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The Partial Transit System. A Medium-Scale Analysis of the Efficiency of the Spanish Railway Network in the 19th Century

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ABSTRACT: *In the mid-19th century, some engineers argued that railway lines should not only connect important points or markets, but also nearby intermediate centres in order to attract more traffic. This vision, known as the 'partial transit system', had a significant influence on the design of the Spanish railway network. This article assesses its effectiveness through a case study of the Madrid–Irun line in 1870, drawing on historical data on traffic, population and distances, as well as spatial analysis tools and gravity models. The results show that along much of the route—particularly in sparsely populated areas—the diversions attracted little traffic and unnecessarily lengthened journeys. Only in more densely populated areas, such as the Basque Country, did the detours generate significant demand. These findings suggest that partial transit, while effective in more densely populated countries, may have been an unsuitable strategy for much of Spain.* (**JEL CODES**: N73, L92, R41, C21)

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El sistema de tránsito parcial. Un análisis a mediana escala de la eficiencia de la red ferroviaria española en el siglo XIX

Víctor Sanchís-Maldonado

RESUMEN: *A mediados del siglo XIX, algunos ingenieros sostuvieron que las líneas ferroviarias no debían limitarse a conectar puntos o mercados importantes, sino también centros intermedios cercanos para atraer más tráfico. Esta visión, conocida como el sistema de tránsito parcial, tuvo una influencia significativa en el diseño de la red ferroviaria española. Este artículo evalúa su eficacia mediante un estudio de caso de la línea Madrid– Irún en 1870, a partir de datos históricos sobre tráfico, población y distancias, así como herramientas de análisis espacial y modelos de gravedad. Los resultados muestran que, en gran parte del recorrido —particularmente en las zonas escasamente pobladas—, los desvíos atrajeron poco tráfico y alargaron los trayectos innecesariamente. Solo en áreas más densamente pobladas, como el País Vasco, los rodeos generaron una demanda significativa. Estos hallazgos sugieren que, aunque el tránsito parcial fue eficaz en países más densamente poblados, pudo haber sido una estrategia inapropiada para buena parte de España.* (**CÓDIGOS JEL**: N73, L92, R41, C21)

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1. Introduction

From 1844 onwards, the construction of railways became one of the main objectives of the liberal State in Spain. For a decade, several Moderate governments tried to promote the construction of a national railway network, but the results were very disappointing. By 1854, barely 500 km of track were in operation. Lack of capital, political instability and—above all—the absence of a transport market prevented the creation of this network, in stark contrast with developments in other European countries at the time (Cameron, 1971; Bongaerts, 1985; Caron, 1997; Maggi, 2003; Casson, 2009). It was not until the Progressive party came to power that this situation changed. The General Railways Act (1855) and the Credit Societies Act (1856) marked the onset of a policy of State intervention which, through guarantees and subsidies, succeeded in attracting the foreign capital needed to launch the first major lines (Artola, 1978; Castellvi and Barquín, 2018). However, although the role of the State was crucial, its capacity to influence the design of the network was very limited: it merely provided vague indications of preferred routes, without undertaking centralised planning as occurred in Belgium or Sweden (Heckscher and Heckscher, 1954; De Block, 2011).

By 1865, Spain had constructed almost 5,000 km of track connecting Madrid to the country's main coastlines and borders (Esteban-Oliver & Martí-Henneberg, 2022). The literature has extensively debated whether this first network adequately responded to the transport needs. On one side, Menéndez and Cordero (1978) and Gómez Mendoza (1982, 1989) argued that the system effectively promoted economic growth because the rigid supply of traditional means of transport would never have sufficed to modernise the economy. On the other side, Tortella (1973) contended that the capital invested in railway construction might have been more effectively allocated to other industries. According to Barquín (2016), the subsidies granted to the sector encouraged the development of a network that exceeded the needs and economic capacity of a country as underdeveloped as Spain. Herranz (2006) lends support to this view: Spanish railways had a low density of use, and the returns on investment were below their opportunity cost. In any case, none of the above implies that a national railway network should not have been built.

Overall, railways were not a profitable enterprise in Spain (Tedde de Lorca, 1978). The 1864 crisis paralysed construction and led to the bankruptcy or absorption of many small companies (Hernández Sempere, 1983; Pascual, 1985; Barquín, 2007). Some authors have attributed these outcomes to what they viewed as an inadequate centralised layout—referred to in the Spanish literature as a 'radial' design (Nadal, 1975; Casañas, 1977; Broder, 2000; Bel, 2013). However, research has long since questioned this hypothesis (Equipo Urbano, 1970; Cordero, 1984; Barquín and Larrinaga, 2020; Martí-Romero et al., 2021). Given Spain's clearly defined peninsular geography, a centralised network design can be regarded as consistent with its territorial structure.

This centralised configuration, however, exhibited a relatively little-studied peculiarity: the recurrent presence of tortuous routes. Rather than proceeding directly to their destinations, many lines followed indirect paths which significantly increased the total journey distances.

While both passengers and freight were affected, the deterrent effect was particularly strong in passenger traffic, where indirect routes often implied more stops, longer travel times and reduced comfort. For freight—mainly bulk and low-value goods—the cost of distance was less decisive.

The Madrid–Irun line provides a good example of this phenomenon. Initially, it extended almost entirely westwards from Madrid towards Ávila, where it turned north towards Valladolid, before veering northeast again towards Vitoria and France—but not without first undertaking a long detour along the Oria and Urumea rivers in Gipuzkoa (see Figure 2). Similar deviations were also evident on the Levante, Andalusia and Lisbon lines. These detours have usually been attributed to the country's rugged relief, which allegedly forced engineers to adopt winding routes to avoid the highest mountain ranges (Tortella, 1973; Wais, 1974; Comín et al., 1999).

This explanation is correct, but not sufficient. At least two additional factors help account for the phenomenon. First, the system of subsidies per kilometre of track created perverse incentives, encouraging the construction of longer routes that avoided costly engineering works such as tunnels and bridges, while also attracting larger subsidies (Barquín, 2007, 2012, 2016; Barquín and Larrinaga, 2020)[1]. But there is another explanation. The tortuous routes responded to a design strategy known as 'partial transit'. This approach was based on the premise that a winding line with many intermediate stations would generate more traffic than a direct connection between major hubs, thereby offsetting its higher operating costs and longer travel times.

This paper investigates how this design strategy shaped the Spanish railway network in the mid-nineteenth century. The central question is whether the tortuous routes adopted in several main lines reduced long-distance traffic by increasing effective travel distances and journey times. To address this question, we draw on the 1870 *Datos Estadísticos* compiled by the *Compañía de los Caminos de Hierro del Norte de España*, which allows us to construct a bilateral dataset of passenger and freight flows between all station pairs on the Madrid–Irun line. A gravity model was employed to estimate the main determinants of traffic between stations. A GIS database (Esteban-Oliver and Martí-Henneberg, 2024) was used to calculate both railway and Euclidean distances between all station pairs. On this basis, we constructed a sinuosity variable—defined as the ratio of railway to straight-line distance— and additional factors such as local population (Beltrán-Tapia et al., 2023) and a binary indicator for connection to other lines were incorporated. The model, estimated in log-log form, allows the degree of locality of traffic and the impact of sinuosity on observed flows to be assessed. In addition, the methodology proposed by Odlyzko (2015) has been applied to measure sensitivity using a population-normalised coefficient, known as the Desart coefficient or *c(D)*. The results yielded by both approaches are consistent: they reveal a high degree of traffic locality and show that sinuosity significantly reduced flows, with a much stronger effect on passenger traffic than on freight.

The paper is divided into six sections. The following section analyses the origins of the concept of partial transit in European railway engineering. Section 3 explores its application in the construction of Spain's first railway network. The fourth section outlines the data sources and variables employed, while section 5 details the econometric methodology. The sixth section presents and discusses the results of the model. Finally, the last section draws some general conclusions.

2. Partial Transit vs. Total Transit: A Technical Debate in 19th Century Railway Engineering.

During the 1830s and 1840s, the first railway lines appeared in several European countries. They were built to address specific transport needs that traditional means could not adequately satisfy—such as linking a coal mine to a port or connecting a major city with a nearby town of economic or cultural significance. These lines were typically financed with private capital and received little or no public support. Their success demonstrated the feasibility of building longer lines that would link major cities and form a cohesive railway network. The scale of these projects meant that, in many cases, State intervention through public support or even direct construction was required (Palau and Palau, 1995; Hylton, 2007; Heinze and Kill, 1988; Taylor, 1989). When planning lines between distant cities, it was necessary to decide whether the routes should be straight or whether it was preferable to deviate to serve the traffic of intermediate cities. This question sparked a wide debate among engineers, administrators, and economists, centred on two opposing approaches: total transit and partial transit[2].

The so-called 'total transit system' advocated direct connections between major economic centres. Its proponents maintained that the value of railways depended on providing fast, efficient journeys with minimal interruptions. The more direct the route between two cities, they argued, the greater the volume of long-distance traffic and, consequently, the higher the social utility of the railway. On the contrary, the advocates of 'partial transit' contended that a line could be more profitable and socially desirable if it included deviations to capture traffic from towns located near the direct route. Although such routes involved longer journeys, the accumulation of short-distance travel between intermediate points could, in total, generate more traffic than long-haul transit. In short, proponents of both systems argued that they would generate more freight and passenger traffic, resulting in greater social utility.

Charles Joseph Minard, engineer and professor at the *École nationale des Ponts et Chaussées* (Chevallier, 1871), defended "the" partial transit system in two works published between 1842 and 1843. In his view, the usefulness of a line should be assessed not only by the number of journeys between its terminals, but also by the total number of journeys between intermediate stations. Based on observations of stagecoaches, canals and the first French railways, Minard argued that local connections accounted for the bulk of traffic. On lines such as Paris-Lille or Paris-Strasbourg, the number of passengers completing the entire journey was far lower than those travelling along segments of the line. Partial transit would therefore be the most common use of rail in densely populated countries. A line with many short journeys could be as valuable—or even more so—than one carrying only a limited number of long-distance travellers. Moreover, since main lines benefited from public subsidies, it would be fair for them to serve the greatest number of taxpayers (Minard, 1842, 1843).

Only three months after the publication of Minard's second text, another engineer from the *Corps des Ponts et Chaussées*, C. Courtouis, presented his reply. His observations (1843) were a defence of the total transit system. According to Courtois, the widespread application of partial transit would undermine the usefulness of the trunk lines, which were designed to provide rapid connections between major urban centres. In his view, the best way to connect these places to the main network was through branch lines built with narrower gauge tracks. Courtois assumed that the elasticity of demand with respect to distance was approximately 2, implying that even minor diversions from direct lines to serve intermediate towns would result in a significant loss of traffic and expected revenue (Courtois, 1844)[3].

In Belgium, the debate on transit patterns was framed in similar terms. There, the conflict was not so much theoretical as it was about the practical consequences that the design of new lines could have on an already operational network in which the state had invested heavily. The controversy between the two models crystallised around the project for a new connection between Brussels and Ghent.

The civil servant and economist Auguste Delaveleye (1844, 1846) criticised direct railway projects. He considered that such lines could upset the balance of the system: they would ruin the intermediate stations already connected and divert traffic from other publicly funded sections. Delaveleye preferred an indirect link between Brussels and Ghent via Termonde because, although longer, it would serve additional localities and enhance the viability of the broader network.

Against this position, the chief engineer of the Belgian corps, Henri-Gustave Desart (1846), defended a direct route via Alost. Since the network's traffic data, he developed a coefficient—hereafter *c(D)* or Desart's coefficient—which measured the number of passengers per 1,000 inhabitants at origin and destination over a given distance. He calculated this value by dividing the annual number of passengers observed between two locations by the product of their respective populations. Desart then grouped these coefficients into distance intervals and compiled a table showing how *c(D)* decreased rapidly as the distance between the locations increased. Based on this analysis, he concluded that route length was a key factor in expected traffic and that to maximise demand—particularly between major cities—priority should be given to the design of direct routes[4].

Plotting *c(D)* on a log-log scale allowed Odlyzko (2015) to observe that the coefficient approximated a potential function with an exponent of -2.25, implying a distance elasticity of demand of the same magnitude. In other words, a 1% reduction in distance would result in a 2.25% increase in expected passenger traffic. From this he deduced that since there was a high level of local traffic, it would have been preferable to design curved lines, as they better matched this demand pattern. Interestingly Odlyzko's reasoning is correct, but it is also the opposite of the conclusion that Desart erroneously derived from the same data two centuries earlier, without the tools of modern analysis.

The debate on transit patterns confronted two opposing visions: one that conceived of the railway as a direct route between major centres, and another that defended longer routes with intermediate stops to attract more traffic, improve profitability, and ultimately contribute to territorial integration. The following section examines how these ideas were transferred to the Spanish context a decade later.

3. The Adoption of Partial Transit in the Design of the Spanish Railway Network: Theory and Practice

Theory

In Spain, the first serious attempt to define the main lines of the future railway network took place in 1850, when the Minister of Public Works, Seijas Lozano, presented a draft railway law. The commission responsible for examining the proposal organised a public hearing—referred to as *Información Parlamentaria*—to gather expert opinions on the main lines of the prospective national network (Mateo del Peral, 1978). The technicians concluded that the new plan contained in the General Law would include four lines: Madrid-Irun, Madrid-Cádiz, Madrid-Levante and Madrid-Portugal. The *Información Parlamentaria* Commission also demanded that the consequential crossing points of these lines be established to limit the influence of local interests on their final alignment[5]. On this specific issue, the interventions of the civil engineers Constantino Ardanaz and Ramón de Echavarría were decisive.

Constantino Ardanaz was a professor at the School of Civil Engineering (Sáenz Ridruejo, 2016, pp. 70-81). Inspired by Minard's work, he defended the adoption of the partial transit system in Spain. In his view, long-distance traffic represented only a small proportion of total passenger and freight movement, so priority should be given to connecting local economic centres, even at the expense of abandoning the most direct route. For the Madrid-Irun line, he therefore recommended a path that would pass through the cities of Ávila, Bilbao and San Sebastián, with branches extending to La Rioja and Aragón. For the southern line, he proposed abandoning the direct route between Madrid and Córdoba in favour of a route via Alcázar de San Juan and Manzanares to Bailén, in order to integrate the production of Granada and Almería. And for the line to Lisbon, he favoured a route parallel to the Guadiana River—longer but connected to potentially more dynamic areas than those of the Tagus basin.

Ramón de Echavarría, an engineer attached to the Directorate General of Public Works (Sáenz Ridruejo, 1993, pp. 69-88), opposed the model defended by Ardanaz and supported the total transit system. His position was partly grounded in the conviction that construction costs would be high. In a series of articles published in the newspaper *El Español* in 1845, he estimated that each league of railway track would cost an average of 5 million reales—substantially more than the 1.5 million per league eventually spent on the MZA network, for instance (Castellvi and Barquín, 2018)[6]. In his proposal to the *Información Parlamentaria*, he gave priority to direct lines between major cities, excluding intermediate points that would increase costs and travel times. Thus, for the southern line, he suggested a direct line from Madrid to Córdoba, via Toledo and Almadén. Regarding the Madrid–Lisbon line, he recommended following the left bank of the Tagus, with a stop at Talavera (on the riverbank), and avoiding a diversion towards the Cáceres valley.

Although the *Información Parlamentaria* was completed on time, the General Railway Law did not progress due to the political weakness of Seijas Lozano's cabinet. With the arrival of a new Minister of Public Works, Mariano Miguel Reinoso, in 1851, the drafting of a plan for railway lines was reactivated, but on very different principles from those of the Commission. Under Reinoso's direction, the routes of the main lines and their transit points—neither of which aligned with the proposals of Ardanaz or Echavarría—were precisely defined. An inland network was proposed, with four direct lines between Madrid and the country's main agricultural centres: Zaragoza, Valladolid, Córdoba and Almansa. Reinoso's railway plan seems to advocate total transit, although sometimes for curious reasons. It was thought that detours would be detrimental to general traffic, but also that long lines would mainly favour foreign trade, so that border connections would be built in a second phase.

In the same year, 1851, Reinoso ordered the construction of the Levante line, to be financed by the Treasury; and the following year the study of the other three main lines of his plan, those from Madrid to Córdoba, Valladolid and Zaragoza. The decree that established this survey coincided with Echevarría's ideas: "the large curves, wide detours, and zigzags proposed to ensure that the main lines pass through one location, or another are detrimental in every respect". Following Courtois's approach, it was suggested that the shortest technically feasible lines should be identified and that adjacent regions should be connected by branches. The text established the route of the Andalusian railway along the Tagus valley towards Talavera and Córdoba—precisely the route suggested by Echavarría in the *Información Parlamentaria*. It also ordered the study of the route of the northern line through the Guadarrama mountain range and the Aragonese line through Guadalajara and Calatayud[7].

This peculiar model of total short-distance transit was echoed in a series of anonymous articles published in *El Heraldo* in the summer of 1852[8]. The author supported State intervention in railway construction but warned that only carefully planned lines could yield acceptable returns. In his opinion, the construction of tortuous lines to connect secondary locations would entail a double risk: dispersing demand and undermining the railway's competitiveness relative to other modes of transport. As a result, the author argued that priority should be given to the construction of medium-length direct lines linking Madrid with León, Llerena, Zaragoza, and Logroño. These railways would concentrate traffic in a single corridor of higher density, making the investment more profitable and reducing costs.

From an opposite perspective, a contributor signing as "M.R." published two articles in 1852 in the newspaper *El Constitucional* about a possible railway line from Barcelona to Zaragoza[9]. He defended the application of the partial transit system against the projects that proposed a more direct route through Fraga. The line he supported would run through Lérida, Monzón, Barbastro, and Huesca, resulting in a route approximately 45 km longer. M.R. argued that the greater route length would not be problematic, so long as it grew in proportion to the increase in partial traffic relative to the total line[10].

Reinoso's project never materialised because the deputies were unable to reach an agreement before the Cortes adjourned. The next Minister of Public Works, Agustín Esteban Collantes, also presented a railway bill that basically returned to the criteria set by the *Información Parlamentaria*. But he also failed to get it approved, due to the same political weakness that had plagued the previous ministries. It was not until 1855 that the General Railway Act was finally passed. Its enactment laid the foundations for the large-scale development of the railway in Spain. Yet, in order to obtain the necessary support, the law established a highly permissive railway plan, effectively allowing almost any line to qualify for public subsidies. In addition, the companies enjoyed almost total freedom to determine their routes (Esteban-Oliver et al., 2025). The consequences of this regulation are analysed below.

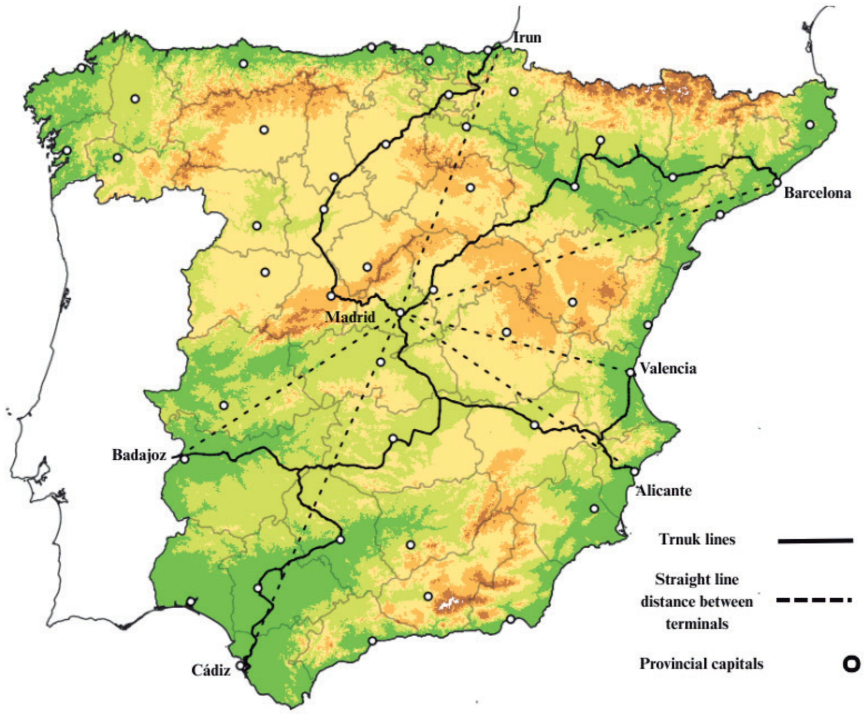
Practice

Conventional wisdom has it that Spain began building its basic railway network in 1855, and that it was completed by the middle of the following decade. By 1870, the country had approximately 5,000 km of track in operation—a relatively high rate of construction for a nation with Spain's comparatively low level of economic development at the time. This network was largely structured around Madrid, with the main lines extending towards major coastal cities and border points. However, as shown in Figure 1, none of these routes followed a straight path from origin to destination. To varying degrees, they all progressed in a winding way, describing very wide detours (Barquín, 2016).

From the perspective of the *Información Parlamentaria*, the route of greatest political and economic interest for Spain was the one that would connect Madrid with Hendaye via Irun. Several alternatives were considered, but ultimately the longest option was selected, passing through Ávila, Medina del Campo, Valladolid, Burgos, and San Sebastián—along with additional detours. While it is difficult to quantify the precise impact this decision had on the development of the railway system, it was likely considerable.

The shortest route would have involved crossing the northern section of the Sistema Central. Many projects were presented in the 19th century, such as the so-called *Ferrocarril del Meridiano* between Madrid and Santander, or those intended to link Madrid with Bilbao: the *Gran Central Peninsular*, the *Compañía Vasco Castellana* or *The Great Central Railway of Spain* (Cobos, 2004). But the only railway that was eventually built was the one from Villalba to Medina del Campo. Since both towns lay on the *Norte* company's existing line, this route essentially served to connect Segovia to the broader network—both to the north and south via the Guadarrama corridor[11]. Due to its rough profile, it was only used for local traffic. Later, in the 1960s, a direct line was finally built between Madrid and Burgos via Somosierra and Aranda de Duero (Wais, 1974).

FIGURE 1. **Operational radial lines in 1870 and their hypothetical direct routes.**

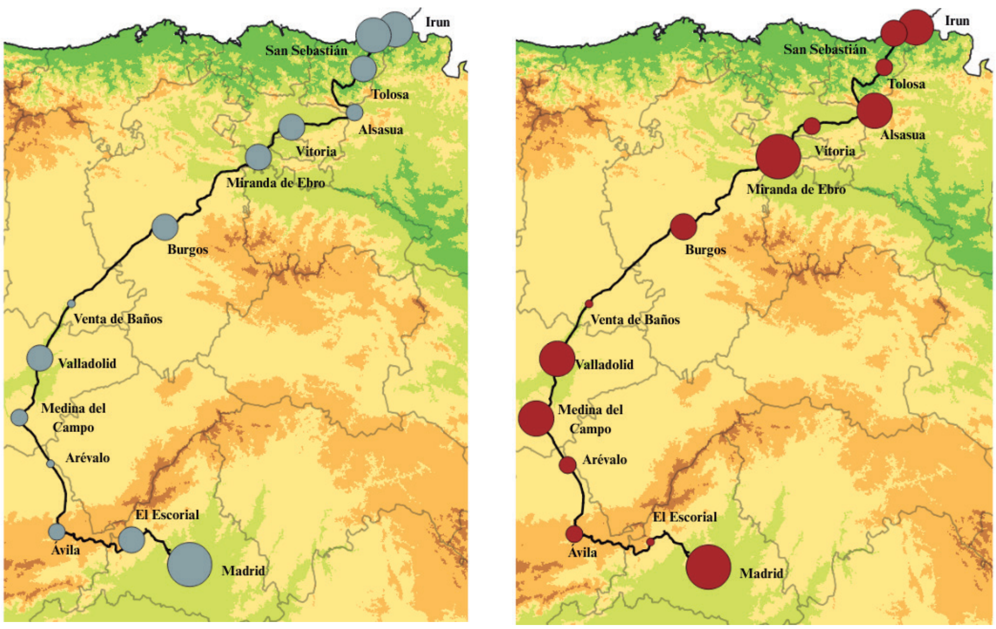


SOURCE: Own work from Esteban-Oliver & Martí-Henneberg (2024) data.

The northern line did not cross the Sistema Central through Guadarrama; instead, the western pass at Puerto de Pilas, near the city of Ávila, was chosen. The decision to run the line through this point gave rise to intense debate and seems to have been clearly erroneous (Barquín, 2012). In any case, it resulted in the northern line following an even more circuitous path than originally envisaged. It left Madrid westwards through the Sierra de Gredos to Ávila. It then turned north to Medina del Campo and again northeast to Alsasua. At this point the line would take a slight detour towards Zumárraga, before finally turning towards San Sebastián and the French border, following a route similar to that proposed by Ardanaz in the 1850 *Información Parlamentaria*, but avoiding Bilbao (see Figure 2).

The other lines of the main network also followed winding routes. The first section of the Southern Railway was shared with two other lines. The first was the Levante line, which branched off at Alcázar de San Juan—111 km from Madrid—to head eastwards. Near Almansa it split into two others: one branch headed north towards Valencia, the other south towards Alicante and Cartagena. In the former case, it made a huge detour to avoid the *carretera de las Cabrillas*[12]. The deviation was smaller, but also important, on the Alicante-Cartagena route (Hernández Sempere, 1983). The Extremadura-Lisbon line diverged from the Andalusian route at Manzanares, 156 km from Madrid. There it made a sharp turn to the west. However, it did not proceed in a straight line; rather, it made several diversions before reaching Badajoz—including a distinct "M"-shaped deviation to serve the towns of Daimiel, Almagro, and Ciudad Real (Wais, 1974).

FIGURE 2. **Details of the Madrid–Irún Line Showing the Contribution of the Main Stations to Passenger (Grey) and Freight (Red) Traffic.**



SOURCE: See Data section.

Thus, the Andalusian line to Cádiz first crossed the plains of La Mancha, Alcázar de San Juan, and Manzanares. Instead of crossing the Sierra Morena through the Andújar massif, as Echavarría had proposed, it turned eastwards towards the Despeñaperros pass and then headed for Linares. From there it descended through the Guadalquivir valley to Córdoba and Seville. Only from this point did it adopt a south-south-westerly direction that would mark an imaginary straight line from Cádiz to Madrid (Cuéllar and Sánchez, 2008).

Finally, the Catalan line went first to Zaragoza, via Calatayud, which implied a slight northward deviation and bypassing the more direct route through Molina de Aragón (Coello, 1855). From the Aragonese capital, the line headed towards Barcelona, avoiding the direct route to Fraga, Lérida, and Igualada. Instead, it described a wide 'M'-shaped path through Alto Aragon via Selgua, Sariñena, and Barbastro—closely resembling the route proposed by 'M.R.' in *El Constitucional*. Further on, in Catalonia, the line described an "N"-shaped deviation to reach the industrial city of Manresa (Barquín, 2007; Pascual, 2015).

TABLE 1. **Railway Distance, Euclidean Distance, and Sinuosity of the Main Railway Lines.**

Railway Line	Railway Distance (km)	Euclidean Distance in Straight Line (km)	Sinuosity Coefficient
Madrid-Irun	637.2	361.3	1.76
Madrid-Valencia	495.3	306.5	1.62
Madrid-Alicante	454.7	357.2	1.27
Madrid-Cádiz	822.7	487.3	1.69
Madrid-Badajoz	628.7	332.3	1.89
Madrid-Barcelona	805.4	505.6	1.59
Total	3,844.2	2,350.3	1.64

SOURCE: Own work from Esteban-Oliver & Martí-Henneberg (2024) and García Raya (2006) data.

Table 1 shows the relationship between railway and linear distance between Madrid and the main destinations of the basic network: Irun, Valencia-Alicante, Cádiz, Badajoz and Barcelona. In every case, the actual rail distance is substantially larger than the Euclidean distance. The average rail distance is 64% greater than the straight-line distance. While part of this disparity can be attributed to Spain's challenging topography—with its extensive inland mountain ranges, high plateaus, and narrow mountain passes—many of the deviations appear not to have been dictated by the terrain. Rather, they reflect deliberate detours intended to connect intermediate cities of administrative, commercial, or strategic importance to the network (Barquín, 2007 and 2012).

TABLE 2. **Traffic data for the Madrid-Irun line in 1870.**

Station Station	Freight Traffic (%)	Average Freight Distance (km per kg)	Passenger Traffic (%)	Average Passenger Distance (km per passenger)
Madrid	28.28	322.83	17.93	185.65
Ávila	1.98	143.30	2.93	103.95
Other stations in sector 1	7.67	121.94	15.56	57.75
Valladolid	6.79	225.21	6.03	99.64
Other stations in sector 2	3.30	186.78	3.15	29.84
Burgos	2.00	150.99	4.54	118.53
Vitoria	3.20	158.39	4.74	83.39
San Sebastián	6.62	82.57	11.18	96.92
Other stations in sector 3	29.02	178.35	25.21	68.62
Irun	11.14	160.45	8.73	98.03
Line Total	100	176.05	100	95.47

SOURCE: Own work from *Anuario Estadístico del Ferrocarril del Norte de España*, 1870, data.

Table 2 presents the distribution of freight and passenger traffic on the Madrid-Irun line in 1870, along with the average distance travelled per kg or passenger. To enhance the territorial analysis, intermediate stations of lower hierarchical status—that is, those that were not provincial capitals—have been grouped into three operational sectors already employed by contemporary planners: Sector 1, between Madrid and Valladolid; Sector 2, between Valladolid and Burgos; and Sector 3, between Burgos and Irun.

These data make it possible to assess the contribution of the intermediate localities to overall traffic. With the exception of the last section, most of the traffic was concentrated in the main cities and at the end of the line, while the contribution of intermediate localities was small. Thus, the average distance travelled was 176 km for goods and 95 km for passengers, a considerable distance which shows the importance of medium and long-distance transport. However, in sector 3—Burgos-Irun—the intermediate localities reached a relevant share of the total traffic: 29% of goods and 25% of passengers. This suggests that Minard's thesis was correct, but only in densely populated areas. In the rest of the country, winding routes increased journey times without significantly improving operating results.

TABLE 3. **Traffic distribution by distance categories on the Madrid–Irun line in 1870.**

Distance Category	Share of trips (passengers,%)	Share of passenger- Share of passenger-km (%)	Share of shipments (freight,%)	Share of kg-km (%)
< 100 km	77.6	29.8	52.5	14.6
100–200 km	9.4	14.1	12.7	10.2
> 200 km	13.0	56.1	34.7	75.2
Total	100	100	100	100

SOURCE: Own work from *Anuario Estadístico del Ferrocarril del Norte de España*, 1870, data.

Table 3 complements this perspective by classifying the traffic according to journey length intervals. The figures reveal that although most trips were short—78% of passenger journeys and 53% of freight shipments involved distances of less than 100 km—these accounted for only 30% and 15% of total passenger-km and kg-km, respectively. By contrast, long-distance journeys of more than 200 km, though relatively few in number, concentrated 56% of passenger-km and 75% of kg-km. This evidence indicates that the overall efficiency of the line depended primarily on long-distance traffic, and that any losses caused by the tortuous nature of the routes could hardly have been offset by additional flows at intermediate stations.

4. Data

The main source for this paper is the *Datos Estadísticos de la Compañía de los Caminos de Hierro del Norte de España* for the Madrid-Irun line in 1870. This dataset provides a solid basis for assessing how the partial transit system worked in practice in Spain. The line passed through areas that were representative of the economic and demographic structure of the country. A large part of its route crossed Castile, a region with a predominantly agrarian economy and low population density—conditions that prevailed in most of Spain at the time. However, the final section passed through the Basque provinces of Alava and Guipúzcoa, which, like other coastal regions of Spain, were more densely populated. By 1870 the basic railway network was already in place and the crisis of 1864-1866 had been overcome. It was, therefore, a period of relative stability before the expansion of the network under the Restoration regime (Hernández Marco, 1997; Sanchís-Maldonado, in press). This source, exceptional for its level of detail, provides annual aggregated information on passenger (number of people) and freight flows (in kg) between all stations on the line. In fact, no records of traffic dispatched from one station to all others are preserved for any other Spanish company at such an early date. Stations are identified by name, and the data are organised by station pairs, allowing the construction of a bilateral database with journeys in both directions.

The 1860 census was used to link each station to its surrounding population. Stations were georeferenced using a GIS database developed by Esteban-Oliver and Martí-Henneberg (2024), which includes both their location and the exact railway route. The linkage between stations and municipalities was carried out following the methodology proposed by Esteban-Oliver (2023). A five-kilometre buffer was applied around the centre of each municipality—based on the ESPOP by Beltrán-Tapia et al. (2023)—under the assumption that this distance is about one hour on foot and represents the station's immediate area of influence.

The GIS database made it possible to calculate both the railway distance between stations—following the actual route of the lines—and the Euclidean distance, measured as a straight line. From these two measurements, a sinuosity variable was constructed as the quotient between the railway distance and the linear distance. A binary variable was also created, taking the value 1 if a station was connected to a railway line other than the Madrid–Irun line. This information comes from the statistical and GIS data of Esteban-Oliver and Martí-Henneberg (2024). Where the two sources differed, corrections were made using external references (Hernández Marco, 1997)[13].

The pairs of stations with zero traffic have been kept in the sample by assigning them a minimum value of one to allow logarithmic transformation without distorting the overall distribution of the data. This approach avoids losing valuable observations, since total traffic volume is high and the occasional absence of traffic between two stations may reflect conjunctural situations or marginal characteristics. The unit of analysis is the ordered pair of stations, including journeys in both directions. In order to avoid distortions, pairs of stations located less than 20 km apart in straight-line distance were excluded from the dataset, since in such short stretches the sinuosity index may not provide a meaningful measure of route deviations. After this adjustment, the passenger model includes 3,300 observations and the freight model 3,528. The difference is explained by the specialisation of some stations in a single trade.

5. Methodology and empirical analysis

This paper employs a classical gravity model to estimate the determinants of inter-station rail traffic. The specification adopted follows a log-log form, in which both the dependent and independent variables—with the exception of the binary connection variable—are expressed in natural logarithms. This formulation allows the estimated coefficients to be interpreted as elasticities, facilitating the quantification of each variable's effect on traffic flows and enabling comparison with the case studied by Odlyzko (2015).

Formally, the estimated model adopts the following specification:

$$\ln(Tij) = \beta 0 + \beta 1 \ln(Pi) + \beta 2 \ln(Pj) + \beta 3 \ln(Dij) + \beta 4 \ln(Sij) + \beta 5\, Cij + \varepsilon ij \quad (1)$$

where Tij is the annual traffic between station *i* (origin) and station *j* (destination), measured in number of passengers or in kg of goods; *Pi* and *Pj* represent the populations of the municipalities in which the origin and destination stations were located, according to the 1860 census; *Dij* is the Euclidean distance between the two stations; *Sij* is the sinuosity index (ratio between the railway distance and the linear distance); *Cij* is a binary variable that takes the value 1 if either station was connected to a railway line other than Madrid-Irun; and *εij* is the error term.

A gravity model postulates that flows between two centres increase with the size of the sending and receiving poles and decrease with the distance between them. This specification has been widely used to analyse trade, migration or transport flows and is particularly useful for estimating the locality of traffic—that is, its degree of spatial concentration (Gutiérrez and Urbano, 1996; Disdier and Head, 2008; Anderson, 2011)—as well as for capturing the determinants of traffic between nodes. As noted in Section 2, Odlyzko (2015) argues that a high negative elasticity of traffic with respect to distance is indicative of a network structure dominated by local traffic. This paper adopts this approach to quantify the degree of locality on the Madrid-Irun line in 1870, and to assess whether the winding routes, designed under the logic of partial transit, contributed to the intensity of rail flows.

The base model was estimated by ordinary least squares (OLS) in log-log form. To address potential heteroskedasticity and correlation across flows sharing the same nodes, robust two-way clustered standard errors were employed, clustering simultaneously by origin and destination stations. The results show that the main coefficients remain stable and highly significant. Potential multicollinearity problems have been assessed by calculating the variance inflation factor (VIF), which yielded very low values for all regressors (mean ≈ 1.05), suggesting an acceptable level of independence between variables. The model displays a reasonable overall fit, although the main objective of the analysis is to identify the elasticities of the determinants of rail transport rather than to optimise its prediction[14].

To confirm robustness of the results, the model was re-estimated by replacing Euclidean distance and the sinuosity index with the total railway distance between stations. The results, presented in Appendix Table A1, are virtually identical to those of the baseline specification: elasticities with respect to population and connection remain stable, and the effect of distance preserves both sign and magnitude. This indicates that the conclusions do not depend on the particular decomposition of distance, although the separation between Euclidean distance and sinuosity remains analytically valuable for isolating the impact of winding routes[15]. Furthermore, alternative models were estimated using Poisson pseudo-maximum likelihood (PPML), a method suitable for gravity models with count data, presence of zeros and heteroskedasticity (Silva and Tenreyro, 2006). These specifications include station fixed effects by origin and destination station, thereby controlling for unobserved heterogeneity at each location. Appendix Tables A2 and A3 report the results and confirm both the direction and magnitude of the effects obtained in the baseline log-log model. In addition, Poisson models without fixed effects have been estimated (Tables A4 and A5), enabling a check of the results' consistency with respect to the functional form and the logarithmic transformation of the dependent variable. In all cases, the coefficients of interest retain the same sign and a comparable magnitude, which reinforces the empirical robustness of the analysis.

In addition, the log-log regression between the Euclidean distance and the Desart coefficient was estimated for rail traffic between stations on the Madrid-Irun line in 1870. For this purpose, *c(D)* was calculated as the quotient between the number of passengers (or kg of goods) and the product of the populations of origin and destination, multiplied by 10^6 to maintain the same scale used by Desart. Unlike the Belgian engineer, who grouped the data by railway distance intervals and worked with averages, this exercise is based on individual observations, includes freight traffic data, and employs ordinary least squares (OLS) regression on the log-transformed values. This approach also enables estimation of the elasticity of demand with respect to distance on the Madrid–Irun line.

6. Results

Table 4 presents the main results of the gravity model estimated by ordinary least squares (OLS) with two-way clustered standard errors, applied to passenger and freight traffic between pairs of stations on the Madrid-Irun line in 1870. The dependent variable is the logarithm of the annual traffic recorded between the stations. The first column reports the results for passengers and the second column for freight traffic.

The first three regressors capture the most common socio-economic determinants in the literature: population at origin and destination and distance between points. In both specifications, the population variables exhibit positive and highly significant coefficients of similar magnitude. Their interpretation is straightforward: a 1% increase in the population of the origin municipality raises the passenger traffic by about 0.66%, while a 1% increase in the population of the destination municipality raises it by 0.68%. This result, although predictable, confirms that small municipalities contribute little traffic and that their inclusion on the route through detours would scarcely offset the additional costs incurred.

TABLE 4. **Gravity model estimates (OLS) for rail traffic between stations on the Madrid-Irun line, 1870.**

Variable	Passengers (1)	Freight (2)
ln Population Origin	0.655***	0.483***
	(0.071)	(0.046)
ln Population Arrival	0.678***	0.646***
	(0.070)	(0.067)
ln Euclidian Distance	-1.463***	-0.903***
	(0.099)	(0.091)
Connection (1 = sí)	0.481***	0.742***
	(0.236)	(0.060)
ln Sinuosity	-1.006***	-0.600***
	(0.359)	(0.224)
Observations	3.300	3.528

Significance levels at 10% *, 5% ** and 1% ***.

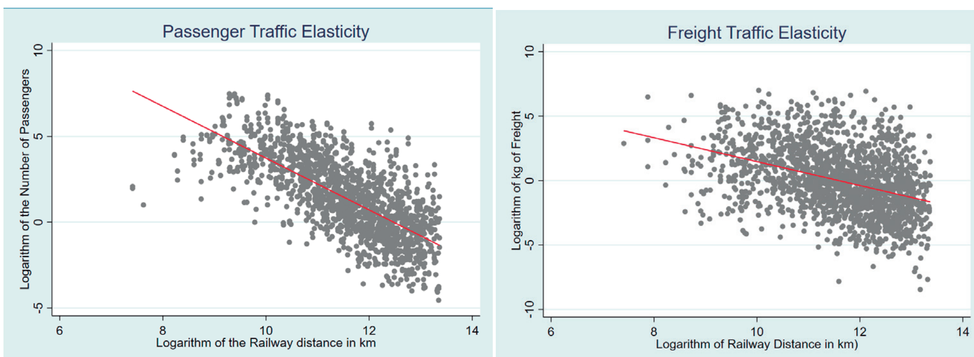
Euclidean distance between stations has a negative and highly significant effect on traffic in both the passenger and freight models. This coefficient allows the elasticity of traffic with respect to distance to be measured—an essential indicator of the degree of locality within the network. In the passenger model, the coefficient reaches −1.43, while in the freight model it is −0.90. Although these values reflect, as expected, a distance penalty, they are lower than the elasticity of passenger traffic assumed by Courtois (1844) for the French network (−2), and than that observed by Odlyzko (2015) for the Belgian network, where it reaches −2.25.

The sinuosity variable has a negative and statistically significant coefficient in both specifications. This means that, given the same Euclidean distance, longer routes in rail terms had lower traffic volumes, suggesting that the extension of the route by detours had a deterrent effect on demand. The magnitude of the coefficient is larger in the passenger model (−1.01 compared to −0.60), consistent with a greater sensitivity of passengers to journey time—or route efficiency—compared to freight. Given that the average sinuosity of the Madrid-Irun line reached a value of 1.76 (see Table 1), it can be estimated that this configuration would have reduced passenger traffic by approximately 44% and freight traffic by 29%, relative to a perfectly straight line[16].

Finally, the variable capturing connections with other lines shows a positive and statistically significant coefficient in both models, with a greater impact on freight transport. For passenger traffic, the presence of a connection multiplied flows by about 1.62, equivalent to a 62% increase, while in the case of freight the multiplier reached 2.10, equivalent to an increase of 110%. These results may be interpreted as an indication that actual average traffic could have been higher than that recorded by the *Compañía del Norte*, since some of the traffic likely continued its journey on other lines, extending the distance travelled beyond the observed section. This finding lends support to the view that local traffic was of limited importance to the companies' overall performance.

Figure 3 shows the relationship between the Euclidean distance and the Desart coefficient for passenger and freight traffic on the Madrid-Irun line in 1870. Each point represents a pair of stations, and two ordinary least squares (OLS) regressions have been estimated separately on the transformed values: one for passengers and one for freight. In both cases a negative relationship between distance and the value *c(D)* is observed, with estimated slopes of −1.51 and −0.93, respectively. These slopes indicate the extent to which relative traffic declines as the distance between stations increases.

FIGURE 3. **Log-log plot of the Desart coefficient derived from passenger and freight traffic data on the Madrid–Irun line operated by the Compañía del Norte, 1870.**



The log-log regression of the Desart coefficient for the Madrid–Irun line produces values of −1.51 for passengers and −0.93 for freight, both estimated with railway distance in line with the nineteenth-century methodology. These results are remarkably close to those obtained in the main OLS specification (Table 4), which uses Euclidean distance (−1.43 for passengers and −0.90 for freight). The robustness check performed with railway distance in the OLS model (Table A1) confirms this convergence (−1.42 and −0.89, respectively). This regression also enables a direct comparison with the Belgian case, since Odlyzko (2015) applied the same procedure to Desart's data. In Belgium, the elasticity of passenger traffic with respect to distance was about −2, notably steeper than the −1.51 estimated for Spain. This implies that passenger traffic in Spain was less sensitive to distance, with the deterrent effect of longer journeys being comparatively weaker. Hence, the rationale for partial transit appears weaker in Spain, consistent with Odlyzko's interpretation.

7. Conclusions

This article uses traffic data from the *Compañía del Norte* to assess the effectiveness of the partial transit system in the layout of the Spanish railway network. In Central and Western Europe, partial transit was the predominant mode of railway use, as shown by Odlyzko (2015) for the Belgian and British networks. Spain followed the same pattern, but under very different conditions: lower levels of economic development, a smaller and more dispersed transport market, and greater distances between the main economic centres (Herranz, 2007). Nevertheless, some coastal regions displayed economic features closer to those of the aforementioned countries. In these specific areas, this research suggests that the adoption of the partial transit system may have been appropriate. However, in the rest of the country, such an approach proved unsuitable.

To evaluate this system in comparison with its alternative, the total transit model, traffic is analysed in 1870 on what was arguably the most important railway line in the country at the time: the route linking Madrid to Irun, which included a major detour through Ávila, Valladolid, and Burgos. In its first two sections, from Madrid to Burgos, the line crossed poor and sparsely populated regions. In contrast, the third section, from Burgos to the French border, was characterised by greater economic activity and higher population density.

The study estimated a log-log gravity model incorporating both socio-economic variables and physical characteristics of the network—sinuosity, connection, population, and distance. In addition, the degree of locality of traffic was calculated using the Odlyzko method, based on the Desart coefficient. The model estimates a negative distance elasticity for the line as a whole, which are lower than those observed in the Belgian case (−2,25 for passenger traffic): −1.46 for passengers and −0.90 for freight. These values would not justify a design pattern based on partial transit. A similar conclusion can be drawn from the average coefficient of sinuosity, which stands at 1.76. The extension of the route would have reduced the potential traffic by 44% for passengers and 25% for freight compared to a more direct alignment. Beyond these estimates, it is important to note that sinuosity imposed greater costs on passenger transport, since longer distances also meant more intermediate stops and longer travel times. Yet freight remained the main component of Spanish railway traffic for much longer than in high-density, high-income countries, where passenger traffic carried more weight.

Since most of the Spanish territory shared the characteristics of the first two sections of the line, the findings suggest that one of the main shortcomings in the design of the Spanish railway network was the decision taken by the railway companies—rather than by the government—to divert the main lines from their most direct course in order to capture the markets of small and medium-sized towns (Barquín, 2017). As shown above, such diversions reduced long-distance flows—the main source of traffic—while the contribution of additional short-distance journeys was insufficient to offset these losses. Applying the estimated elasticities to the distribution of traffic by distance confirms this point: the reduction in long-distance flows implied losses of around 25% of total passenger-kilometres and 22% of kg-kilometres. To compensate, short-distance traffic would have needed to expand by more than 80% in the case of passengers and almost 150% in freight—levels of growth that were unlikely under the prevailing conditions[17].

Future research might build on these results in several directions. Least-cost path methodologies, for example, would allow a complementary perspective on route efficiency. Incorporating transport prices—particularly for freight—would make it possible to analyse how costs interacted with distance and sinuosity. Temporal comparisons could show whether the relevance of partial transit evolved over time, perhaps becoming more suitable in more developed contexts. Finally, broader spatial comparisons, such as those already drawn with the Belgian case, could help place the Spanish experience within the wider European debate.

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Appendix

TABLE A1. **Gravity model estimates (OLS) for rail traffic between stations on the Madrid–Irun line, 1870, using railway distance as the sole distance measure**

Variable	Passengers (1)	Freight (2)
ln Population Origin	0.670***	0.478***
	(0.071)	(0.048)
ln Population Arrival	0.692***	0.638***
	(0.071)	(0.063)
ln Railway Distance	-1.423***	-0.890***
	(0.094)	(0.089)
Connection (1 = yes)	0.424*	0.740***
	(0.238)	(0.163)
Observations	3.361	3.587

NOTE: Significance levels at 10% *, 5% ** and 1% ***.

TABLE A2. **Results of the PPML Model (Passengers).Estimates with origin and destination station fixed effects.**

Variable	Coefficient	Standard Error
ln origin population	0.00	-
ln destination population	0.00	-
ln Euclidean distance	−1.54***	0.054
Connection (1 = yes)	−0.52**	0.226
ln Sinuosity	−1.54***	0.101
Constant	25.06***	0.642

NOTE: Significance levels at 10% *, 5% ** and 1% ***.

Estimates with origin and destination station fixed effects

TABLE A3. **Results of the PPML Model (Freight)**

Variable	Coefficient	Standard Error
ln origin population	0.00	-
ln destination population	0.00	-
ln Euclidean distance	−0.73***	0.107
Connection (1 = yes)	0.27	0.304
ln Sinuosity	−0.79***	0.314
Constant	15.13***	1.312

NOTE: Significance levels at 10% *, 5% ** and 1% ***.
Estimates with origin and destination station fixed effects

TABLE A4. **Poisson Model without Fixed Effects (Passengers)**

Variable	Coefficient	Standard Error
ln origin population	0.831***	0.042
ln destination population	0.800***	0.040
ln Euclidean distance	-1.237***	0.047
Connection (1 = yes)	0.615***	0.161
ln Sinuosity	-1.237***	0.181
Constant	5.560***	0.555

NOTE: Significance levels at 10% *, 5% ** and 1% ***.
Estimates without origin and destination station fixed effects.

TABLE A5. **Poisson Model without Fixed Effects (Freight)**

Variable	Coefficient	Standard Error
ln origin population	0.519***	0.046
ln destination population	-0.710***	0.049
ln Euclidean distance	−0.647***	0.086
Connection (1 = yes)	1.325***	0.186
ln Sinuosity	−0.811***	0.342
Constant	1.283***	0.922

NOTE: Significance levels at 10% *, 5% ** and 1% ***.
Estimates without origin and destination station fixed effects

Notas

1. Almost all lines built during the initial phase received a direct subsidy per kilometre of track constructed. To grant this support, the state auctioned the concession, awarding it to the company that offered to build the line with the lowest required subsidy.
2. Both terms are translations from the French *parcours partiel* and *parcours total*. In Spain, technical literature commonly used the terms *tránsito parcial* and *tránsito total*.
3. Strictly speaking, Courtois did not use the term 'elasticity'. His reasoning is based on an inverse relationship between the utility of a line and the square of its length. If utility (U) is inversely proportional to distance (L) squared, i.e. $U \propto$ L*^−2, then the elasticity of U with respect to L is equal to −2. This implies that a 1% increase in distance would result in an approximate 2% decrease in utility, reinforcing his argument that even minimal deviations can have significant cumulative effects.
4. Desart introduced the concept of *reduced population* to estimate the potential of a station. This was a fictitious value representing how many inhabitants a place should have to generate the observed passenger volume, according to the coefficient *c(D)* corresponding to its distance. This theoretical population replaced the real population in the profitability calculations. Delaveleye (1847) criticised this method for its circular nature: by adjusting the population based on traffic already known, the model ceased to be a predictive tool and only justified total traffic *ex post*.
5. «Libro de Actas de la Comisión de ferrocarriles. Legislatura de 1849 a 1850», *Expediente sobre el proyecto de ley de ferrocarriles e información parlamentaria sobre los mismos* (1850). Archives of the Spanish Congress of Deputies, File 88, no. 1, Session of 11 February 1850.
6. *El Español*, 9 and 23 October 1845.
7. *Gaceta de Madrid*, 30 January 1852.
8. *El Heraldo*, 19 and 23 June 1852.
9. *El Constitucional,* 18 and 25 November 1852. In the second article of the series, M.R. stated that he would address the details of the layout in the following issue, but *El Constitucional* changed its editorial team and the article was never published. M.R. possibly refers to the engineer Mariano Royo, who graduated from the *Escuela de Caminos, Canales y Puertos* in 1850. Royo worked mainly in Aragon and Catalonia and was chief engineer of the province of Huesca until 1862. *Revista de Obras Públicas*, 1913, pp. 516-17.
10. The article supported this idea with the formula: L=l(1+A/C), where L is the length of the diverted line, l is the length of the most direct line, A is the traffic on the line by the most direct route and C is the increase in traffic that would be caused by the diversion. In other words, it would be advantageous to lengthen the line as long as the traffic increases in the same proportion, which implicitly suggests a unit elasticity criterion between length and traffic as a minimum threshold for the viability of the diversion.
11.. Further east, since the 1850s, there had been plans for a railway to cross the Iberian Peninsula and reach Calatayud, Soria, Tudela, and Pamplona. From the capital of Navarre, the railway

would run through the valley of Los Alduides to Bayonne, hence its name: *Ferrocarril de Los Alduides* (Larrinaga, 2002). With the exception of this last section, which presented considerable technical difficulties, the entire line was built throughout the 19th century, albeit as part of other railways. The connection between Pamplona and France was also built, but not via Los Alduides, but via Alsasua and Irun.

12. *Revista de Obras Públicas*, 1853, pp. 9-13, 99-105 and 133-140.
13. For the connection between the Madrid-Irun line and the Alar del Rey line, Venta de Baños and not Palencia was taken as the actual junction.
14. Two specific issues affect the dataset. First, traffic at interchange stations may be biased, since flows continuing onto other lines were recorded as terminating there; however, these cases are limited and do not alter the main results. Second, some station pairs show zero traffic. To preserve these observations, a value of one was assigned before logarithmic transformation, an approach that avoids distortions in the distribution while retaining the information.
15. This specification makes it possible to quantify the impact of sinuosity with precision: since we know the sinuosity coefficient of the line, we can directly calculate how much traffic was lost due to the winding layout of the route.
16. To estimate the impact of the average sinuosity on traffic, the formula is applied: $\Delta \ln(T) = \beta \cdot \ln(S)$. Where β is the estimated sinusoidal coefficient and S is its mean. So, for passengers: $-1.006 \times \ln(1.76) \approx -0.569$. Converting back from logarithms, this implies that traffic was reduced to $\exp(-0.569) \approx 0.57$ of its potential level in a perfectly straight line—that is, a reduction of about 44%.
17. Overall losses of 25% (passenger-km) and 22% (kg-km) compared with short-distance shares of 30% and 15% imply required increases of ≈25/30 ≈ 80% and ≈22/15 ≈ 150%, respectively.