From Sail to Steam[1]

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Abstract: Technological changes can transform markets and economies, but often it is difficult to isolate their effects. 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, ship agents, and a distance-based instrument to isolate the causal effect of steam. The results show that steam reduced travel times at sea by 68-72 percent. Our estimates imply that steamships substantially increased the level of trade. We go further by providing the first analysis of steamship's effect on trade composition. 1,035 products included in the cargoes entering Barcelona are digitized and linked with individual voyages. Using the same identification strategy, we show that steamships increased the probability that ships carried passengers along with several high value goods, industrial raw materials, live animals, and perishables. We also show that steamships increased the probability that a voyage carried new goods. More generally 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 history. Steam-power notably revolutionized transport in the 19th century. The effects of steam are found in railways, but also in steamships, transforming one of the oldest sectors in the global economy. Sailing ships would be replaced by steamships during the second half of the nineteenth century, and in the process contributed to an unprecedented surge in international trade (O'Rourke and Williamson, 1999; Pascali, 2017; Meissner, 2024).

Speed was the steamship's main advantage over sailing ships. Speed contributed to lower capital and labor costs, which helped to offset steamships' higher fuel costs. While speed was crucial, it has been difficult to precisely identify the time savings *caused* by the adoption of steam technology because it is unclear whether the higher speeds of steamships were partly due to differences in the crew or other voyage characteristics. Steamships did not appear randomly on different routes and ship owners likely chose to deploy them where they expected commercial gain, implying selection. The steamship's impact on trade is also unclear, especially trade composition (i.e., products and partners). Steamships were known to carry higher value to weight goods because of their speed advantage, yet it is unclear to what degree this reflects selection by shippers versus opening markets for such products.

In this paper, we identify the causal effect of steam-power on shipping times and trade composition using new data on nearly 70,000 arrivals into Barcelona, one of the largest ports in the Mediterranean.[5] Our data contain 1,023 departure ports from 1795 to 1915, including journey times, ship's type and name, tonnage, shipmaster's name, a list of cargo, and the ship agent and owner. Our identification strategy uses variation in steam vs. sail voyages at the origin, month, year, shipmaster, and shipping agent level. We also use origin-distance interacted with year fixed effects as an instrument for the use of steam in a voyage. The OLS and IV estimates show that steam reduced travel time by a range of 68 to 72%. We show that such large reductions in travel time imply a large effect on trade levels.

We also estimate the causal effect of steamships on the probability that particular products were shipped using our rich data on cargoes into Barcelona. Using the same instrumental variable strategy, we show that steamships increased the probability that ships carried passengers along with several high value goods, industrial raw materials, live animals, and perishables. We also show that steamships increased the probability that a ship carried a new good, defined as a novel product-origin combination.

Given the importance of steamships, it is surprising there are few studies empirically examining their time saving or speed advantage 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 broader comparison across many origins. A second is Pascali (2017), who uses data from 1,667 vessels working the Canadian coast, to estimate that steam reduced shipping times by 36%. Similar to our paper, Pascali examines several routes and uses origin and year fixed effects in a regression analysis. We demonstrate how our estimates differ in the Barcelona context by controlling for seasonality and including shipmaster surname fixed effects, in addition to instrumenting for steam.

[5] Observations were collected at five-year intervals. This sampling strategy allows the dataset to remain tractable while preserving sufficient temporal resolution to capture long-run patterns and trends.

We also contribute to the debate on how much steamships affected trade. Several studies examine how lower maritime transport costs affected bilateral trade between countries. Notably, Jacks and Pendakur (2010) and Jacks, Meissner, and Novy (2010) argue for smaller effects, despite the revolutionary changes brought by steam. This conclusion has been challenged by Pascali (2017), who argues that greater exposure to steamships substantially increased bilateral trade. 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 and to reevaluate impacts on trade levels.

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. By 1880, Barcelona accounted for over one-third of Spain's total shipping tonnage and roughly one-fifth of all passenger traffic. The Mediterranean routes linking Barcelona to Southern European neighbors, the Atlantic routes to the Americas, 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…were the first to acquire steamers". Thus, Barcelona offers a general 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 travel speed at sea between sailing ships and steamships over time. The calculation of speed requires identifying the distance travelled and the duration of the voyage, 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. The routes minimize distance considering the prevailing winds for each month of the year. 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. Thus, an aggregated comparison implies steam reduced times by 71%.

Next, we exploit variation in travel time at the origin, month, year, and shipmaster surname level to evaluate the effect of steam on travel time at sea. We focus on a sample of 58,092 non-stop voyages to Barcelona from 964 origins with 17,183 unique shipmaster surnames. The data covers the years 1795 to 1915. Our most demanding OLS specification shows that steam lowered shipping time by 68%. Nonetheless, there is still a concern that journeys which used steam were selected. We address this issue by using a novel instrumental 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. However, as engines improved after 1850 steamships were increasingly used on longer journeys. Thus, 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 72%.

We also estimate heterogeneity effects. The results 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 on travel time has several implications. First, without such a significant time advantage, steamships would have been much less productive and less competitive with respect to sail. A second implication is that the advent of steamship technology dramatically boosted trade levels. We draw on the elasticity of trade with respect to differences in steam versus sail time estimated by Pascali (2017). We find steam increased per capita trade by approximately 293%. The adoption of steam would then account for much of the trade growth in the Catalan economy.

We apply the same instrumental variable 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 show that steamships increased the probability that ships carried passengers along with several high value goods, like wine, fabrics, footwear, glass, and hardwares; industrial raw materials, like cotton, wool, hides, and paper, and live animals, like pigs, and perishables like sardines and oranges. We also show that steamships increased the probability that a ship carried a new good, defined as a novel product-origin combination.

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 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 the adoption of steamships in Spain, where the broad outlines are established and set up our analysis of Barcelona.

2.1 From sail to steam 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 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).

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).

Early steamships 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). Technological improvements like high-pressure, compound, and later triple-expansion engines in the 1860s transformed the viability of steam propulsion, reducing fuel use and extended voyage range. Moreover, the shift from wooden to iron and later steel hulls allowed for larger, more durable steamships. 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.

As steam proved increasingly profitable, traditional trading and shipping houses evolved into modern steamship enterprises. 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).

Steamships 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).[6] 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.

2.2 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).[7] Despite this, Barcelona handled more than 30% of Spain's imports (Estadística General del Comercio, 1880).

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. In 1870, legislative approval was secured for the issuance of port bonds, tapping capital markets to 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).

A second major port expansion started in 1903. Major components included: the extension of the east breakwater further into the Mediterranean, the construction of three new perpendicular

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

[7] 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.

quays, and the creation of a vast new basin on the port's western side. Emphasis was also placed on 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).

More detail will be added on the second wave of industrialization in Barcelona, including electrification and the rise of the chemical and metallurgical sectors

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 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.).[8] 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 (a.k.a. the shipping agent), 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.[9] A key 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. One issue in the data is rounding. Despite the time away occurring in days and hours (e.g., 3 days and 5 hours) it is often reported in days only (3 days), somewhat adding noise in the estimates.

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 ceased.

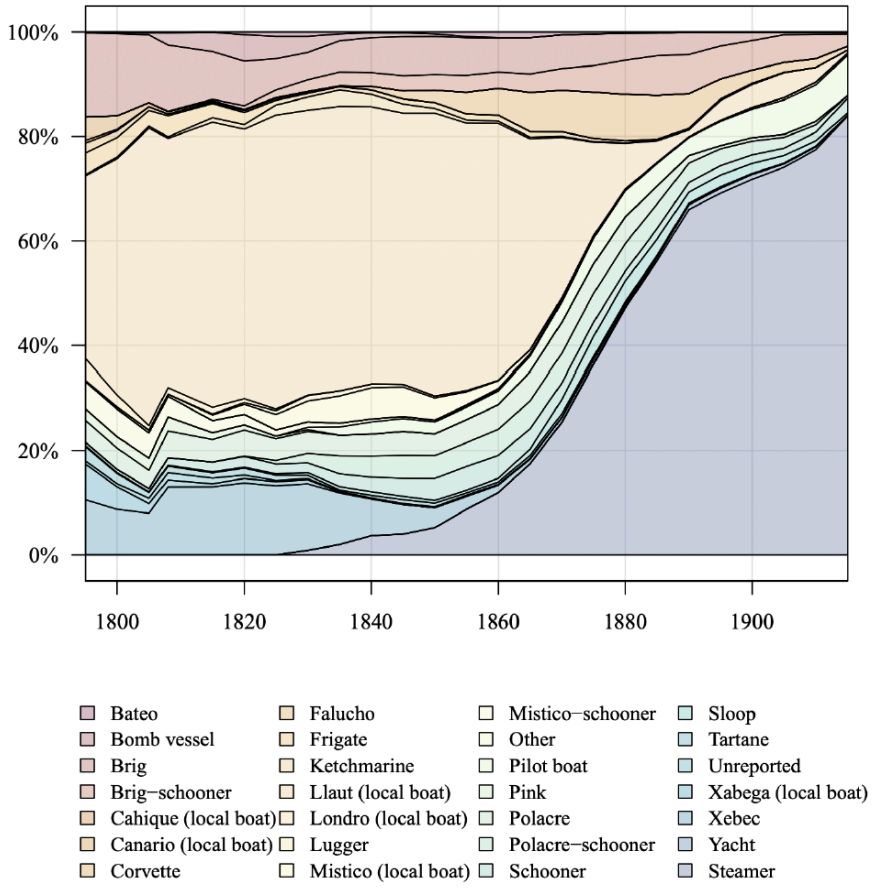
For coding the data, we used automated text-recognition techniques. However, given the age of the documents, the OCR was error-prone (due to transparency of the paper), requiring substantial post-processing. We manually validated each of the entries, which was necessary to

[8] 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.
[9] From 1850 to 1855, a daily edition was published, from April 1855, two editions, and, starting in 1909, three

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 1830, but by 1835, the number had increased to 96 in 1840 and 339 in 1845. Then steamships rise sharply in the 1850s/60s and eventually dominate by the 1880s. Table A2 offers additional insights and description into the types of sailing vessels that played a role in this transitional phase.

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 and steamships differed in size, measured by registered tonnage. In 1825, average sail tonnage stood at 47.1. The first steamship arriving in Barcelona was already higher at 164 tons. 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.

We standardize the entries in the cargo variable, which records listed items for each ship. Generally the first few items represented 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 low 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 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.[10] 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

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

these voyages were by steam and 30 were by sail. Thus within common origin-shipmaster surname combinations, like València-Llopis, we can compare travel times by sail and steam.

Details on the coding of ship agents will be added.

We have also digitized departures of ships from Barcelona using the same newspaper source. The departures also list the ship name and date, which we use to link with the closest ship entry with a prior date. The linking of entries and departures yields the time at Barcelona port.

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).[11] 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 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 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%) were 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.[12]

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

[11] 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.

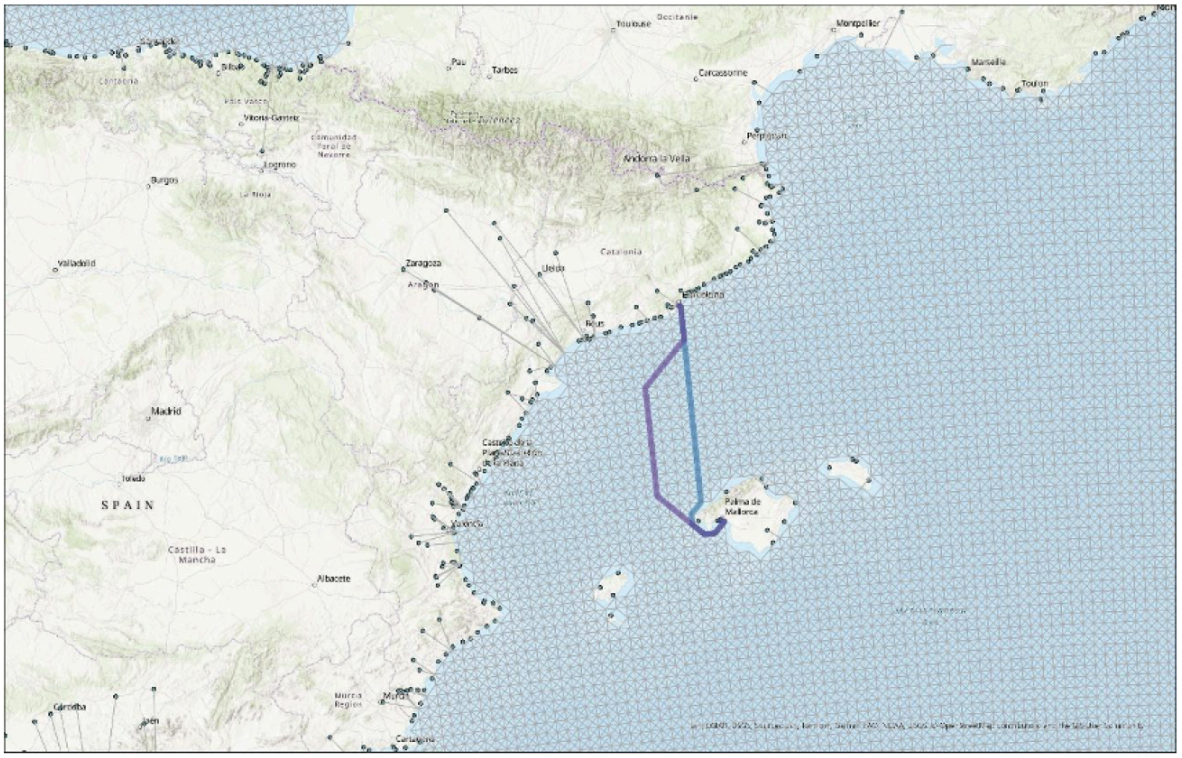
[12]

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 one 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 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 (see the appendix for details).

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.

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

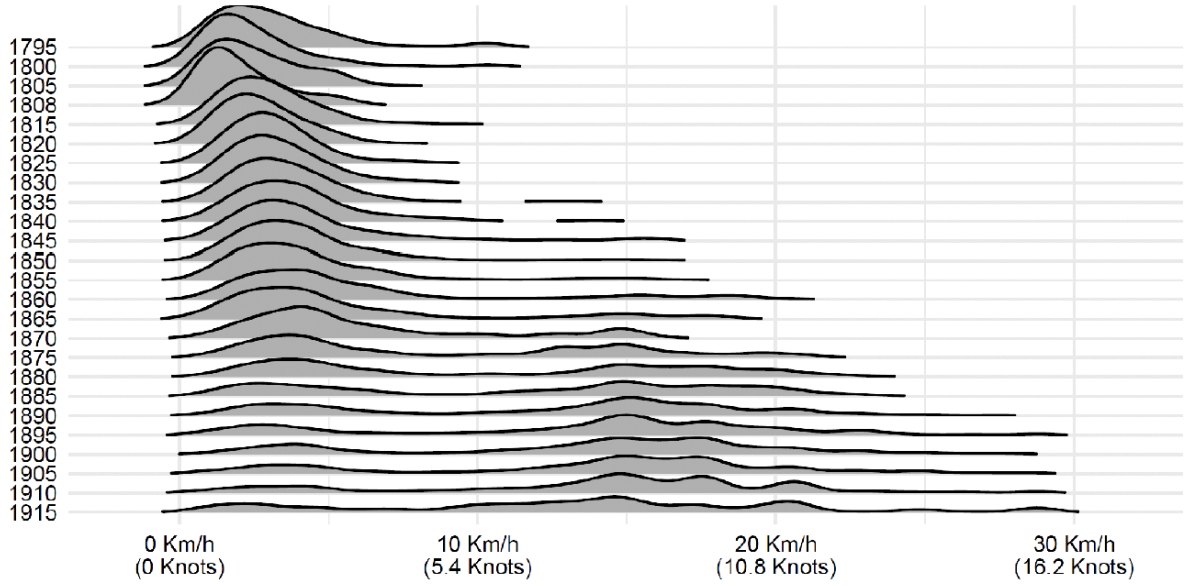
rate data, it offers a reasonable substitute (Kelly and Ó Gráda, 2019; Rönnbäck, 2012; Solar, 2013; Vinnal, 2014).

Speed is also noteworthy because it played a crucial role in steamships competition with sail ships. Steamships competed with sailing ships on two levels: price and quality. 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. Harley estimated that for a 1,000 mile voyage, travelling at a speed of 5 knots, steam's total costs per ton mile exceeded sail, whereas at 6 or 7 knots steam's costs per ton mile was lower than sail. Thus, in theory the competitive advantage of steam was only achieved at speeds beyond 5 knots (in the case of a 1,000 mile voyage).

We begin by dividing our estimated route distance by journey time to estimate 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%.[13] 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. 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.

[13] Velocity rose from 2 to 7.5 knots, an absolute increase of 5.5, equivalent to a 275% rise relative to the initial value.

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.

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.[14] 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,[15] 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.

To illustrate the added significance, 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 in nineteenth century shipping, 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%. While this

[14] 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).
[15] This is the distance reported on MarineTraffic's website.

is an extreme shift in technological capability and practice, it illustrates how speed was crucial to the rise of the steamship.

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. 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 and agents involving different ships. The main specification is given in equation (3):

$$\ln(\text{time}_{ijmsat}) = \alpha_j + \eta_m + \lambda_s + \theta_a + \gamma_t + \beta\ \text{Steam}_i + \mu x_i + \varepsilon_{ijmsat} \quad (3)$$

where $\ln(\text{time}_{ijmsat})$ is the natural log of travel time of voyage i 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, θ_a is a fixed effect for the ship agent, γ_t is a fixed effect for the year, $steam_i$ is an indicator equal to 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.[16]

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. Some shipmasters likely had different skills or preferences for faster travel, and they might also favor steam. The same skills or preferences could apply to shipping agents. 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 only controls are temperature and year fixed effects. Steam is estimated to reduce shipping time by -1.233 in logs. The percentage decline in travel

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

time is given at the bottom, -70.85%. Higher temperatures are also associated with lower times. In col. 2, origin and month fixed effects are added. The estimate for steam is little affected. Temperature no longer has an effect, which is not surprising given we add month fixed effects. Col. 3 adds ship agent fixed effects and two control variables for 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 -1.145 in logs, which is smaller but 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. Col. 4 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. 5 adds shipmaster surname fixed effects to the specification in col. 3. 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 -1.189. In col. 6 we add shipmaster surname by origin fixed effects to the specification in col. 5. 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: -1.237. Finally, in col. 7 we add origin specific trends, with little change in the estimates.

Table 1: OLS estimates for the effect of steam on travel time

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Steam = 1	-1.233***	-1.233***	-1.145***	-1.142***	-1.189***	-1.237***	-1.232***
	(0.033)	(0.033)	(0.038)	(0.040)	(0.046)	(0.084)	(0.078)
Temperatures	-0.005***	0.0001	0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
Tonnage			-0.009**	-0.009**	-0.007***	-0.004*	-0.004**
			(0.003)	(0.003)	(0.002)	(0.002)	(0.002)
Captain (dummy)			-0.043*	-0.052*	-0.033	-0.018	-0.029
			(0.021)	(0.021)	(0.019)	(0.019)	(0.018)
Observations	42313	42313	37438	36492	30716	23538	23538
Year fes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month fes	No	Yes	Yes	Yes	Yes	Yes	Yes
Origin fes	No	Yes	Yes	Yes	Yes	Yes	Yes
Ship agent fes	No	No	Yes	Yes	Yes	Yes	Yes
Origin x Month fes	No	No	No	Yes	No	No	No
Master surname fes	No	No	No	No	Yes	Yes	Yes
Route specific trends	No	No	No	No	No	No	Yes
Origin x Surname fes	No	No	No	No	No	Yes	Yes
Avg. Effect (in %)	-70.858	-70.858	-68.178	-68.082	-69.547	-70.975	-70.829

The dependent variable is the natural log of travel time (measured in days). Temperatures are in degrees Celsius and tonnage x 1000. 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 for 1785 to 1915, while all columns after have data from 1815 to 1915. 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 1.232 log points lower, or 70.83% [=100*(exp(-1.232)-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.

In appendix table A5, we focus on two subperiods 1845 to 1885 and 1885 to 1910. In the first, steamships were an emerging technology. In the second, steamships had become dominant on most routes. The estimates show that steamships had a slightly smaller effect on travel time

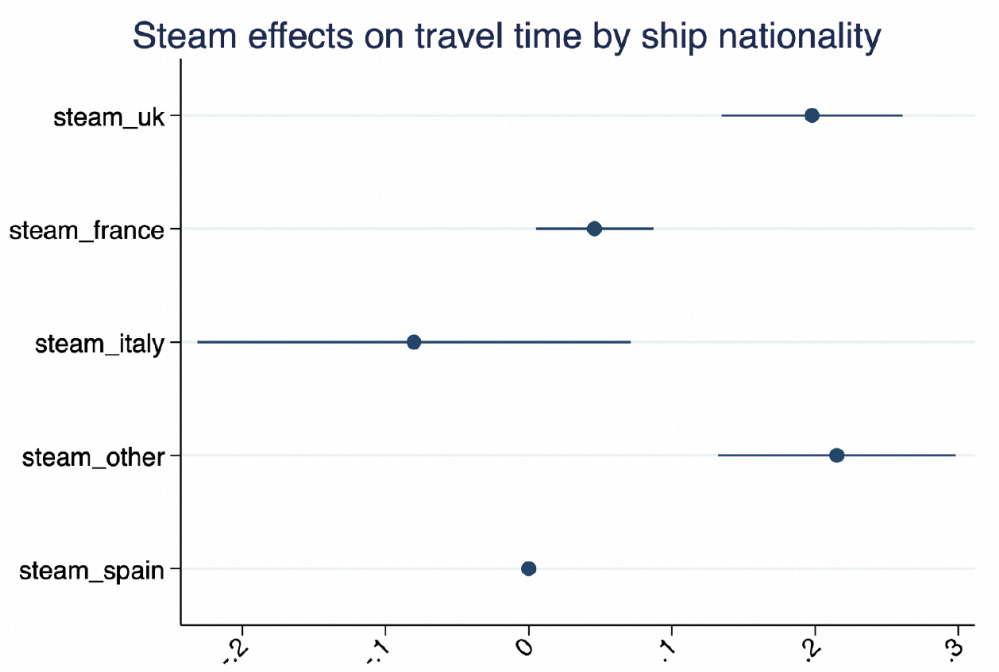
from 1845 to 1885: a 66% decline in our most demanding specification. The estimated effect is similar to our baseline and slightly larger in the period 1885 to 1910.

In appendix table A6, we split the sample into Spanish origin ports and non-Spanish origin ports. The estimates show that steamships had a slightly smaller effect on travel time in non-Spanish ports: a 67% decline in our most demanding specification.

We also estimate the heterogeneity effects by calendar month. 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 (see figure A11). That makes sense as sailing was more dangerous in these months.

Finally, we estimate heterogeneity 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 4 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 4: Steam effect on travel time by ship nationality



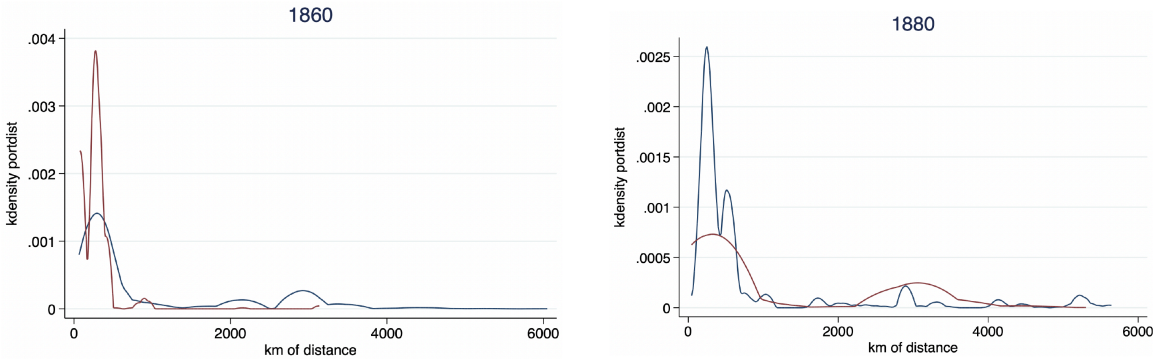
This figure shows coefficients with their 95% confidence intervals. Specification includes ship nationality, origin, month, and year fixed effects.

5.2 Instrumental variable results

The estimated effects of steam are remarkably similar across the OLS specifications. However, one might still be concerned that journeys which used steam were selected based on need for speed. We now 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 5 (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 5 (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 5: The distribution of voyage distance by steam and sail in 1860 and 1880



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:

$$Steam_i = \alpha_j + \eta_m + \gamma_t + \gamma_t * \ln(Distance_i) + x_i\varsigma + \omega_{ijmst} \quad (4)$$

where γ_t * ln (Distance$_i$) is the product of year fixed effects γ_t and ln (Distance$_i$) the natural log distance to the origin port. In appendix Figure A10 we plot the coefficients for γ_t * ln (Distance$_i$) 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. In col. 2 we use our estimated distance based on no wind in the IV. In col. 3 we use distance derived from Pascali's (2017) model in the IV. The rows correspond to specifications with increasing controls, starting with month, year, and origin port fixed effects. The third row is our most demanding and includes captain surname fixed effects. The first stage F-stat is large in all cases indicating the instrument is strong. The IV estimate in row 1, 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. In rows 2 and 3 the IV estimates are larger and more similar to OLS when additional controls are added. We think this makes sense as route (i.e. origin) specific trends and captain surnames captain preferences for speed which could influence selection.

Table 2: Instrumental variable estimates for the effect of steam on travel time

	OLS	IV	F-stat	IV	F-stat
		Month, year, and port fes + baseline controls			
		Own		Pascali	
Steam = 1	-1.219***	-0.949***	43.147	-0.857***	49.35
	(0.039)	(0.097)		(0.072)	
		+ Route specific trends			
		Own		Pascali	
Steam = 1	-1.236***	-1.106***	43.902	-1.103***	49.772
	(0.043)	(0.093)		(0.117)	
		+ Captain surname fixed effects			
		Own		Pascali	
Steam = 1	-1.248***	-1.142***	31.389	-1.180***	32.446
	-0.049	0.139		0.128	

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.

Generally, we find economically large effects of steam on travel time. The IV estimate in row 3 imply that steamships reduced travel times by 68%.[17] One implication is that steamships had a

[17] 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.

large effect on Barcelona's trade. To illustrate, we use Pascali (2017)'s estimates for the effect of reduced shipping time on per capita trade. 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 where subscript i is the country in question and j is its $ln(steamtimeij)-ln(sailtimeij)$,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).

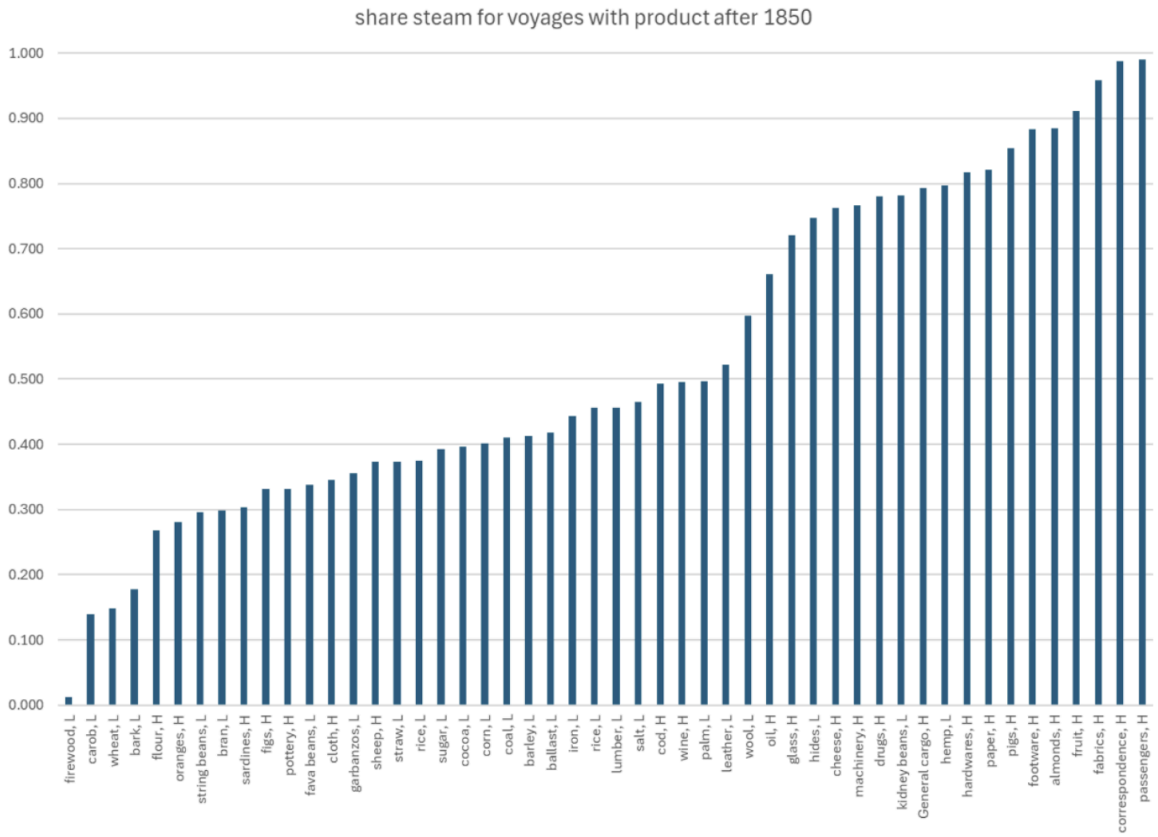
Our estimates suggest for economies like Barcelona, the steamship contributed to even greater reduction in time and therefore contributed to an even greater increase in trade. We find a -0.949 estimate for the log-difference in the duration of voyages between sail and steam. Using Pascali's model, this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

6 STEAMSHIPS AND THE COMPOSITION OF IMPORTS

In this section, we examine the steamship's effect on trade composition. 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 6). 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.

Figure 6: Share steam for voyages with products after 1850



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):

$$\text{Prob}(\text{Product } k \text{ in cargo}_{ijmt}=1) = \alpha_j + \eta_m + \gamma_t + \beta\ \text{Steam}_i + \mu x_i + \varepsilon_{ijmt} \quad (5)$$

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). 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, γ * ln (Distance_i), are the instruments for $Steam_i$. The exclusion restriction requires that over time, greater distance 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.

Figure 7 reports the IV estimates for the effect of steam on the probability of cargoes into Barcelona containing one of the top 24 high value products, including passengers. 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 show that steamships significantly increased the probability that ships carried passengers. This is not surprising since faster ships should increase the willingness to travel. We also find that steamships increase the probability that cargoes included several high value goods, like wine (vino), fabrics (tejidos), footwear (calzado), glass (vidrios), and hardwares (quincalla); Moreover, steam increased several industrial raw materials, like cotton (algodon), wool (lana), hides (cueros), copper (cobre), and paper (papel), and live animals, like pigs (cerdos).

Figure 7: IV estimates for the effect of steam on probability a voyage carries each high-value product.

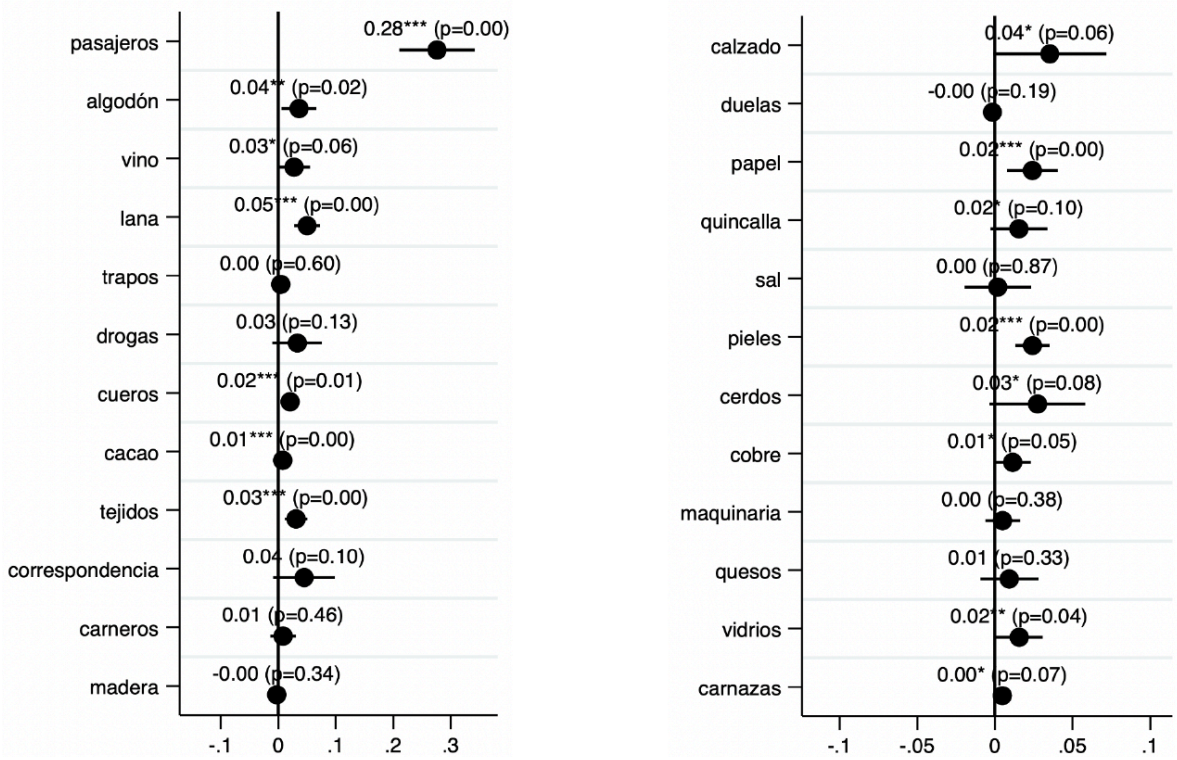
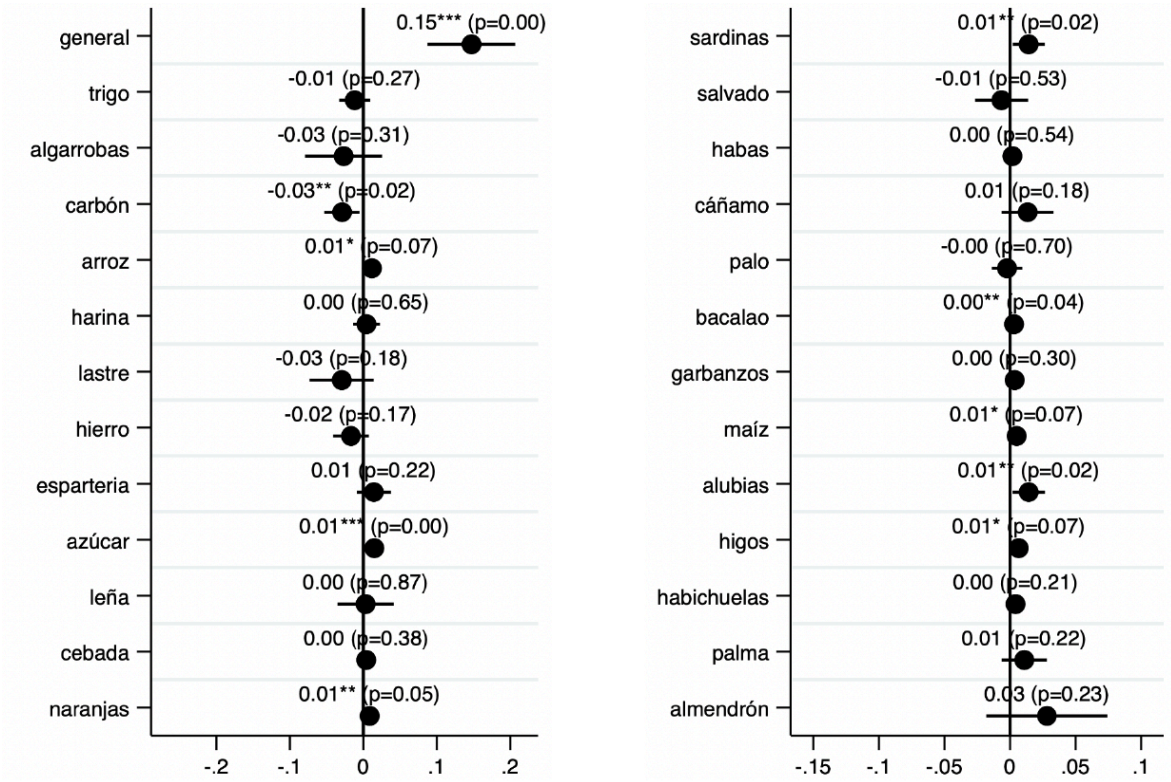


Figure 8 reports the IV estimates for the effect of steam on the probability of cargoes into Barcelona containing one of the top 24 low value products, including general cargoes. We find that steamships increased the probability of general cargoes. This result has many interpretations given the vague nature of the general cargo. One possibility is that steamships increased the variety of goods which got added on as cargo. Concerning low value goods, we generally find that steamships were less likely to increase their probability. The exceptions were

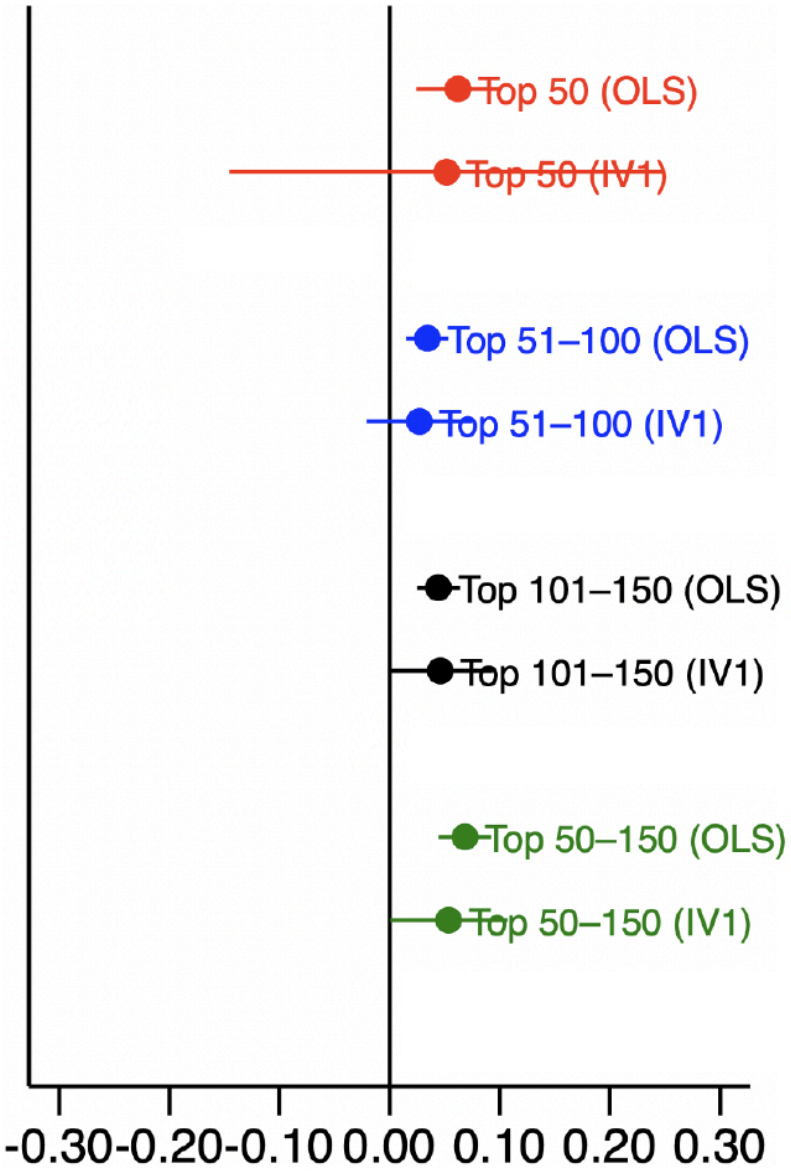
the staples of rice (arroz) and sugar (azucar). In this category we do find that steamships increased the probability of some low value goods which were perishable. Examples are sardines, cod (bacalao), and oranges (naranjas). Another interesting finding is that steamships reduced the probability of cargoes with coal (carbon).

Figure 8: IV estimates for the effect of steam on probability a voyage carries each low-value product.



Steamships also increased the probability that voyages contained new goods. We define new goods as a novel origin-product combination. We identify the first year that a product in the top 150 goods arrived from each origin. If a ship carried a novel origin-product then it is said to have a cargo with a new good. We then estimate the effect of steamships on the probability of a new good being carried. Figure 9 shows OLS and IV estimates for various product groups. New goods from products in the top 50 to 100 were most affected by steam. Steamships therefore increased product variety.

Figure 9: Estimated effect of steamships on the probability a voyage carried a new good



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 68-72 percent. We also show that steamships shifted the composition of trade.

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.

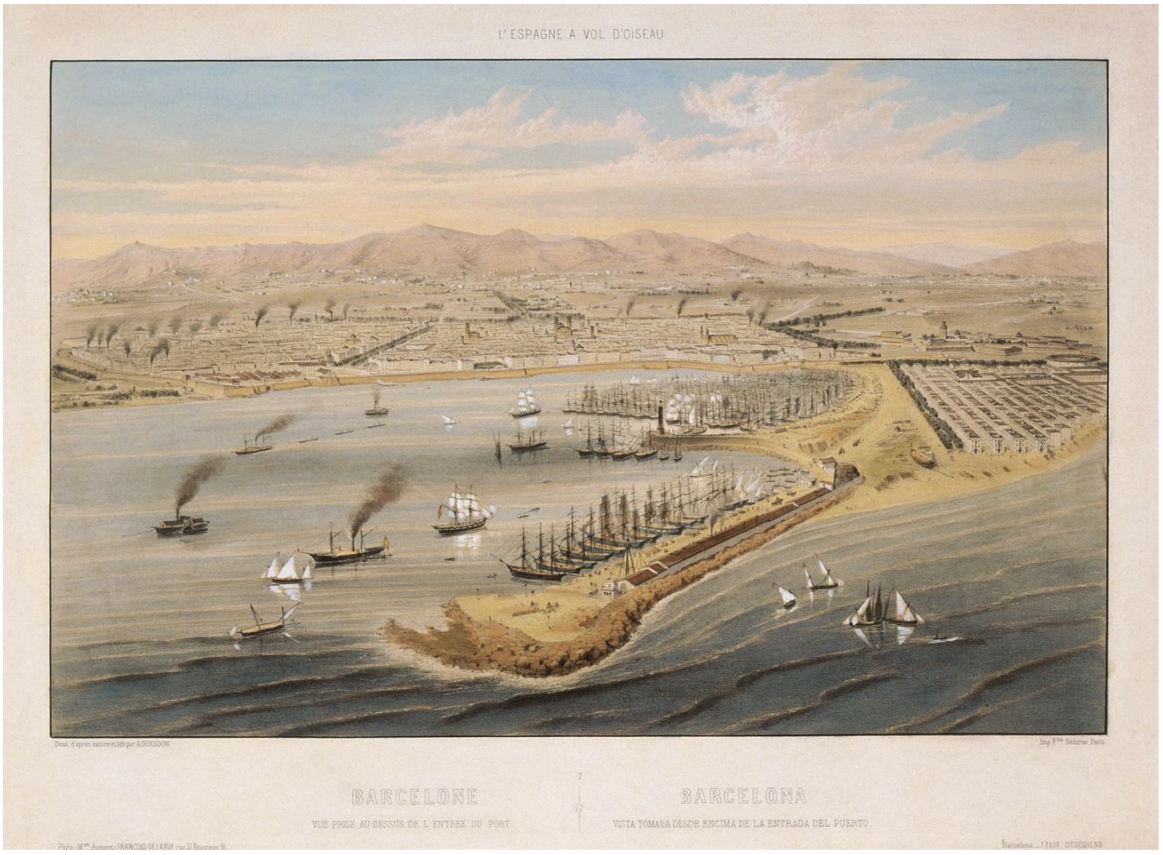
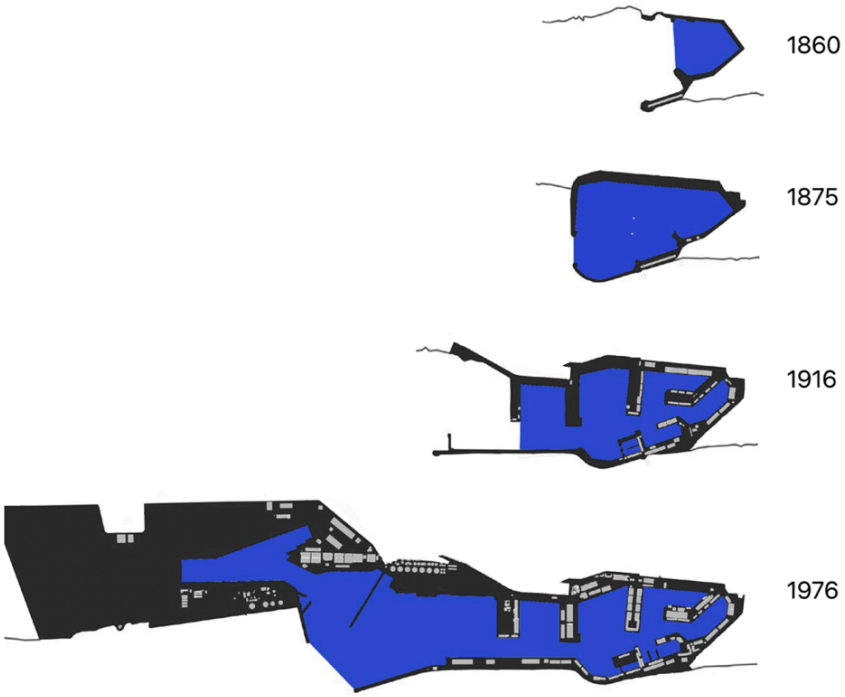


Figure A3. Lithograph showing the new industrial port during the 1888 Universal Exhibition, with the various fleets sent by the participating countries.

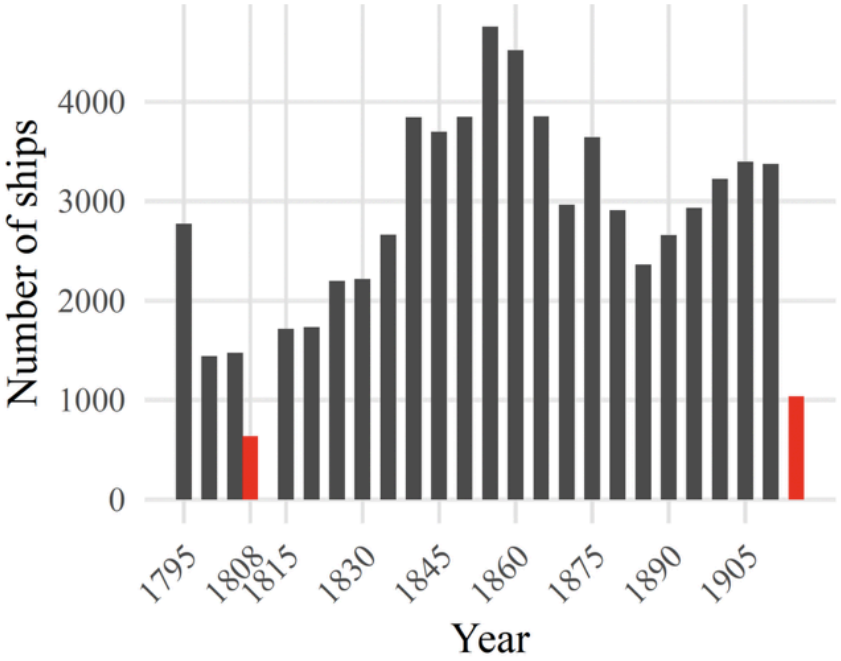


Figure A4. The port of Barcelona in different times



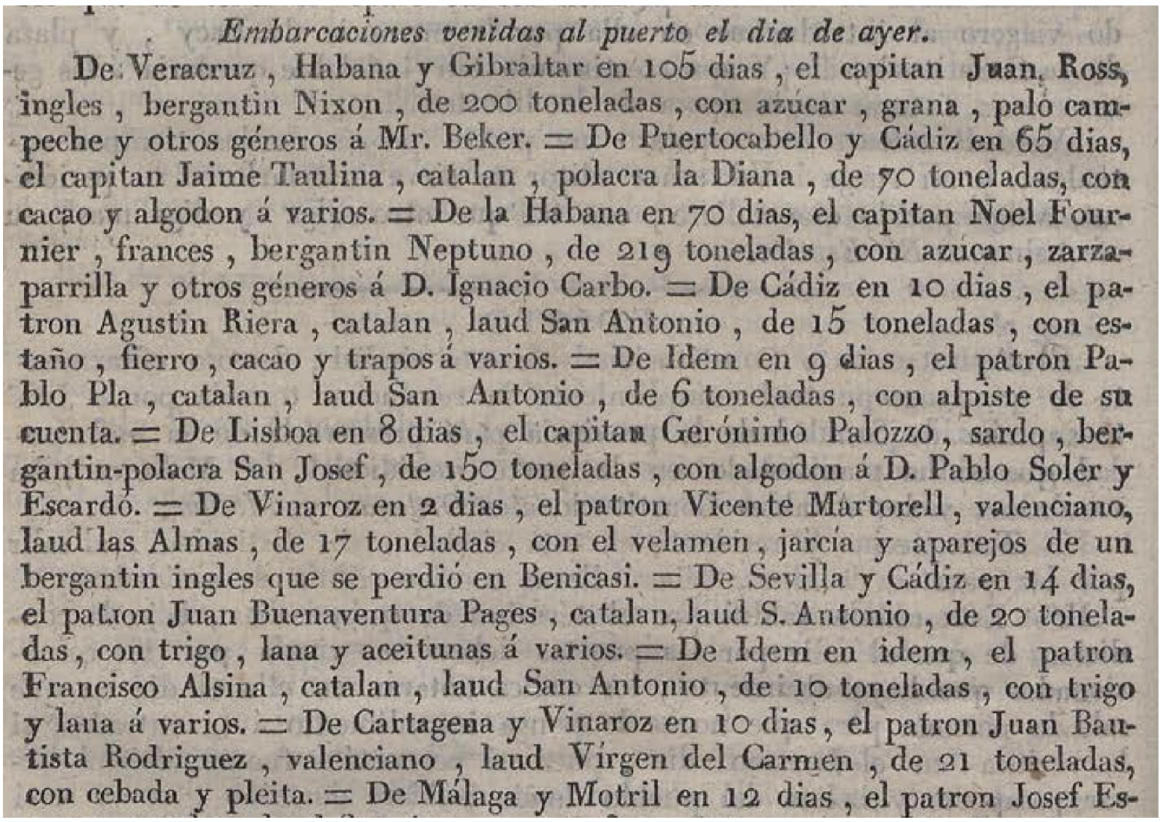
Notes and sources: Since the establishment of the Board of Works in 1869, the Port of Barcelona has expanded through four major development projects and their corresponding construction phases. The 1859 project was implemented between 1869 and 1875; the 1900 project between 1901 and 1925; the 1965 project 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: illustration of Newspaper entry

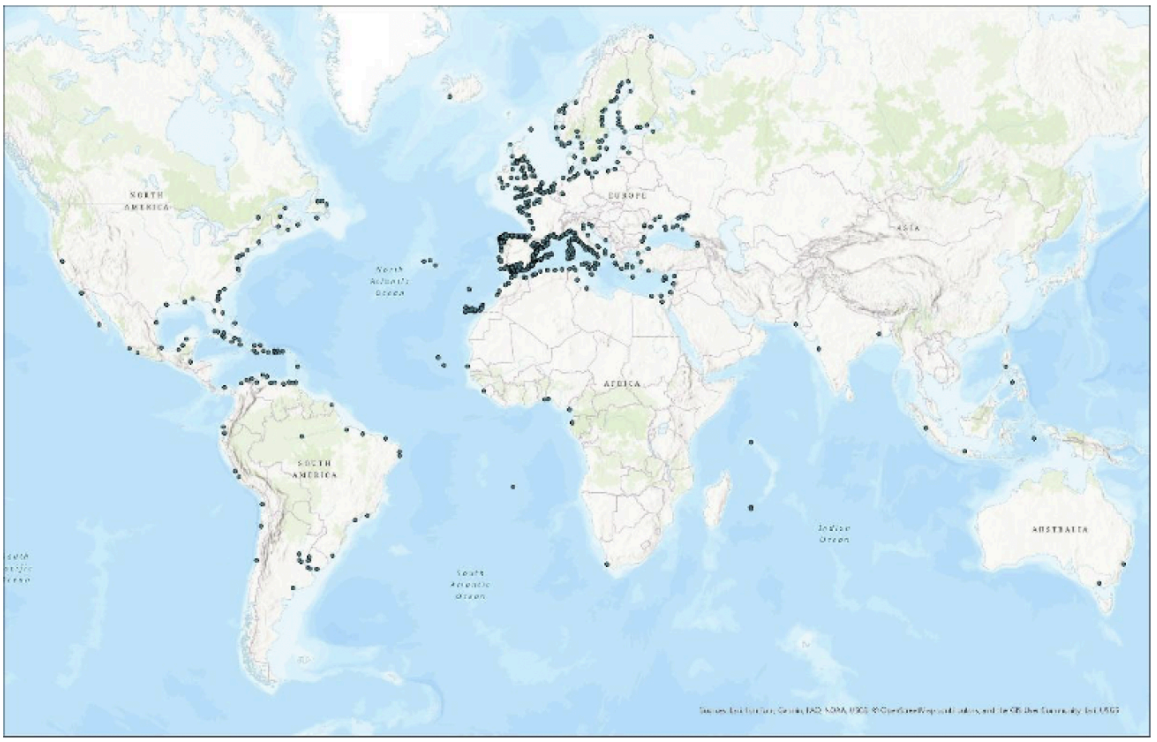


Embarcaciones venidas al puerto el dia de ayer.

De Veracruz, Habana y Gibraltar en 105 dias, el capitan Juan Ross, ingles, bergantin Nixon, de 200 toneladas, con azúcar, grana, palo 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, jarcia 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-

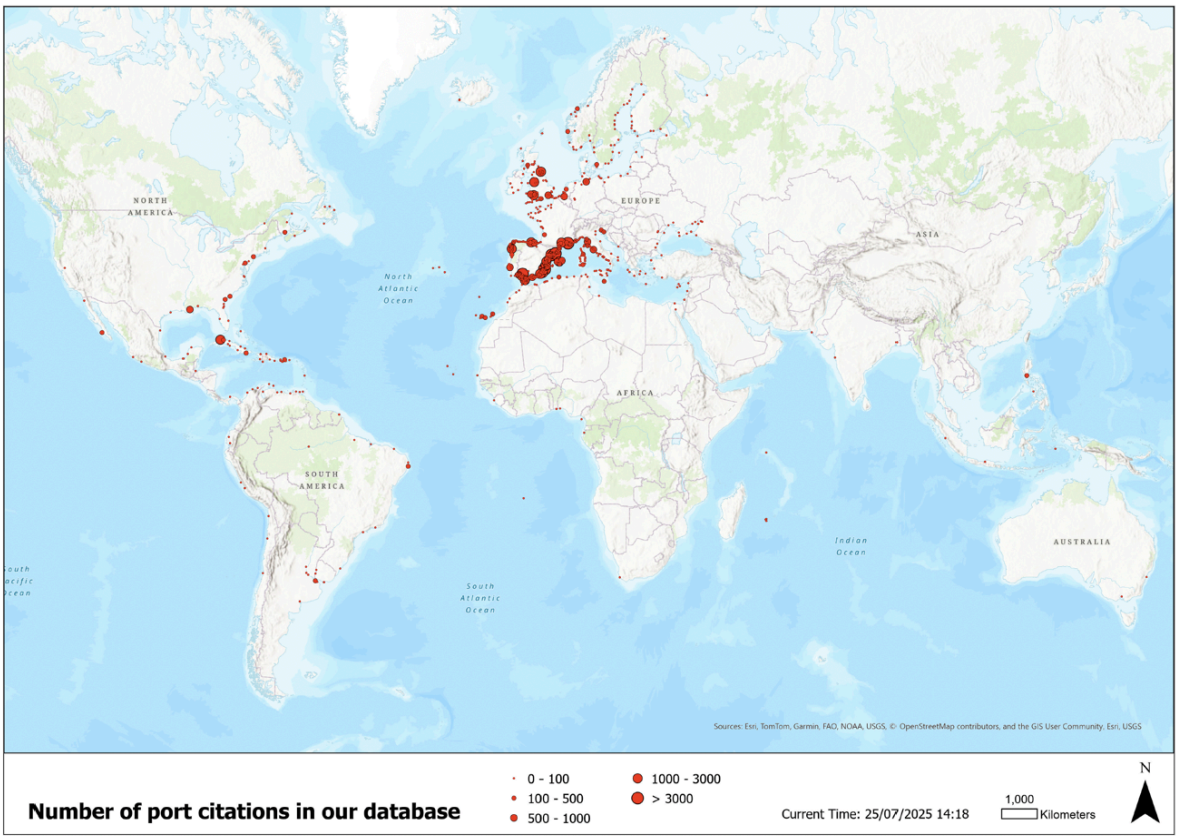
Image, 19 January 1820

Figure A7: Origin Ports



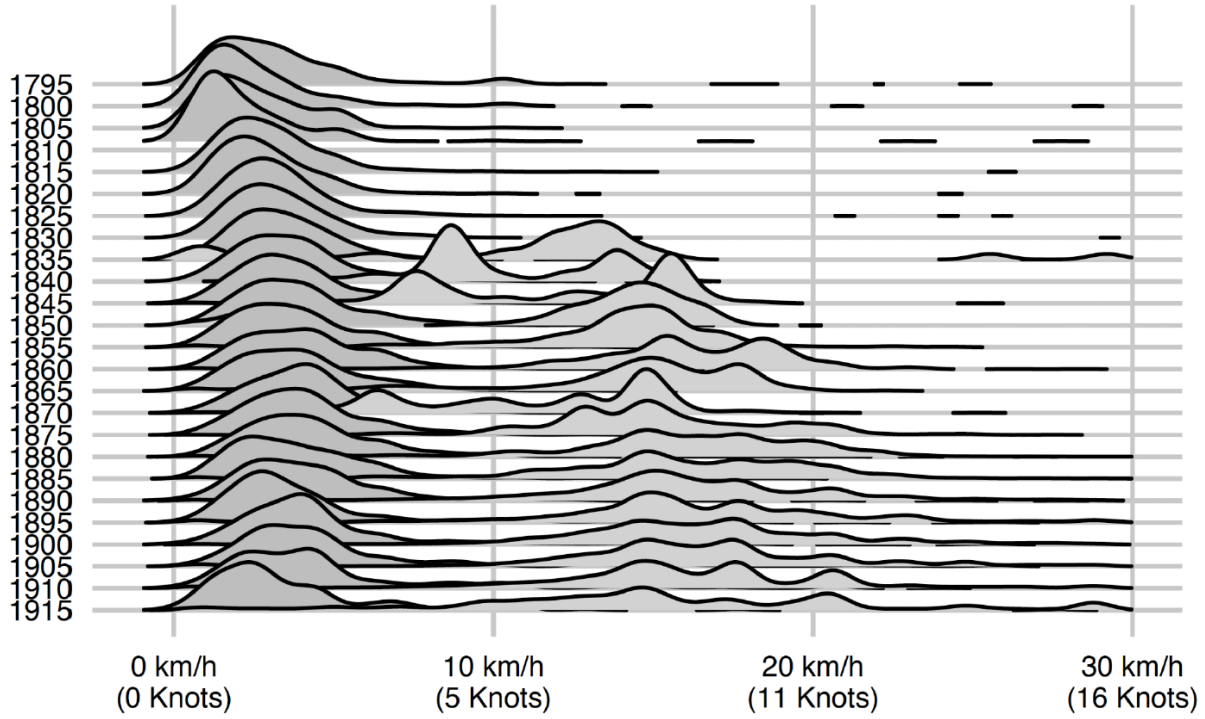
Sources and notes: Authors calculations based on *Diario de Barcelona*.

Figure A8: Number of port citations in our database



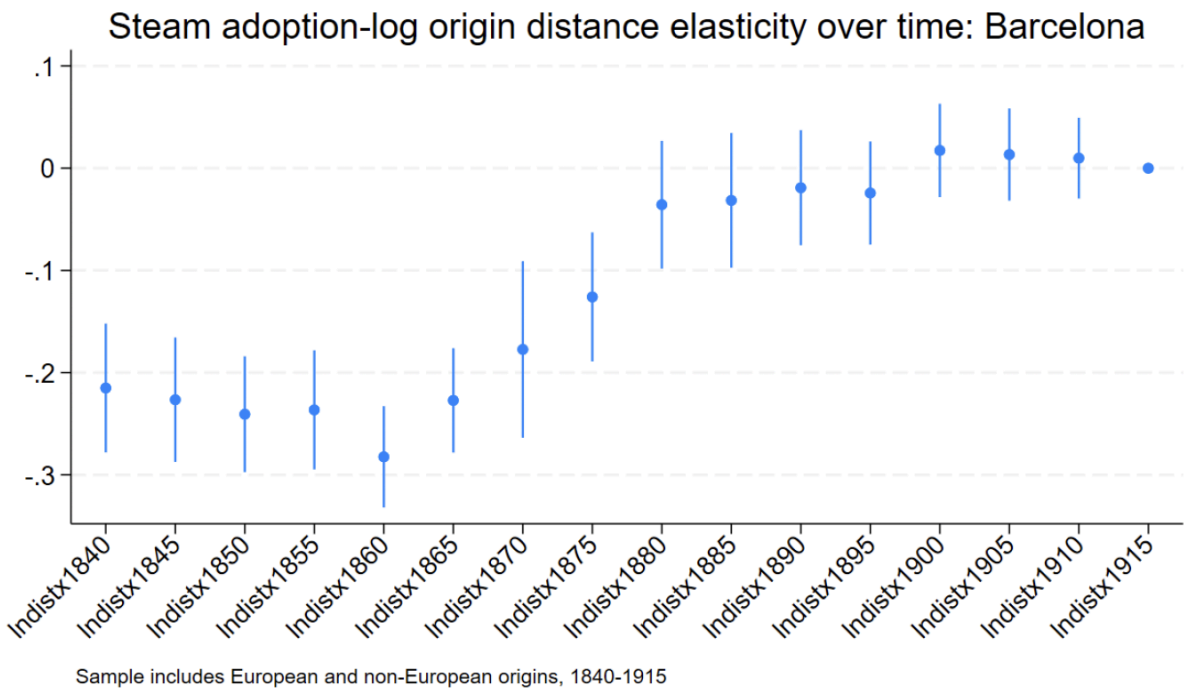
Sources and notes: Authors calculations based on *Diario de Barcelona*.

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



Sample includes European and non-European origins, 1840-1915

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

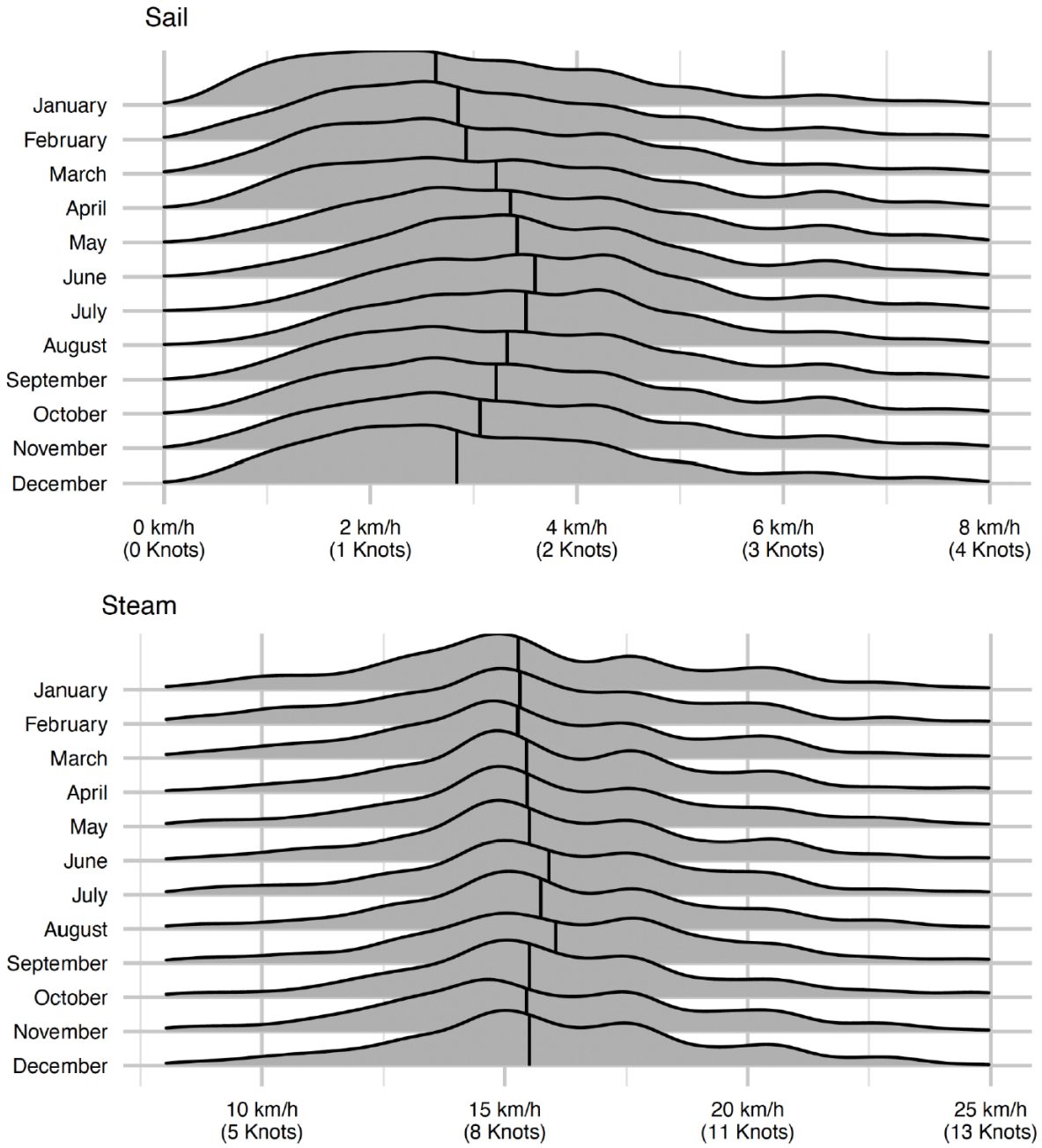


Figure A12: The kernel density of coefficients of variation in travel time for sail and steam voyages from 70 top origin ports

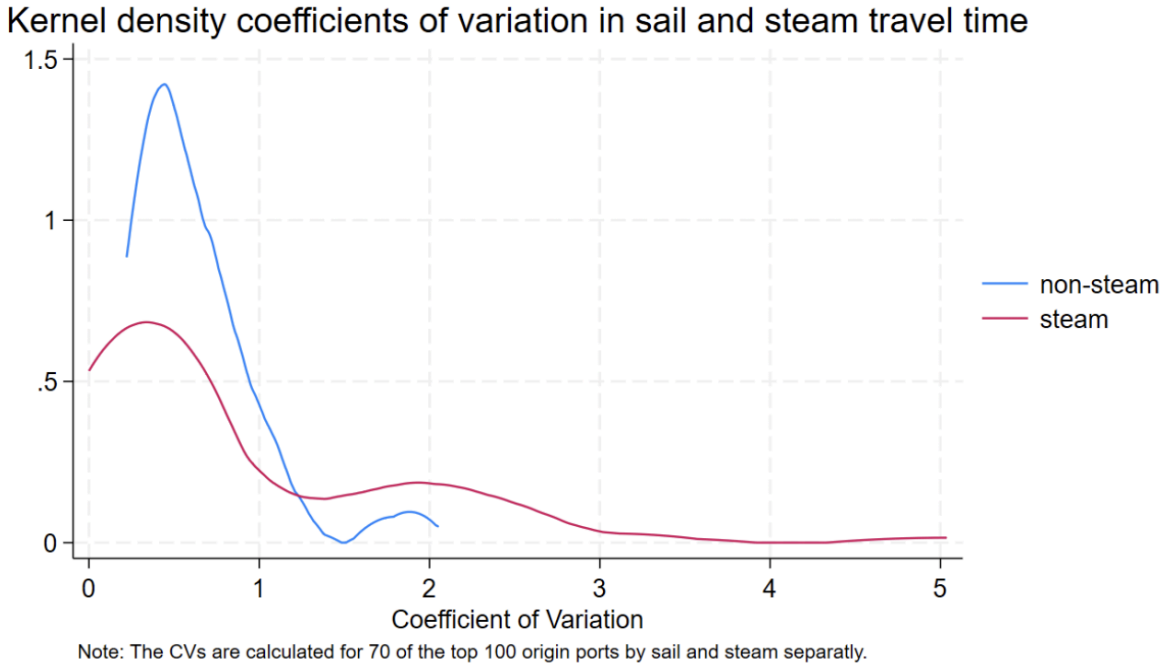
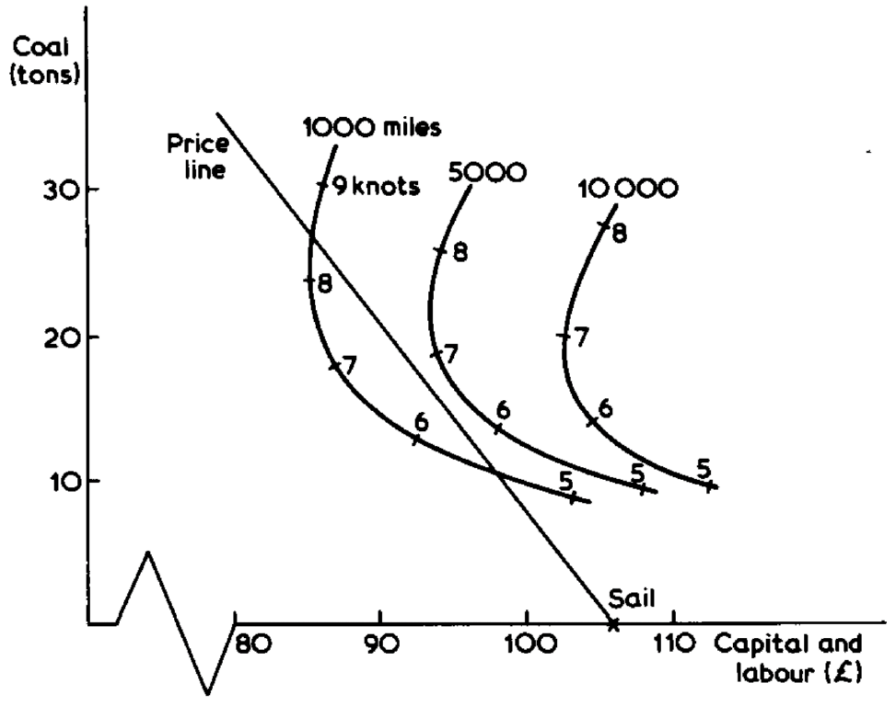


Figure A13: Harley's cost model for steam and sail

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.

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 the effect of steam on travel time including voyages with intermediate stops

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Steam = 1	-1.276***	-1.275***	-1.189***	-1.189***	-1.239***	-1.305***	-1.296***
	(0.034)	(0.034)	(0.042)	(0.043)	(0.047)	(0.066)	(0.067)
Observations	57732	57732	50482	49425	42500	32912	32912
Year fes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month fes	No	Yes	Yes	Yes	Yes	Yes	Yes
Origin fes	No	Yes	Yes	Yes	Yes	Yes	Yes
Ship agent fes	No	No	Yes	Yes	Yes	Yes	Yes
Origin x Month fes	No	No	No	Yes	No	No	No
Master surname fes	No	No	No	No	Yes	Yes	Yes
Route specific trends	No	No	No	No	No	No	Yes
Origin x Surname fes	No	No	No	No	No	Yes	Yes
Stop fes	No	No	Yes	Yes	Yes	Yes	Yes
Ctrl. temp, ton., cap.	No	No	Yes	Yes	Yes	Yes	yes
Avg. effect	-72.085	-72.057	-69.547	-69.547	-71.033	-72.883	-72.638

The dependent variable is the natural log of travel time (measured in days). Temperatures are in degrees Celsius and tonnage x 1000. 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 for 1785 to 1915, while all columns after have data from 1815 to 1915. 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 1.232 log points lower, or 70.83% [=100*(exp(-1.232)-1)] lower.

Table A5: OLS estimates for the effect of steam on travel time splitting the sample into two time periods.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Panel A: Period 1845-1885			
Steam = 1	-1.184***	-1.184***	-1.125***	-1.127***	-1.091***	-1.010***	-1.043***
	(0.046)	(0.045)	(0.049)	(0.050)	(0.040)	(0.084)	(0.072)
Observations	21906	21906	21476	20835	17700	13416	13416
				Panel B: Period 1885-1910			
Steam = 1	-1.288**	-1.289***	-1.188***	-1.209***	-1.305***	-1.339***	-1.361***
	(0.045)	(0.045)	(0.048)	(0.052)	(0.082)	(0.097)	(0.198)
Observations	12889	12889	12674	11989	9722	7492	7492
Year fes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month fes	No	Yes	Yes	Yes	Yes	Yes	Yes
Origin fes	No	Yes	Yes	Yes	Yes	Yes	Yes
Ship agent fes	No	No	Yes	Yes	Yes	Yes	Yes
Origin x Month fes	No	No	No	Yes	No	No	No
Master surname fes	No	No	No	No	Yes	Yes	Yes
Route specific trends	No	No	No	No	No	No	Yes
Origin x Surname fes	No	No	No	No	No	Yes	Yes
Ctr. temp. ton., cap.	No	No	Yes	Yes	Yes	Yes	Yes

The dependent variable is the natural log of travel time (measured in days). Temperatures are in degrees Celsius and tonnage x 1000. 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 for 1785 to 1915, while all columns after have data from 1815 to 1915. 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 1.232 log points lower, or 70.83% [=100*(exp(-1.232)-1)] lower.

Table A6: OLS estimates for the effect of steam on travel time splitting the sample by Spanish and non-Spanish origin ports.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Panel A: Excluding Spanish ports			
Steam = 1	-1.173***	-1.175***	-1.074***	-1.064***	-1.069***	-1.096***	-1.081***
	(0.041)	(0.041)	(0.029)	(0.030)	(0.048)	(0.053)	(0.065)
Observations	14586	14586	13285	12808	8564	6161	6261
				Panel B: Only Spanish ports			
Steam = 1	-1.278***	-1.277***	-1.257***	-1.250***	-1.302***	-1.336***	-1.332***
	(0.041)	(0.041)	(0.061)	(0.062)	(0.069)	(0.087)	(0.085)
Observations	25170	25170	21460	21223	19348	16309	16309
Year fes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month fes	No	Yes	Yes	Yes	Yes	Yes	Yes
Origin fes	No	Yes	Yes	Yes	Yes	Yes	Yes
Ship agent fes	No	No	Yes	Yes	Yes	Yes	Yes
Origin x Month fes	No	No	No	Yes	No	No	No
Master surname fes	No	No	No	No	Yes	Yes	Yes
Route specific trends	No	No	No	No	No	No	Yes
Origin x Surname fes	No	No	No	No	No	Yes	Yes
Ctr. temp. ton., cap.	No	No	Yes	Yes	Yes	Yes	Yes
AE excl. Spanish ports	-69.056	-69.118	-65.836	-65.492	-65.664	-66.579	-66.074
AE Spanish ports	-72.140	-72.112	-71.549	-71.349	-72.801	-73.710	-73.605

The dependent variable is the natural log of travel time (measured in days). Temperatures are in degrees Celsius and tonnage x 1000. 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 for 1785 to 1915, while all columns after have data from 1815 to 1915. 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 1.232 log points lower, or 70.83% [=100*(exp(-1.232)-1)] lower.

Appendix 1: TYPOLOGY OF SHIPS

Definitions below are taken from the Official list of warships and merchant vessels of the Spanish Navy (*Lista official de los buques de Guerra y mercantes de la marina Española*), published by the *Ministerio de Marina*. We use the edition of 1900 (pp. vii-viii). Names in english are reported in brackets.

Balandra [Sloop]. Decked vessel that has a single mast with a gaff sail and a jib.

Bergantin [Brig]. Two-masted vessel (main and foremast) with its bowsprit, square sails, stays, jibs, etc.

Bergantin-barca [Barquentine/Bark]. The brig that carries a third mast (mizzen). It is also called a bark-brig or brig-corvette (*Brik-barca bergantin-corbeta*).

Bergantin-goleta [Hermaphrodite Brig / Brig-Schooner]. The brig that uses a schooner rig on the mainmast. There are also those with two topsails.

Bombarda [Bomb Vessel]. Two-masted vessel, but without tops; one triple-masted, almost at the center, and another at the stern: in addition to the square sails, it can set a gaff sail and three jibs.

Corbeta [Corvette]. The same as the bark-brig (*brik-barca*), brig-bark (*bergantin-barca*), and brig-corvette (*begantin-corbeta*).

Falucho [Felucca]. A vessel whose main rig consists of a single mast, heavily inclined toward the bow, on which a lateen sail is set. Some carry a small mizzen mast and a jibboom for a jib.

Fragata [Frigate]. A square-rigged ship with three masts and tops, with the same rigging as the ancient ships of the line.

Goleta [Schooner]. Vessel with two masts (and even three) with gaff sails; on the foremast, it usually carries a topmast to set topsails and topgallants. If the mainmast is of the same form, it is called a two-topsail schooner (*goleta de dos gavias*).

Jabeque [Xebec]. Mediterranean vessel that navigates by sail and oar; it has three masts, the foremast with a lateen rig, the mainmast almost vertical, and the mizzen with a gaff sail.

Laúd [Laud]. A small vessel in the Mediterranean, long and narrow, similar to a felucca (*falucho*), without a jib, quarters, or mizzen. It is also used for fishing.

Lorcha [Lorcha]. A Chinese vessel used in coastal navigation: it has two masts and uses mat sails, divided horizontally by parallel slats or small yards.

Lugre [Lugger]. Small boat from the North coast of Spain with three masts and lug sails (tarquinas), over which it usually carries some flying topsails.

Místico [Mistico]. Vessel with two or three masts and a rig similar to a lateen rig. It uses a fixed bowsprit with a jibboom, and its mizzen is the same as those of xebecs and feluccas. It is native to the Mediterranean.

Mistico-goleta [Mistico-Schooner]. The *mistico* whose mainmast is like that of a schooner.

Pailebot/*Pailebote* [Pilot Boat]. Name taken from the English “Pilot’s boat”. This name is given to a small schooner, without topsails, flush-decked and sleek.

Panco [Panco]. A vessel from the Philippines, larger than the *pontin*, which usually uses outriggers and mat sails on three masts distributed from stern to bow.

Patache [Patache]. Coastal vessel from the North coast of Spain, with two masts without tops or cross-trees; the mainmast rigged as a schooner, and the foremast as a polacre, but without a topgallant.

Polacra [Polacre]. Square-rigged vessel with two “pole” (triple) masts without tops or cross-trees and with the same sails as brigs and some have a schooner rig on the mainmast and are called Polacre-schooners (*polacras goletas*).

Pontin [Pontin]. Vessel from the Philippines used in coastal trade.

Queche [Ketch]. In some places, called a *quechemarin*.

Quechemarin [Quechemarin]. Vessel from the North coast of Spain, with two masts, lug sails (al tercio), and some with a small mizzen at the stern and jibs on a jibboom at the bow.

Tartana [Tartane]. Boat used in the Mediterranean, with a vertical mast in its center and another small mast at the stern, on which they usually set a small mizzen, and a jibboom at the bow for jibs.

Appendix 2: Modeling sailing distance using winds

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:

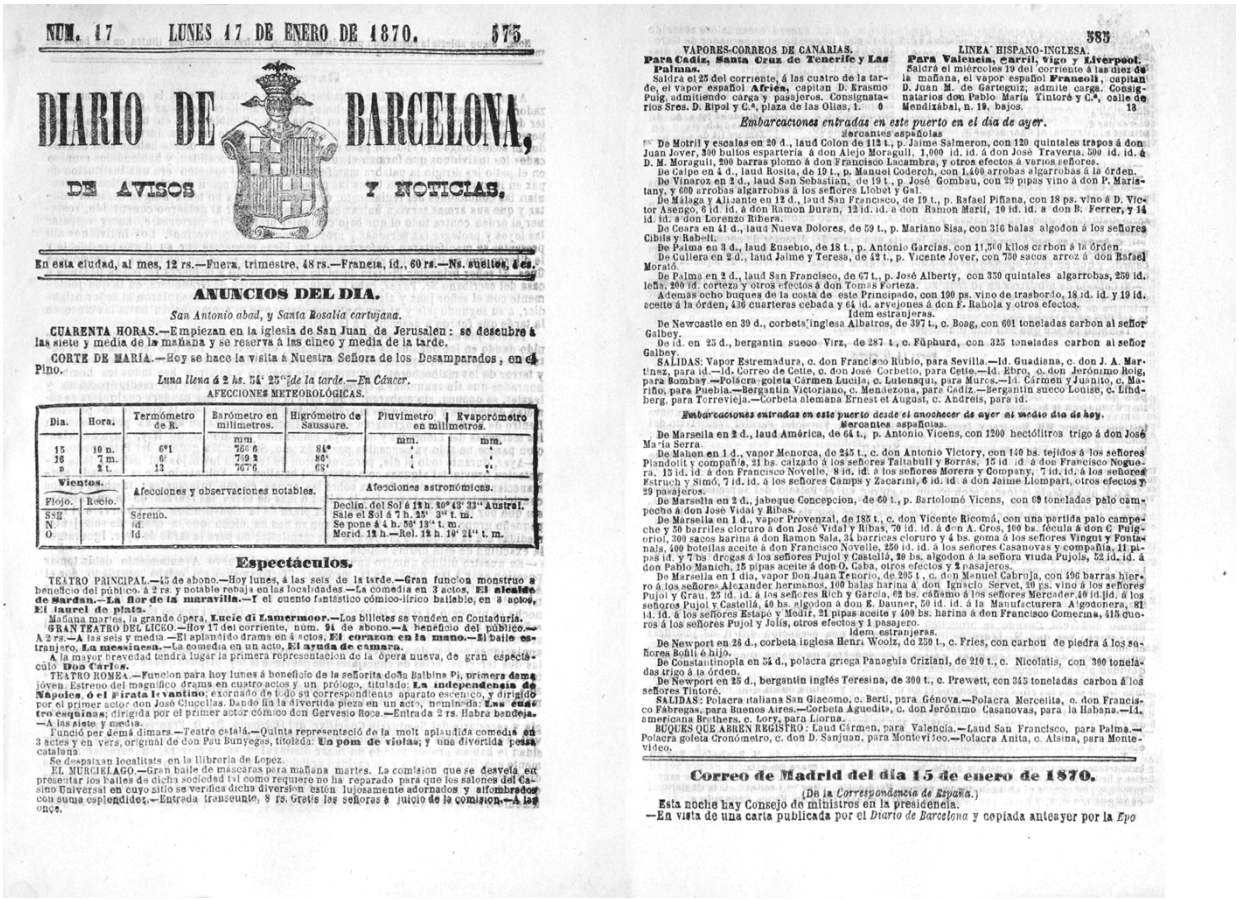
$$\text{Corrected wind direction} = (\text{Wind direction} + 180) / 360 \quad (1)$$

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:

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

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* = $1 + \cos(\Delta\theta \text{ wind flow}) * 0.25$, reflecting the alignment between wind and flow directions; *Flow coefficient* = $0.75 + |\cos(\Delta\theta \text{ line flow})| * 0.25$, 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.

Appendix 3: MAIN SOURCE OF DATA



NUM. 17 LUNES 17 DE ENERO DE 1870. 575

DIARIO DE BARCELONA,

DE AVISOS Y NOTICIAS.

En esta ciudad, al mes, 12 rs.—Fuera, trimestre, 48 rs.—Francia, id., 60 rs.—Ns. sueltos, &c.

ANUNCIOS DEL DIA.

San Antonio abad, y Santa Rosalía cartujana.

CUARENTA HORAS.—Empiezan en la iglesia de San Juan de Jerusalen: se descubre á las siete y media de la mañana y se reserva á las cinco y media de la tarde.

CORTE DE MARÍA.—Hoy se hace la visita á Nuestra Señora de los Desamparados, en el Pino.

Luna llena á 2 hs. 54' 25" de la tarde.—En Cáncer.

AFECCIONES METEOROLÓGICAS.

Dia.	Hora.	Termómetro de R.	Barómetro en milímetros.	Higrómetro de Saussure.	Pluvímetro en milímetros.	Evaporómetro en milímetros.
		núm			mm.	mm.
15	10 n.	6°1	760 6	84°	"	"
16	7 m.	6°	760 2	86°	"	"
»	2 t.	13	760 6	68°	"	"

Vientos.		Afecciones y observaciones notables.	Afecciones astronómicas.
Flojo.	Rocío.		
SSE		Sereno.	Declin. del Sol á 12 h. 20° 49' 33" Austral.
N.		id.	Sale el Sol á 7 h. 25' 3" t. m.
O.		id.	Se pone á 4 h. 55' 13" t. m.
			Merid. 12 h.—Rel. 12 h. 19' 21" t. m.

Espectáculos.

TEATRO PRINCIPAL.—45 de abono.—Hoy lunes, á las seis de la tarde.—Gran funcion monstruo á beneficio del público, á 2 rs. y notable rebaja en las localidades.—La comedia en 3 actos, **El alcalde de sardan.—La flor de la maravilla.**—Y el cuento fantástico cómico-lírico bailable, en 4 actos, **El laurel de plata.**

Mañana martes, la grande ópera, **Lucie di Lamermoor.**—Los billetes se venden en Contaduría.

GRAN TEATRO DEL LICEO.—Hoy 17 del corriente, num. 91 de abono.—A beneficio del público.—A 2 rs.—A las seis y media.—El aplaudido drama en 4 actos, **El corazon en la mano.**—El baile estranjero. **La messinesa.**—La comedia en un acto, **El ayuda de cámara.**

A la mayor brevedad tendrá lugar la primera representacion de la ópera nueva, de gran espectáculo **Don Carlos.**

TEATRO ROMEA.—Funcion para hoy lunes á beneficio de la señorita doña Balbina Pi, primera dama jóven. Estreno del magnífico drama en cuatro actos y un prólogo, titulado: **La independencia de Nápoles, ó el Pirata levantino**; exornado de todo su correspondiente aparato escénico, y dirigido por el primer actor don José Clucellas. Dando fin la divertida pieza en un acto, nominada: **Las cuatro esquinas**; dirigida por el primer actor cómico don Gervasio Rosa.—Entrada 2 rs. Habrá bandeja.—A las siete y media.

Funció per demá dimars.—Teatro catalá.—Quinta representació de la molt aplaudida comedia en 3 actes y en vers, original de don Pau Bunyeges, titolada: **Un pom de violas**; y una divertida pessa catalana.

Se despatxan localitats en la llibreria de Lopez.

EL MURCIÉLAGO.—Gran baile de máscaras para mañana martes. La comision que se desvela en presentar los bailes de dicha sociedad tal como requiere no ha reparado para que los salones del Casino Universal en cuyo sitio se verifica dicha diversion estén lujosamente adornados y alfombrados con suma esplendidez.—Entrada trascendo, 8 rs. Gratis los señores á juicio de la comision.—A las once.

585

VAPORES-CORREOS DE CANARIAS.

Para Cádiz, Santa Cruz de Tenerife y Las Palmas.

Saldrá el 25 del corriente, á las cuatro de la tarde, el vapor español **Africa**, capitan D. Erasmo Puig, admitiendo carga y pasajeros. Consignatarios los Sres. D. Ripol y C.ª, plaza de las Olas, 1. 0

LINEA HISPANO-INGLESA.

Para Valencia, Carril, Vigo y Liverpool.

Saldrá el miércoles 19 del corriente á las nueve de la mañana, el vapor español **Francolí**, capitan D. Juan M. de Garteguiz, admite carga. Consignatarios don Pablo María Timoré y C.ª, calle de Mendizábal, n. 19, bajos. 13

Embarcaciones entradas en este puerto en el dia de ayer.

Mercantes españolas

De Motril y escalas en 20 d., laud Colon de 112 t., p. Jaime Salmeron, con 120 quintales trapos á don Juan Jover, 200 bultos esparteria á don Alejo Moragull, 1,000 id. id. á don José Travesa, 500 id. id. á D. M. Moragull, 200 barras plomo á don Francisco Lacambra, y otros efectos á varios señores.

De Calpe en 4 d., laud Rosita, de 19 t., p. Manuel Coderch, con 1,400 arrobas algarrobas á la órden.

De Vinaroz en 3 d., laud San Sebastian, de 19 t., p. José Gombau, con 29 pipas vino á don P. Maristany, y 600 arrobas algarrobas á los señores Llobet y Gal.

De Málaga y Alicante en 12 d., laud San Francisco, de 19 t., p. Rafael Piñana, con 18 ps. vino á D. Victor Asenjo, 6 id. id. á don Ramon Duran, 12 id. id. á don Ramon Marti, 19 id. id. á don B. Ferrer, y 14 id. id. á don Lorenzo Ribera.

De Ceara en 41 d., laud Nueva Dolores, de 59 t., p. Mariano Sisa, con 316 balas algodon á los señores Cibils y Rabell.

De Palma en 3 d., laud Eusebio, de 18 t., p. Antonio Garcias, con 11,500 kilos carbon á la órden.

De Cullera en 2 d., laud Jaime y Teresa, de 42 t., p. Vicente Jover, con 750 sacos arroz á don Rafael Morató.

De Palma en 2 d., laud San Francisco, de 67 t., p. José Alberty, con 350 quintales algarrobas, 250 id. leña, 200 id. corteza y otros efectos á don Tomas Forteza.

Ademas ocho buques de la costa de este Principado, con 190 ps. vino de trasbordo, 18 id. id. y 19 id. aceite á la órden, 436 cuarteras cebada y 64 id. arvejones á don F. Rahola y otros efectos.

Idem estranjeras.

De Newcastle en 30 d., corbeta inglesa Albatros, de 397 t., c. Boag, con 601 toneladas carbon al señor Galbey.

De id. en 25 d., bergantin sueco Virz, de 287 t., c. Fúphurd, con 325 toneladas carbon al señor Galbey.

SALIDAS: Vapor Estremadura, c. don Francisco Rubio, para Sevilla.—Id. Guadiana, c. don J. A. Martinez, para id.—Id. Correo de Cette, c. don José Corbetto, para Cette.—Id. Ebro, c. don Jerónimo Roig, para Bombay.—Polacra goleta Cármen Lucila, c. Lutensqui, para Mures.—Id. Cármen y Juanito, c. Mariño, para Puebla.—Bergantin Victoriano, c. Mendiezona, para Cádiz.—Bergantin sueco Louise, c. Lindberg, para Torrevieja.—Corbeta alemana Ernest et August, c. Andreis, para id.

Embarcaciones entradas en este puerto desde el anochecer de ayer al medio dia de hoy.

Mercantes españolas.

De Marsella en 2 d., laud América, de 64 t., p. Antonio Vicens, con 1200 hectólitros trigo á don José María Serra.

De Mahon en 1 d., vapor Menorca, de 245 t., c. don Antonio Victory, con 140 bs. tejidos á los señores Piandolfi y compañía, 21 bs. calzado á los señores Taltabull y Borras, 15 id. id. á don Francisco Noguera, 13 id. id. á don Francisco Novelle, 8 id. id. á los señores Morera y Company, 7 id. id. á los señores Estruch y Simó, 7 id. id. á los señores Camps y Zacarini, 6 id. id. á don Jaime Llompart, otros efectos y 29 pasajeros.

De Marsella en 2 d., jabeque Concepcion, de 60 t., p. Bartolomé Vicens, con 60 toneladas palo campeche á don José Vidal y Ribas.

De Marsella en 1 d., vapor Provenzal, de 185 t., c. don Vicente Ricomá, con una partida palo campeche y 70 barriles cloruro á don José Vidal y Ribas, 70 id. id. á don A. Cros, 100 bs. fécula á don C. Puigoriol, 300 sacos harina á don Ramon Sala, 34 barriles cloruro y 4 bs. goma á los señores Vinyet y Fontanals, 400 botellas aceite á don Francisco Novelle, 250 id. id. á los señores Casanovas y compañía, 11 pipas id. y 7 bs. drogas á los señores Pujol y Castelló, 30 bs. algodon á la señora viuda Pujols, 52 id. id. á don Pablo Manich, 15 pipas aceite á don O. Caba, otros efectos y 2 pasajeros.

De Marsella en 1 dia, vapor Don Juan Tenorio, de 295 t., c. don Manuel Cabruja, con 196 barras hierro á los señores Alexander hermanos, 100 balas harina á don Ignacio Servet, 20 ps. vino á los señores Pujol y Grau, 25 id. id. á los señores Rich y García, 62 bs. cáñamo á los señores Mercader, 40 id. id. á los señores Pujol y Castelló, 40 bs. algodon á don E. Dauner, 50 id. id. á la Manufacturera Algodonera, 81 id. id. á los señores Estapé y Modif, 21 pipas aceite y 400 bs. harina á don Francisco Comerma, 415 cuoros á los señores Pujol y Jolis, otros efectos y 1 pasajero.

Idem estranjeras.

De Newport en 26 d., corbeta inglesa Henri Woolz, de 220 t., c. Fries, con carbon de piedra á los señores Bofill é hijo.

De Constantinopla en 54 d., polacra griega Panaghia Criziani, de 210 t., c. Nicolatis, con 300 toneladas trigo á la órden.

De Newport en 25 d., bergantin inglés Teresina, de 300 t., c. Prewett, con 345 toneladas carbon á los señores Tintoré.

SALIDAS: Polacra italiana San Giacomo, c. Berú, para Génova.—Polacra Mercelita, c. don Francisco Fábregas, para Buenos Aires.—Corbeta Aguedita, c. don Jerónimo Casanovas, para la Habana.—Id. americana Brothers, c. Lory, para Liorna.

BUQUES QUE ARRIBEN REGISTRO: Laud Cármen, para Valencia.—Laud San Francisco, para Palma.—Polacra goleta Cronómetro, c. don D. Sanjuan, para Montevideo.—Polacra Anita, c. Alsina, para Montevideo.

Correo de Madrid del dia 15 de enero de 1870.

(De la *Correspondencia de España.*)

Esta noche hay Consejo de ministros en la presidencia.

—En vista de una carta publicada por el *Diario de Barcelona* y copiada anteayer por la *Epo*

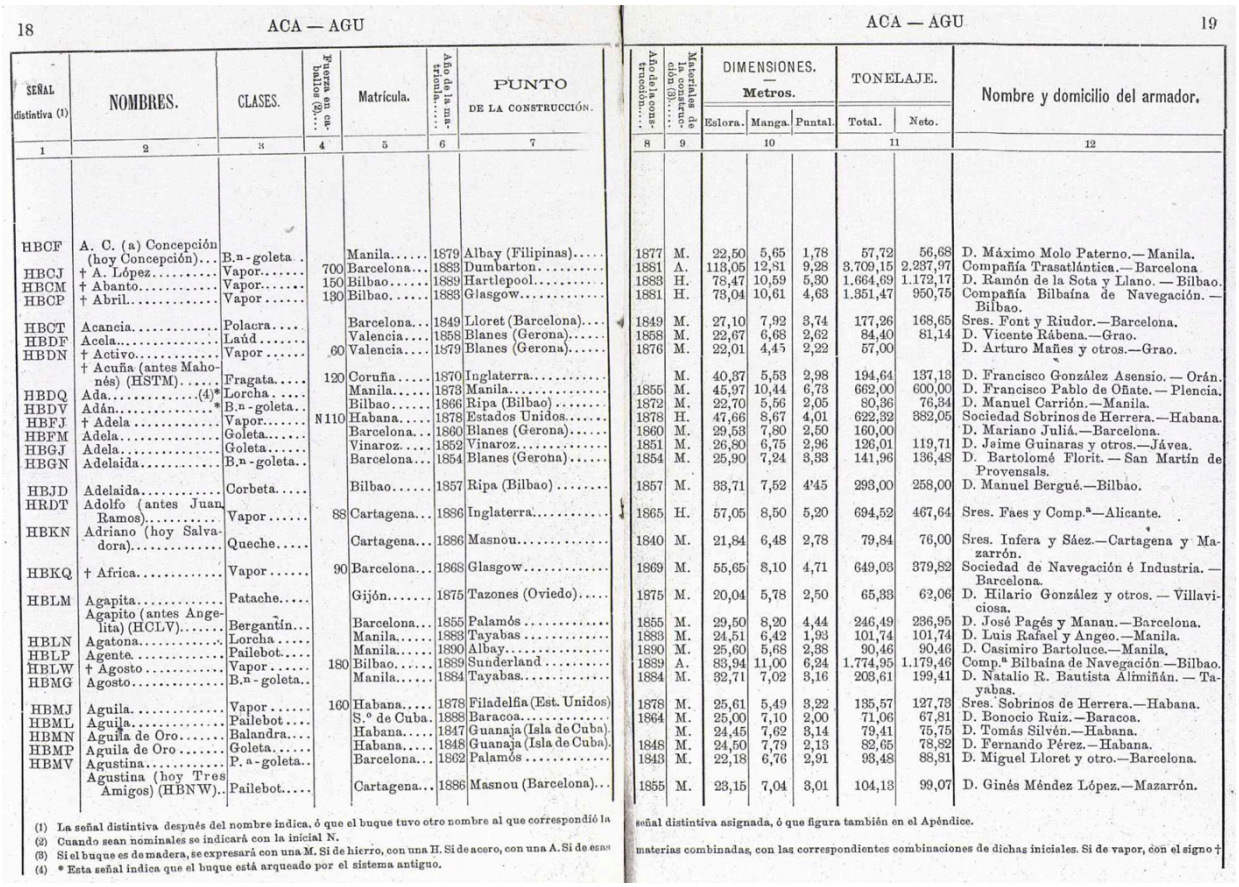
We linked arrivals and departures using a matching algorithm designed to pair each recorded departure with the most plausible corresponding entry into the port of Barcelona. Exits detailed ship's type, ship's name, captain name, new destination and cargo. The algorithm relied primarily on two identifiers recorded in the registers: the ship's type and the ship's name. For each departure record, the procedure searched the set of entry records for observations sharing these characteristics and then selected the entry whose date was closest to the entry date. In other words, the algorithm restricted the pool of candidate matches to entries reporting the same vessel type and ship name as the departure record and, among these candidates, it identified the entry whose date was nearest to the departure date. Additionally, the captain's surname (also recorded in the exits) was used as an additional consistency check. Because captains could change between voyages (or family tides owned the ships), the surname was not imposed as a strict matching requirement, but it served to verify matches where possible and to flag potential ambiguities in cases where the other identifiers were not sufficient. Finally, we checked manually all the matches to reconstruct likely arrival-departure pairs.

We constructed these links for the years 1840, 1850, 1860, and 1870, as after 1880 cargo information was no longer fully recorded (only general cargo or ballast was reported). Unfortunately, in contrast to entries, departures were not consistently documented in the newspapers, likely reflecting a greater interest in imports than exports. In total, XYZ departures were reported for these four benchmark years, of which we successfully linked XYZ. These cases most likely correspond to ships for which the entry into the port of Barcelona is recorded

but the corresponding departure cannot be identified. There is also limited coverage in January of each year, as entries for ships that likely arrived in the preceding month (December) are missing. Similarly, departures occurring in January of the following year are not observed (for example, ships entering in December 1840 whose departures occurred in January or February 1841). It is also possible that some ships were reported collectively (e.g., “8 ships arriving from Levante”). In such cases, although departures may be recorded individually, the entries lack ship-level details, so we cannot link entries and exits.

Appendix 4: OFFICIAL LIST OF SPANISH VESSELS

We augmented the master dataset by linking it to an additional source: the "Official List of Warships and Merchant Vessels of the Spanish Navy" (*Lista oficial de los buques de guerra y mercantes de la marina Española*). Published by the Ministry of the Navy, this official government register catalogued Spanish vessels (both military and commercial) exceeding 50 tons. The volumes provide detailed technical and administrative information, including vessel name, classification, tonnage, construction characteristics, registration details, and ownership records. An example of the source is shown in the image below. This publication functioned as standard reference work for naval authorities, port officials, and mariners, facilitating ship identification and the correct interpretation of signal flags. As noted in the volumes themselves, "for the most part, if not generally, these vessels are well known to seafarers who frequent the coasts of the Peninsula" (List of 1884, p. vi).



18 ACA — AGU

SEÑAL distintiva (1)	NOMBRES.	CLASES.	Fuerza en caballos (2)...	Matrícula.	Año de la matrícula.....	PUNTO DE LA CONSTRUCCIÓN.
1	2	3	4	5	6	7
HBCF	A. C. (a) Concepción (hoy Concepción)....	B.n-goleta		Manila.....	1879	Albay (Filipinas).....
HBCJ	† A. López.....	Vapor.....	700	Barcelona...	1883	Dumbarton.....
HBCM	† Abanto.....	Vapor.....	150	Bilbao.....	1889	Hartlepool.....
HBCP	† Abril.....	Vapor.....	130	Bilbao.....	1883	Glasgow.....
HBCT	Acancia.....	Polacra....		Barcelona...	1849	Lloret (Barcelona)....
HBDF	Acela.....	Laúd.....		Valencia....	1858	Blanes (Gerona).....
HBDN	† Activo.....	Vapor.....	60	Valencia....	1879	Blanes (Gerona).....
	† Acuña (antes Mahonés) (HSTM).....	Fragata....	120	Coruña.....	1870	Inglaterra.....
HBDQ	Ada.....(4)*	Lorcha....		Manila.....	1873	Manila.....
HBDV	Adán.....*	B.n-goleta..		Bilbao.....	1866	Ripa (Bilbao).....
HBFJ	† Adela.....	Vapor.....	N 110	Habana.....	1878	Estados Unidos.....
HBFM	Adela.....	Goleta.....		Barcelona...	1860	Blanes (Gerona).....
HBGJ	Adela.....	Goleta.....		Vinaroz....	1852	Vinaroz.....
HBGN	Adelaida.....	B.n-goleta..		Barcelona...	1854	Blanes (Gerona).....
HBJD	Adelaida.....	Corbeta....		Bilbao.....	1857	Ripa (Bilbao).....
HRDT	Adolfo (antes Juan Ramos).....	Vapor.....	88	Cartagena...	1886	Inglaterra.....
HBKN	Adriano (hoy Salvadora).....	Queche.....		Cartagena...	1886	Masnou.....
HBKQ	† Africa.....	Vapor.....	90	Barcelona...	1868	Glasgow.....
HBLM	Agapita.....	Patache....		Gijón.....	1875	Tazones (Oviedo).....
	Agapito (antes Angelita) (HCLV).....	Bergantín...		Barcelona...	1855	Palamós.....
HBLN	Agatona.....	Lorcha.....		Manila.....	1883	Tayabas.....
HBLP	Agente.....	Pailebot....		Manila.....	1890	Albay.....
HBLW	† Agosto.....	Vapor.....	180	Bilbao.....	1889	Sunderland.....
HBMG	Agosto.....	B.n-goleta..		Manila.....	1884	Tayabas.....
HBMJ	Aguila.....	Vapor.....	160	Habana.....	1878	Filadelfia (Est. Unidos)
HBML	Aguila.....	Pailebot....		S.º de Cuba.	1888	Baracoa.....
HBMN	Aguila de Oro.....	Balandra....		Habana.....	1847	Guanaja (Isla de Cuba).
HBMP	Aguila de Oro.....	Goleta.....		Habana.....	1848	Guanaja (Isla de Cuba).
HBMV	Agustina.....	P. a-goleta..		Barcelona...	1862	Palamós.....
	Agustina (hoy Tres Amigos) (HBNW)..	Pailebot....		Cartagena...	1886	Masnou (Barcelona)...

(1) La señal distintiva después del nombre indica, ó que el buque tuvo otro nombre al que correspondió la señal distintiva asignada, ó que figura también en el Apéndice.
(2) Cuando sean nominales se indicará con la inicial N.
(3) Si el buque es de madera, se expresará con una M. Si de hierro, con una H. Si de acero, con una A. Si de esas materias combinadas, con las correspondientes combinaciones de dichas iniciales. Si de vapor, con el signo †
(4) * Esta señal indica que el buque está arqueado por el sistema antiguo.

ACA — AGU 19

Año de la construcción....	Materiales de la construcción (3).....	DIMENSIONES. — Metros. Eslora.	Manga.	Puntal.	TONELAJE. Total.	Neto.	Nombre y domicilio del armador.
8	9	10			11		12
1877	M.	22,50	5,65	1,78	57,72	56,68	D. Máximo Molo Paterno.—Manila.
1881	A.	113,05	12,81	9,28	3.709,15	2.237,97	Compañía Trasatlántica.— Barcelona
1883	H.	78,47	10,59	5,30	1.664,69	1.172,17	D. Ramón de la Sota y Llano. — Bilbao.
1881	H.	73,04	10,61	4,63	1.351,47	950,75	Compañía Bilbaína de Navegación. — Bilbao.
1849	M.	27,10	7,92	3,74	177,26	168,65	Sres. Font y Riudor.—Barcelona.
1858	M.	22,67	6,68	2,62	84,40	81,14	D. Vicente Rábena.—Grao.
1876	M.	22,01	4,45	2,22	57,00		D. Arturo Mañes y otros.—Grao.
	M.	40,37	5,53	2,98	194,64	137,13	D. Francisco González Asensio. — Orán.
1855	M.	45,97	10,44	6,73	662,00	600,00	D. Francisco Pablo de Oñate. — Plencia.
1872	M.	22,70	5,56	2,05	80,36	76,34	D. Manuel Carrión.—Manila.
1878	H.	47,66	8,67	4,01	622,32	382,05	Sociedad Sobrinos de Herrera.—Habana.
1860	M.	29,53	7,80	2,50	160,00		D. Mariano Juliá.—Barcelona.
1851	M.	26,80	6,75	2,96	126,01	119,71	D. Jaime Guinaras y otros.—Jávea.
1854	M.	25,90	7,24	3,33	141,96	136,48	D. Bartolomé Florit. — San Martín de Provensals.
1857	M.	33,71	7,52	4'45	293,00	258,00	D. Manuel Bergué.—Bilbao.
1865	H.	57,05	8,50	5,20	694,52	467,64	Sres. Faes y Comp.ª—Alicante.
1840	M.	21,84	6,48	2,78	79,84	76,00	Sres. Infera y Sáez.—Cartagena y Mazarrón.
1869	M.	55,65	8,10	4,71	649,03	379,82	Sociedad de Navegación é Industria. — Barcelona.
1875	M.	20,04	5,78	2,50	65,33	62,06	D. Hilario González y otros. — Villaviciosa.
1855	M.	29,50	8,20	4,44	246,49	236,95	D. José Pagés y Manau.—Barcelona.
1883	M.	24,51	6,42	1,93	101,74	101,74	D. Luis Rafael y Angeo.—Manila.
1890	M.	25,60	5,68	2,38	90,46	90,46	D. Casimiro Bartoluce.—Manila.
1889	A.	83,94	11,00	6,24	1.774,95	1.179,46	Comp.ª Bilbaína de Navegación.—Bilbao.
1884	M.	32,71	7,02	3,16	203,61	199,41	D. Natalio R. Bautista Alminñán. — Tayabas.
1878	M.	25,61	5,49	3,22	135,57	127,78	Sres. Sobrinos de Herrera.—Habana.
1864	M.	25,00	7,10	2,00	71,06	67,81	D. Bonocio Ruiz.—Baracoa.
	M.	24,45	7,62	3,14	79,41	75,75	D. Tomás Silvén.—Habana.
1848	M.	24,50	7,79	2,13	82,65	78,82	D. Fernando Pérez.—Habana.
1843	M.	22,18	6,76	2,91	93,48	88,81	D. Miguel Lloret y otro.—Barcelona.
1855	M.	23,15	7,04	3,01	104,13	99,07	D. Ginés Méndez López.—Mazarrón.

The Official List served as Spain's principal maritime directory, integrating vessel identities, signal codes, and technical characteristics within the international communication system used by late 19th-century shipping. Beginning in 1871, the Ministry of the Navy (*Ministerio de Marina*) issued the publication on an annual basis. We link our dataset to the 1884 and 1893 editions because these volumes provide substantially more detailed information on individual vessels (see more below). Earlier editions from the 1870s generally report only signal codes, vessel names, ship type, and engine power for steamships. We match these records to our dataset using vessel type, name, and approximate tonnage as linking variables. In 1884 the Official List records 2,168 commercial vessels, declining to 1,997 in 1893 and to 946 by 1905. We focus on the earlier benchmark years because they broadly overlap with our period of

analysis and follow the initial publication of the register, when vessel-level reporting expanded beyond signal codes and names to include detailed technical and ownership information.

Using these editions, we successfully match 21,992 entries in our dataset. Relative to the initial total of 69,845 ship-level observations, this implies that we are able to identify owners for slightly more than one third of all entries. For comparison, Spanish-flagged vessels account for roughly half of the ships in the sample. The unmatched observations (roughly 15-20 percent of the sample) primarily reflect limitations of the Official List, which reports only medium and large vessels and ships below 50 tons are excluded. In addition, the register lists do not represent the complete universe of ships operating (just the most common ones). Our master dataset also includes warships, which we do not attempt to link, as these vessels are excluded from the analysis.

The Official List provides the following information. Column 1 reports the vessel's distinctive signal (*señal distintiva*), while column 2 records the ship's name (*nombres*). Column 3 identifies the vessel's class (*clases*), and column 4 lists engine power for steamships (*fuerza en caballos*). Column 5 indicates the maritime province of registry (*matrícula*), followed by the year of registration in column 6 (*año de la matrícula*). Column 7 reports the place of construction (*punto de la construcción*), and column 8 records the year of construction (*año de la construcción*). Column 9 identifies the materials used in construction (*materiales de la construcción*) being either wood or iron. Column 10 provides the vessel's dimensions in meters (*dimensiones en metros*), including length (*eslora*), beam (*manga*), and depth (*puntal*). Column 11 reports gross and net tonnage (*tonelaje, total* and *neto*). Finally, column 12 lists the name and address of the shipowner (*nombre y domicilio del armador*).

The *armador* refers to the individual or corporate entity responsible for equipping, provisioning, and preparing a vessel for commercial operation. This party hired the captain and crew, covered operating expenses (including maintenance, coal fuel, and insurance) and bore the legal and commercial responsibility for maritime voyages. In 19th-century shipping, the *armador* typically functioned as the principal operating manager on behalf of multiple investors and, in modern terms, can be interpreted as the effective owner or controlling operator of the vessel. In total, we identify 1,237 *armadores* in our master. Because the sample covers several decades, ownership is time-varying, and individual vessels may therefore be associated with multiple *armadores*. We collected all of them. Approximately half of all ships in the sample are linked to a single owner. The maximum number of owners observed for any vessel is four, although such cases are uncommon. A large number of ships are associated with two owners at different points in time (40.54 percent of vessels), while cases involving three (3.47 percent) or for *armadores* (0.5 percent) are small.

Ownership and management structures, however, were neither static nor uniform. In the mid-19th century, sailing vessels were rarely owned by a single individual due to the considerable risks associated with maritime transport, including shipwreck, piracy, and storms. Instead, ownership was commonly divided into twenty-four shares, known as *quirates*. Within this co-ownership system, maritime law required the designation of a single *armador* director or managing agent to act as the vessel's legal and commercial representative. Consequently, the individual listed in official records typically identifies the managing partner (often the principal shareholder or the individual entrusted with operational control) rather than necessarily the sole owner.

In addition to this, the diffusion of steam navigation contributed to important changes in these arrangements. Steamships required substantially larger capital investments for engines, fuel,

and specialized maintenance, which encouraged the expansion of joint-stock companies (*sociedades anónimas*) as financing and operating structures. As a result, individual *armador* names tend to be associated with wooden sailing vessels, while corporate entities (such as Compañía Trasatlántica) are more commonly linked to iron-hulled steamships. In some cases, ownership structures evolved over time, with vessels or fleets initially recorded under individual proprietors and later appearing under corporate entities. For example, the steamship *León de Oro* was first owned by Jerónimo Estades of Sóller and, after 1905, by the Compañía de Navegación Sóller. Similarly, fleets associated with individual proprietors, such as *Sota*, later appear under corporate partnerships such as Sota y Aznar.

Institutional developments in commercial law further reinforced these transitions. Prior to Spain's 1885 reform of the Commercial Code, the legal recognition of companies as separate juridical persons was relatively limited within the shipping sector. Under earlier legal frameworks, the ***armador*** was often personally liable for the vessel's debts or damages, and official registers therefore emphasized the identification of the individual bearing legal responsibility. Nonetheless, even after the 1885 reforms, many established shipowners continued to operate under their personal names, reflecting the importance of reputational capital and creditworthiness in maritime commerce. In practice, well-known individual proprietors could provide stronger assurances to creditors and commercial partners than newly established corporate entities.

Finally, in our study, the *armador* was institutionally distinct from the *consignatario*, who typically managed or owned the cargo (see details on page ADD PAGE). Nevertheless, in Barcelona (consistent with patterns observed in other major ports) shipping activities frequently exhibited vertical integration. Shipowners often participated directly in mercantile activities, implying that some *armadores* simultaneously operated vessels and owned the cargo they transported.

Appendix 5: LOCATION OF PORTS

Some place names were straightforward to identify, for example, the port referred to as "Constantinopla," known today as "Istanbul". In other instances, however, identification required accounting for historical name changes. For instance, "Essaouira" (in Africa), was widely known as "Mogador" until the 1960s or the port listed as "Bone" (referring to "Bône"), refers to Annaba, a seaport city in the northeastern corner of Algeria, close to the border with Tunisia. Similar challenges to locate ports arise frequently with Nordic place names. On a few occasions, Spanish newspapers also reported foreign names using Spanish phonetic renderings, such as "Suancy" for "Swansea" in Wales. We standardized these names across the dataset.

Appendix 6: CLEANING SHIP ENTRIES, CARGO, MERCHANTS AND OWNERS

Ship entries: To construct ship identifiers, we match observations based on ship type and ship name. We first standardize names to improve comparability, converting all entries to lowercase and removing diacritical marks. Matching is then restricted within ship types. For instance, corvettes are compared only with other corvettes, and steamships only with other steamships. This substantially reduces the number of potential comparisons within each ship-type category. Within each ship-type group, we further restrict comparisons by partitioning ship names according to their initial letter. Names beginning with a particular letter are compared only with names sharing the same initial. We also restrict comparisons to names whose lengths differ by no more than two characters. These restrictions jointly reduce the likelihood of false matches while improving computational efficiency.

We then apply fuzzy matching techniques to identify typographical errors and minor variations in ship names. For vessels sharing the same type, initial letter, and similar name length, we compute a similarity score using a standard fuzzy-matching algorithm. The algorithm treats each name as a sequence of characters and identifies the longest matching character blocks appearing in the same order across the two strings.

The algorithm penalizes missing characters, substituted characters, and reordered segments, producing a similarity score ranging from 0 to 1, where 1 indicates identical strings. Scores between 0.95 and 0.99 almost certainly refer to the same name, while scores between 0.90 and 0.94 indicate highly probable matches reflecting minor typographical errors or name variants. Scores between 0.80 and 0.89 suggest a possible but uncertain match, and scores below 0.80 likely correspond to distinct vessels. As a baseline rule, we classify name pairs with similarity scores of 0.90 or higher as referring to the same ship. Using this threshold, we assign a unique group identifier to each cluster of near-duplicate names within a given ship type. Finally, we manually review all entries to implement any additional corrections. The resulting database contains 14,094 unique ships.

Cargo: For cargo items, we apply a procedure broadly analogous to that used for ship names. We first standardize cargo descriptions by converting all entries to lowercase, removing diacritical marks, and implementing basic text harmonization. We then employ fuzzy matching techniques to identify likely typographical inconsistencies, which are subsequently reviewed and corrected manually. The cargo data comprise 124,811 individual entries, reflecting the fact that a single voyage often includes multiple commodities. After consolidating the data into unique cargo descriptions, we identify 1,258 distinct items. As discussed in the text, cargo information is coded at ten-year intervals due to the volume of the underlying archival material.

During the cleaning process, entries are combined only when they unambiguously refer to the same imported commodity. For example, *vegetals* (vegetables), *verdures* (greens), and *hortalisses* (garden produce) are treated as equivalent categories despite minor differences in usage, as each denotes closely related types of food imports. Likewise, terms commonly used interchangeably, such as *vidre* (glass) and *cristall* (crystal), and singular and plural forms such as *tint* and *tints*, are harmonized. While this process generates a standardized dictionary, we adopt a deliberately conservative approach and avoid aggregating items into broader commodity groups at this stage. Aggregation is instead conducted later in the analysis (see Section ADD SECTION NUMBER WHEN READY). Thus, we maintain distinctions between general product classes such as *vegetals* and more specific goods including tomatoes, onions,

legumes, or fruits. In certain instances, items are also kept separate due to ambiguity regarding their end use. For example, *piedras* (stones) and *lastre* (ballast) are coded as distinct items because stones may have been imported either for construction or for ship stabilization, and the surviving records do not permit us to distinguish between these uses. The table below reports the 50 most frequently observed cargo items in the dataset. This classification is intended to be descriptive and is refined in subsequent stages when commodities are grouped into broader analytical categories, such as perishables or manufactured goods.

Main 50 items in the cargo

Item	Cases	Item	Cases
Càrrega general [general cargo]	13,955	Maquinària [machinery]	896
Blat [wheat]	5,910	Teixits [textiles]	885
Passatgers [passengers]	4,988	Cacau [cocoa]	870
Carbó [coal]	4,368	Bacallà [cod]	860
Garrofes [carob pods]	4,177	Paper [paper]	843
Vi [wine]	3,195	Cànem [hemp]	810
Cotó [cotton]	3,103	Moltons [rams]	782
Arròs [rice]	3,081	Blat de moro [corn (maize)]	779
Farina [flour]	2,171	Correspondència [mail]	776
Ferro [iron]	2,098	Dogues [staves]	759
Llana [wool]	1,830	Calçat [footwear]	732
Llast [ballast]	1,798	Vidres [glassware]	728
Draps [rags]	1,625	Pal brasil, etc [brazilwood, etc.]	725
Drogues [drugs]	1,564	Sal [salt]	719
Cuirs [hides]	1,464	Pells [furs]	703
Sucre [sugar]	1,419	Mongetes [white beans]	684
Llenya [firewood]	1,382	Coure [copper]	647
Espart [esparto (fiber)]	1,355	Quincalla [hardware goods]	647
Sardines [sardines]	1,350	Figues [figs]	612
Fusta [timber]	1,281	Panses [raisins]	610
Ordi [barley]	1,146	Porcs [pigs]	579
Faves [broad beans]	1,050	Tabac [tobacco]	568
Taronges [oranges]	1,028	Palma [palm products]	566
Segó [bran]	1,003	Pisa [earthenware]	563
Cigrons [chickpeas]	909	Fesols [beans]	559

Merchants: Information on merchants is reported at the vessel level in *El Diario de Barcelona*. We interpret this variable as identifying merchants rather than consignees or shipping agents, as the individuals listed appear to correspond to cargo owners rather than intermediaries responsible solely for port logistics. Since a single vessel can be associated with multiple merchants (reflecting the presence of several cargo owners on the same voyage) the dataset contains 49,305 merchant entries. After standardizing and consolidating names, these correspond to 6,592 distinct merchants. Consistent with contemporary commercial practice, we treat lineages and family-based business entities as separate observations. For instance, a merchant may initially appear as “J. Smith,” later as “J. Smith y Compañía,” and following succession as “J. Smith e hijos” or “J. Smith viuda.” Each of these entities is coded as a distinct merchant.

To standardize merchant identities, we harmonize surnames and names. For names we use first-name initials, as full first names are not consistently reported whereas initials are almost always provided. We then apply fuzzy-matching procedures using an algorithm similar to that employed for ship names to identify and correct typographical variations of the surname and first-name initial. In the cleaned dataset, vessels are linked to an average of 7.48 merchants. Merchant participation is unevenly distributed, with 56.87 percent of merchants appearing only once. The most frequent entries are “A la orden” (7,089 observations), indicating the absence of a named merchant, and “A varios” (1,041 observations), denoting delivery to multiple unspecified merchants. Among identified merchants, the most frequently observed include Vidal Ribas (827), “Su cuenta” (654), Solà Amat (640), J. M. Serra (498), A. Cros (293), F. Carbó (273), V. Ferrer y Cía. (269), and P. Bohigas (264).