A Hybrid Network: Sea-Land Connectivity in the Global System of Cities

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May 12, 2023

Noname manuscript No.
(will be inserted by the editor)

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Abstract The main objective of this research is to analyze the connectivity of cities in a coupled network made of planar (railways) and non-planar (maritime) topologies. It takes the state of the network during the period 1880-1925, namely the context of the First Globalization wave (1880-1914), when trade and urban development were closely tied to progress in communications systems and especially steam propulsion. Edges represent intercity physical infrastructure on land, and inter-port ship voyages at sea. We test several hypotheses in terms of inter-network specialization and port-city relationships. Main results underline a crucial influence of railway proximity on vessel traffic volume and steam specialization.

Keywords coupled networks ; globalization ; hinterlands ; ports ; maritime transport ; multilayer networks ; multigraph ; railway networks ; steam shipping ; urban network

1 Introduction

A relative consensus has been reached among scholars about the importance of both ports and railways in the rapid development of cities during the late 19th and early 20th centuries (Bretagnolle, 2015). Ports in particular had to "race for constant adaptation" to keep their position in an increasingly competitive environment (Marnot, 2005). Attracting maritime trade became more and more dependent on their ability to connect inland markets efficiently. Such

This research acknowledges funding from the Agence Nationale de la Recherche (ANR) research project MAGNETICS (MAritime Globalization, Network Externalities, and Transport Impacts on CitieS), 2023-2026.

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dynamics had the effect of expanding the hinterland boundaries of successful gateways, at the expense of numerous, less-equipped nodes, like French ports for instance (Merger, 2004).

While the growth or decline of port cities in this context has been well documented by historians, such across the Atlantic (Konvitz, 1994) and in Asia (Murphey, 1969), we still miss a “global picture” of such a global transportation system connecting cities of the world. Recent research has been done on the global maritime network in the age of steam, notably examining the relationship between maritime connectivity, technological innovation, and urban development (Ducruet and Itoh, 2022), but leaving aside the land-based network and ignoring inland cities. Some parent works investigated such dynamics in other contexts, such as inter-network externalities among ports, canals, and roads in England between 1760-1830 (Bogart, 2009), or the combination of airline and maritime global networks in recent years (Ducruet et al., 2011). Three main hypotheses are tested in the present paper:

H1 : railway proximity to ports fosters maritime traffic volume;
H2 : railway proximity to ports fosters steam shipping specialization;
H3 : railway proximity to ports fosters global shipping connectivity.

2 Data and methodology

We first reconstituted the global railway network between 1880-1920 on the basis of digitized historical maps[1] using QGIS. In this software, a manual work has been done to recreate the railway edges over the Open Street Map layer, together with two types of nodes: stations related to cities near railways, and intermediate junctions like crossroads. Ports and cities were attributed to this network using additional urban databases and the *Lloyd’s Maritime Atlas* (see Figure 1). The global maritime network is derived from the *Lloyd’s Shipping Index* on global inter-port vessel movements between 1880 and 1925, for both sailing and steam ships.

3 Preliminary results

As the Geographical Information System (GIS) environment allows calculating land distances between railway segments and port nodes, the first hypothesis can be verified with Figure 2. We observe that port-railway proximity has a noticeable influence on steam traffic size, as the volume of ship calls declines with distance. A similar distribution applies to the evolution of steam specialization (Figure 3). However, it is the fourth class (5 – 9.9km) which keeps being more advanced in terms of shipping technology. Distance also influences steam specialization levels but in weaker ways than total traffic.

[1] The sources are David Rumsey collection, Bibliothèque Nationale de France (BNF), and Library of Congress.

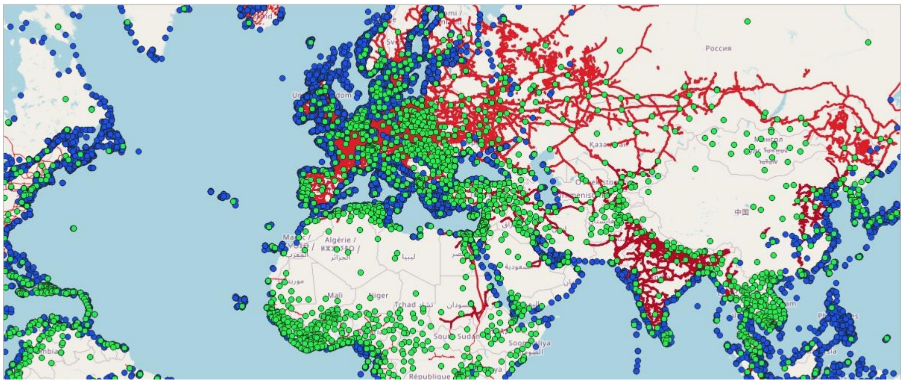

Fig. 1 Snapshot of railway connections in 1920 (red), ports (blue), and cities (green)

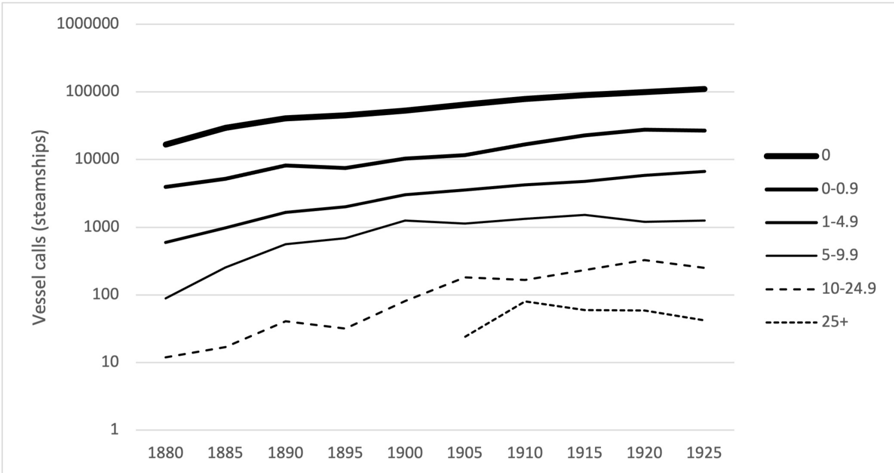

Fig. 2 Steam traffic evolution and distance from railway junctions (km)

The third step has been to shift the focus from port and railway nodes to urban nodes as the spatial unit of analysis, based on the delineation of cities proposed by Ducruet et al. (2018). We calculated the linear correlation between railway proximity (i.e. for each city, average of 1 / distance to all railway segments) and global maritime centrality in the steam and sailing ship networks (Table 1). Results are significant, again showing a stronger connection between steam shipping and railways. The sudden surge of correlation in 1925 for sailing comes from its near-disappearance (i.e. less than 3% global traffic) and its retreat around a few ports well-equipped with railways. The correlation with degree is always lower than with betweenness, while the latter is fading over the period.

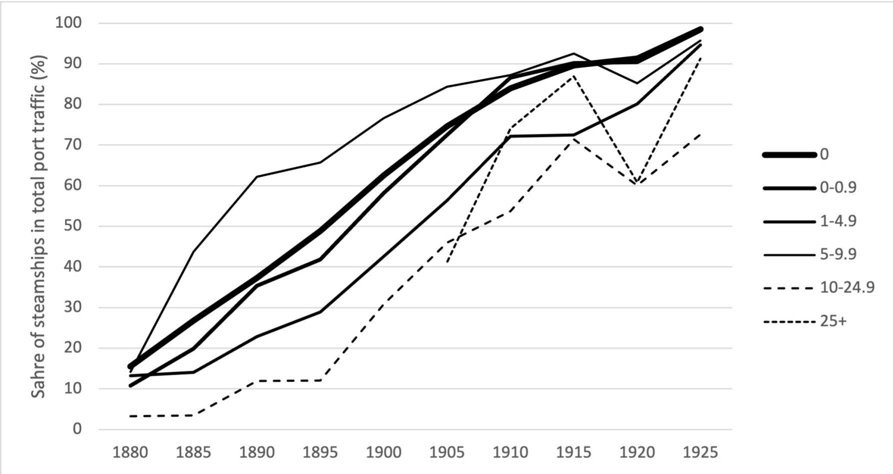

Fig. 3 Steam traffic specialization and distance from railway junctions (km)

Table 1 Correlation between (local) railway proximity and (global) maritime centrality

Network	Measure	1880	1885	1890	1895	1900	1905	1910	1915	1920	1925
Steam	Betweenness	0.475	0.416	0.362	0.368	0.336	0.319	0.336	0.331	0.314	0.285
	Degree	0.314	0.233	0.202	0.211	0.203	0.196	0.189	0.186	0.192	0.191
Sail	Betweenness	0.287	0.280	0.273	0.263	0.266	0.194	0.200	0.223	0.114	0.443
	Degree	0.177	0.170	0.170	0.180	0.170	0.161	0.167	0.193	0.145	0.320

4 Concluding thoughts and further research

This research confirmed the close relationship between railway proximity to ports and steam shipping distribution across the world between 1880 and 1925. The precision offered by the GIS calculations allow to conclude that not only the presence or proximity of railways matter for ports, but their connexion *within* ports.

Further research is ongoing for testing the relationship between city size, growth (i.e., population) and modal as well as intermodal centrality/accessibility. Another research avenue is the integration of the global road network backbone, navigable rivers and canals as additional layers. In such a multilayered system, attention will also be paid to the centrality and development of non-port, inland cities, including a view on the influence of maritime shipping on their overall connectivity. As in recent works focusing on the non-port capital cities of coastal countries (Ducruet and Guerrero, 2022), a variety of trade, logistical, and economic variables will be used to control for country-level effects, depending on their availability, as the present study is planned to cover a century of transport and urban development at the global scale.

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