance to a first-order paved road. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Using the same control variables as in Table 7, along with population growth between 1877 and 1887 and the distance to the nearest first-order paved road, we regressed the natural logarithm of MA and PA in 1890 against annual population growth rates between the 1887 and 1900 census years (POPGR) for municipalities with populations of up to 5,000 inhabitants in 1887 (Instituto Geográfico y Estadístico 1892; Dirección General del Instituto Geográfico y Estadístico, 1883-1884; 1902). The results, displayed in Table 9, confirm the expected positive relationship. However, this was highly significant between MA and POPGR but not for PA. Again, this is possibly due to sample size, as there are very few observations of municipalities with fewer than 5,000 inhabitants that had access to a port. Nevertheless, if we focus on the MA variable, it is important to note that the results hold whether MA is introduced as a continuous variable (columns 1 and 2) or as a categorical variable (columns 3 and 4)—the latter showing that rural localities with MA above the 50th percentile were demographically more dynamic than other rural municipalities. Importantly, similar results are obtained whether MA is instrumented or not. The positive relationship between MA and POPGR is particularly notable given that Catalonia's rural population had already begun a declining trend between 1887 and 1900.[16]

If transport linkages, and, in this specific case MA, fostered rural development, as indicated by population growth, an important question arises: was this development also linked to improved biological well-being? In other contexts, rural population growth, coupled with increasing agricultural specialisation and commercialisation, has sometimes led to nutritional deterioration due to dietary changes (see Section 2).

Table 10. OLS and IV Estimates of the impact of the interaction between Market Access (MA) and POPGR on the Height (HE) of the 1890 male cohort enlisted in 1911 in localities of Catalonia up to 5,000 inhabitants

	(1)	(2)
Estimator	OLS	IV
Dependent Variable	HE (mm)	HE (mm)
MA≤50% x POPGR <0	Ref.	Ref.
MA≤50% x POPGR ≥0	-0.503 (2.167)	-0.428 (2.283)
MA>50% x POPGR <0	3.072* (2.093)	4.073 (2.793)
MA>50% x POPGR ≥0	3.012 (2.225)	3.137 (2.525)
Access to a port (PA)	10.57*** (3.77)	10.60*** (3.77)
Territorial Units	Yes	Yes
Additional controls	Yes	Yes
Constant	23,448 (11,479)	23,370** (11,495)
Observations	10,040	10,040
R-squared	0.012	0.012

Notes: Robust Standard errors are clustered at the municipal level. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

[16] As an extension of our analysis, we also tested whether this relationship holds when considering Railway Access (RA) instead of MA. As in previous exercises, RA equals 1 if the distance between a municipal centre and the nearest railway station is less than 4.5 km; otherwise, it equals 0. Again, we also instrumented this variable using LCPs, following the procedures described in Section 5. Table A.10 in the Appendix shows that while the relationship between RA and POPGR persists in the OLS regressions, it does not hold when RA is instrumented. Although railways is a primary component of MA, this may suggest that, for rural municipalities, RA may not always fully capture the effects of transport linkages.

To examine this, we follow the same approach as in Table 7, analysing the interaction between MA and population growth (POPGR) and its effect on HE. MA is divided into two groups: municipalities at or below the 50th percentile (MA ≤ 50%) and those above it (MA > 50%). Similarly, municipalities are categorised based on population growth: those with positive growth (POPGR ≥ 0) and those with negative growth (POPGR < 0).

Table 10 presents the results of both the OLS and IV specifications. These results are not statistically significant, and when significance is observed, it is only at the 10% level. While we cannot confirm that young males from demographically dynamic rural localities with better MA were significantly taller than the rest, a positive relationship between the former and the latter remains.[17] Additionally, the results suggest that population growth in villages with more limited transport accessibility (MA ≤ 50% and POPGR ≥ 0) may have led to a decline in biological living standards. As a further check, we also interact PA with POPGR to examine the impact of international market accessibility on HE (Table A.12). The results do not differ significantly from those in Table 10.

Taken together, this evidence demonstrates that while inhabitants of demographically dynamic rural localities with better MA may not have been significantly taller than other well-connected rural populations, those from villages with enhanced transport connectivity were relatively taller than residents of larger municipalities (over 5,000 inhabitants) with poorer transport infrastructure (Table 7, columns 3–4). Furthermore, improved MA fostered rural development, as reflected in population growth, without adversely affecting wellbeing. Although definitive quantitative evidence for the rural development mechanism remains elusive, we posit its contribution to the MA-HE nexus—in some cases through income gains, in others by ensuring a consistent supply of nutrients, and in some instances through a combination of both.

8. Discussion

In the context of the existing literature, the results presented in Sections 6 and 7 are remarkable and provide fresh evidence on the historical causes of improvements in biological living standards. They validate the net positive effect of better transport linkages on well-being. This positive association is consistent with previous studies conducted on Western countries for the late 19th century (see Section 2). Specifically,

[17] The same holds when we regress POPGROWTH against HE in rural Catalonia, although the results are not statistically significant either.

our findings suggest that by the late 19th century, the potential negative impacts of market integration were already outweighed, both in rural and urban areas.

One potential negative impact was the increased risk of disease transmission due to rising population density and overcrowding. Another possible consequence of market integration was a decline in protein intake in rural areas. However, we find no evidence that this occurred in late 19th-century Catalonia. This absence of negative effects could be attributed to a well-integrated and unified market, including microbial factors, as suggested by Heyberger (2011a, 2011b) in the case of France. While we do not dismiss this possibility, our focus has been on disentangling the specific mechanisms underlying the transportation-HE positive nexus we identified.

In doing so, we have also contributed to another area of discussion: whether urban residents benefited more from improved transport connectivity than those living in rural areas. Baten and Fertig (2009) found evidence supporting this urban-rural divide in the German region of North-Rhine-Westphalia during the early 1880s, which vanished by the late 1890s. Zehetmayer (2013) also found that in Postbellum USA, railways improved urban dwellers' nutrition but could not counterbalance the negative effects of industrialisation and urbanisation. For the Antebellum period, Zimran (2020) found that population density, which grew more in agriculturally suitable counties due to better transport linkages, was a mechanism explaining why improved MA deteriorated biological living standards. He refers to this as the local development mechanism.

In late 19th century Catalonia, we find otherwise. While better MA resulted in increased population density, rising urbanisation, and overcrowding, our evidence suggests that greater MA also facilitated more abundant, protein-rich, and cheaper food products, enhanced productivity, and higher real incomes through specialisation, scale, and agglomeration economies during a period of urban growth. We refer to this as the urban economies' mechanism. Therefore, contrary to Zimran (2020) for Antebellum USA and Zehetmayer (2013) for Postbellum USA, we argue that in late 19th-century Catalonia, food accessibility and urban economies, already outweighed the negative impacts of population growth and overcrowding in urban areas. We also discussed the potential influence of urban health externalities, but they likely played only a modest role, at least before the early 1890s. These findings on the positive impact of urban economies align with Esteban-Oliver (2023), who found that larger municipalities closest to stations experienced significantly greater population growth, and Ramon-Muñoz and Ramon-Muñoz (2024), who identified an urban HE premium for cohorts born in 1890 and living in Catalonia in 1910. Interestingly, our findings also suggest that transportation connectivity and market integration disproportionately benefited urban dwellers, without negatively affecting the nutritional status of rural residents.

This latter finding holds particular significance. While urban populations gained the most, rural residents not only avoided potential negative impacts associated with enhanced domestic and international MA but also exhibited comparative advantages. Contrary to arguments advanced for the first half of the 19th century in the USA and Bavaria (Komlos, 1987; Komlos & Coclanis, 1997; Haines, 1998; Craig & Weiss, 1998; Baten, 1999; Haines, Craig & Weiss, 2003; Baten, 2009; Yoo, 2012; Zimran, 2020), we observe that rural areas with improved transportation featured taller populations compared not only to less-connected rural localities but also to worse-connected, non-rural municipalities. This implies that we find no evidence that commercial agricultural expansion led to dietary deterioration in late-nineteenth-century Catalonia, contrasting with patterns observed elsewhere.

For Catalonia, our analyses support the claim that transportation improvements facilitated demographic dynamism in rural areas with better market accessibility—likely through specialisation processes and the consolidation of commercial agriculture. Within a context of international market integration and oversupply, enhanced connectivity also ensured the reliable inflow of food products. While the most dynamic and well-connected rural areas were not home to the tallest rural populations, we argue that this rural development mechanism averted the nutritional decline observed in other historical and geographical contexts.

The magnitude of the coefficients obtained in our regression analysis warrants further discussion. Our findings indicate that young males residing in areas with better MA were about half a centimetre taller –between 0.46 and 0.34 cm depending on whether MA was instrumented or not– than those living farther away. Differences of almost 1 cm were observed when MA was interacted with population size, between those residing in municipalities with higher and lower MA (Table 7).

Given that a relevant percentage of MA should be explained by railway access, these figures are consistent with studies in Western European countries. For instance, in North-Rhine-Westphalia, recruits from municipalities closer to railways were between 0.64 and 0.9 cm taller than their counterparts, with variations depending on whether the municipality was classified as urban or rural. Similarly, in Switzerland, the body HE of young males residing in districts that gained railway access increased by 0.93 cm between 1889 and 1893. In the USA, researchers observed differences of around 1 cm when considering the impact of railways on body HE (Baten & Fertig 2009, Büchel & Kyburz 2020, Guven Solakoglu 2006).

In late 19th century Catalonia, differences of half to one cm should not be overlooked. This aligns with the HE disparity of between half and three-quarters of a cm observed among young males residing in cities with a population over 20,000 compared to those in villages with up to 5,000 inhabitants (Ramon-Muñoz & Ramon-Muñoz, 2024). However, when comparing literate and illiterate conscripts, as well as individuals engaged in manual and non-manual occupations, differences of less than a cm appear more modest. This is because HE differences exceeding one cm were observed in certain industrial Catalan municipalities (Ramon-Muñoz & Ramon-Muñoz, 2016, p. 102-103).

While males living in municipalities at the top of the MA percentiles enjoyed a higher physical stature of about 0.5 cm, access to ports with customs offices had an even greater correlation, suggesting an increased body height by around one cm or more. This indicates that the impact of PA on height could be twice that of MA. This is a significant finding, suggesting that residing in a municipality with a seaport could contribute to HE gains comparable to being literate or engaging in manual work in late 19th century Catalonia. It also contrasts with recent literature on the impact of transport. For Ireland, Fernihough and Lyons (2022) observed that MA brought about by railroads had an opposite effect compared to international market accessibility via ports: improvements in railroads had a substantial positive impact on both population density and land values between the 1840s and the 1990s, whereas the opposite was true when access to ports improved. In our case, rather than cancelling each other out, MA and PA reinforce each other. However, our results for PA should be interpreted with caution, as the IV approach remained at the tolerance limit. That is, while we believe that a strong correlation between PA and HE can be asserted, reinforcing the overall conclusions, we cannot claim straight causality and effect sizes from this relationship.

A final point of discussion broadens the scope of our analysis. By examining a region in Southern Europe, our study contributes to recent research suggesting that the impact of transportation should be understood within a general-equilibrium framework of Market Access—considering all forms of transport and multiple interacting markets, rather than a single infrastructure and a single market. Our findings indicate that the net impact of transportation linkages may historically vary. In our case, we find a net positive impact of MA on late 19th-century Catalonia, driven mainly by increased access to cheaper food, as well as urban economies and rural development. For the same period, Donaldson and Hornbeck (2016) found a positive impact of MA on USA counties' agricultural land value in 1890, alongside population and worker utility. Additionally, for the USA in the latter half of the 19th century, Hornbeck and Rotemberg (2019) also found a substantial favourable impact of greater MA on aggregate manufacturing productivity and real wages. For the 19th and early 20th centuries, Ciccarelli, Fenske, and Martí-Henneberg (2023) documented greater nuptiality of young women and income gains associated with MA, which also delayed the fertility transition of the Old Continent between 1840 and 1940. In the case of Ireland, Fernihough and Lyons (2022) found that between the 1840s and the 1910s, improved MA appreciated land values, although access to ports restrained this appreciation. For England between 1680-1830, Álvarez-Palau et al. (2024) observed that MA allowed population growth in inland towns and increased occupation in skilled manual and non-manual categories, although it also led to higher child mortality likely as MA fostered migration and through this channel overcrowding.

9. Conclusions

This study examined the impact of domestic and international market access (MA and PA) on biological living standards in late 19th-century Catalonia. Our hypothesis posited that improved accessibility to transport linkages had an overall beneficial effect, ultimately contributing to the enhancement of biological living standards. To test this, we utilised a comprehensive dataset that combined male individual heights with newly created data on domestic MA—as defined by Donaldson and Hornbeck (2016)—and international MA—using a port access proxy—at the municipal level in Catalonia. In the methodological section, our primary identification strategy employed an instrumental variables (IV) approach based on Least-Cost Paths (LCPs) and lighthouses (ALGH) to address potential endogeneity issues.

Our preferred specification revealed that doubling the MA statistic, relative to the average municipality, led to an increase in height (HE) of approximately 0.5 cm. Moreover, males in municipalities with an MA statistic above the 50th percentile were, on average, about half a centimetre taller than those in areas below this threshold.

Additional evidence confirms that improved connectivity had a generally positive impact on both urban dwellers and rural residents, although the former benefited more than the latter. Our econometric analysis indicates that young males living in localities with more than 5,000 inhabitants and an MA statistic above the 50th percentile could be up to 1 cm taller than those in smaller municipalities with lower MA levels.

We also assessed the impact of international market accessibility through port connectivity (PA). Our results indicate that 21-year-old men living in municipalities with a port were approximately 1 cm taller than their counterparts. However, due to the challenges encountered in instrumenting and in isolating this variable effect we prefer to interpret the causal link between these two variables with caution.

We propose that the mechanisms underpinning this positive association are primarily linked to improved and more affordable access to food, as well as urban economies and rural development. These factors may have mitigated the potential negative effects of industrialisation and urbanisation, including pollution and overcrowding.

Our findings have several important implications and advance the literature in multiple ways. Most significantly, we demonstrate that by the end of the 19th century, modern transportation, as measured by MA and PA, contributed to improved biological living standards, particularly in more industrialised and urbanised areas. Therefore, this paper offers a novel perspective on the impact of industrialisation, urbanisation, and market integration on well-being. More broadly, our study underscores the potential benefits of transport linkages. Finally, we add to the emerging literature on transport infrastructure, which contends that the impact of transportation is best assessed using a general-equilibrium approach.

We also recognise the limitations of this study. For instance, although our dataset is comprehensive—integrating individual-level height (HE) data with novel information on municipal MA—one potential limitation is the varying robustness of certain findings, particularly those related to international market access as proxied by the port accessibility (PA) variable. Nevertheless, despite these and other possible caveats, this research makes a pioneering contribution by bridging two previously distinct strands of literature and employing novel methodologies and datasets to explore the historical relationship between transport linkages and biological living standards biological living standards in 19th century Europe.

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Appendix Tables and Figures

Table A.1. Distance to a port and its effect on the Height (HE) of male conscripts born in 1890 and enlisted in 1911 in Catalonia

	(1)
Estimator	OLS
Dependent variable	HE
< 4km	Ref.
4-8km	-9.566***
	(3.436)
> 8km	-7.768**
	(3.073)
Ln of Market Access, MA (1890)	Yes
Territorial Units	Yes
Control Variables	Yes
Constant	33,110***
	(9,958)
Observations	12,023
R-squared	0.013

Notes: Additional controls include an indicator equal to 1 if the municipality was a district capital, the natural logarithm (ln) of the municipal population size in 1860, the ln of the average land suitability for wheat, olive, and citrus, the literacy rate of the municipality in 1887, the latitude and longitude, the squared latitude and longitude, and the interaction between the latitude and longitude of the municipal centres. Nodes were excluded from the sample, and standard errors are clustered at the municipal level. Statistical significance is denoted as follows: ***p<0.01, **p<0.05, *p<0.10.

Table A.2. OLS estimates on the impact of 1890 Market Access (MA) and its instrument (Least-Cost Paths, MALCP) and Port Access (PA) and its instrument (Access to Lighthouses, ALGH) on the Height (HE) of male conscripts born in 1890 and enlisted in 1911 in Catalonia

	(1)	(2)	(3)	(4)
Estimator	OLS	OLS	OLS	OLS
Dependent variable	HE	HE	HE	HE
Ln of Market Access (MA)		8.569**	8.097***	7.703***
		(3.660)	(1.856)	(1.768)
Ln of LCPs Market Access	6.193***	-1.016		
	(1.719)	(3.534)		
Access to a Port (PA) in 1890	9.258***	9.376***		8.979***
	(3.109)	(3.045)		(3.227)
Access to a lighthouse (ALGH)			5.136*	1.468
			(2.921)	(2.976)
Territorial Units	Yes	Yes	Yes	Yes
Additional Variables	Yes	Yes	Yes	Yes
Constant	27,998***	26,879***	32,917***	26,640***
	(9,760)	(9,697)	(9,400)	(9,786)
Observations	12,023	12,023	12,023	12,023
R-squared	0.013	0.013	0.012	0.013

Notes: Standard errors are clustered at the municipal level. For a list of controls see Table A.1. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Table A.3. IV estimates of the effect of 1890 Market Access (MA) and Port Access (PA) on the Height (HE) of male conscripts born in 1890 and enlisted in 1911 in Catalonia by percentiles (> 60th and > 40th percentiles=1)

	(2)	(3)
Estimator	IV	IV
Dependent Variable	HE	HE
	>40th percentile	>60th percentile
Market access, instrumented (MALPS)	5.641***	4.215***
	(1.736)	(1.600)
Access to a port in 1890 (PA)	10.53***	10.43***
	(3.410)	(3.412)
Territorial Units	Yes	Yes
Additional Variables	Yes	Yes
Constant	27,811***	23,172**
	(9,836)	(10,010)
Observations	12,023	12,023
R-squared	0.012	0.012

Notes: Robust standard errors are clustered at the municipal level. For a list of controls see Table A.1.The 1890 Port Access variable has not been instrumented. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Table A.4. OLS and IV estimates of the impact of 1890 Market Access (MA) and Port Access (PA) on the Height (HE) of male conscripts born in 1890 and enlisted in 1911 in Catalonia

	(1)	(2)
Estimator	OLS	IV
Dependent Variable	HE	HE
Ln of Market Access (MA)	7.624***	7.246***
	(1.765)	(2.020)
Access to a port in 1890 (PA)	9.342***	12.42*
	(3.045)	(7.108)
District capital dummy (Yes=1)	-0.486	-0.341
	(2.636)	(2.638)
Ln of Population size 1860	-0.820	-1.165
	(1.073)	(1.333)
Municipal literacy rate 1887 (%)	-0.000880	-0.00213
	(0.0866)	(0.0878)
Latitude	76.88	30.37
	(195.1)	(223.0)
Longitude	-1,235***	-1,103**
	(470.7)	(558.0)
Latitude squared	3.462*	2.770
	(1.899)	(2.447)
Longitude squared	14.98***	13.38**
	(5.699)	(6.746)
Latitude*Longitude	-2.091	-0.936
	(4.701)	(5.402)
Ln of land suitability index for wheat	1.535	1.557
	(1.535)	(1.529)
Ln of land suitability index for olives	0.495	0.516
	(0.471)	(0.476)
Ln of land suitability index for citrus	0.508	0.548*
	(0.317)	(0.325)
Territorial Units	Yes	Yes
Constant	27,028***	24,297**
	(9,716)	(11,535)
Observations	12,023	12,023
R-squared	0.013	0.013

Notes: Robust standard errors are clustered at the municipal level. For a list of controls see Table A.1. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Table A.5. Multilevel model estimates of the relationship between municipal Market Access (MA) and Port Access (PA) in 1890 and the Height (HE) of male conscripts born in 1890 and enlisted in 1911 in Catalonia

	(1)	(2)	(3)
Estimator	OLS	OLS	OLS
Dependent variable	HE	HE	HE
Ln of Market Access (MA)	4.602***	6.596***	7.467***
	(0.974)	(1.489)	(1.785)
Access to a port (PA) in 1890	10.96***	9.912***	9.538***
	(3.088)	(2.913)	(3.256)
Territorial Units	No	Yes	Yes
Additional controls	No	No	Yes
Constant (Overall)	1,598***	1,575***	26,089**
	(8.764)	(14.76)	(10,682)
Overall random intercept	2.139***	1.972***	1.808***
	(0.126)	(0.161)	(0.209)
Residual intercept	4.115***	4.115***	4.116***
	(0.00666)	(0.00665)	(0.00665)
Observations	12,023	12,023	12,023
Number of groups	861	861	861

Notes: Robust standard errors are reported in brackets. For a list of controls see Table A.1. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Table A.6 OLS estimates on the impact of 1890 Market Access (MA) and Port Access (PA) on the Height (HE) of male conscripts born in 1890 and enlisted in 1911 in Catalonia, using Judicial Districts (District) as the territorial categorical variable

	(1)	(2)
Estimator	OLS	OLS
Dependent variable	HE	HE
Ln of market access (MA)	8.148***	6.413***
	(2.089)	(2.329)
Access to a port (PA) in 1890	9.945***	8.073***
	(2.692)	(2.79)
District (*Partido Judicial*/*Judicial District*)	Yes	Yes
Additional controls	Yes	Yes
Constant	1,563***	54,601*
	(19.57)	(31,787)
Observations	12,023	12,023
R-squared	0.016	0.017

Notes: Robust standard errors are clustered at the municipal level. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Table A.7. OLS and IV estimates of the impact of 1890 Market Access (MA) on the Height (HE) of male conscripts born in 1890 and enlisted in 1911 in Catalonia, using MA as a continuous variable interacted with 1887 Population Size (POPSZ)

	(1)	(2)
Estimator	OLS	IV
Variables	HE	HE
Ln of market Access (MA)	7.004***	6.844**
	(1.755)	(3.324)
Population Size in 1887 (POPSZ)	-24.23	-36.09
	(25.34)	(30.90)
Ln of Market Access (MA) * Population Size (POPSZ) ≤ 5,000	Ref.	Ref.
Ln of Market Access (MA) * Population Size (POPSZ) > 5,000	3.107	4.390
	(2.742)	(3.374)
Access to a Port (PA) in 1890	Yes	Yes
Territorial Units	Yes	Yes
Additional controls	Yes	Yes
Constant	30,234***	30,299***
	(9,965)	(10,009)
Observations	12,023	12,023
R-squared	0.014	0.014

Notes: Robust Standard errors are clustered at the municipal level. For a list of controls see Table A.1. The 1890 port access variable has not been instrumented. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Table A.8. OLS and IV estimates of the impact of Railways Access (RA) in 1890 interacted with Population Size (POPSZ) in 1887 on the height (HE) of male conscripts born in 1890 and enlisted in 1911 in Catalonia by categories

	(1)	(2)
Estimator	OLS	IV
Dependent variable	HE (mm)	HE (mm)
Access to railways*municipality > 5,000 inhabitants	Ref.	Ref.
Access to railways*municipality ≤ 5,000 inhabitants	-5.552*	-6.197*
	(3.148)	(3.500)
No access to railways*municipality > 5,000 inhabitants	-6.943**	-9.689
	(3.130)	(7.935)
No access to railways*municipality ≤ 5,000 inhabitants	-8.353**	-9.149**
	(3.327)	(3.879)
Access to a port in 1890	Yes	Yes
Territorial Units	Yes	Yes
Additional controls	Yes	Yes
Constant	27,733***	27,210***
	(10,064)	(10,291)
Observations	12,023	12,023
R-squared	0.012	0.012

Notes: Robust Standard errors are clustered at the municipal level. For a list of controls see Table A.1. The 1890 port access variable has not been instrumented. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Table A.9. OLS and IV Estimates of the effects of the interaction between Port Access (PA) and Population Size (POPSZ) on the Height (HE) of male conscripts born in 1890 and enlisted in 1911 in Catalonia

VARIABLES	(1) OLS HE (mm)	(2) IV HE (mm)
Without PA * POPSZ ≤5,000	Ref.	Ref.
Without PA * >5,000	6.167*	6.288*
	(3.374)	(3.486)
With PA * POPSZ ≤5,000	10.94***	11.93*
	(3.564)	(7.250)
With PA * POPSZ >5,000	13.13***	13.38***
	(4.424)	(4.856)
Territorial Units	Yes	Yes
Additional controls	Yes	Yes
Constant	25,494***	24,961**
	(9,816)	(10,536)
Observations	12,023	12,023
R-squared	0.012	0.012

Notes: Robust Standard errors are clustered at the municipal level. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Table A.10. OLS and IV estimates of the impact of 1890 Railways Access (RA) on municipal Population Growth (POPGR) between 1887 and 1900 in localities of Catalonia up to 5,000 inhabitants

	(1)	(2)
Estimator	OLS	IV
Dependent variable	POPGR	POPGR
	1887-1900	1887-1900
Railways Access (RA) (> 4.5km=1)	Ref.	Ref.
Railways Access (RA) (≤ 4.5km=1)	0.005***	0.002
	(0.001)	(0.002)
Access to a port in 1890	Yes	Yes
Territorial Units	Yes	Yes
Additional controls	Yes	Yes
Constant	10.010	13.030*
	(6.515)	(6.703)
Observations	843	843
R-squared	0.176	0.167

Notes: Robust Standard errors are clustered at the municipal level. The interaction between the latitude and longitude of the municipal centres has been excluded from the regressions to avoid multicollinearity. Instead, the regression includes two additional controls: the municipality's average population growth between 1877 and 1887, and its distance to the nearest first-order paved road. Population growth is expressed as annual growth rates. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Table A.11. OLS and IV estimates of the impact of Population Growth (POPGR) between 1887 and 1900 on the Height (HE) of male conscripts born in 1890 and enlisted in 1911 in rural Catalonia

	(1)	(2)
	OLS	IV
Dependent Variable	HE (mm)	HE (mm)
Population Growth (POPGR)	32.92	32.11
	(56.18)	(55.77)
Ln Market Access (MA)	7.458***	
	(2.036)	
Ln Market Access, instrumented (MALCP)		7.766***
		(2.340)
Access to a port in 1890 (PA)	11.03***	11.07***
	(3.721)	(3.728)
Territorial Units	Yes	Yes
Constant	19,361*	19,129*
	(11,380)	(11,445)
Observations	10,040	10,040
Number of groups (municipalities)	843	843
R-squared	0.013	0.013

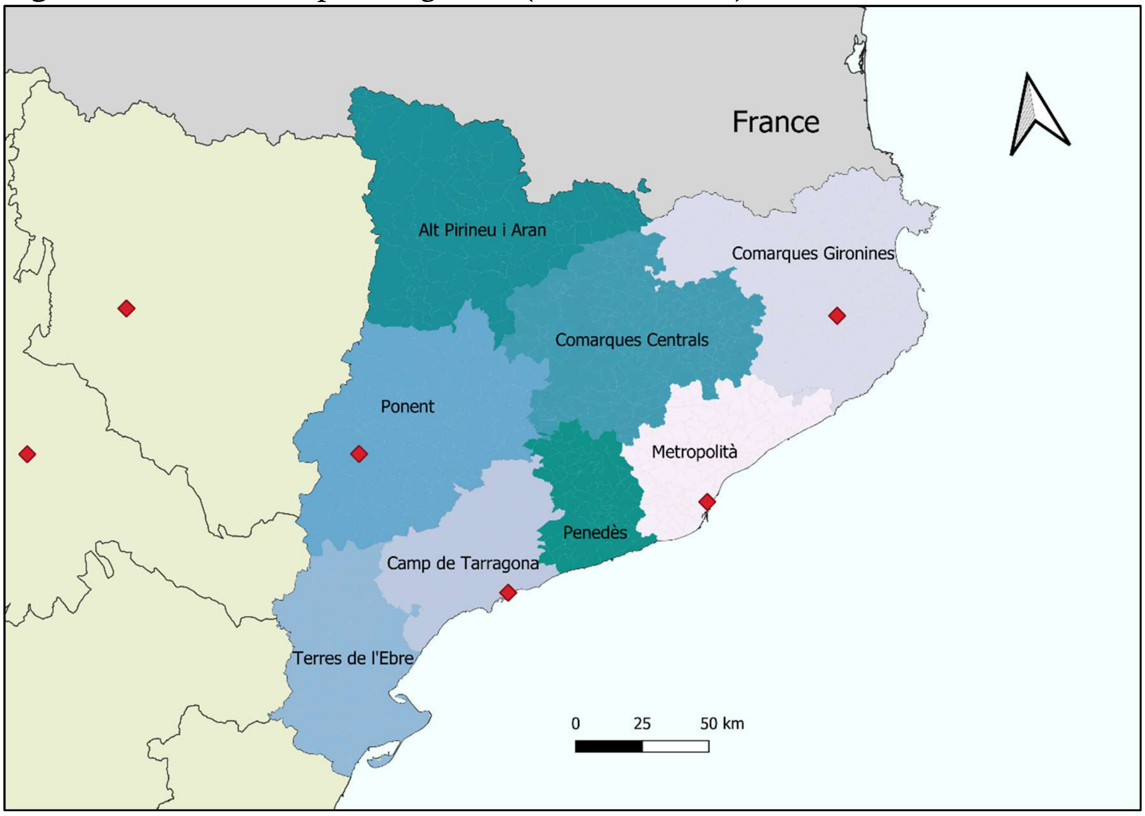
Notes: See Table A.10.

Table A.12. OLS and IV estimates of the impact of the interaction between Port Access (PA) and Population Growth (POPGR) on the Height (HE) of the 1890 male cohort enlisted in 1911 in localities of Catalonia up to 5,000 inhabitants

	(1)	(2)
Estimator	OLS	IV
Dependent Variable	HE (mm)	HE (mm)
Without PA* POPGR <0	Ref.	Ref.
Without PA* POPGR ≥0	-0.354	-0.265
	(1.526)	(1.551)
With PA* POPGR <0	23.17***	29.78
	(7.224)	(20.81)
With PA * POPGR ≥0	6.000	6.417
	(3.806)	(4.049)
Territorial Units	Yes	Yes
Additional controls	Yes	Yes
Constant	23,448	23,370**
	(11,479)	(11,495)
Observations	10,040	10,040
R-squared	0.012	0.012

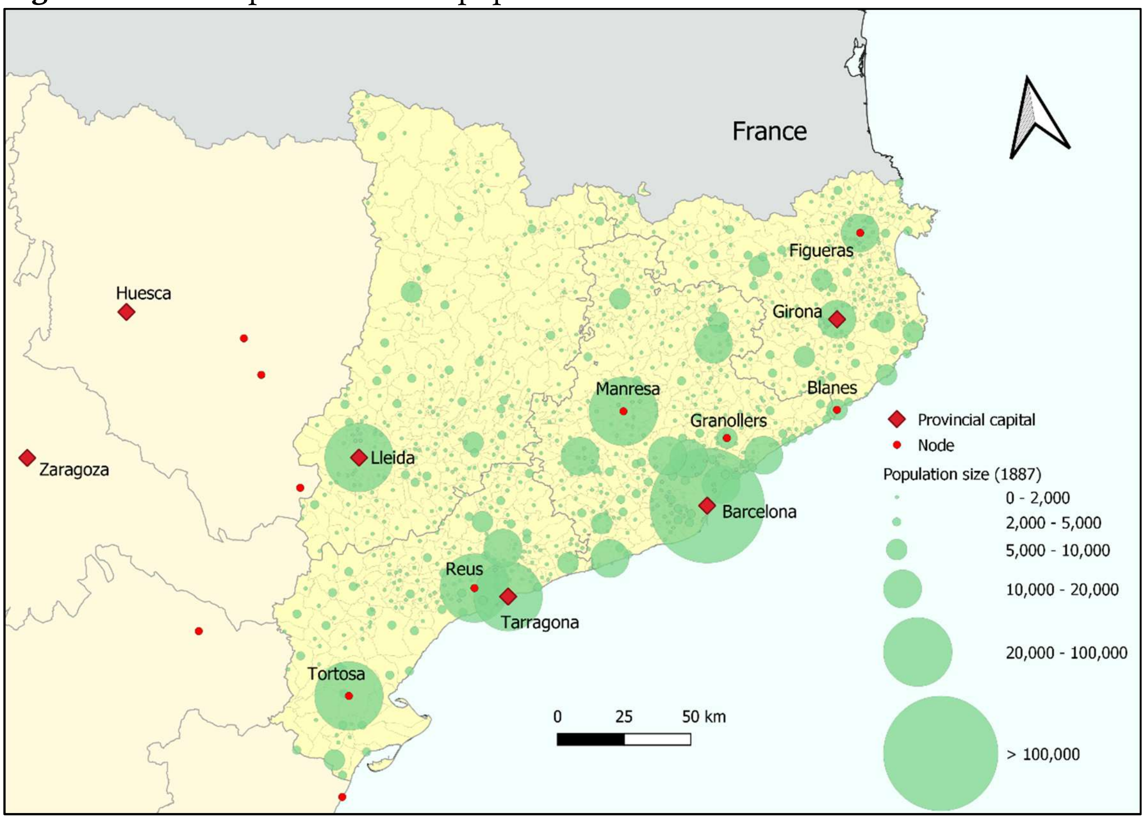
Notes: Robust Standard errors are clustered at the municipal level. Statistical significance is denoted by: ***p<0.01, **p<0.05, *p<0.10.

Figure A.1. Territorial planning areas (territorial units) in current Catalonia



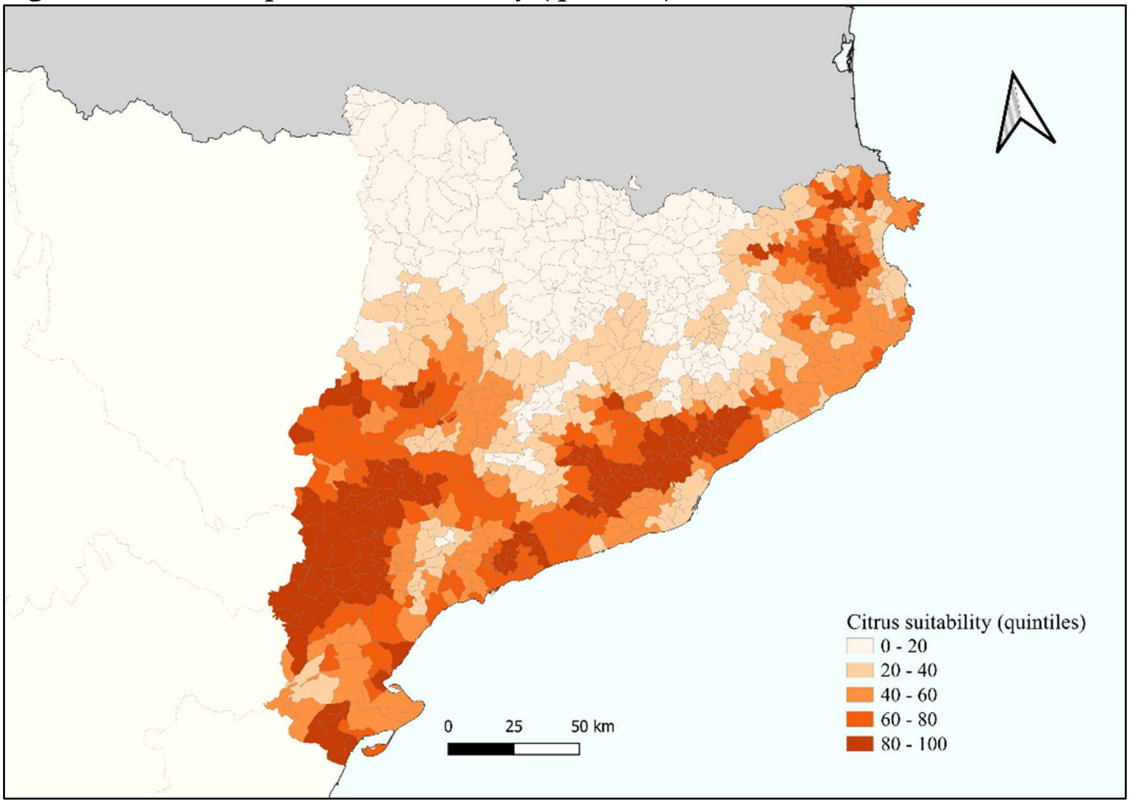
Source: Authors' elaboration using https://www.idescat.cat/. The rhombus indicates a provincial capital.

Figure A.2. Transport nodes and population size in 1887 Catalonia



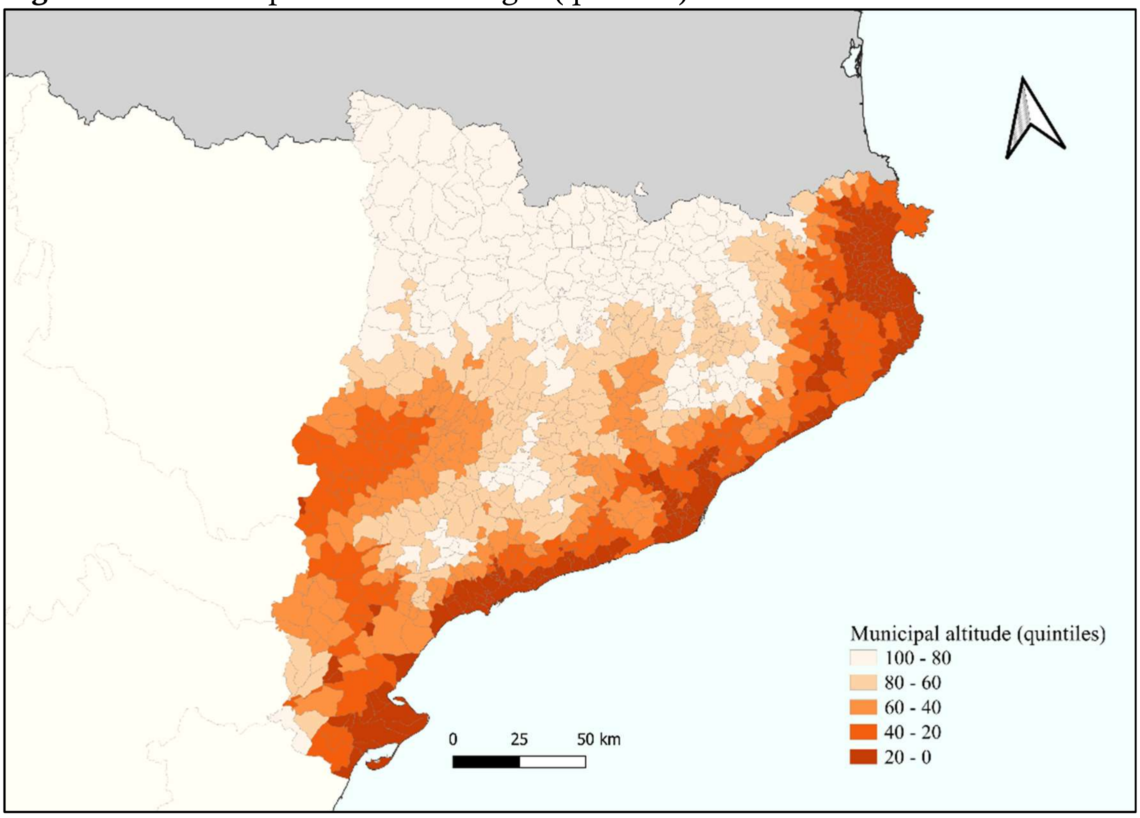
Source: Authors' elaboration.

Figure A.3. Municipal citrus suitability (quintiles)



Source: Authors' elaboration using https://gaez.fao.org/pages/data-viewer.

Figure A.4. Municipal altitude averages (quintiles)



Source: Authors' elaboration using IGN (2018) data.

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