Title: From Sail to Steam

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Abstract: This article examines how the transition from sail to steam reshaped maritime transport and trade using novel evidence from Barcelona, one of the largest ports in the Mediterranean. We digitize nearly 70,000 voyages between 1795 and 1915, recording origins, ship type, travel times, and cargoes. Our identification strategy leverages variation across origins, months, years, shipmasters, and a distance-based instrument to isolate the causal effect of steam. The results show that steam reduced travel times by roughly 61-70 percent, with larger effects in winter months. We also find that steam influenced trade composition, decreasing general cargo and increasing raw material imports such as coal, firewood, and wool. These findings highlight how speed advantages were central to steam's competitiveness and suggest that the adoption of steamships accounted for much of Barcelona's trade expansion during the 19th century. Our analysis offers new insights into the technological drivers of globalization.

Keywords: Steamships, Sailing ships, Maritime technology, Trade, Globalization, Trade routes, Barcelona.

JEL codes: F14, F43, F63; L92, N70, O33, R4.

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1. Introduction

The invention of steam-power is one of the major technological advances in human history with wide-ranging implications. Most notably, steam-power revolutionized transport and world trade in the 19th century. The effects are seen in steam-powered railways, but also in steamships, transforming ocean shipping, one of the oldest sectors in the global economy. Speed was the steamships main advantage over sailing ships, the incumbent technology. Speed was crucial in contributing to lower capital and labor costs. Over time as engines improved in efficiency, the savings on capital and labor would offset steamship's higher fuel costs. Steamships would come to dominate sailing ships on most routes, contributing to an unprecedented surge in international trade during the late 1800s (Jacks and Pendakur, 2010; Meissner, 2024; O'Rourke and Williamson, 1999, 2002; Pascali, 2017).

While speed was crucial for the rise of steamships, it has been difficult to precisely identify the time savings *caused* by the adoption of steam technology, especially at a micro-level where the data has been less accessible. In this paper, we identify the causal effect of steam-power on shipping times using new data on nearly 70,000 arrivals into Barcelona, one of the largest ports in the Mediterranean Sea. Our data involve 1,023 departure ports from 1795 to 1915, including journey times, ship's type and name, tonnage, shipmaster name and a list of cargo. Our novel identification strategy uses variation in steam vs. sail voyages at the origin, month, year, and shipmaster level, along with a distance-based instrument explained below. The estimates show that steam reduced travel time by a range of 61 to 70%.

The steamship's impact on trade composition is also difficult to establish given current data and methods. Selection of steam based on product characteristics, like value to weight, is a key challenge. We estimate the causal effect of steam-power on the probability of particular products being shipped using our rich data on the cargo of ships into Barcelona and our instrumental variable strategy. The estimates show that adopting steam reduced the probability of general cargo (meaning no dominant product) and increased the probability of cargoes containing raw materials like coal, firewood, and wool. Steam also reduced cargoes with fabrics, a product which was increasingly produced in Barcelona during its industrialization.

Our analysis significantly advances on previous studies examining the time savings of steam and trade impacts. There are surprisingly few studies empirically examining the time savings or speed advantage of steamships over sail ships. One is Hatton (2024), who documents that passage times from Liverpool to New York declined from around 40 days in 1853 to just 8 days by 1913 (an 80% decline). Our data contains hundreds of different ships carrying passengers and freight, offering a new comparison, across many origins. A second is Pascali (2017), who uses data from 1,667 vessels, along the Canadian coast, to estimate that steam reduced shipping times by 36%.[1] Similar to our paper, Pascali (2017) examines several routes and uses origin and year fixed effects in a regression analysis. We demonstrate how our estimates differ in the Barcelona context and by including ship-master surname fixed effects and moreover by instrumenting for steam.

Pascali's paper, however, is primarily concerned with global trade and its relationship to long-run economic development. We use Pascali's framework to gauge the impact of steam on trade for Barcelona. There are studies on how lower maritime transport costs affected the value of bilateral trade between countries (e.g., Jacks and Pendakur, 2010; Jacks, Meissner, and Novy 2010), yet to our knowledge there is no research on trade-composition effects. We leverage our identification strategy for steamships and micro-data to estimate composition effects for the first time.

Barcelona is a useful context as it was a key Mediterranean port embedded within a rapidly expanding urban and industrial hinterland. Barcelona's geographical position facilitated connections not just with Spanish ports but with nearby European markets and colonial routes after 1765 when trade with the Antilles was no longer controlled exclusively via Cádiz (Álvarez-Palau et al., 2025; Ellingsen, 2025; Fisher 1993). By 1880, Barcelona accounted for over one-third of Spain's total shipping tonnage and roughly one-fifth of all passenger traffic (Estadística General del Comercio, 1880: 734-737). The Mediterranean routes linking Barcelona to European neighbors, the Atlantic routes to the Americas, with the colonial markets operating until 1898, and later to Asia via Suez, provide natural variation in the distances and wind conditions that ships faced.

There are further advantages to studying steamships in Barcelona. For instance, Valdaliso (1991, 38) notes how "the diffusion of steam in Spain was similar to what occurred in Great Britain, France and Germany, which together with Spain and Belgium led the process of maritime modernization. Shipowners in Barcelona and Bilbao, which in 1860 owned the greatest amount of sail tonnage flying the Spanish flag, were the first to acquire steamers".[2] Thus, Barcelona offers a context to examine the impacts of steamships in an economy where they were widely adopted and where there were different trading partners than those of northern Europe.

We begin by reporting differences in speed between sail and steamships over time. The calculation of speed requires identifying the distance travelled as well as the days travelled, which we observe in the data. Distance travelled is approximated by routes which we create using a new model of sailing for hundreds of ports into Barcelona. At the moment, the routes minimize distance considering the shape of the coastline. In the future, factors like

[1] Data are from the *Atlantic Canada Shipping Project*. The impact of steam technology on travel times is examined in the Appendix (see Table A6 in Pascali, 2017).

[2] See also Valdaliso (1992) and also Fischer and Nordvik (1986). While we searched for comparable data on individual ships for British ports, we were unable to locate sources equivalent in detail to those available for Spain. Previous studies have primarily focused on freight rates, rather than travel times, to capture the impact of steam (see Harley, 1988; North, 1958; 1968). However, freight rates are an endogenous measure, reflecting not only technological change but also simultaneous shifts in economic activity and broader market structure.

the prevailing winds will be incorporated. We find that throughout the 19th century the average speed of ships increased from around 2 knots to 7.5 knots (or from 4 to 14 km per hour) and that most of this was driven by the switch from sail to steam.[3] Thus an aggregated comparison implies steam reduced times by 71%. We also examine differences in the variance of speeds on voyages by steam and sail. Here we find that the variance was higher for voyages with steam. Thus steam's main advantage was greater speed, not greater reliability.

Next we use variation in travel time at the origin, month, year, and shipmaster surname level along with ship's observables like tonnage to evaluate the effect of steam on travel time. We focus on a sample 58,092 non-stop voyages to Barcelona from 964 origins with 17,183 unique shipmaster surnames. The data cover the years 1795 to 1915. The OLS estimates turn out to be similar across various specifications which include fixed effects for route, month, year, and shipmaster surname. The consistent finding is that steam lowered shipping time by 70%, similar to our conclusion from the aggregate analysis of speed. Nonetheless, there is still a concern that journeys which used steam were selected based on need for speed. Simply put, steamships did not appear randomly on different routes and ship owners likely chose to deploy them where they expected commercial gain, and shipping lines introduced steam services first on certain lucrative routes.

We address this issue by using a novel instrument variable (IV) based on distance to the origin port interacted with year fixed effects. The rationale of the instrument is as follows. Before 1850 steamships used a lot of coal, meaning they were only cost efficient on short journeys (Harley, 1988, 2013; Valdaliso, 1992). However, as engines improved after 1850 steamships were increasingly used on longer journeys. Thus, it is reasonable to assume that longer distance routes were increasingly likely to have steamships over time regardless of their market conditions. The first-stage of our IV estimate works well, yielding a large F-statistic. The second stage IV estimates imply that steam lowered times by 61%, which is smaller than our OLS estimate. Thus we are able to confirm that OLS analysis of steam vs. sail is upward biased. Nevertheless the degree of bias is not so significant as to render OLS estimates as practically useless.

We also estimate heterogeneity effects. The results show that steam had a greater effect on travel times in winter months than summer months. That makes sense, as sailing in winter was more dangerous and time was likely sacrificed for safety. The results also show that steam had a smaller effect on ships of a UK nationality, compared to ships of Spanish, French, or Italian nationality. This result is interesting as it suggests that when steamship technology was transferred from the UK, it did not necessarily imply that actors in the receiving country (e.g., Spain) were less efficient in using steamship technology.

Our new estimate of the effect of steam has several implications. First, it implies that without such a significant time advantage, steamships would have been substantially less

[3] For comparison, today commercial cargo vessels typically cruise at 14-16 knots (26-30 km/h).

productive and less competitive with respect to sail. A 250% increase in travel time (the inverse of steam reducing time by 70%) would imply that capital and labor costs would increase by approximately 250%. As labor and capital represented 50% of steamship costs (Harley, 1988), this would imply that steamship costs would rise by 125% without its speed advantage. Under such conditions, steamships could not compete with sailing ships.

A second implication of our estimate is that the advent of steamship technology dramatically boosted trade volumes. We draw on the elasticity of trade with respect to differences in steam versus sail time estimated by Pascali (2017), approximately -1.44,[4] and our result that steamships decreased time by at least 0.95 log points. Multiplying the two yields an estimated increase in per capita trade of roughly 1.37 log points, or approximately 292%. Strikingly, this figure is close to the observed average growth in per capita trade between 1850 and 1905 (Federico and Tena-Junguito, 2019). In an economy like the Catalan one it would imply that the adoption of steam can account for nearly all its trade growth.

Concerning steamships and the products they shipped, we document new but yet sensible patterns. Our data reveals that higher value to weight products were more likely to be shipped by steam than lower value to weight products from 1850 to 1915. However, it is not clear that steamships caused more shipments of high value products as steam was likely to have been selected. We apply the same instrumental variables strategy to estimate the causal effect of steam on the probability that a voyage had a cargo containing a specific product. Our list of products is based on the 50 most common. We find that steam reduced the probability of a voyage having general cargo (implying specialization of shipments) and increased the probability for a set of products related to raw materials, like coal, firewood, and wool. Notably all of these latter products were central for 19th century industrialization. We also find that steam reduced the probability that cargoes contained fabrics, an industrial product increasingly produced in Barcelona. Overall, we find that steamships themselves significantly altered Barcelona's imports.

Our findings are related to a literature on emphasizing the importance of the 19th century macro-inventions (Harley, 1988; Mokyr, 2010; Pascali, 2017). Steam-power has been rarely analyzed at a micro-level as we do here. We also add to a broader literature studying the drivers and impacts of globalization in the 19th century (Jacks, Meissner, and Novy 2008, 2010; O'Rourke and Williamson, 1999, 2002), giving emphasis to the role of technology (steamships) as well as contributing to a broader literature of the drivers of globalization (see for instance recent works on the Suez Canal by Jacks, Meissner, and Wolf, 2024) and on technology adoption and its impacts (Syverson, 2011).

Of course, we also contribute to a literature on the diffusion of steam-power in shipping. The replacement of traditional sailing vessels by steam-powered ships did not occur overnight; on the contrary, it stretched over several decades and varied significantly by

[4] That is, ln(steam time)-ln(sail time).

route and cargo. With high fuel and capital costs, steamships initially gained dominance on short-haul and time-sensitive routes, where the premium for speed was worth the expense, and only later did they encroach upon the longer transoceanic trades (Graham, 1956; Hamilton, 1883; Harley, 1972; Kaukiainen, 1992, 1995; Valdaliso, 1992). Early steamers were constrained by limited fuel efficiency and the need to coal frequently, which made them less competitive on long voyages until technological improvements (such as more efficient engines and larger coal capacity) reduced these limitations (Craig, 1980; Jackson, 1988; Scroggs, 1919; Valdaliso, 1992). Moreover, far from being a static backdrop, sailing ship technology also continued to improve well into the late 19th century, boosted by innovations like hull coppering, improved rigging, and the introduction of faster clipper ships (Armstrong, 2009; Bogart et al. 2021; Harley, 1988; Hatton, 2025; Ville, 1986) and remained prevalent in low-value bulk trades (such as coal, grain, nitrates, or guano) and on very long routes. The transition from sail to steam was thus a protracted process of overlapping technologies, rather than a sudden upheaval.

Our analysis adds by demonstrating how steamship effects differed by time of year and ship nationality. Some conjectures are that steam had a larger effect in winter months with worse weather (Bogart et al., 2021; Kelly and O'Grada, 2019; Miotto and Pascali, 2025). Another conjecture is that steam had a smaller impact if the ship was operated by crew from a less skilled country (Hamilton, 1883; Harley, 1988; Kaukiainen, 1995; Palmer, 1978; Sager 1989; Valdaliso, 1992). We find evidence that steam's effect was indeed larger in winter months. However, we find no evidence that steam's effect was larger in the UK, presumably the most skilled shipping country.

Since our dataset also includes sailing vessels, we also speak directly to the literature of productivity changes during the Age of Sail (roughly the mid-16th to the mid-19th century) and the work from Bogart et al. (2021), Hatton (2025), Kelly and Ó Gráda (2019), Rönnbäck (2012), and Solar and Hens (2015). More broadly, we add to a growing body of literature using micro-level data to assess the economic impact of steam. For example, Atack et al. (2022) examine how mechanization altered task completion times in U.S. manufacturing (see also Goldin et al. (1998), Mokyr (1992), and Sokoloff (1984)). By analogy, our work shows how steam reduced the "production time" of moving goods over distance. We also connect with the literature on the use of steam in transport, that associates the expansion of the railway with productivity gains and broader economic and demographic consequences (Álvarez-Palau et al. 2024; Donaldson and Hornbeck, 2016).

The next section provides more background on the transition from sail to steam in the context of the port of Barcelona. The following section introduces the new datasets. The effects of steamships on speed, travel times, and trade composition follow in sections 4, 5, and 6. Section 7 concludes.

2. Background

Barcelona provides a rich historical context to study the transition from sail to steam and its impacts on trade. We start by providing general background on Barcelona's port. We then turn to the adoption of steamships in Spain, where the broad outlines are established and set up our analysis of Barcelona.

2.1. The Port of Barcelona

A key turning point in the history of the port of Barcelona came in 1778, when Spain liberalized its colonial trade system (Ellingsen, 2025; Fisher, 1993; 1985). The reform ended the longstanding monopoly held by Cádiz and allowed select ports, including Barcelona, to engage in direct trade with the Americas. Maritime traffic surged in Barcelona, which emerged as a dynamic European hub of trade and an *entrepôt* for Atlantic commodities such as sugar, rum, and raw cotton, as well as for the export of manufactured goods. Nonetheless, this trade boom happened in a port of minimal physical infrastructure (Figure A1). By 1800, there was barely enough space to beach a few ships and store some cargo on the sand. The port also lacked key maritime infrastructure, such as a sheltered and properly engineered facility, leaving ships vulnerable to storms in open waters. Infrastructures increasingly lagged demand, and merchants and elites repeatedly called for reforms (for a review see Alemany, 2019; MUHBA, 2021).

Despite some efforts, such as the construction of a new western quay in 1822 and deepening of the port's basin in the 1830s using steam-powered dredging equipment, the port continued to suffer from chronic sedimentation and lagged infrastructures (Alemany, 2019).[5] Despite this, Barcelona handled more than 30% of Spain's imports (Estadística General del Comercio, 1880). The introduction of large steamships with deeper drafts further required a port to meet the new technological demands.

The first comprehensive modernization plan, drafted by engineer Josep Rafo and approved in 1860, envisioned a reorganization of the inner harbor and a system of new breakwaters and quays. However, political instability and military distractions delayed implementation (Alemany, 2019; García-Sanz, 1977). Only with the liberal Revolution of *La Gloriosa* in 1868, did the political conditions emerge for institutional reform. A year later, the new administration created the *Junta de Obras del Puerto* (Port Works Board), giving local stakeholders, especially merchants and industrialists, significant control over port development (Álvarez-Palau, et al. 2025; Frax, 1996; López, 2016).[6]

Under the Junta's authority, the port embarked on a new phase of construction. In 1870, legislative approval was secured for the issuance of port bonds, tapping capital markets to

[5] As illustrated in Figure A2, Alfred Guesdon's 1856 lithograph captures the persistent obsolescence of the port and its facilities: ships anchored offshore, cargo ferried ashore by small barges, and rudimentary quay structures hemmed in by urban space and shallow waters.

[6] The "Junta" was a pioneering institution, unique in Spain at the time. Unlike typical government bodies, it included representatives from local maritime and commercial sectors, such as shipowners, merchants, industrialists, and other stakeholders, rather than being composed solely of state officials.

finance modernization. Dredging commenced immediately, and between 1870 and 1875, nearly 2 million cubic meters of sediment were removed, increasing the port's average depth to 8 meters (Alemany, 2019; MUHBA, 2021). This facilitated the entry of large, ocean-going steamships, transforming the port's capacity and strategic value. Concurrently, massive stone blocks were deposited to create stable foundations for new quays and protective moles. By 1875, the eastern breakwater had been reinforced and extended, while a new secondary breakwater improved shelter from storm surges and wave action (see Figure A3).

This period also witnessed the integration of local industry into port development. Ironworks and shipbuilding companies such as the *Nueva Vulcano* provided machinery and structural components (Sánchez-Carrión, 2013), highlighting the interdependence between regional manufacturing and infrastructure (Bird, 1971; Delgado and Guimerá, 2000). The modernization of the port thus became both a driver and a product of Catalonia's broader industrialization. The opening of the Suez Canal in 1869 also reoriented maritime flows, making Barcelona a key node in Mediterranean-Asian trade. Yet new challenges emerged by the end of the 19th century (Alemany, 2019; Valdaliso, 1992). The 1898 loss of Cuba and Puerto Rico and the Philippines in Asia, a blow for Catalan merchants heavily involved in colonial trade, called for economic diversification. At the same time, the second wave of industrialization, including electrification and the rise of the chemical and metallurgical sectors, required an even larger and more efficient port.

Responding to these pressures, a new plan was approved in 1903 with the aim to guide the port into the twentieth century. In this second expansion, major components included the extension of the east breakwater further into the Mediterranean, the construction of three new perpendicular quays, and the creation of a vast new basin on the port's western side. Emphasis was also placed on enhancing intermodal connectivity, integrating the port with railway and road networks to facilitate the inland distribution of goods (Alemany, 2019; Álvarez-Palau, et al. 2025; Esteban-Oliver et al., 2024). These projects effectively tripled the port's area. Work began around 1905, and by 1913, the expanded port infrastructure was operational. Overall, if in 1859 the port encompassed just 10 hectares of land and 60 hectares of water, with a quay line of 0.35 km by 1913, it spanned 90 hectares of land and 220 hectares of water, totaling 310 hectares and 8.5 km of quay line. A more than fourfold increase (Alemany, 2019; MUHBA, 2021).[7]

2.2. Steam adoption in Spain

Spain had a long history of relying on sailing ships for maritime trade and exploration. Spain's shift to steamships was driven by economic necessity and institutional reforms, carried by a generation of maritime entrepreneurs. As a peripheral industrial country, Spain's industrial base to support a steam fleet was limited, and shipowners purchased

[7] Port size in different benchmark years is available in Figure A4.

steamboats from British shipyards and sold much of their long-distance sailing fleet abroad to acquire new ones. As noted by Valdaliso (1991, 54), "The expansion in the Spanish fleet during the last four decades of the nineteenth century was based largely on the acquisition of vessels from abroad, principally from Great Britain." Indeed, Spain became the second-largest importer of steamships (by tonnage) in the late 19th century, only after Italy (Pollard and Robertson, 1979; Valdaliso, 1991).

The fixed capital costs of steamships required new forms of organization and finance (Carrera Pujal, 1961; Valdaliso, 1992, 2000). Informal fraction shares among a handful of partners were replaced by joint-stock companies, pooling capital from a wider array of investors, like merchant families and ship captains, along foreign investment (Boyce, 1992; Ville, 1993; Valdaliso, 2000; 2011). Some examples were the Sociedad de Navegación e Industria (1841), Bofill, Martorell y Cía. (1852), and Pablo Ma Tintore y Cía. (1852). Leading shipowners were major merchants who, beyond trade and carriage, internalized consignment and insurance, applying them to goods they marketed and the vessels they operated, consolidating risks and revenues into integrated enterprises (Valdaliso, 2000; 2011). It has been suggested that steam offered not only faster and more reliable services, but also access to new markets and more regular schedules, which proved attractive for both new cargo and passenger traffic (for a review see Valdaliso, 2011).

Human agency was also a decisive factor for adopting steam. In the mid-19th century, the merchant marine remained in the hands of private shipowners, often small-scale merchants operating sailing vessels (Rotllan, 2025; Valdaliso, 1992). However, as steam technology became more practical, entrepreneurs moved decisively to embrace it. Antonio López y López is a good illustration in this shift (Rodrigo-Alharilla, 2021). Originally from Cantabria but active in Barcelona, López y López began investing in steamships in the 1850s. By 1861, he had launched regular steam service to Cuba, and his efforts culminated in the founding of the *Compañía Trasatlántica Española* in 1881. The company quickly grew, commanding nearly half of Barcelona's steam tonnage by the 1880s (Valdaliso 1992). As steam proved increasingly profitable, traditional trading and shipping houses evolved into modern steamship enterprises.

Steamships also brought deeper changes to the port economy and the organization of maritime services (González-Lebrero, 1989; Nieto, 1960; Rotllan, 2025; Valdaliso, 1992). Under sail, ship captains had often handled much of the business side themselves, managing cargo, customs, and supplies through personal networks. With steam, however, the need for fast turnaround and tight scheduling elevated the role of *consignatario* (shipping agent), who took on many of these responsibilities. Agents became essential intermediaries, securing fuel, arranging loading and unloading, and managing port logistics, allowing captains to concentrate solely on navigation. The broader shipping industry also adapted: shipowners sometimes integrated vertically by investing in coal imports or horizontally by aligning with railways to ensure steady cargo flows (Gómez Mendoza, 1988; Valdaliso, 1991). Others joined cartels to stabilize rates and coordinate services (Nieto, 1960;

Valdaliso, 2011). These developments reflect a broader organizational restructuring of maritime commerce in response to the demands and opportunities of steam navigation.

Political interests also played a role. Freer trade policies arising from the 1868 Glorious Revolution, including the abolition of the differential flag duty in November 1868, which had imposed a 20% tariff on goods carried by foreign ships, forced a reorientation as firms had now to compete on efficiency and modernize their fleets (Carrera Pujal, 1961; Estasen-Cortada, 1880, Sánchez de Toca, 1898). However, while these measures accelerated steam adoption, some have argued that sail's decline was already underway by mid-1860 (Vives, 1959). Direct intervention also helped, and mail subsidies were awarded to major steamship lines and regulatory changes also favored steamers, allowing them to bypass paperwork, unload cargo after hours, and operate under more flexible rules than sailing ships (Estasen-Cortada, 1880). Valdaliso (1992) also notes that the loss of Spain's overseas Empire in 1898 meant that traditional transatlantic routes, previously dominated by sailing ships, were replaced by coastal and European steamship routes, creating strong incentives to adopt steam technology.

In sum, in 1860, Spain ranked as the eighth-largest steam fleet worldwide, and by 1880 ranked fifth, surpassed only by Britain, France, Germany, and the United States (Valdaliso, 1992).[8] A notable position for a country on the periphery of industrial Europe. The late-19th century stands out as a period when Spain exceeded expectations in maritime modernization. Its early and substantial embrace of steam technology enabled it to hold a prominent position in global shipping, at least temporarily, during a transformative era for world trade. In other words, the switch to steam did not strictly follow the richest economies; in the case of Spain, it was accelerated by specific trade needs and policy choices. Of course, this modernization had its limits: it was uneven (favoring certain ports and companies), it relied significantly on foreign technology and finance, and it was ultimately unable to prevent a decline in Spain's relative standing as new competitors emerged by 1900.

3. Data

In this paper, we introduce new data on steam and sail ships arriving into Barcelona drawn from a long-running newspaper. We also reconstruct the typical routes travelled by ships arriving to Barcelona from hundreds of ports across Europe. This section describes the data and reconstruction.

3.1. Barcelona shipping data

We construct a novel dataset of 69,846 voyages involving around 13,634 ships that departed

[8] Valdaliso (1992, 66) also notes that "In 1900, Spain had the highest percentage of steamships in its merchant fleet, surpassed only by Belgium."

from any port and arrived at the port of Barcelona between 1795 and 1915. For the study's design, data were collected at five-year intervals (1795, 1800, 1805, etc.).[9] For the annual entry of ships in our data see Figure A5. In the absence of surviving administrative or commercial records that documented maritime traffic (i.e., customs office records.), we rely instead on daily news from the *Diario de Barcelona*, a well-known newspaper which began publishing in 1792. Alongside news on culture, politics, and finance in Barcelona, *Diario* published detailed records of vessel arrivals. This underscores how crucial it was for merchants and businessmen to stay informed about the goods arriving in the city by sea.

A typical entry includes the ship's name, its type (distinguishing between steamers and above 15 sailing vessels), tonnage (only after 1815), flag or country of registration, the captain's surname (and before 1880 also his name), the departure port and any intermediate stops, the cargo on board, the consignee or receiving merchant, and the transit time, reported in days or hours. Descriptive statistics are available in Table A1 and Figure A6 provides illustrative examples of the reporting ships from the newspapers.[10] The main variable in our analysis is the travel time. It is listed for 58,092 voyages. The mean travel time across voyages into Barcelona was 327.13 hours with a standard deviation of 511.43. The mean tonnage of ships was 275.2. The mean number of intermediate stops was 0.37, with the median being 0.

Unfortunately, after April 30, 1915, the variable travel time was no longer reported, making the records useless for our purposes. During the Napoleonic invasion of Spain, and the outbreak of the Peninsular War (1808-1814) the port was closed, with no details on the arrival of ships. Instead of 1810 we collected data for the first half of 1808, after which the records cease.

For coding the data, we used automated text-recognition techniques. However, given the age of the documents, the OCR was error-prone (due to transparency of the paper), requiring substantial post-processing. We manually validated each of the entries, which was necessary to ensure accuracy. Of the original 69,846 recorded voyages, we excluded 645 associated with warships (i.e., frigates, corvettes, battleships, etc.), 4,016 in which the number of ships was reported collectively (e.g., "five ships from Levante"), and 6,319 that listed ports or stops as "various ports" without further specification. The resulting dataset comprises 58,866 voyages.

After classifying ship types in the dataset, we find that approximately one-quarter of all recorded vessels were steam-powered. Nonetheless, as Figure 1 shows, a temporal breakdown reveals a clear upward trend in steamships that navigated in the Mediterranean. The earliest steamship in our sample appears in 1825, a single vessel, the Corbeta-vapor Reina Amalia, which departed from Gibraltar and reached Barcelona in 11 days, with intermediate stops in Málaga, Águilas, and Tarragona. No steamships were recorded in

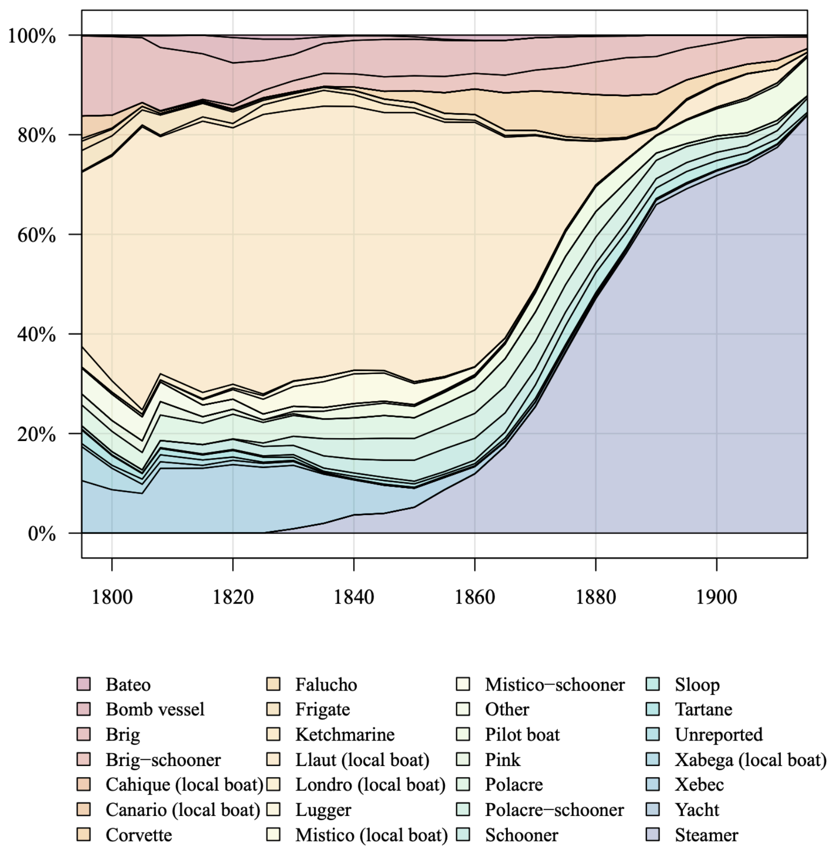
[9] Because the port was closed in 1810 due to the Napoleonic Wars, we instead use data from the most recent prior year in which it remained operational, 1808.

[10] From 1850 to 1855, a daily edition was published, from April 1855, two editions, and, starting in 1909, three.

1830, but by 1835, the number had increased to 96 in 1840 and 339 in 1845. Then steamships rise sharply and eventually dominate. Table A2 offers additional insights and description into the types of sailing vessels that played a role in this transitional phase.

Prior to the 1830s, maritime transport was entirely reliant on sail and when the early steamships began to appear they faced major technical and economic limitations. Early adopters were equipped with low-pressure, single-cylinder engines that consumed large amounts of coal, required heavy maintenance, and restricted their use to short routes. These drawbacks confined steam vessels to short routes and prevented broader adoption in long-distance trade (Valdaliso, 1992; Harley, 1988). Nonetheless, technological improvements like high-pressure, compound, and later triple-expansion engines in the following decades transformed the viability of steam propulsion, reducing fuel use and extended voyage range. By the 1870s, steam-powered vessels made up nearly half the fleet, rising to over 80 percent by 1910.

Figure 1. Steam adoption over time



Sources and notes: Authors calculations based on *Diario de Barcelona*. The shares are based on arrivals, not tonnage of ships.

Sail tonnage remained stable through much of the early period, but from the 1830s onward, steam tonnage began to rise steadily.[11] In 1825, average sail tonnage stood at 47.1, while steam tonnage was already higher at 164. By 1915, sail tonnage had increased modestly to 174.9 (roughly a 3.5-fold rise). In contrast, steam tonnage surged to 1,020.2, representing a sixfold increase. The shift from wooden to iron and later steel hulls allowed for larger, more durable steamships. Compound engines and triple-expansion engines in the 1860s and 1870s also greatly enhanced fuel efficiency. These innovations addressed earlier constraints. As Bernstein (2008) notes, steamships in the 1850s often dedicated up to 40% of cargo space to coal, limiting range and profitability. Garcia Domingo (2016) also observes that a single 10,000-ton steamship making eight voyages annually could move 10-12 times the cargo of the largest sailing ship. Amengual (1880) also reported that one steamship equaled three and a half sailing vessels.

We standardize the entries in the cargo variable, which records listed items for each ship. We assume the first few items represent the most significant components of the cargo, as the documentation typically lists three or four goods before noting "and other items or general cargo" leaving out many secondary products. Unfortunately, the data refer only to the types of goods carried, not their values. So far, we have collected and cleaned the cargo data at 5-years intervals from 1795 and 1830 and decade intervals between 1840 and 1910 but plan to have the cargo at 5-years intervals until 1915. We also plan to add quantities for each type of cargo when available.

There were 1035 unique product names in the data. We use the term 'product' as it is generally applicable, but there are exceptions. Passengers were listed with products and should be viewed as a passenger service. Ballast was used to stabilize the ship, and was mostly kept in port, although it had some value in construction. We counted the number of occurrences of each product across all voyages with such information from 1795 to 1915. Then we selected the top 50 products with the highest share among all occurrences in the voyage lists. Together the top 50 accounted for 68.9% of all product occurrences. Table A3 lists the top 50 products, including our translation and their share in all product occurrences.

The most common was *otros efectos*/general or general cargo, representing 8.1% of all product occurrences. The second most common was trigo or wheat, representing 4.5% of product occurrences. Coal, an important commodity for industrialization, was fourth, representing 3.9% of occurrences. Many of the top 50 products were stables, like wheat, rice, and oil. Others describe manufactured goods, like machinery, drugs, and fabrics. We assign a classification of low value to weight or high value to weight to each product based on our knowledge. Most classifications are indisputable (e.g., coal is low value to weight), while others are more ambiguous like general cargo, which we consider high value. The classifications give a general guide to the products and are not essential to our analysis.

We also create 50 dummy variables equal to one if the voyage had the product listed in its

[11] For the vessel tonnage we use gross register tons, a standard reflecting a ship's total internal volume, including cargo space.

cargo. Table A3 gives the share of voyages with cargoes containing each product. The share of voyages generally aligns with the share of product occurrences. The product's voyage share was larger if it was more commonly listed with other products. General cargo, wheat, and coal were listed on 12.1%, 6.9%, and 5.6% of all voyages respectively. Later we will analyze the probability that a voyage had a certain product in its cargo as a function of steam.

We also standardize ship names using a combination of typology and spelling. All names are first converted to lowercase, with accents and punctuation removed. We then apply a Levenshtein similarity score[12]. A match is flagged when the score reaches 0.85 or higher. These matches are reviewed manually, with final inclusion based on consistent ship category. This process yields 13,634 distinct vessels. For shipmasters listed before 1880 we have names and surnames; afterward, records typically contain only surnames or surnames with a name's initials. As with ships, we begin with manual cleaning to address OCR errors. We then use the Levenshtein score to link entries over time. Matches scoring over 0.85 are flagged for potential equivalence and manually coded. Using this approach, we identify 13,162 shipmasters by full name, 11,303 by surname and name's initial, and 6,931 by surname alone. As an illustration, there were 1,046 unique shipmaster surnames for the largest origin port of València. The top ten surnames accounted for 10% of the voyages from Valencia. The third most common surname was Llopis with 129 voyages or 2.6% from València. Crucially, for our identification, 99 of these voyages were by steam and 30 were by sail. Thus within common origin-shipmaster surname combinations, like València-Llopis, we can compared travel times by sail and steam.

Before moving to the empirical sections, one limitation worth noting is that despite having details on intermediate stops for multi-leg journeys, we do not have the time between them, which includes the time at port (just the time between origin and Barcelona). Nonetheless, 73% of the ships into Barcelona make no stops. Another issue in the data is rounding, as despite the time away was often recorded by hours (e.g., 3 days and 5 hours) it is often reported in days (3 days), somewhat adding noise in the estimates.

3.2. Distance between port-pairs

While in our data we observe the duration between origins and Barcelona, we do not know the specific routes that the ships followed (only its origin, intermediate stops, and Barcelona). To approximate routes, we standardized port names to a consistent set of locations, ultimately yielding 1,023 distinct ports and assigned each geographic coordinates (WGS84) (see Figure A7).[13] From the initial collection of 69,846 voyages, in 179 cases the port of origin was unreported or impossible to read, in 4,267 observations (or 6.11%) observations were grouped from different ships (i.e., 5 ships from Levante) or the voyage is

[12] Specifically, we used Python's difflib.SequenceMatcher.

[13] A challenge in the data is the variation in port names, which appear in Catalan, Spanish, or occasionally in foreign forms. In addition, some entries refer not to formal ports but to small landing spots or beaches.

described as “different ports”, and in 650 voyages (or less than 1%) we were unable to locate the port. This involved a total of 285 ports and given the low number of observations for each one (in 228 of these ports only one ship is listed) we assume that these were transcript errors from using different languages. This group also involves observations that the port of origin was reported as “The Sea” (181 voyages) or too general (“Norvega” or “Reyno de València”). Nonetheless, since European ports are disproportionately represented in the data (Figure A8) and given that transoceanic routes differ from sailing conditions in the Mediterranean and North and Baltic seas, we restrict our analysis to Europe in examining route distance. Excluding for now routes that crossed the Atlantic or arrived from Asia, whether through Suez or the Cape, leave us with 945 ports.

From the ports we located (92.71% of the initial voyages involving 82 countries following the current political borders), half of our voyages (55.34%) was engaged in cabotage trade and departed from a Spanish port, mostly from the ports of València (8.35% of the voyages), Palma de Mallorca (5.78%), Alacant (4.82%), Sevilla (3.57%), Cádiz (2.53%) and Mao (2.39%). The other half came from European neighbors, including France (9.25%), where the second most important port connected to Barcelona was Marseille (with 6.29% of the voyages) and Sète being also important (2.12%), Great Britain (6.32% with Cardiff accounting for 2.13% of the voyages) and Italy (5.98% and Genova accounting for 2.57% of the voyages). Then comes the trade with the Americas, with 2.48% coming from North America, 2.11% from Cuba, and 1.75% from Colombia followed by a mix of countries: Germany (0.79%), Argentina (0.67%), Norway (0.62%), Belgium (0.61%), Canada (0.56%), Algeria (0.55%), and Brazil (0.51%). The numbers then get small.[14]

The second step was to construct a coastal transport network. We implemented an eight-directional grid across the study area, with nodes spaced at 10 km intervals. This spacing provides sufficient geographic detail while preserving a rational computing time when solving the model. Each node is linked to its immediate neighbors in all eight directions (N, NE, E, SE, S, SW, W, NW), creating a flexible structure to model long-distance shipping routes. Each port was linked to its nearest grid node using a geodesic connection, integrating port infrastructure into the movement network. To preserve connectivity across narrow passages such as the Dardanelles, Bosphorus, and Kerch Straits, we introduced manual links to maintain topological continuity. The network was projected in EPSG:8857 (World Equidistant Cylindrical), which preserves distance accuracy over large areas.

We estimated minimum coastal navigation distances between ports using ArcGIS network analysis over the grid. The tool applies the Dijkstra algorithm to identify the least-cost path between any origin and destination. In this scenario, distance was the sole impedance attribute, producing relatively direct routes. Based on travel costs, we also generated distances that account for prevailing wind patterns to assess how sailing conditions could

[14] In Figure A7 we provide a map of the principal ports to emphasize that the unit of observation is the port itself.

alter effective distances. The model assesses each route segment based on four parameters: its geometric direction, the directional flow associated with the port, wind direction, and wind speed.

The geometric direction of each segment was derived from its start and end coordinates and discretized into four categories: 0°, 45°, 90°, and 135°. These correspond to the main axes and diagonals of the grid and capture the movement directions embedded in the network topology. Port-specific flow directions were obtained by creating raster layers that indicate the bearing toward Barcelona. Azimuth values from each grid point to Barcelona were calculated and stored as attributes of the base grid.

Incorporating wind into the model required several steps. We drew on the *European Climate Assessment & Dataset* (Klein Tanke et al., 2002), which provides daily observations from more than 10,000 meteorological stations across Europe since 1950. We selected stations located near the coast and for each station, we calculated the modal value of wind speed and direction for June and November. These values were then interpolated using Inverse Distance Weighting (IDW) to generate continuous raster surfaces. In total, we produced four rasters: wind speed (m/s) and wind direction (degrees) for June and November.

Wind direction is reported in azimuthal format, where 0° corresponds to North, 90° to East, and so on. By convention, these values indicate the direction from which the wind originates. For modelling purposes, however, we require the direction toward which the wind is blowing. To make this adjustment, wind direction was corrected using the following formula:

$$\text{Corrected wind direction} = (\text{Wind direction} + 180) / 360 \quad \textbf{(1)}$$

To ensure that wind aligns with travel direction, each route segment was assigned values (in degrees) through spatial extraction from the corresponding raster layers. Directional data (also in degrees) were treated as azimuth angles, and differences between directions were used to calculate angular alignment via cosine transformations. This allowed the model to capture how favorable or adverse wind conditions were for movement along each segment. The final cost of each segment was computed using the following equation:

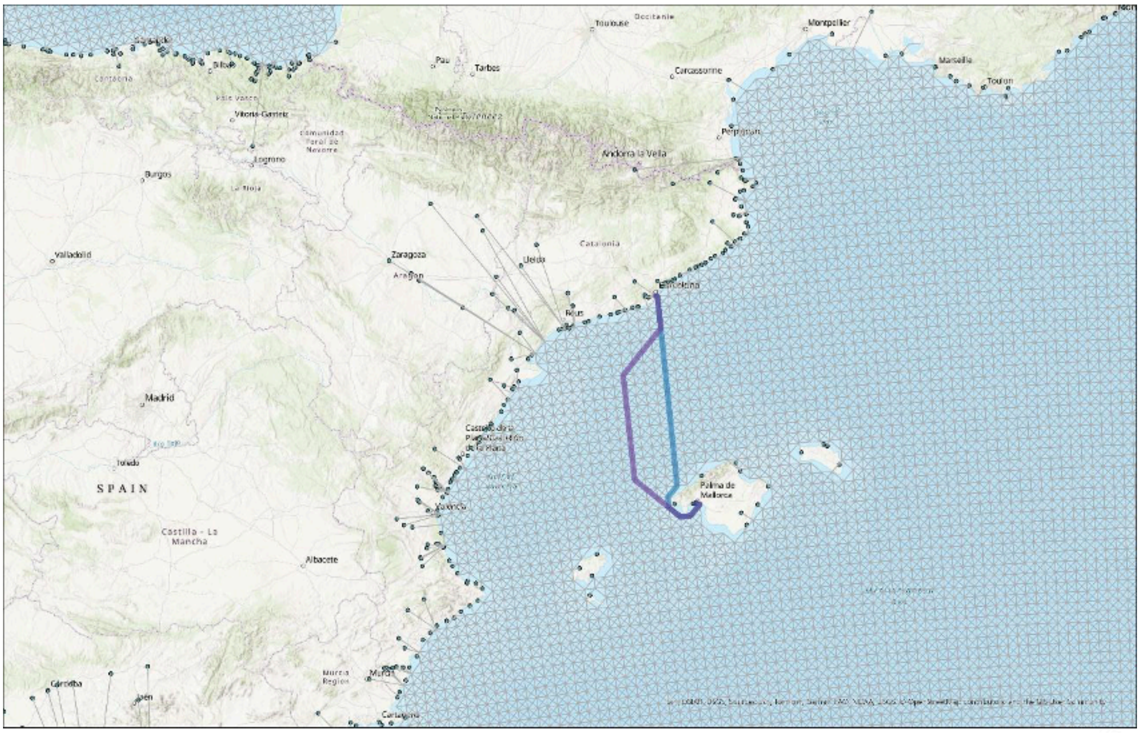
$$\text{Cost} = \text{Length} \times \text{Wind coefficient} \times \text{Flow coefficient} \times \text{Speed coefficient} \quad \textbf{(2)}$$

where *length* is the physical length of the segment (in kilometers), and it represents the geodesic distance of each segment, calculated using the network's projected coordinate system (EPSG:8857, World Equidistant Cylindrical), which preserves distance for coastal modelling; *Wind coefficient* = 1 + cos (Δθ wind flow) × 0.25, reflecting the alignment between wind and flow directions; *Flow coefficient* = 0.75 + |cos(Δθ line flow)| × 0.25, captures the alignment between the route's direction and the flow toward the target port; and *Speed coefficient* = 0.85 (if wind speed < 25 or > 60 km/h), else 1.1, models the impact of extreme wind speeds on navigation.

As an illustration, Figure 2 shows the estimated routes between Palma de Mallorca and

Barcelona, with the wind of June and without wind. The route without wind follows a relatively direct path, while the wind-adjusted route shifts slightly to the west. The final set of OD matrices includes all 945 ports as both origins and destinations (for intermediate connections), producing a 945 × 945 matrix.

Figure 2. Comparative routes under wind and no-wind conditions



Sources and notes: Each green dot represents a port. The blue line represents the route without wind and the purple one the route adjusted for the wind of June. Nodes in the grid are spaced at 10 kilometers intervals, and each note is linked to its immediate neighbors in all eight directions.

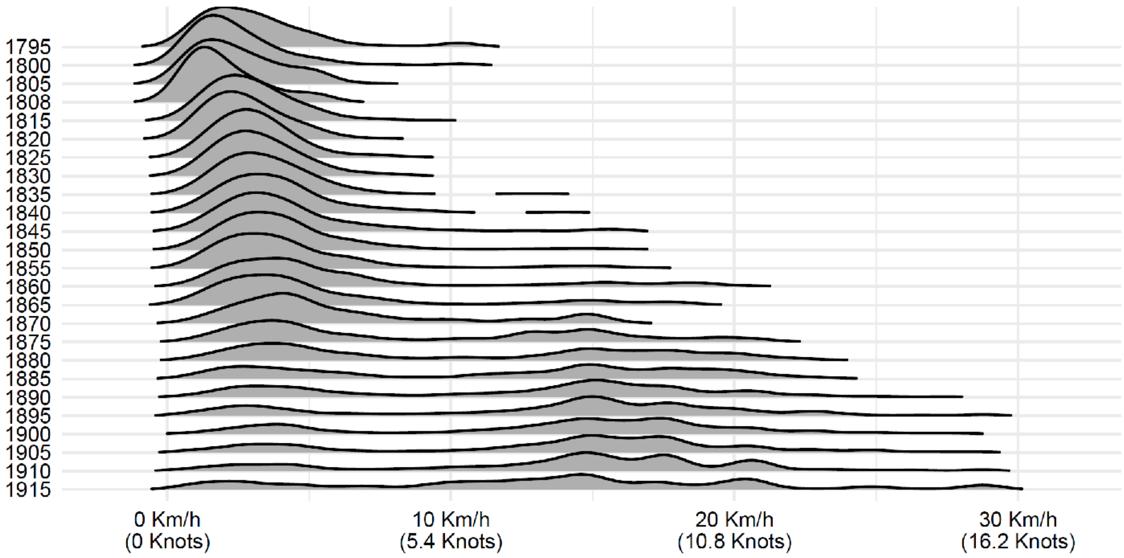
4. Analysis of speeds by sail and steam

We begin our analysis by describing differences in speed between sail and steamships over time. In the shipping literature, shipping speeds have been employed as a metric because travel time was a major determinant of labor and capital costs, and in the absence of reliable freight rate data, it offers a reasonable substitute (Kelly and Ó Gráda, 2019; Rönnbäck, 2012; Solar, 2013; Vinnal, 2014). Indeed, while speed was fundamental to the competitive advantage of steamships, this study is the first to systematically identify the time savings directly attributable to the adoption of steam technology.

The calculation of speed requires identifying both the distance traveled and the number of days/hours at sea. While the journey time from the port of departure to Barcelona is known with certainty in our data, the precise routes followed by ships can only be approximated. Ships can move freely across the sea (unlike railroads, which are bound to the rails) and even the same ship with the same captain and crew, adverse weather or currents could force ships onto longer routes. At present, the reconstructed routes for over a thousand voyages minimize distance by considering the shape of the coastline. In the future, factors such as prevailing winds will be incorporated. Dividing route distance by journey time gives a measure of speed in miles per day.

As Figure 3 shows, average ship speeds rose from about 2 knots at the start of the 19th century to 7.5 knots (4 to 14 km/h) by its end. In line with the work from Harley (1988) and Pascali (2017), we argue that almost all of this acceleration came from the transition from sail to steam, which increased speeds by 275%.[15] Before 1850, there was only one mode of travel, sailing, so the distribution of speeds was tightly clustered at a fixed speed (3-4 knots). With the arrival of steam, a second, distinct mode emerged and became independent from the old one. Crucially, this is the case of two technologies that coexisted, but only steam saw continuous gains in speed and the other one remained static. Sailing speeds hardly changed, despite some documented incremental and contextual improvements in ship design or hull coppering (Armstrong, 2009; Bogart et al. 2021; Harley, 1988; Hatton, 2025; Ville, 1986). The decisive break came with steam, a macro-innovation that redefined what was technologically possible.[16]

Figure 3. The bi-modal distribution of speeds into Barcelona using shortest distance



Sources and notes: Authors calculations based on *Diario de Barcelona*. The density ridge plots are generated using the ggridges package in R. This function applies kernel density estimation, smoothing the raw data by centering a kernel (Gaussian by default) on each observation and aggregating across all points, thereby producing continuous curves instead of discrete or jagged histograms.

[15] Velocity rose from 2 to 7.5 knots, an absolute increase of 5.5, equivalent to a 275% rise relative to the initial value.
[16] Figure A9 in the Appendix reinforces this point by presenting the distributions separately for sailing vessels (excluding all steamships) and for steamships alone. The contrast is striking: sailing speeds exhibit minimal improvement, while steamship speeds show a clear upward trend over time.

How do these speeds align with earlier findings? While comparisons are always difficult (ship types differ as do routes and distances) some benchmarks exist in the literature. Dunn (2020) estimates that average sailing speeds in 17th-century England and Wales ranged between 2.24 and 3.01 knots. Bogart et al. (2020, p. 96) further report 3.34 knots for coastal vessels in mid-19th century southern England. Kelly and Ó Gráda (2019, 469), using logbooks from naval vessels, estimate median speeds of 4 knots around 1780, 5 knots in the early 1800s, and roughly 6 knots by the late 1820s. Nonetheless, Royal Navy ships were among the largest and heaviest vessels of their time and built with strategic and military objectives in mind, prioritizing durability, stability in combat, and the ability to carry heavy artillery and large crews. Rönnbäck (2012, p. 489) documents that slave trade voyages achieved 2.6 knots in 1700, 3.5 knots in 1800 and 5.8 knots in 1850.[17] While we do not have estimates for steam, following Hatton (2024), if we assume that the distance from Liverpool to New York is at 3,169 nautical miles,[18] the decline from 40 days in 1853 to 8 days in 1913 can be translated into 3.3 knots in 1853 and 16.5 knots in 1913.

5. Steamship's effect on travel time

A simple comparison of the average speed differences by sail and steamship could be conflated by other factors. For example, speed could depend on the time of year, the origin, and characteristics of the crew, all of which might be related to steam. There is a further issue: the use of steam vs. sail was a choice, the particulars of which could influence speed directly or indirectly though unobservable factors. In this section, we develop a novel empirical strategy to estimate the effect of steamships on travel time accounting for these issues. After presenting our methods and baseline results, we turn to heterogeneous impacts by calendar month and ship nationality. The final subsection considers the implications of our estimates.

5.1. Empirical strategy and baseline results

Our empirical strategy uses variation at the voyage-level and especially the presence of repeated origins, months, and years, and repeated ship masters involving different ships. The main specification is given in equation (3):

$$ln(time_{ijmst}) = \alpha_j + \eta_m + \lambda_s + \gamma_t + \beta steam_i + \mu x_i + \varepsilon_{ijmst} \quad \textbf{(3)}$$

where $ln(time_{ijmst})$ is the natural log of travel time measured in days, α_j is a fixed effect for origin j, η_m is a fixed effect for the month of arrival into Barcelona, λ_s is a fixed effect for the shipmaster surname, γ_t is a fixed effect for the year, $steam_i$ is an indicator equal to

[17] Although direct measures of speed are lacking, evidence from the East India Company indicate a that the journey to Asia declined from 154 days in the 1770s to 130 days by the 1820s (Solar and Rönnbäck, 2013).
[18] This is the distance reported on MarineTraffic's website.

one if the vessel associated with voyage i was a steamship and zero otherwise, and x_i is a set of voyage-level controls, like vessel tonnage, temperature in Barcelona on arrival (measured at port), and an indicator for the master being described as a captain in the newspaper source.[19]

The various fixed effects address unobserved heterogeneity in voyage time, which may be associated with the selection of steam vs. sail. Some origins might inherently take less time and also have products which favor steam. Some months might be associated with faster travel because of favorable weather (e.g., summer months) and be associated with seasonal products which favored steam. Some years might have had different trade conditions, affecting time, and were also linked with steam. Finally, shipmasters likely had different skills or preferences for faster travel, and they might also favor steam. The control variable for tonnage is potentially a bad control as steamships were generally larger than sail ships, yet we retain this variable as tonnage may affect speed. In equation (3), our assumption is that conditional on fixed effects and controls, assignment into steam vs. sail was independent of potential outcomes or essentially random. We relax this assumption momentarily by introducing an instrumental variable.

Table 1 reports the estimates omitting voyages with intermediate stops before arriving in Barcelona. Voyages with intermediate stops introduce additional heterogeneity in time, which we address in robustness. In col. 1, the controls are year, origin, and month fixed effects. Steam is estimated to reduce shipping time by -1.231 in logs. Col. 2 adds three control variables for temperature in Barcelona, tonnage of ship, and an indicator if the shipmaster was described as a captain. This sample loses all observations before 1815, where there is no tonnage information. Regardless, steam is estimated to reduce time by -1.186 in logs, which is relatively similar to Col. 1. Two additional findings here are that greater tonnage and the master being called a captain both reduce time. They capture additional characteristics of the ships and crew which were relevant beyond steam.[20] Col. 3 adds origin by month fixed effects. It addresses monthly wind and weather patterns specific to each origin. The estimated effect of steam is similar. Col. 4 adds shipmaster surname fixed effects to the specification in col. 2. Note the shipmaster surname does not always uniquely identify an individual shipmaster. However, as surnames were often shared by related shipmasters, we potentially control for unobserved factors associated with family networks with these variables. The estimate with shipmaster surname fixed effects is slightly larger in magnitude -1.214. Finally, in col. 5 we add shipmaster surname by origin fixed effects to the specification in col. 3. These fixed effects more closely capture family shipping networks, which were likely to have the same surname at an origin. The estimate is slightly larger in magnitude: -1.229.

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[19] The log transformation of time helps to reduce outlines and gives a percentage change interpretation.

[20] Temperature in Barcelona is not statistically significant in Col. 2. One reason is that the month fixed effects capture seasonal features, of which temperature is one. Without month fixed effects, we find that higher temperature is significantly associated with lower speed.

Table 1. OLS Estimates for effect of steam on travel time

	(1)	(2)	(3)	(4)	(5)
Steam = 1	-1.231***	-1.186***	-1.188***	-1.214***	-1.229***
	(0.034)	(0.039)	(0.040)	(0.043)	(0.073)
Temperatures		-0.000	-0.000	-0.000	-0.000
		(0.001)	(0.001)	(0.001)	(0.001)
Tonnage		-0.009***	-0.009***	-0.007***	-0.005***
		(0.003)	(0.003)	(0.002)	(0.002)
Master = captain		-0.047**	-0.054**	-0.034*	-0.021
		(0.023)	(0.023)	(0.019)	(0.016)
Observations	42,561	37,836	36,619	31,137	23,764
R-squared	0.874	0.888	0.891	0.895	0.899
Year FEs	YES	YES	YES	YES	YES
Origin FEs	YES	YES	YES	YES	YES
Month FEs	YES	YES	YES	YES	YES
OriginxMonth FEs	NO	NO	YES	NO	YES
Master surname FEs	NO	NO	NO	YES	NO
OriginxSurname FEs	NO	NO	NO	NO	YES

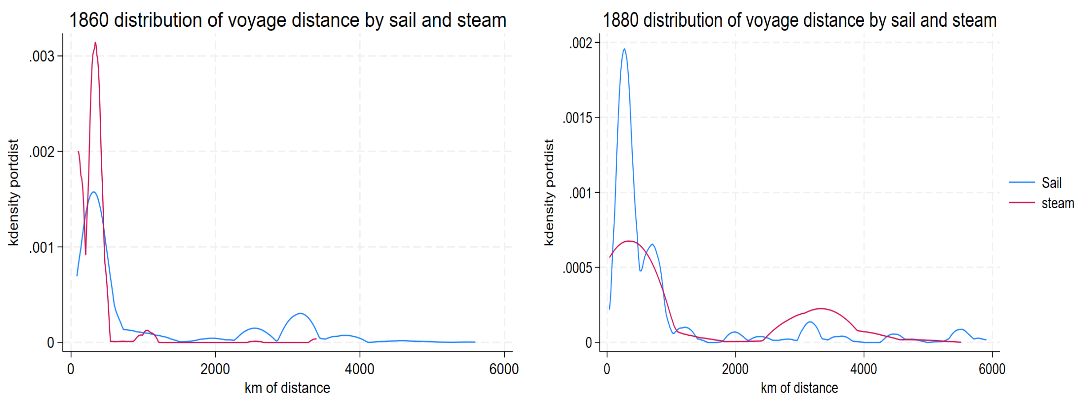
Sources and notes: The dependent variable is the natural log of travel times (measured in days). Temperatures are in degrees Celsius and tonnage x 100. Master is a dummy = 1 for the master being described as a captain in the newspaper source. The sample omits voyages with intermediate stops. Column 1 has data from 1795 to 1915, while all columns after have data from 1815 to 1915. Columns 3, 4, and 5 use HDFE Linear regression, which omit singleton obs. Standard errors clustered on origin ports are reported. *, **, and *** indicate statistical significance at the 10, 5, and 1\% levels. When controlling for origin, month, year, and master surname fixed effects, voyages using steam were 1.230 log points lower, or 70.74% [= 100*(exp(-1.229)-1)] lower.

In appendix table A4, we include voyages with intermediate stops *en route* to Barcelona. The sample size in column 1 increases to 58,059 as a result. The intermediate stops introduce heterogeneity in the time and to partly address this we include fixed effects for the number of intermediate stops. The estimates are similar to Table 1 and slightly larger in magnitude.

Overall, the estimated effects of steam are remarkably similar across the OLS specifications. Adding fixed effects for origin port, month, year, and shipmaster surname and other controls does not alter the estimates to any great degree. However, one might still be concerned that journeys which used steam were selected based on need for speed. We address this issue by developing a voyage-level instrument for steam. It builds on the following features. Before 1850 steamships used a lot of coal, meaning they were only cost efficient on short journeys. As engines improved after 1850 steamships were increasingly used on longer journeys. According to Harley, 1988, "After 1850 steamers only gradually displaced sailing ships on longer voyages because the length of a voyage increased the proportion of capacity that had to be devoted to fuel. Coaling stations along the route alleviated the problem only slightly during most of the period (p. 863)." Valdaliso (1992) describes a similar process, "steam was first introduced on short routes—coastal navigation and routes between European ports—and only after the adoption of the compound engine and, especially… could steam effectively compete on oceanic routes (Valdaliso 1992, p. 65).

Our data confirms that steam was more common on short distance routes to Barcelona up to 1860. We use our measure of distance from origin port to Barcelona, currently calculated for European origins only. Figure 4 (left) shows the distribution of voyage distances for sail and seam in 1860. Both sail and steam were most common at distances around 500km, but steam was almost exclusively observed at 500km, while sail had more long-distance journeys. Figure 4 (right) shows the distribution of voyage distances for sail and seam in 1880. Although short-distance journeys were still more common for both, steam was now relatively common at distances ranging from 2000-4000km. If anything, steam appears more common in longer-distance journeys than sail, the opposite of 1860.

Figure 4. The distribution of voyage distance by steam and sail in 1860 and in 1880.



Sources and notes: Authors calculations from all European origins with ship classification in *Diario de Barcelona,* and estimates of voyage distance calculated by the authors.

The key assumption in our identification is that the shift to more steam voyages from origins of greater distance after 1860 was associated with the greater fuel efficiency of the steam engine and was exogenous with respect to the travel times into Barcelona. We find this assumption to be plausible, as there is no reason to expect Barcelona trade to affect the evolution of engine fuel efficiency. Building on these points, our instrument will be the interaction between year fixed effects and the natural log of origin distance. As there were practically no steam engines before 1840, we focus on the 5-year sample from 1840 to 1915 (e.g., 1840, 1845, ...,1915). We also omit voyages with intermediate stops as they introduce additional heterogeneity in evaluating time. Our first stage equation is the following:

$$steam_i = \alpha_j + \eta_m + \gamma_t + \gamma_t \cdot ln(distance_j) + x_i \varsigma + \omega_{ijmst} \quad \textbf{(4)}$$

where $\gamma_t \cdot ln(distance_j)$ is the product of year fixed effects γ_t and $ln(distance_j)$ the natural log distance to the origin port. In appendix Figure A10 we plot the coefficients for

$\gamma_t \cdot ln(distance_j)$ from the first stage and demonstrate how the distance steam adoption elasticity was significantly larger in magnitude from 1840 to 1875.

Our IV estimates are reported in table 2. We restrict to the sample of European origins where we measure distance and omit voyages with intermediate stops. The sample is also restricted to years from 1840 to 1915. Before 1840 steam voyages were exceptional. The OLS estimates are reported in col. 1 for comparison. The first stage has a large F-stat indicating the instrument is strong. The IV estimate in col. 2 implies that steam reduced time by -0.949 in logs. This coefficient is smaller than OLS and indicates an upward bias in the latter. One plausible explanation is that voyage selection into steam was partly based on the need for speed. Our takeaway is that selection aspects make the IV estimate more credible than OLS. Note that our OLS and IV estimates are significantly larger than those found by Pascali (2017) (the only comparison for our estimate). The different context of the datasets, the Mediterranean vs. Canada and the North Atlantic, could explain some of the differences. Varying specifications does not seem to be the main explanation as our col. 1 in table 1 replicates Pascali's specification with the exception of adding month fixed effects.

Table 2. IV Estimates for effect of steam on travel time

	(1)	(2)
	OLS	IV
Steam = 1	-1.216***	-0.949***
	(0.041)	(0.096)
Observations	30,952	30,952
R-squared	0.862	0.858
Kleibergen-Paap F-stat		41.39
Year FEs	YES	YES
Origin FEs	YES	YES
Month FEs	YES	YES

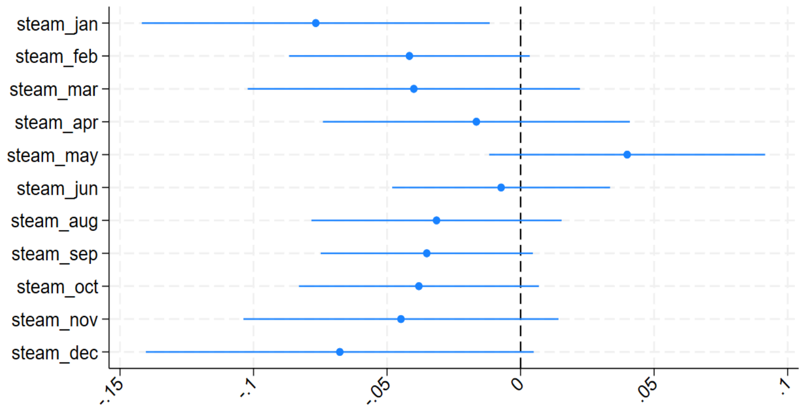
Sources and notes: The dependent variable is the natural log of travel times (measured in days). The IV is the distance to the origin port interacted with year fixed effects. The sample only includes European origin ports and years from 1840 to 1915. When controlling for origin, month, and year fixed effects, voyages using steam were 0.949 log points lower, or 61.3% [= 100*(exp(-0.949)-1)] lower. Standard errors clustered on origin ports are reported. *, **, and *** indicate statistical significance at the 10, 5, and 1% levels.

We have shown that steamships reduced travel time, but what about the variance in time? It is generally believed that steamships increased the 'reliability' of travel, which we interpret to mean lower variance in time. In order to examine steam's impact on variance, we consider the coefficient of variation (CV) in travel time for voyages from 70 of the top 100 origin ports, where both sail and steam were observed. We calculate the CV for voyages from each origin using steam and sail separately. Figure A12 plots the kernel density for the CVs across the two voyage types. Strikingly, the CVs are generally larger for steam than sail. Steam did not reduce variance in travel time, and perhaps it increased variance.

5.2. Heterogeneity.

The effects of steam varied by at least two factors: the time of year and the nationality of the ship. We estimate the heterogeneity effects along both dimensions in this section. Figure 5 summarizes steamships effects by calendar month. It shows the coefficients on the interaction of $steam_i$ with all calendar months, omitting the July. There is some evidence that steam's time reducing effect was larger in the winter months of December and January relative to July, and similarly larger relative to other summer months like May and June. That makes sense as sailing was more dangerous in these months. We conjecture that in winter sailing ships likely followed the coastline more, implying a longer route, or took shelter in coves during their journeys. Steamships would have had less need to seek safety and therefore took relatively less time. Consistent with this view, Figure A11 shows the distributions of speed for sail and steam across months. In December and January the sail speed distribution is shifted to the left more than the steam speed distribution. For example, the mean sail speed in January was 3.93 kmph vs. 4.55 in July. For steam, the mean speed in January was 16.92 kmph in January vs. 16.82 in July.

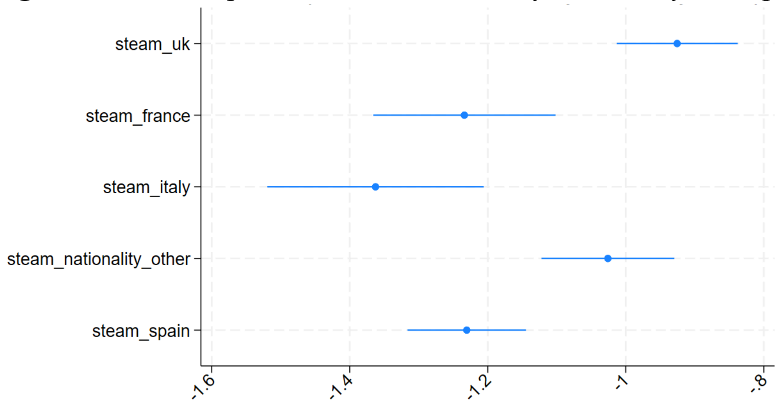
Figure 5. Steamship effects on travel time by calendar month relative to July



Sources and notes: This figure show the Steam x month interaction coefficients with their 95% confidence intervals. Specification includes origin, month, and year fixed effects. OLS estimate is marked by dashed line.

We now examine effects by nationality of the ship. There were many nationalities in our data. Yet the most common were Spain (including Catalan and Valencian), UK, France, and Italy. They represented 75.05%, 7.23%, 3.75%, and 3.04% of voyages respectively. We create dummy variables for each, including a generic all other ship nationality. Figure 6 summarizes the estimated effect of steam interacting with 5 mutually exclusive and exhaustive ship nationalities. In this specification, we include fixed effects for the nationality of ships. We find steam had smaller effects for ships of the UK and other nationalities, compared to ships from Spain, France, or Italy. These findings are interesting for several reasons. First, if one assumes that the crews for UK ships had the greatest skill (not unreasonable) then there is no clear evidence that steam was skill biased. If so, then the effects of steam should have been greater in the UK, which it was not. Second, Spain, Italy, and France adopted the steamship, largely based on the earlier innovations made in the UK. Therefore, ships from the adopting economies demonstrated greater efficiency than ships from the innovating country.

Figure 6. Steamship effects on travel time by nationality of ship



Sources and notes: This figure shows coefficients with their 95% confidence intervals. Specification includes ship nationality, origin, month, and year fixed effects.

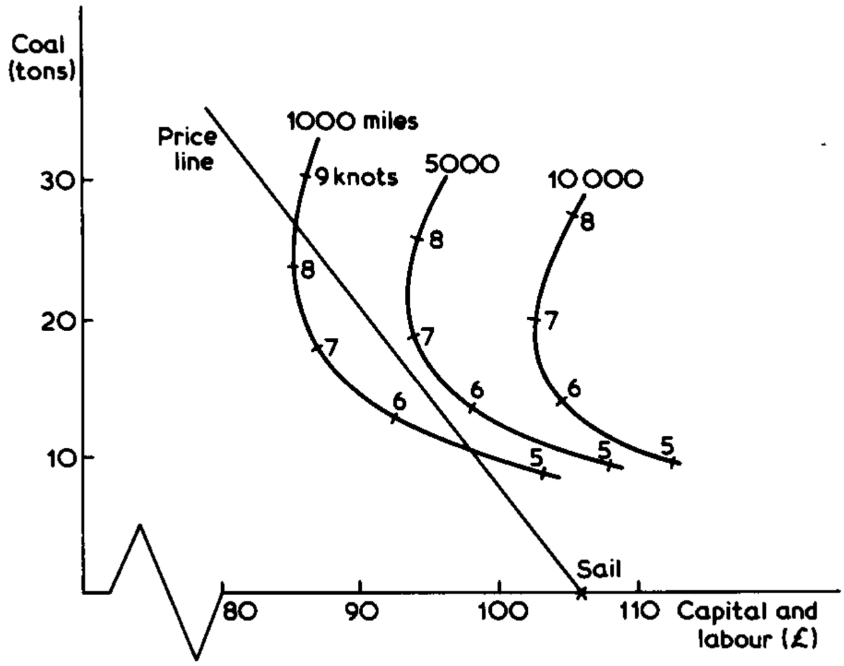
5.3. Implications

Steam's large and significant speed advantage over sail has several implications. First, speed played a crucial role in steamships competition with sail ships. Our estimates illustrate speed's centrality quantitatively. Second, steam's speed advantage contributed to an expansion in trade for economies like Barcelona, which we can estimate in the aggregate using the framework from Pascali (2017) and our estimates.

Steamships competed with sailing ships on two levels: price and quality of service. Quality was multifaceted but greater speed was certainly central. The higher speed would have been especially preferred by shippers of high-value or perishable goods. Thus, steam's speed advantage gave it a competitive edge in such markets. In terms of price competition, the most important factor was the difference in cost per ton mile shipped. Here steam had advantages and disadvantages relative to sailing ships. Steamship's advantage was lower capital and labor costs per ton mile, which derived almost entirely from greater speed. As explained by Harley (1971, p.217), "The greater speed and regularity of steamships reduced capital and labor costs per ton mile; the increase in speed more than compensated for the increase in capital embodied in the steamship and the larger crew carried by steamships." Steam's disadvantage was higher fuel costs per ton shipped. Sail had no fuel costs being propelled by the wind and currents, while steamships burned coal to run engines which provided propulsion. Steam's fuel costs were related to speed as well. According to Harley (1971, p. 217), coal consumption per mile increased with the square of speed. To summarize, as speeds increased fuel costs per ton mile went up, while capital and labor costs per ton mile went down.

The implications of speed for costs per ton mile are graphically illustrated in Harley's model shown in Figure 7. The vertical axis measures coal consumption in tons per million ton miles shipped and the horizontal axis measures capital and labor costs in 1872 British pounds per million tons shipped. The isoquants summarize steam's coal consumption and capital/labor requirements for each speed in knots and at different voyage distances. The price line is an isocost line showing the combination of coal and capital/labor for steamships which generate a total cost per ton mile equal to sail, approximately 106. Generally, if steam's isoquant always lies above the price line, then it has higher costs per ton mile.

Figure 7. Harley's cost model for steam and sail



Sources and notes: Image from Harley (1971, p. 219). This figure shows the production function per million ton-miles of shipping services, steam and sail voyages: 1.000-, 5.000-, and 10.000-miles length around 1872.

Now consider the case of a 1,000 mile voyage illustrated in Figure 7. At a speed of 5 knots (about 9 kmph) steam's total costs per ton mile will exceed sail, whereas at 6 or 7 knots (about 11 or 13 kmph) steam's costs per ton mile will be lower than sail. Notice that the marginal rate of transformation in the isoquant is crucial in assessing the impact of higher speed. From 5 to 7 knots, fuel costs rise modestly compared to the more significant reduction in capital/labor costs.[21] Also notice, if steamships hypothetically had a maximum

[21] Steam's cost disadvantages become greater for voyages of greater distance, as we have stressed in our instrument. In this illustration, applicable to about 1872, steam has a cost disadvantage relative to sail at all speeds for voyages with distances of 5,000 and 10,000 miles.

speed of 5 knots, then their costs would always be higher than sail. Going faster was essential for steam's competitiveness on price.

We use our estimates to consider a counterfactual where steam had no speed advantage over sail, and all else was held constant. According to Harley (1988, p. 861), capital and labor represented approximately 50% of total costs, with coal and miscellaneous inputs accounting for the remaining 50%. If we assume that steam lost its speed advantage over sail, falling from 14 kmph to 4 kmph, then its capital and labor costs per ton mile would rise by approximately 250% (=100*(10/4)) assuming inverse proportionality in speed and capital/labor costs. As capital and labor costs per ton mile were 50%, then steam's total costs per ton mile should rise by approximately 125%. Note, we assume that coal consumption is held constant, therefore there is no cost saving from less fuel with less speed. While this is an extreme shift in technological capability and practice, it illustrates that steam would have little chance competing with sail if it did not have such a large speed advantage.

Our estimates also have implications for the growth in trade. As steamships became more widely adopted, they contributed to lower costs per ton mile shipped. Shipping freight rates were pushed downward as a result, although competition was mixed due to proto-cartels which sought to raise prices. On a global scale, it is estimated that maritime freight rates fell by 50% (Jacks and Pendakur, 2010). The general impact of lower freight rates on international trade has been debated. Jacks and Pendakur (2010) argue that lower maritime transport costs between countries did not cause their trade to increase. Instead, they argue transport costs were endogenous. Using their preferred instruments, these authors argue the effect of lower maritime transport costs was close to zero.

Pascali (2017) reaches a different conclusion concerning shipping and trade by isolating the effect of the difference between steam and sail shipping times. Briefly, Pascali (2017) simulates the time to travel by sail and steamship between the major ports of countries using a network model with wind features. For each country, the weighted average change in shipping times is calculated across all its trade partners, with each being $ln(steamtime_{ij}) - ln(sailtime_{ij})$, where subscript i is the country in question and j is its trading partner. The exports per capita for country i are then regressed on the change in shipping times, yielding a range of coefficients for different samples with -1.44 being the preferred. Pascali draws on his own estimate of the log-difference in the duration of voyages between sail and steam among Canadian vessels, which is stated as -50 log points. In the last step, it is estimated that the steamship raised exports per capita by 72 log points (-0.5*-1.44).

Our estimates suggest for economies like Barcelona, the steamship contributed to even greater reduction in time and therefore contributed to an even greater increase in trade. We find a -0.949 estimate for the log-difference in the duration of voyages between sail and steam. Using Pascali's model, this would imply the steamship raised exports per capita by

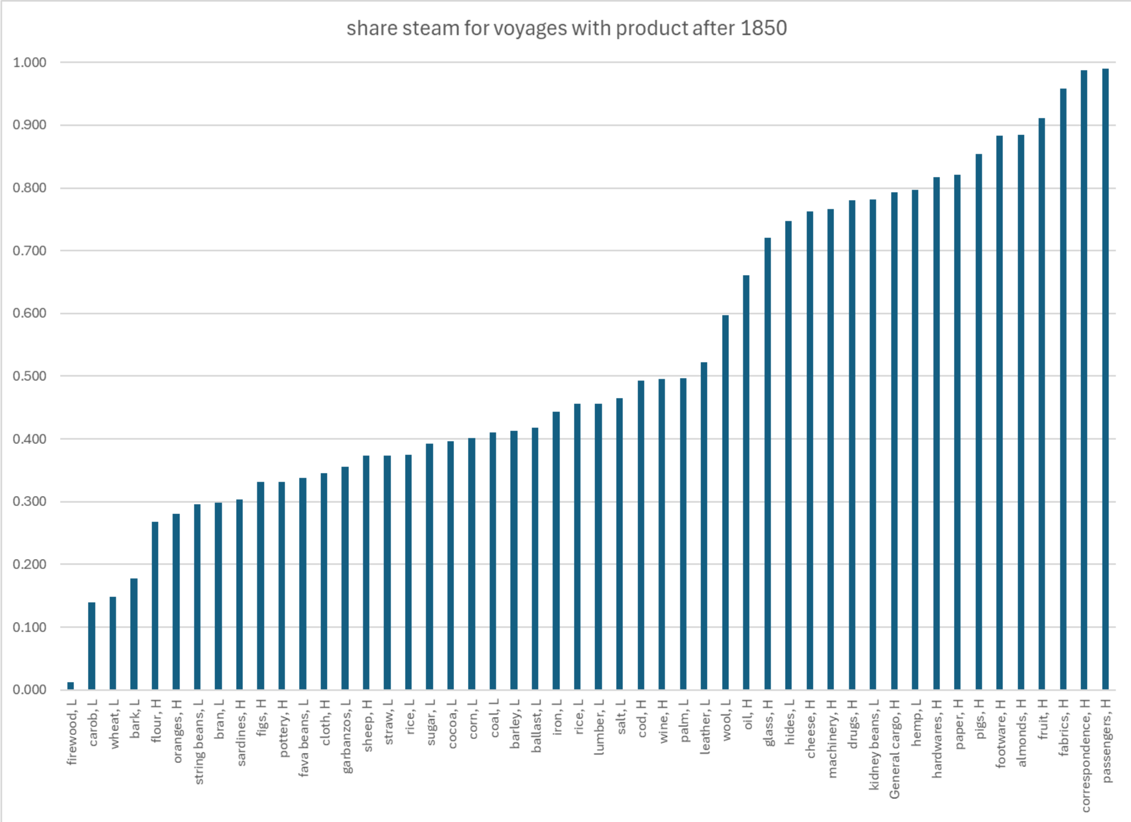
137 log points (-0.949*-1.44). This dramatically large effect, a 293% increase, likely accounts for most of the growth in the value of Barcelona's imports from 1850 to 1910. We are gathering data to confirm this importance, but the main point is clear. The steamship increased Barcelona's trade substantially.

6. Steamships and the composition of imports

Trade composition plays a central role in the welfare effects of trade. Increasing higher value imports is generally associated with increasing incomes for example. Alternatively, increasing raw material imports is generally associated with industrialization, which in the 19th century ultimately led to higher income. In this section, we examine how steamships changed the composition of trade. To our knowledge, no previous study has examined steam from this perspective.

It is useful to begin by plotting the steam voyage share from 1850 to 1915 for the top 50 products (see Figure 8). The shares are calculated for voyages with cargoes containing each product. It is clear that products generally associated with higher value to weight, like fabrics, fruit, and footwear, have a higher steam voyage share. Passengers and correspondence have the highest steam voyage share. They were services, but still fit the high value categorization. The lower value to weight products like firewood, carob, wheat, and bark have the lowest steam voyage share. In appendix Table A3 we report that the share of steam voyages that contain at least one high-value top-50 product was 0.536. The share of steam voyages that contain at least one low-value top-50 product was lower at 0.366.

Figure 8. Share of voyages that were steam from 1850 to 1915 if cargo contained following products



Sources and notes: Authors calculations based on *Diario de Barcelona*. Voyage shares by steam are calculated for voyages that had cargo containing products listed. Product classification H means high value to weight, while L means low value to weight.

There are some important exceptions to the pattern where low-value goods had a lower steam voyage share. Coal was a low-value to weight product and it had a medium steam voyage share, just above 0.4. The same for ballast with a very low value to weight. These products likely reflect how voyages to Barcelona were linked with voyages from Barcelona. In some cases, the product being shipped to Barcelona represented the ‘back haul’, and was selected for convenience to expedite the primary product being shipped in the other direction (a.k.a. the front haul). Therefore, the steam voyage share to Barcelona may capture exporter decisions from Barcelona in some cases.

While figure 8 gives some evidence that steam affected the composition of imports, there is a significant empirical challenge which affects the interpretation. If given the choice, shippers of higher value to weight products should select steam as it was faster. Therefore, it is not clear whether having a steam voyage caused the cargo to be higher value, or whether there was a different causal effect of steamships.

We estimate the effects of steam on the probability that a voyages’ cargo contained each of the top-50 products separately. Our primary equation of interest is (5):

$$prob(product\ k\ in\ cargo_{ijmt} = 1) = \alpha_j + \eta_m + \gamma_t + \beta steam_i + \mu x_i + \varepsilon_{ijmt} \quad \textbf{(5)}$$

where $product\ k\ in\ cargo_{ijmt}$ is an indicator variable equal to one if voyage i from origin j, in month m, and in year t has product k listed in its cargo, and 0 otherwise. The main variable is $steam_i$. All the other control variables are the same as in equation (3). In table A5 we present OLS estimates for each of top 50 products classified as low value to weight. Steam has a positive and significant coefficient for 8 of 25 low value products, many of which have a higher steam voyage share in Figure 8, like hides, wool, and leather. In table A6 we present OLS estimates for each of top 50 products classified as high value. Steam has a positive and significant coefficient for 16 of 25 high value products. No steam coefficients are negative in the high value product regressions.

The OLS regressions are likely biased, however, because the choice of steam or sail was selected partly on product type. We address the identification challenge by using our instrumental variables strategy. We use the same first-stage equation as (4) where the product of year fixed effects and the natural log distance to origin port, $\gamma_t \cdot ln(distance_j)$, are the instruments for $steam_i$. The exclusion restriction requires that over time, greater distance time is not systematically related to changing export supply, which would affect cargo types, independent of steam. We are developing robustness checks to address this issue. The key idea of the IV is that we are able to identify the causal effect of switching a voyage from sail to steam.

Table 3 reports the IV estimates for the effect of steam on the probability of cargoes into Barcelona containing various low value to weight goods (panel A). The sample includes years from 1840 to 1915, where steamships were primarily used. The first stage F-statistics is large for all regressions, indicating the instruments are strong. The results are striking in that steam increased the probability of several low-value goods belonging to the cargo. These include coal, rice, wool, ballast, firewood, and sugar. The low value of coal, rice, ballast, and firewood, implies that steam did not increase the shipment of these products because of any need for speedy delivery. Rather it must be that steam was associated with some other driver. One conjecture is that these low value goods were ideally suited for steam's back haul from various origins. That would explain the effect of steam on ballast and perhaps coal, which could be used instead of traditional forms of ballast, like rocks or gravel. Coal is also the fuel source for steamships, so it is perhaps natural that a voyage assigned to steam could sell its remaining coal in Barcelona as an extra product. The positive effect of steam on wool cargoes is notable. Wool was a key raw material used in Barcelona's woolen manufacturing industry. Thus, the results imply that steamships helped the woolen industry grow by providing cheaper raw materials.

Table 3 (panel B) reports the IV estimates for the effect of steam on the probability of cargoes containing various high value to weight goods. The first striking finding is that steam reduced the probability of general cargo. Recall that general cargo had a higher steam voyage share. The IV results suggest this correlation was driven by general cargo exports selecting steam. Our conjecture is that steamship companies aimed for more specialized shipment, or in other words more specific cargoes. On voyages, where steamship considerations dominated mode choice, the result was more specialized cargo.

In panel B, we also find that steam voyages reduced the probability of cargoes with fabrics. Barcelona was a growing center for textile production in the 19th century and lower shipments of fabrics into Barcelona likely indicates how steam increased its competitiveness. We also find that steam reduced the probability of cargoes with fruit. As a perishable product, with a need for speed, this is perhaps surprising. However, Barcelona was itself a center for fruit exports, and thus steamship companies may have discouraged fruit exporters in other origins from entering the Barcelona market, where fruit exports were common.[22]

Broadly our results indicate that steamships altered the composition of imports to Barcelona. They increased raw materials like coal, firewood, and wool, which helped Barcelona industrialize. They also decreased the products like fabrics and fruit, which Barcelona exported in the 19th century. Steamships themselves shaped Barcelona’s trade in significant ways.

[22] It is notable that in panel B, there is no high-value good for which steam increased the probability of it being included in the cargo. The association between high-value goods and higher share of steam voyages appears to be the result of steam being selected by exporters of high value products.

Table 3. Effect of steam on probability of carrying various low and high value goods into Barcelona

Panel A: Effect of steam on probability of carrying various low value goods into Barcelona

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**
	Coal	Wheat	Carob	Rice	Wool	Ballast	Iron	Straw	Barley	Firewood	Kidney beans	Fava beans	Bran
Steam = 1	0.111***	-0.002	-0.013	-0.040*	0.074***	0.089*	-0.069	0.013	-0.004	0.048**	-0.070**	-0.003	-0.009
	(0.039)	(0.028)	(0.030)	(0.023)	(0.026)	(0.050)	(0.045)	(0.012)	(0.008)	(0.022)	(0.035)	(0.007)	(0.017)
R-squared	0.438	0.235	0.249	0.220	0.121	0.079	0.104	0.121	0.063	0.250	0.046	0.097	0.098
	(14)	**(15)**	**(16)**	**(17)**	**(18)**	**(19)**	**(20)**	**(21)**	**(22)**	**(23)**	**(24)**	**(25)**	
	Leather	Hemp	Salt	Chickpeas	Lumber	Hides	Corn	Cocoa	Palm	String beans	Bark	Sugar	
Steam = 1	0.020	-0.018	0.010	-0.003	0.0010	0.021	-0.005	0.003	-0.028	0.002	0.001	0.022**	
	(0.016)	(0.013)	(0.010)	(0.012)	(0.010)	(0.013)	(0.013)	(0.004)	(0.023)	(0.006)	(0.008)	(0.011)	
R-squared	0.053	0.086	0.127	0.099	0.125	0.050	0.093	0.066	0.077	0.055	0.065	0.053	

Panel B: Effect of steam on probability of carrying various high value goods into Barcelona

	(26)	**(27)**	**(28)**	**(29)**	**(30)**	**(31)**	**(32)**	**(33)**	**(34)**	**(35)**	**(36)**	**(37)**	**(38)**
	General	Wine	Flour	Cotton	Oil	Passen-gers	Cloth	Drugs	Oranges	Fabrics	Footware	Sardines	Sheep
Steam = 1	-0.154***	-0.051	-0.021	0.015	0.008	0.087	0.014	0.010	0.007	-0.081**	-0.053	0.003	0.055
	(0.036)	(0.038)	(0.027)	(0.021)	(0.054)	(0.117)	(0.024)	(0.024)	(0.010)	(0.032)	(0.037)	(0.011)	(0.035)
R-squared	0.338	0.162	0.311	0.147	0.130	0.390	0.062	0.185	0.154	0.056	0.132	0.220	0.124
	(39)	**(40)**	**(41)**	**(42)**	**(43)**	**(44)**	**(45)**	**(46)**	**(47)**	**(48)**	**(49)**	**(50)**	
	Machinery	Hardwares	Paper	Cod	Corresp-ondence	Almonds	Fig	Glass	Cheese	Pigs	Fruit	Earthen-ware	
Steam = 1	-0.013	-0.004	0.012	-0.000	0.064	0.025	0.006	-0.010	0.011	0.003	-0.029**	0.007	
	(0.018)	(0.017)	(0.016)	(0.007)	(0.044)	(0.022)	(0.004)	(0.020)	(0.012)	(0.012)	(0.012)	(0.007)	
R-squared	0.151	0.106	0.087	0.319	0.089	0.127	0.040	0.061	0.078	0.082	0.036	0.048	

Notes: The dependent variable is 1 if the voyage listed the particular good and zero otherwise. All specifications use IV. The instruments are log distance to origin port interacted with year fixed effects. The controls are year, month, and origin fixed effects, and also temperature and shipmaster is called a captain. The number of observations is 31,289 in all regressions. The Kleibergen-Paap rk Wald F statistic is 45.80. For description of controls see text. Standard errors clustered on the origin are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

7. Conclusions

This article has provided new causal evidence on how steamships transformed transport costs and international trade. Using a novel dataset of nearly 70,000 voyages into Barcelona between 1795 and 1915, and an identification strategy leveraging within-route variation and a distance-based instrument, we estimate that steamships reduced travel times by 61-70 percent. We also show that these gains were not uniform: steamships offered disproportionate advantages in adverse conditions, such as winter months, and shifted the composition of trade toward raw materials critical for industrialization.

Our findings make three contributions to the broader literature. First, we offer micro-level evidence on the mechanisms behind one of the key technological advances of the 19th century. Much of the productivity advantage of steamships stemmed from reductions in voyage duration, which directly lowered labor and capital costs per ton-mile. This mechanism is central for understanding why steamships, despite higher fuel costs, displaced sail across most routes. Second, we show that the adoption of steamships can account for the bulk of Barcelona's 19th-century trade expansion. Following the work of Pascali (2017), our estimates imply that steam raised trade by nearly 300 percent, comparable to the aggregate growth observed in the period. This underscores the role of transport innovations as a fundamental driver of globalization, complementing work on railroads, canals, and tariffs. Third, we highlight that technology adoption not only reduced average trade costs but also reshaped the margins of trade, altering the composition of imports. The rise of raw material shipments illustrates how technological change interacts with the structure of industrial economies.

More generally, the results speak to ongoing debates in economics on the determinants of globalization and the role of technology in reducing trade costs. By isolating a large and plausibly exogenous decline in travel times, we show how reductions in effective distance contributed to both the scale and scope of international trade. The evidence suggests that accounting for the distributional effects of technology, who benefited, when, and in which products, is central to understanding globalization's dynamics.

While our setting is historical, the broader implications remain relevant. The transition from sail to steam illustrates how general-purpose transport innovations alter the geography and composition of trade, even when initial adoption is uneven and costly. Similar dynamics can be observed today with the diffusion of containerization, digital logistics, or even potential low-carbon shipping technologies. Our study thus provides a historical benchmark for evaluating how new transport technologies affect global markets.

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Figure A1. Leopold, Joseph Friderich. Barcino. Barcelona. Lithograph, circa 1720.

Figure A2. Lithograph showing the location of the port and the placement of some industries in the city. Alfred Guesdon, 1856. It is possible to see how sailing ships and steamboats coexisted in the port.

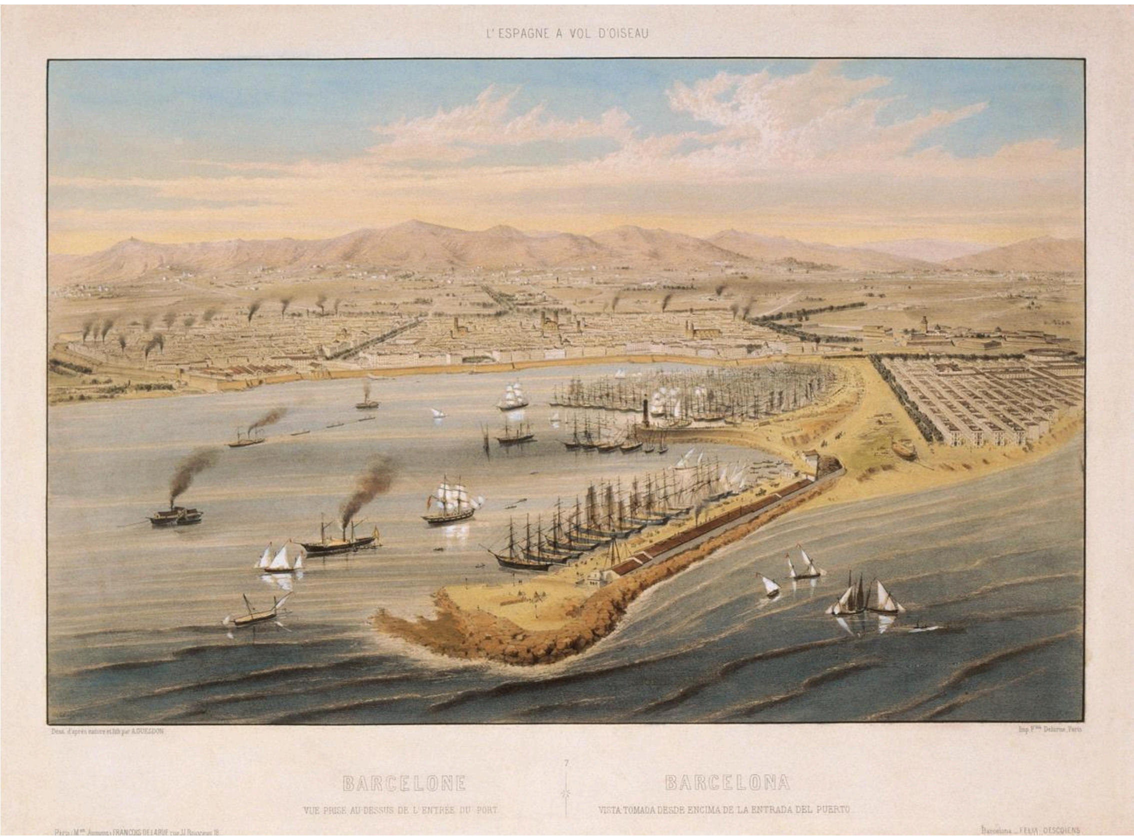
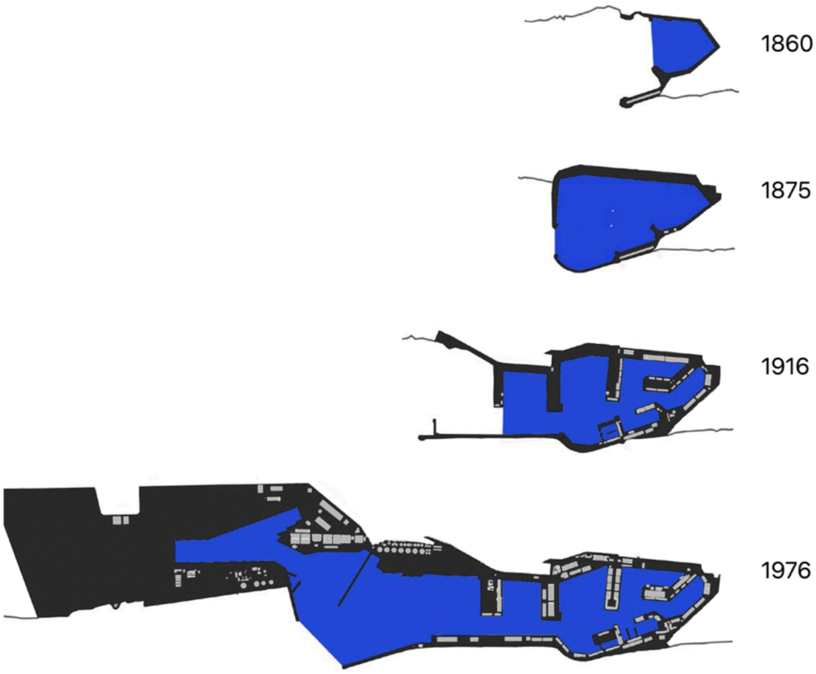


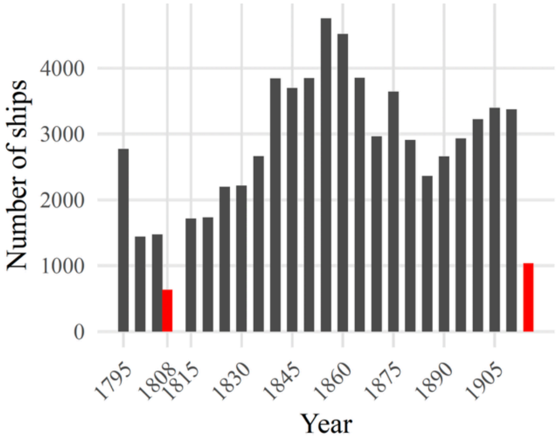
Figure A3. Lithograph showing the new industrial port during the 1888 Universal Exhibition, with the various fleets sent by the participating countries.

Figure A4. The port of Barcelona in different times



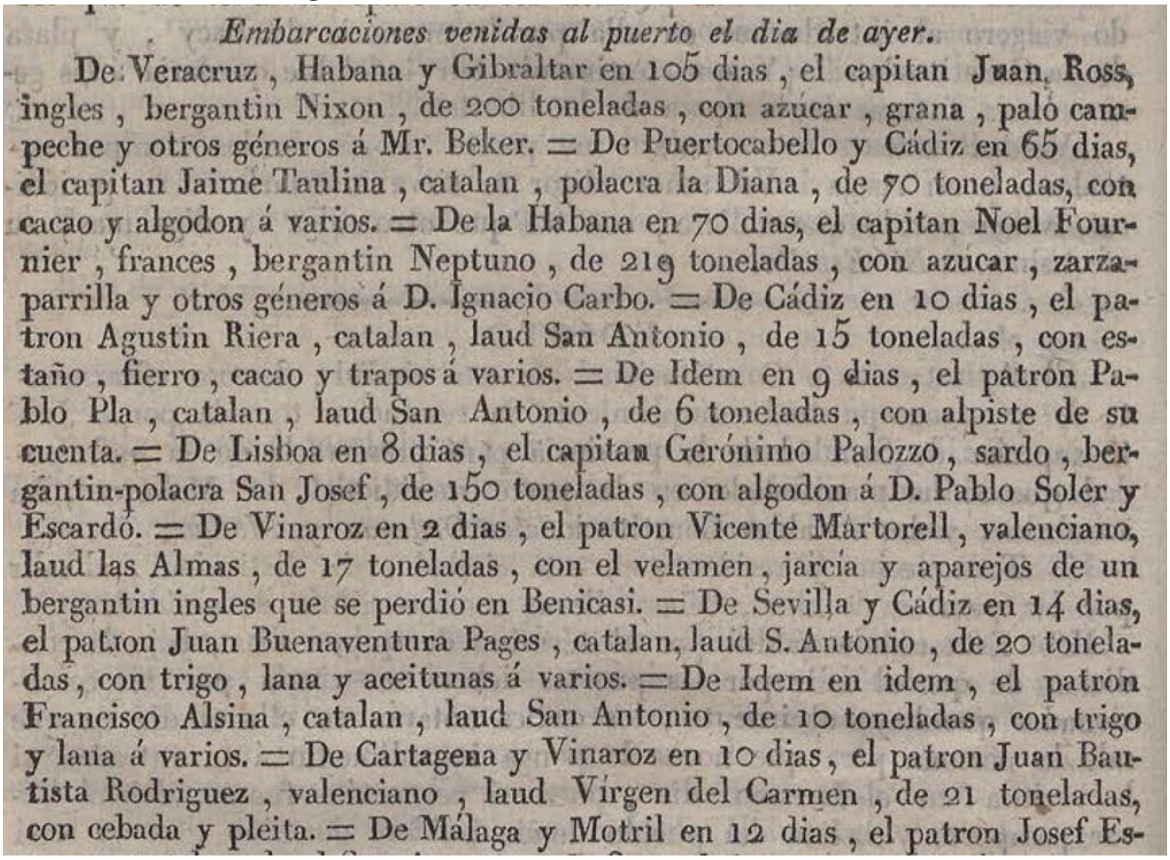
Notes and sources: Since the establishment of the Board of Works in 1869, the Port of Barcelona has expanded through four major development projects and their corresponding construction phases. The 1859 project was implemented between 1869 and 1875; the 1900 project between 1901 and 1925; the 1965 project between 1966 and 1975; and the 1998 master plan was carried out between 2000 and 2011. Images are from the MUHBA (2021). In the original figures, no scale is reported.

Figure A5. Number of voyages entering the port of Barcelona



The data for 1915 (in red) include ship entries only up to April 4. While the newspaper continued to publish information on arrivals thereafter, it ceased reporting the variable indicating time away between ports, rendering the entries unusable for our purposes. Additionally, since the port was officially closed in 1810 due to the Napoleonic Wars, we use data from 1808 instead (also colored in red). The port remained functionally open through June 1808, with activity sharply declining by July and September, when only five ships are recorded. For more details see Section 3.

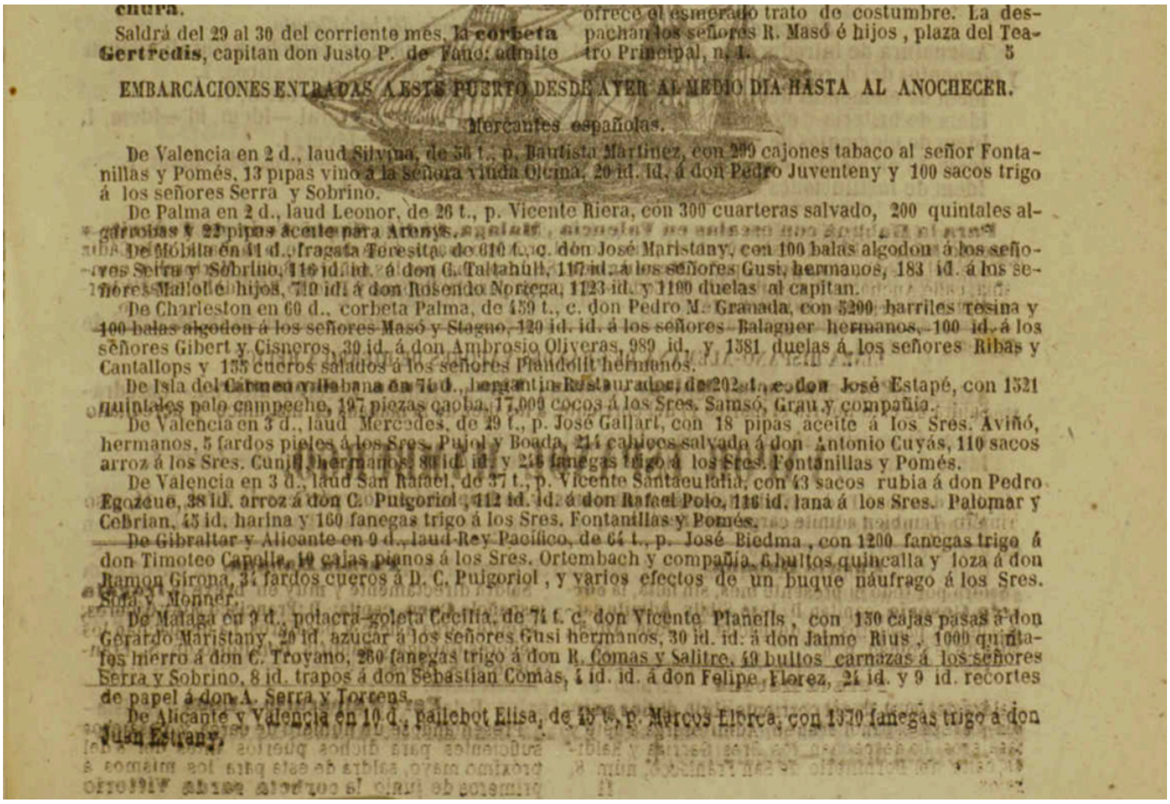
Figure A6. Records from *Diario de Barcelona*



Embarcaciones venidas al puerto el dia de ayer.

De Veracruz, Habana y Gibraltar en 105 dias, el capitan **Juan Ross**, ingles, bergantin Nixon, de 200 toneladas, con azúcar, grana, paló campeche y otros géneros á Mr. Beker. = De Puertocabello y Cádiz en 65 dias, el capitan Jaime Taulina, catalan, polacra la Diana, de 70 toneladas, con cacao y algodon á varios. = De la Habana en 70 dias, el capitan Noel Fournier, frances, bergantin Neptuno, de 219 toneladas, con azúcar, zarzaparrilla y otros géneros á D. Ignacio Carbo. = De Cádiz en 10 dias, el patron Agustin Riera, catalan, laud San Antonio, de 15 toneladas, con estaño, fierro, cacao y trapos á varios. = De Idem en 9 dias, el patron Pablo Pla, catalan, laud San Antonio, de 6 toneladas, con alpiste de su cuenta. = De Lisboa en 8 dias, el capitan Gerónimo Palozzo, sardo, bergantin-polacra San Josef, de 150 toneladas, con algodon á D. Pablo Soler y Escardó. = De Vinaroz en 2 dias, el patron Vicente Martorell, valenciano, laud las Almas, de 17 toneladas, con el velamen, jarcía y aparejos de un bergantin ingles que se perdió en Benicasi. = De Sevilla y Cádiz en 14 dias, el patron Juan Buenaventura Pages, catalan, laud S. Antonio, de 20 toneladas, con trigo, lana y aceitunas á varios. = De Idem en idem, el patron Francisco Alsina, catalan, laud San Antonio, de 10 toneladas, con trigo y lana á varios. = De Cartagena y Vinaroz en 10 dias, el patron Juan Bautista Rodriguez, valenciano, laud Virgen del Carmen, de 21 toneladas, con cebada y pleita. = De Málaga y Motril en 12 dias, el patron Josef Es-

Image 19 January 1820



chura.

Saldrá del 29 al 30 del corriente mes, la **corbeta Gertrudis**, capitan don Justo P. de Fano: admite ... ofrece el esmerado trato de costumbre. La despachan los señores R. Masó é hijos, plaza del Teatro Principal, n. 1. 5

EMBARCACIONES ENTRADAS A ESTE PUERTO DESDE AYER AL MEDIO DIA HASTA AL ANOCHECER.

Mercantes españolas.

De Valencia en 2 d., laud Silvina, de 56 t., p. Bautista Martinez, con 299 cajones tabaco al señor Fontanillas y Pomés, 13 pipas vino á la señora viuda Olcina, 20 id. id. á don Pedro Juventeny y 100 sacos trigo á los señores Serra y Sobrino.

De Palma en 2 d., laud Leonor, de 26 t., p. Vicente Riera, con 300 cuarteras salvado, 200 quintales algarrobas y 22 pipas aceite para Arenys.

De Móbila en 41 d., fragata Teresita, de 610 t., c. don José Maristany, con 100 balas algodon á los señores Serra y Sobrino, 116 id. id. á don G. Taltabull, 117 id. á los señores Gusi, hermanos, 183 id. á los señores Mallol é hijos, 710 id. á don Rosendo Noriega, 1123 id. y 1100 duelas al capitan.

De Charleston en 60 d., corbeta Palma, de 459 t., c. don Pedro M. Granada, con 5200 barriles resina y 100 balas algodon á los señores Masó y Stagno, 120 id. id. á los señores Balaguer hermanos, 100 id. á los señores Gibert y Cisneros, 30 id. á don Ambrosio Oliveras, 989 id. y 1581 duelas á los señores Ribas y Cantallops y 155 cueros salados á los señores Plandolit hermanos.

De Isla del Carmen y Habana en 76 d., bergantin Restaurador, de 202 t., c. don José Estapé, con 1521 quintales palo campeche, 197 piezas caoba, 17,000 cocos á los Sres. Samsó, Grau y compañía.

De Valencia en 3 d., laud Mercedes, de 29 t., p. José Gallart, con 18 pipas aceite á los Sres. Aviñó, hermanos, 5 fardos pieles á los Sres. Pujol y Boada, 214 cahices salvado á don Antonio Cuyás, 110 sacos arroz á los Sres. Cunill hermanos, 80 id. id. y 236 fanegas trigo á los Sres. Fontanillas y Pomés.

De Valencia en 3 d., laud San Rafael, de 37 t., p. Vicente Santaeulalia, con 43 sacos rubia á don Pedro Egozcue, 38 id. arroz á don C. Puigoriol, 412 id. id. á don Rafael Polo, 116 id. lana á los Sres. Palomar y Cebrian, 45 id. harina y 160 fanegas trigo á los Sres. Fontanillas y Pomés.

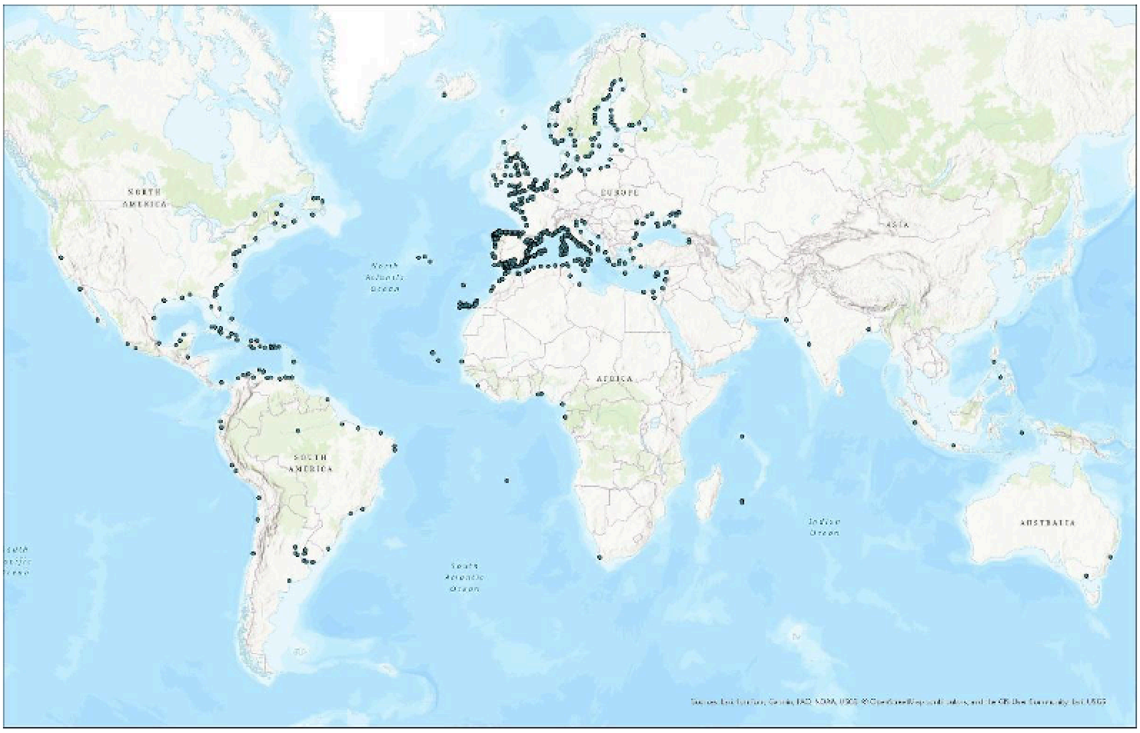
De Gibraltar y Alicante en 9 d., laud Rey Pacífico, de 64 t., p. José Biedma, con 1200 fanegas trigo á don Timoteo Capella, 10 cajas pianos á los Sres. Ortembach y compañía, 6 bultos quincalla y loza á don Ramon Girona, 34 fardos cueros á D. C. Puigoriol, y varios efectos de un buque náufrago á los Sres. Sala y Monner.

De Málaga en 9 d., polacra-goleta Cecilia, de 74 t. c. don Vicente Planells, con 150 cajas pasas á don Gerardo Maristany, 20 id. azúcar á los señores Gusi hermanos, 30 id. id. á don Jaime Rius, 1000 quintales hierro á don C. Troyano, 260 fanegas trigo á don R. Comas y Salitre, 49 bultos carnazas á los señores Serra y Sobrino, 8 id. trapos á don Sebastian Comas, 4 id. id. á don Felipe Florez, 24 id. y 9 id. recortes de papel á don A. Serra y Torrens.

De Alicante y Valencia en 10 d., pailebot Elisa, de 45 t., p. Marcos Llorca, con 1370 fanegas trigo á don Juan Estrany.

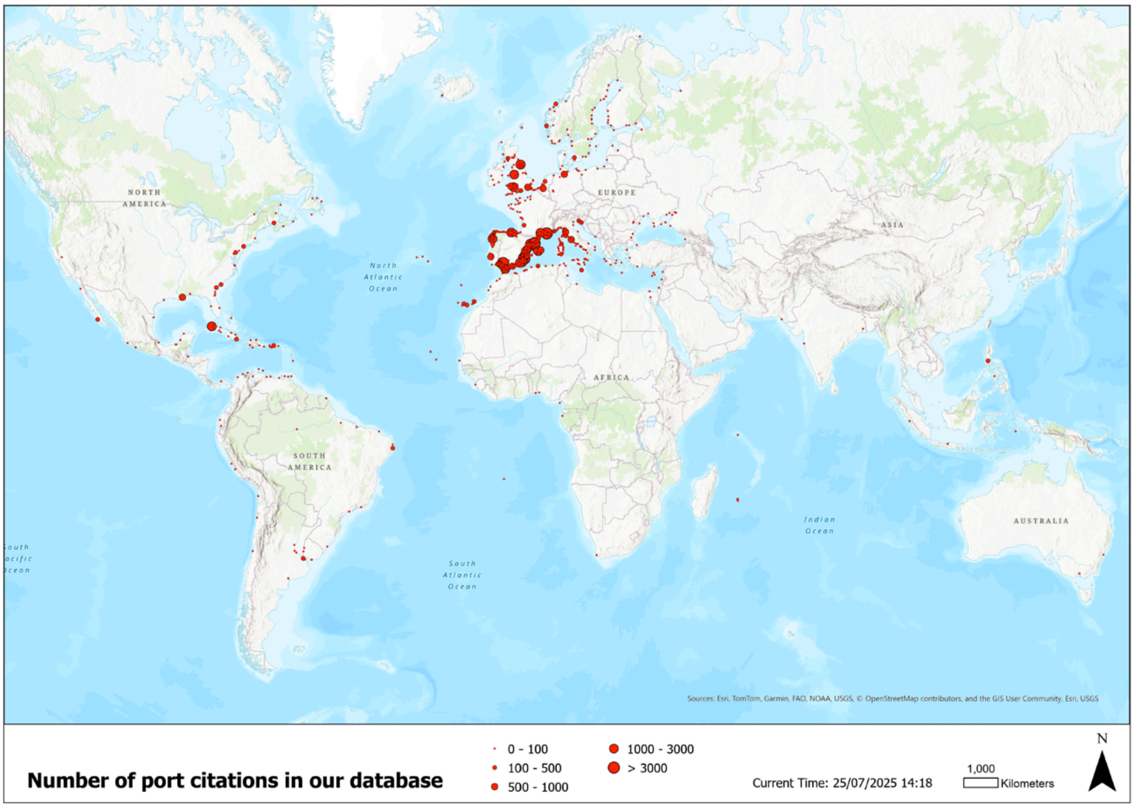
Image April 15 1860

Figure A7. Distribution of ports with presence in our database



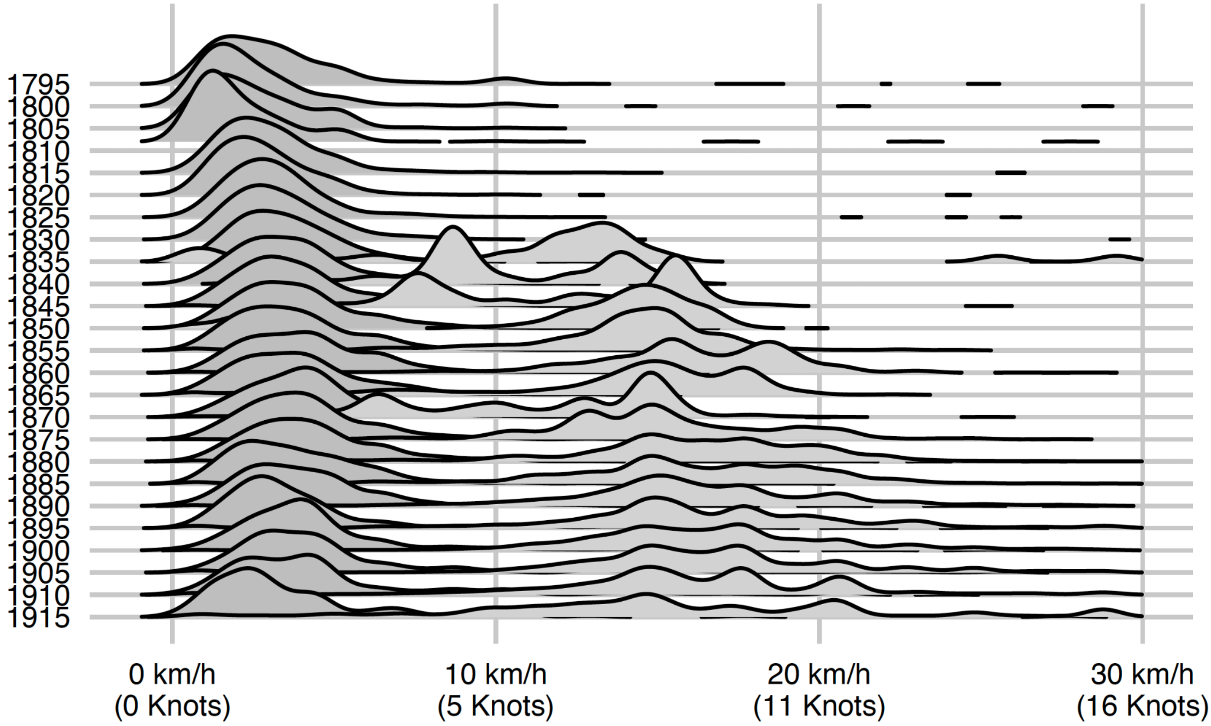
Sources and notes: Authors calculations based on *Diario de Barcelona*.

Figure A8: Number of port citations in our database



Sources and notes: Authors calculations based on *Diario de Barcelona*.

Figure A9: Speeds for sail ships and steamships entering Barcelona



Notes and sources: Authors calculations based on *Diario de Barcelona*. Dark grey distributions are from sail ships and light grey distributions for steamships. The density ridge plots are generated using the ggridges package in R. This function applies kernel density estimation, smoothing the raw data by centering a kernel (Gaussian by default) on each observation and aggregating across all points, thereby producing continuous curves instead of discrete or jagged histograms.

Figure A10: Estimates of steam-log origin distance elasticity drawn from first stage

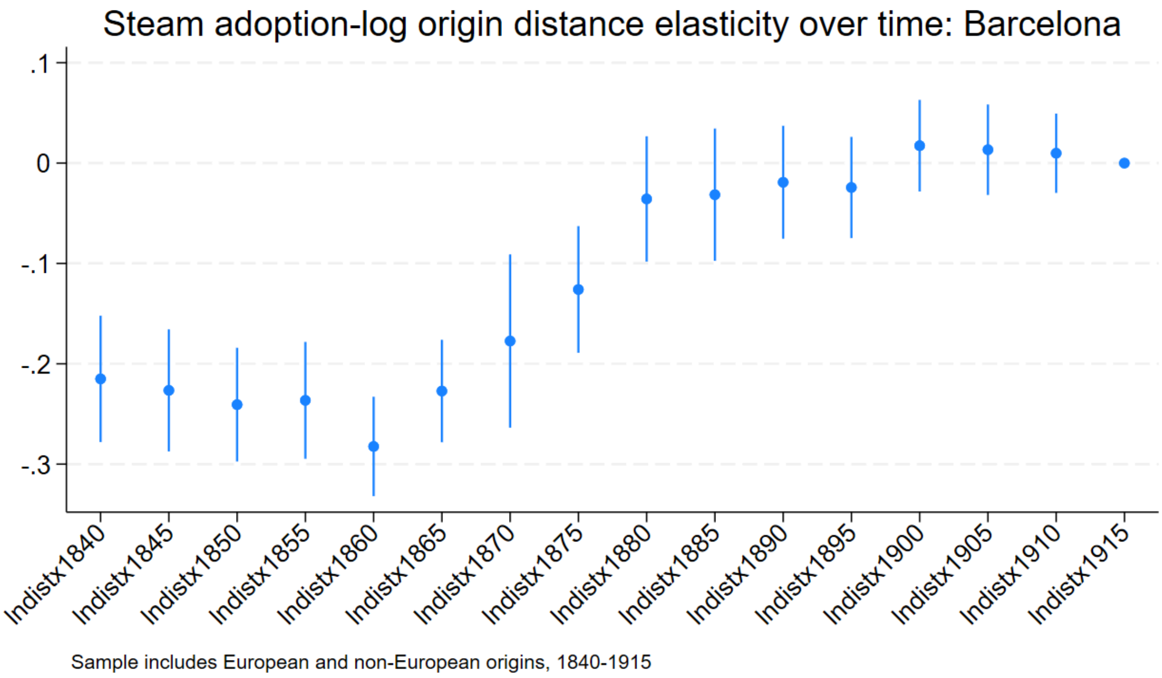
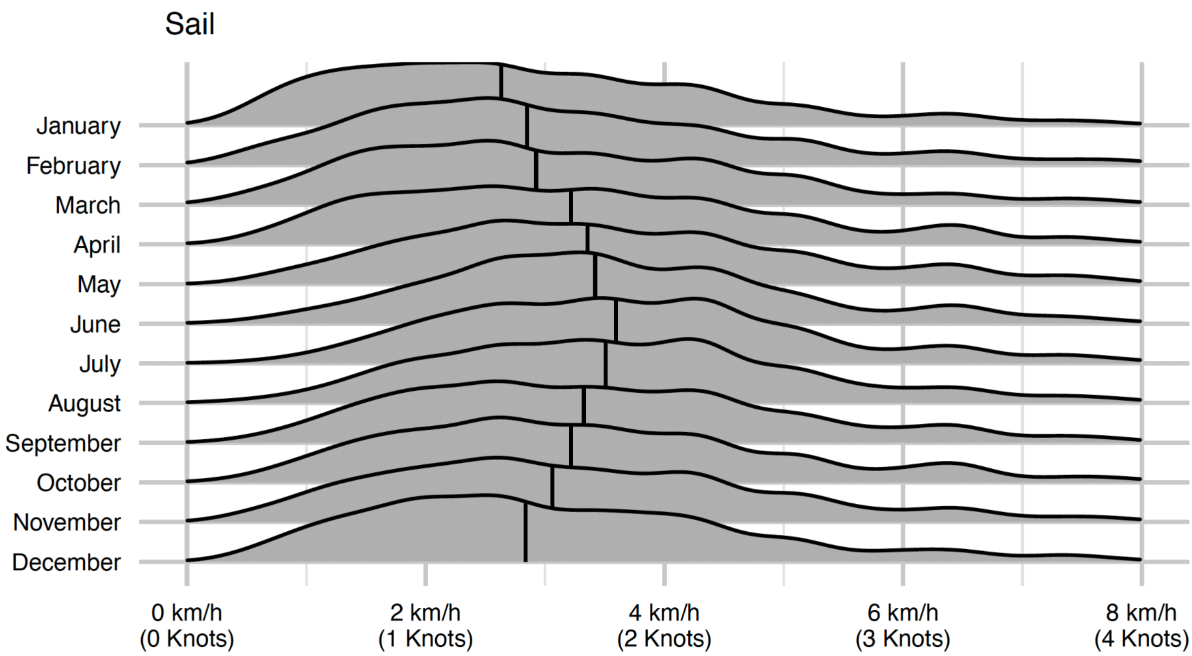


Figure A11: The distribution of speed for sail and steam across calendar months. The solid line shows the mean speed in each month.



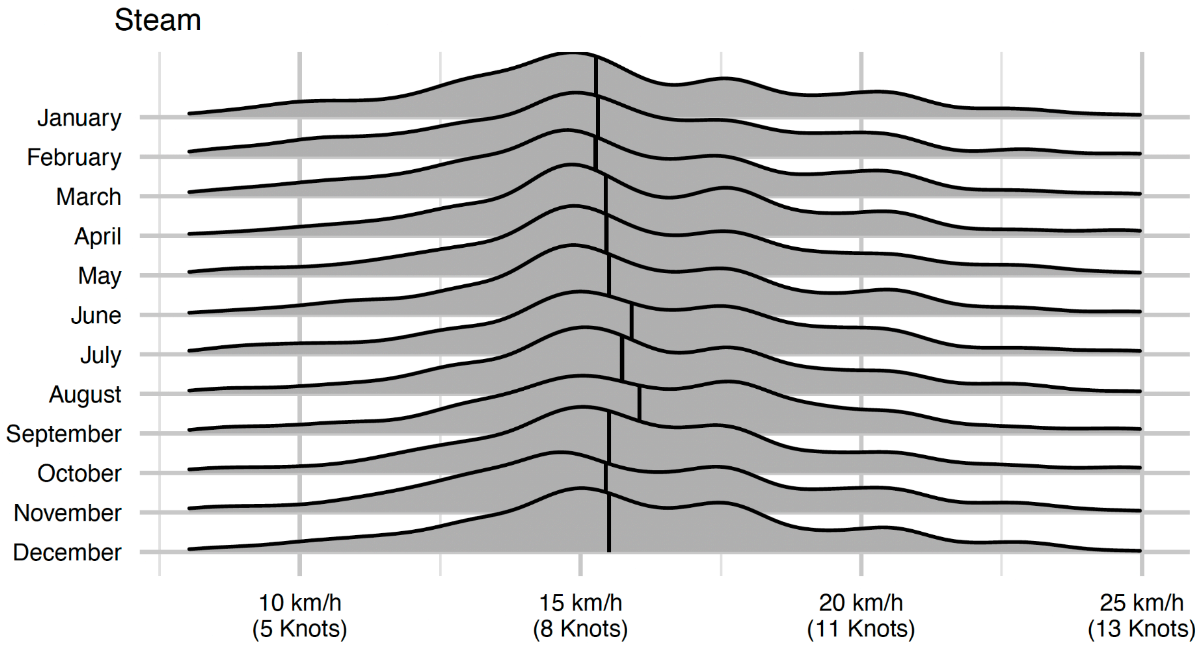


Figure A12: The kernel density of coefficients of variation in travel time for sail and steam voyages from 70 top origin ports

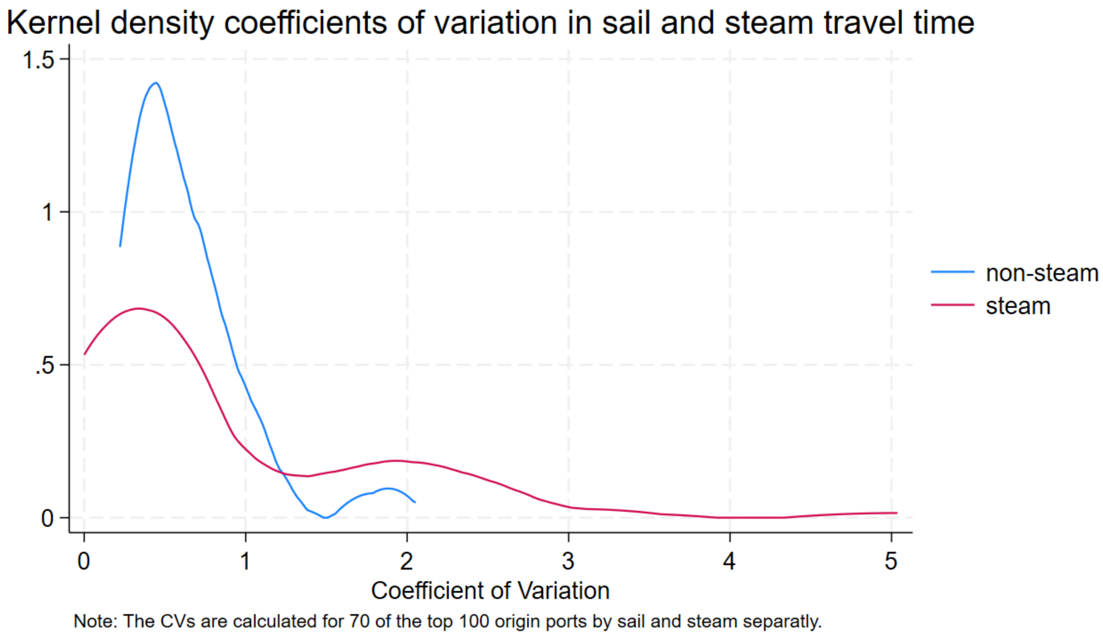


Table A1. Main descriptive statistics

	Voyages	Mean	Std. Dev.	Min	Max
Time away (hours)	58,092	327.13	511.43	0.5	39,168
Tonnage	51,192	275.52	555.39	1.00	48,770
Number of stops	58,722	0.37	0.73	0.00	9.00
Temperature	58,866	13.23	5.86	-8.00	32.00

The variable for number of stops records whether the voyage included any intermediate ports; a value of 0 indicates a direct sailing from the port of origin to Barcelona. Temperature is measured daily at the port of Barcelona, with readings also published each day in the *Diario de Barcelona*.

Table A2. Typology of ships over time (in percentages)

	1795	1800	1805	1808	1815	1820	1825	1830	1835	1840	1845	1850	1855	1860	1865	1870	1875	1880	1885	1890	1895	1900	1905	1910	1915
Bateo	0.0	0.0	0.3	0.0	0.1	0.0	1.4	1.0	0.2	0.1	0.1	0.2	0.6	1.6	0.9	0.5	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bomb vessel	0.1	0.0	0.6	0.8	4.5	4.1	6.7	2.3	1.1	1.0	0.8	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brig	16.1	13.8	17.1	1.6	12.9	8.2	4.6	5.3	5.7	6.6	7.5	8.3	6.4	7.2	5.9	8.0	5.7	4.2	5.5	3.5	4.1	0.6	0.3	0.6	0.4
Brig-schooner	0.0	0.0	0.0	0.0	0.2	0.5	1.4	2.4	2.7	2.7	2.5	3.5	2.9	3.4	3.1	4.4	5.3	5.7	9.7	7.8	5.6	5.8	5.7	4.5	2.3
Cahique (local boat)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Canario (local boat)	4.5	0.9	0.5	1.0	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Corvette	0.5	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.0	0.2	1.5	2.8	2.6	6.8	6.2	10.2	7.9	8.4	11.1	6.2	3.6	2.0	2.0	1.7	0.7
Falucho	1.9	1.0	0.5	0.5	0.1	0.1	0.9	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Frigate	4.2	2.2	4.5	1.5	4.6	1.3	1.1	0.4	0.7	0.7	1.1	1.1	1.1	1.2	1.1	0.8	0.6	0.4	0.1	0.1	0.4	0.2	0.0	0.0	0.0
Ketchmarine	0.2	0.9	0.0	0.0	0.7	1.4	0.6	3.7	3.1	3.0	1.3	0.9	0.5	0.4	0.3	0.2	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0
Llaut (local boat)	35.0	63.3	46.5	66.4	41.7	62.8	50.0	55.7	56.7	52.0	51.4	52.0	57.8	43.4	45.0	29.8	14.3	7.9	0.9	2.9	0.1	7.9	4.8	1.5	0.6
Londro (local boat)	4.1	0.4	0.6	2.6	1.2	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lugger	0.0	0.0	0.0	0.0	0.1	0.4	0.5	1.2	1.3	0.6	0.4	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mistico (local boat)	0.2	0.8	0.3	0.3	0.5	2.0	3.3	3.6	4.8	6.3	6.4	4.2	2.5	1.0	0.8	0.3	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Mistico-schooner	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.2	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	5.2	5.3	5.5	2.1	3.2	1.6	1.3	0.8	1.1	0.5	0.3	0.4	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.6	0.6	0.4
Pilot boat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	2.7	2.8	2.0	2.1	3.0	2.7	3.0	6.1	5.8	2.5	4.2	3.5	6.1	6.7	7.0	7.7
Pink	2.2	0.4	3.8	3.2	1.5	0.3	1.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polacre	4.2	2.2	5.7	1.3	6.1	3.6	5.1	3.6	3.9	4.1	4.4	5.1	3.2	5.0	6.3	5.4	5.9	5.7	3.0	1.5	0.3	0.2	1.5	0.0	0.0
Polacre-schooner	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.7	3.1	4.6	4.2	4.4	4.5	4.7	5.9	5.5	5.2	5.8	4.6	3.6	3.0	3.1	1.8	1.3	0.5
Schooner	0.6	0.4	0.9	0.6	2.2	2.0	2.0	1.7	1.8	3.3	3.0	4.1	5.3	4.2	3.5	3.9	2.1	2.1	1.3	2.4	1.8	1.3	1.9	1.0	2.8
Sloop	0.2	0.1	0.2	0.0	0.2	0.2	0.1	0.4	0.9	0.6	0.7	0.7	0.3	0.6	1.4	1.9	5.0	4.5	1.8	2.8	1.8	2.2	1.8	0.5	0.5
Steamer	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	2.2	2.9	5.5	3.6	6.3	15.5	14.6	24.0	39.8	47.1	58.9	63.4	73.8	69.7	72.0	80.7	83.9
Tartane	2.7	0.7	1.6	0.8	1.1	1.0	1.9	0.2	0.1	0.4	0.9	0.9	0.3	0.1	0.9	0.8	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unreported	0.6	0.4	0.7	3.1	1.4	0.1	0.5	0.2	0.0	0.2	0.1	0.3	0.1	0.3	0.0	0.1	0.1	0.0	0.2	0.0	0.1	0.0	0.0	0.2	0.0
Xabega (local boat)	6.8	1.7	2.1	1.6	0.5	0.2	1.8	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Xebec	10.5	5.5	8.4	12.6	17.1	9.1	15.0	15.3	9.0	7.5	5.2	4.3	2.3	1.0	0.8	0.9	1.0	0.4	0.0	0.3	0.2	0.2	0.0	0.0	0.0
Yacht	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5	0.3	0.9	1.3	0.6	0.9	0.4	0.1

For data and sources see Section 3.

Table A3. Top 50 products listed as cargo with additional details

(1)	(2)	(3)	(4)	(5)	(6)
Product in source	Translation	Share of all product occurrences	Share of voyages with product	Share steam on voyages with product after 1850	High (H) or low (L) value to weight
Otros efectos/Cargo general	General cargo	0.081	0.121	0.793	H
Trigo	Wheat	0.045	0.069	0.149	L
Algarrobas	Carob	0.043	0.059	0.139	L
Carbón	Coal	0.039	0.056	0.410	L
Pasajeros	Passengers	0.038	0.059	0.990	H
Arroz	Rice	0.031	0.042	0.375	L
Vino	Wine	0.029	0.031	0.495	H
Aceite	Oil	0.025	0.033	0.661	H
Harina	Flour	0.018	0.025	0.268	H
Algodón	Rice	0.018	0.040	0.456	L
Lana	Wool	0.016	0.022	0.597	L
Lastre	Ballast	0.016	0.024	0.418	L
Trapos	Cloth	0.016	0.021	0.346	H
Hierro	Iron	0.015	0.021	0.444	L
Drogas	Drugs	0.014	0.016	0.780	H
Espartería	Straw	0.011	0.016	0.374	L
Cebada	Barley	0.011	0.015	0.413	L
Naranjas	Oranges	0.010	0.014	0.280	H
Tejidos	Fabrics	0.010	0.012	0.959	H
Calzado	Footware	0.010	0.011	0.883	H
Leña	Firewood	0.009	0.013	0.012	L
Alubias	Kidney beans	0.009	0.009	0.782	L
Habas	Fava beans	0.009	0.012	0.338	L
Salvado	Bran	0.009	0.013	0.298	L
Sardinas	Sardines	0.009	0.013	0.303	H
Cueros	Leather	0.008	0.017	0.522	L
Cáñamo	Hemp	0.008	0.011	0.797	L
Maquinaria	Machinery	0.007	0.007	0.767	H
Quincalla	Hardwares	0.007	0.008	0.817	H
Sal	Salt	0.007	0.009	0.465	L
Papel	Paper	0.007	0.010	0.821	H
Garbanzos	Chickpeas	0.007	0.010	0.356	L
Bacalao	Cod	0.007	0.011	0.493	H
Madera	Lumber	0.007	0.012	0.456	L
Pieles	Hides	0.006	0.009	0.747	L
Correspondencia	Correspondence	0.006	0.010	0.988	H
Almendrón	Almonds	0.006	0.007	0.885	H
Higos	Figs	0.006	0.008	0.331	H
Maíz	Corn	0.006	0.008	0.402	L
Vidrios	Glass	0.005	0.008	0.720	H
Cacao	Cocoa	0.005	0.011	0.396	L
Palma	Palm	0.005	0.008	0.497	L
Quesos	Cheese	0.005	0.008	0.762	H
Cerdos	Pigs	0.005	0.008	0.854	H
Frutas	Fruit	0.005	0.005	0.911	H
Loza	Pottery	0.005	0.006	0.331	H
Habichuelas	String beans	0.005	0.007	0.296	L
Corteza	Bark	0.005	0.007	0.177	L
Azúcar	Sugar	0.004	0.016	0.393	L
all top 50 products			0.503	0.393	
all top 50 low value products			0.391	0.380	
all top 50 high value products			0.217	0.241	

Sources and notes: Authors calculations based on Diario de Barcelona.

Table A4. OLS Estimates for effect of steam on travel time including voyages with intermediate stops

	(1)	(2)	(3)	(4)	(5)
Steam = 1	-1.274***	-1.236***	-1.237***	-1.264***	-1.289***
	(0.034)	(0.040)	(0.041)	(0.040)	(0.060)
Observations	58,059	50,925	49,504	42,959	33,094
R-squared	0.875	0.888	0.893	0.900	0.912
Intermediate stop # FEs	YES	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES	YES
Origin FEs	YES	YES	YES	YES	YES
Month FEs	YES	YES	YES	YES	YES
OriginxMonth FEs	NO	NO	YES	NO	YES
Master surname FEs	NO	NO	NO	YES	NO
OriginxSurname FEs	NO	NO	NO	NO	YES

Notes: The dependent variable is the natural log of travel times (measured in days). The sample includes voyages with intermediate stops. . Columns 3, 4, and 5 use HDFE Linear regression, which omit singleton obs. Standard errors clustered on origin ports are reported. *, **, and *** indicate statistical significance at the 10, 5, and 1% levels. When controlling for origin, month, year, and master surname fixed effects, voyages using steam were 1.230 log points lower, or 70.74\% [= 100*(exp(-1.229)-1)] lower.

Table A5: Effect of steam on probability of carrying various low value goods into Barcelona: OLS estimates

VARIABLES	(1) coal	(2) wheat	(3) carob	(4) rice	(5) wool
steam	-0.019*	-0.0101	-0.0294	0.0130*	0.0476***
	(0.0106)	(0.00899)	(0.0257)	(0.00713)	(0.0112)
R-squared	0.462	0.244	0.251	0.228	0.123
VARIABLES	(6) ballast	(7) iron	(8) straw	(9) barley	(10) firewood
steam	-0.027	-0.0158	0.0144	0.00301	-0.000167
	(0.0205)	(0.0128)	(0.0122)	(0.00401)	(0.0136)
R-squared	0.079	0.104	0.121	0.063	0.250
VARIABLES	(11) kidney beans	(12) fava beans	(13) Bran	(14) Leather	(15) Hemp
steam	0.014**	0.00291	-0.00530	0.0214***	0.0145
	(0.0062)	(0.00227)	(0.0102)	(0.00807)	(0.00988)
R-squared	0.046	0.097	0.098	0.053	0.086
VARIABLES	(16) salt	(17) garbanzos	(18) lumber	(19) hides	(20) corn
steam	0.001	0.00438	-0.00183	0.0247***	0.00501*
	(0.0108)	(0.00310)	(0.00286)	(0.00561)	(0.00268)
R-squared	0.127	0.099	0.125	0.050	0.093
VARIABLES	(21) cocoa	(22) palm	(23) string beans	(24) bark	(25) sugar
steam	0.007***	0.0102	0.00419	-0.00165	0.0155***
	(0.0020)	(0.00892)	(0.00315)	(0.00399)	(0.00527)
R-squared	0.066	0.077	0.055	0.065	0.053

Notes: The dependent variable is 1 if the voyage listed the particular good and zero otherwise. The sample includes ports where distance to origin is measured. IV estimates will only apply to this sample. The controls are year, month, and origin fixed effects, and also temperature and shipmaster is called a captain. The number of observations is 31,289 in all regressions. For description of controls see text. Standard errors clustered on the origin are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

Table A6: Effect of steam on probability of carrying various high value goods into Barcelona: OLS estimates

VARIABLES	(1) general	(2) wine	(3) flour	(4) cotton	(5) oil
steam	0.128***	0.0282*	0.00826	0.0336**	0.0509***
	(0.0298)	(0.0146)	(0.00777)	(0.0154)	(0.0160)
R-squared	0.338	0.162	0.311	0.147	0.130
VARIABLES	(1) passengers	(2) cloth	(3) drugs	(4) oranges	(5) fabrics
steam	0.260***	0.00671	0.0365*	0.00800**	0.0312***
	(0.0291)	(0.00721)	(0.0216)	(0.00348)	(0.0102)
R-squared	0.390	0.062	0.185	0.154	0.056
VARIABLES	(1) footware	(2) sardines	(3) sheep	(4) machinery	(5) hardwares
steam	0.036*	0.0143**	0.00978	0.00796*	0.0121
	(0.0189)	(0.00630)	(0.0107)	(0.00473)	(0.00901)
R-squared	0.132	0.220	0.124	0.151	0.106
VARIABLES	(1) paper	(2) cod	(3) correspond ence	(4) almonds	(5) fig
steam	0.024***	0.00324**	0.0365*	0.0287	0.00651*
	(0.0086)	(0.00156)	(0.0209)	(0.0240)	(0.00373)
R-squared	0.087	0.319	0.089	0.127	0.040
VARIABLES	(1) glass	(2) cheese	(3) pigs	(4) fruit	(5) earthenwar e
steam	0.016**	0.0125*	0.0245*	0.0158***	0.00425
	(0.0077)	(0.00685)	(0.0137)	(0.00522)	(0.00397)
R-squared	0.061	0.078	0.082	0.036	0.048

Notes: The dependent variable is 1 if the voyage listed the particular good and zero otherwise. The sample includes ports where distance to origin is measured. IV estimates will only apply to this sample. The controls are year, month, and origin fixed effects, and also temperature and shipmaster is called a captain. The number of observations is 31,289 in all regressions. For description of controls see text. Standard errors clustered on the origin are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.