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César Ducruet
Hidekazu Itoh
Bruno Marnot
Barbara Polo Martin
Elyass Sayd
Dimitris Tsiotas

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EconomiX - UMR 7235 Bâtiment Maurice Allais
Université Paris Nanterre 200, Avenue de la République
92001 Nanterre Cedex

Site Web : economix.fr
Contact : secreteriat@economix.fr
Twitter : @EconomixU

Université Paris Nanterre

Structural change in the world maritime network (1880-2020): globalization, optimization, and vulnerability

César Ducruet[1], Dimitrios Tsiotas[2], Bruno Marnot[3], Barbara Polo Martin[1], Hidekazu Itoh[4], &

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ABSTRACT

Port infrastructure and related freight flows that support international trade are not distributed evenly across the globe, but are instead heavily concentrated in a few hubs and gateways. Remoteness from such key nodes is a major barrier to overall development, while overconcentration leads to the congestion and vulnerability of transport and supply chains. Advancing the maritime accessibility of smaller ports in favor of a more balanced development has so far been unsuccessful. Due to its closeness with trade and socio-economic welfare making it highly strategic, maritime connectivity has attracted international efforts to accurately measure it through a wide array of studies in the past two decades[1]. Here we develop a novel analysis of the global maritime network, over the last 140 years (1880-2020), based on untapped vessel movement data published by the insurer Lloyd's List. Our results demonstrate that while the network has become more optimal to connect the global market, its topological and spatial structure became increasingly sparse and vulnerable to crises and shocks. We also show that contrary to what is commonly claimed, containerization prolonged rather than initiated the contemporary transformation of the maritime network.

[1] French National Centre for Scientific Research (CNRS), UMR 7235 EconomiX, University of Paris-Nanterre, 200 Avenue de la République, 92100 Nanterre, France.
[2] Department of Regional and Economic Development, Agricultural University of Athens, Amfissa, Greece.
[3] UMR 7266 LIENSs, University of La Rochelle, France.
[4] School of Business Administration, Kwansei Gakuin University, Nishinomiya, Japan.

CONTEXT AND OBJECTIVES

Maritime transport is one of the oldest forms of human interaction. Since the late nineteenth century, it fostered – and adapted to – three successive waves of globalization, through technological progress in shipping and ports, and decreased transport costs. It supports no less than 80% of global trade volumes today and about 70% of its value, according to the United Nations Conference on Trade and Development (UNCTAD)[2]. As such, maritime connectivity is of great concern to key international bodies, such as the International Maritime Organization (IMO), a specialized agency of the UN, the International Association of Ports and Harbors (IAPH), the European Commission with the European Sea Ports Organization (ESPO), the Organisation for Economic Co-operation and Development (OECD) about global port-cities[3], the World Bank, and the International Monetary Fund (IMF) about maritime big data[4]. Mergers and acquisitions in the shipping sector, shipping alliances, and vertical integration across the whole transport and logistics chain, especially since the advent of containerization in the 1950s, are increasingly worrisome as world trade falls in the hands of an ever more concentrated oligopoly[5]. Over time, the number of ports capable of welcoming ships of rapidly growing size regularly declined, while trucking absorbed the bulk of continental freight flows across hinterlands, at the expense of smaller ports and environmental quality. Traffic concentration had proven to be a major issue during the COVID-19 pandemic, with huge bottlenecks and delays happening around the largest ports, and during the shutdown of Suez Canal[6]. While a fully connected and more homogenous maritime network would be more costly and less efficient – from the ship operator's perspective – concentration reaches its limits in terms of social and environmental costs in the core ports (pollution, congestion), and traffic / employment loss at the bypassed peripheral ports.

Such concentration processes in port systems have long been observed by geographers in various regions and time periods[7]. But it is only recently that historians defended the idea according to which contemporary changes in shipping and ports take their roots in the 19th century[8,9], with globalization, industrial revolution, and technological breakthroughs. Yet, a global and long-term picture remains lacking, especially from a network perspective. Given that network rationalization, naval gigantism, port competition, and intermodalism are common features of the sail-to-steam and breakbulk-to-container transitions[10], this motivates a longitudinal study that questions how have technological and economical changes impacted the structure of the contemporary maritime network, and discuss its possible evolution in the future.

It is now commonly accepted that maritime connectivity matters for socio-economic development[11,12,13], but what constitutes maritime connectivity varies among existing studies, as seen with UNCTAD's liner shipping connectivity index for containers[14] and the World Bank study on Mediterranean maritime and hinterland connectivity[15] for instance. Academic research on this topic, in particular about network vulnerability, flourished in recent years[16,17,18,19,20], but most studies focused on container shipping and remained static, covering issues like the COVID-19, natural disasters, and simulating targeted attacks. In this article, we consider connectivity by constructing an undirected network (or *graph*) made of ports (nodes, or *vertices*) connected by inter-port ship voyages (links, or *edges*). All vessel types are considered. The data source, the *Lloyd's Shipping Index*, provides for each ship its latest inter-port movement at the date of publication (Fig. 1), thus consisting in a global origin-destination matrix (cf. From, For) also figuring intermediate ports of call (cf. Latest Reports). Despite its long existence, availability in libraries, and unique character (it is the only information allowing to track and map global maritime flows at the port level over such a long period), this source remained unknown to scholars until the first analysis of the global container shipping network in the late 1990s[21]. It was employed a decade later as first-hand data to analyze North Korea's maritime connectivity[22], until two research projects, financed by the European Research Council (ERC)[23] and the French National Research Agency (ANR)[24] expanded the spatial and historical scope. To our knowledge, the *Shipping Index* has never been used in history, economics or geography to study the pre-1990 era.

Ship	Master	Flag	Rig	From	For	Latest Reports
Agnes	*Rasmussen*	Da	sc	Antwerp Mar 12	Saffi	
Agnes	*Pagels*	Ge	bq	Pernambuco Mar 21	Liverpool	
Agnes	*Gerdes*	Ge	bq	New York Feb 5	Hamburg	Ar Mar 9
Agnes	*Schiepler*	Ge	bq	New York Feb 26	Lisbon	✠ Mar 27
Agnes	*Runsey*	Po	bq	Oporto Nov 23	Buenos Ayres	Ar Jan 13
Agnes	*Wirolainen*	Ru	bg	Cette Feb 23	Memel	Off Gibraltar Mar 13
Agnes Cairns	*Davies*	Br	bq	Patras Jan 16	Falmouth	Cd Gibraltar Mar 12
Agnes Campbell	*Nielsen*	No	bq	Mobile Feb 22	Liverpool	Ar Mar 29
Agnes Edgell	*Bahlmann*	Ge	bg	Duke of York Is Jan —	Sydney	
Agnes Muir	*Lowe*	Br	sh	Manilla Dec 15	Liverpool	Sd St Helena Feb 16
Agnes Oswald	*Mc Gibbon*	Br	sh	Cardiff Jan 14	Colombo	
Agnes Stevenson		Br	bq	Marseilles Oct 31	Cayenne	Sd Teneriffe Dec 6
Agnes Sutherland		Br	sh	Dunkirk Mar 24	Cardiff	
Agon	*Sorensen*	No	bq	Cardiff Mar 7	Martinique	Pd Lundy Mar 8
Agostino C	*Premuda*	Au	bq	Port Said	St Thomas	Ar Mar 16
Agostino C	*Onsto*	It	bq	Savona Jan 21	New York	Sp Feb 24, 30 N 18 W
Agostino Felugo	*Chiesa*	It	bq	Newport Mar 13	Genoa	
Agostino Giuseppe		It	bg	Cardiff Mar 23	Taranto	
Agostino Merello		It	bq	Cardiff Aug 8	Singapore	Ar Jan 26
Agostino Pizzorno	*Podesta*	It	sc	Genoa Aug 21	Buenos Ayres	At Montevideo Nov 15
Agostino Repetto	*Bozzo*	It	bq	Table Bay Jan 15	Philadelphia	Ar about Mar 22
Agostino Rombo	*Vincenzo*	It	bq	Sourabaya Oct 27	Lisbon	Ar Mar 8
Agostino S	*Bertolotto*	It	bq	Cadiz Nov 6	Montevideo	Ar Jan 20
Agra	*Hogemann*	Ge	sh	Bremen Mar 2	Baltimore	Sp Mar 8, 49 N 6 W
Agricola	*Beguinot*	Fr	bq	Havre Mar 9	Bordeaux	Off Pointe de Grave Mar 17

Figure 1. Extract from the Lloyd's Shipping Index, April 2nd 1885

DATA AND METHODS

An important phase of digitization, image processing, and Optical Character Recognition (OCR) was necessary before the printed data could be used. Nodes and links are weighted by the total number of vessel calls occurring around early April every five years since 1880, namely 28 successive time points. The outcome is a temporal network made of 5459 ports, 100126 links, 500531 vessels, and 931792 vessel calls for the whole period. In terms of representativity, *Lloyd's of London* has always been the world's main maritime insurer, and it is estimated that it covers about 80% of the current world fleet. The year 1880 was chosen as it marks an important turning point, i.e., when Lloyd's started to report the ship movements of most of the world's major fleets; it did report the movements of the sole British fleet between 1746 and 1879.

To represent the evolution of the maritime network over time, three key years were selected for mapping: 1880, the beginning of the study period and the eve of the First Globalization Wave; 1951, a pivotal year just before containerization emerged in the U.S. and diffused globally afterwards; and 2020, the last year of the period. We are aware that the year 2020 is marked by the COVID-19 pandemic, so maritime traffic in that year is lower than expected but it still offers valuable insights into shifts when compared with the previous snapshots. In order to represent the routes as lines, we map the number of vessel movements between subregions based on a maritime grid. The cartography is complemented by the measurement of continental traffic, intraregional traffic, and a graph visualization of hubs and their nodal regions using the single linkage analysis[25], which is a useful method to study forms of node domination in a network.

We then explore the structural properties of this network using relatively classical graph-theoretical measures. The *density* is the proportion of existing links in the maximum possible number of links. The lower the density, the sparser the network, and thus the more rationalized in terms of optimal connectivity and centralization. The *average clustering coefficient* is relatively similar, as it measures the proportion of connected triangles in the maximum possible number of connected triangles. *Scale-freeness* is a measure of hierarchy among port nodes, corresponding to the exponent of the power-law line that fits the distribution of ports' degree centrality. Degree centrality is the most common measure to characterize nodes in a network, defined by the number of adjacently connected nodes. The lowest the exponent (between –2 and –3), the more likely is the network scale-free, i.e., with few giant hubs connecting many small nodes. Intermediate values may refer to a more polycentric structure, with transversal connections among hubs, in what is commonly called a *rich-club phenomenon*. To verify this, we also use the *rich-club coefficient*, that corresponds to network density among the largest ports above a certain degree value[26], namely the upper quartile (75%). This is complemented by a look at *assortativity*, which is the Pearson correlation between the respective degrees of adjacently connected nodes[27]. The network is said *disassortative* (negative values) when large degree nodes connect low degree nodes, and *assortative* when nodes of comparable degree are connected.

To examine vulnerability with more precision, we develop a *vulnerability index* counting the speed of disconnection of the network until the point it entirely collapses, namely the relative number of targeted attacks until all of its nodes become disconnected. In general, measuring a graph's vulnerability by considering the effect of targeted attacks on degree connectivity is the most common and appropriate method to do so[28], as a network hub is primarily defined in terms of node degree[29,30]. In this context, the algorithm in this paper calculates, at the first step, the node degrees in the global maritime network and removes the first hub in ranking (the maximally connected node) with its associated links from the graph; then it recalculates the node degrees and removes the second in ranking with its associated links; the process iterates until the network becomes totally disconnected. The algorithm runs across all the available temporal network layers (1880, 1885, …, 2015, 2020) and counts the respective number of attacks until the network collapses ($N_{a|1880}$, $N_{a|1885}$, …, $N_{a|2015}$, $N_{a|2020}$). The relative number of attacks computed by the ratio $N_{a|i=1880,\ldots,2020} / n_{i=1880,\ldots,2020}$ of targeted attacks ($N_{a|i=1880,\ldots,2020}$) to the number of a layer's nodes ($n_{i=1880,\ldots,2020}$) defines the vulnerability index (vindex), as used in this study. By definition, the lower the values of the index the more vulnerable is the network and vice versa.

MAPPING THE NETWORK

The first outcome of this research is a collection of maps at key dates, which illustrates the growing concentration of maritime flows along major routes and hub ports (Fig. 2), as well as important regional shifts of maritime connectivity across the globe (see also Fig. 3 and Appendix 1 and 2). The year 1880 marked the moment when steam transport accelerated its rise in world tonnage transported by sea, while heavy goods traffic became predominant. The North Atlantic line was the strategic link par excellence in the globalization of the 19th century and was organized around the two North American and British port ranges (Appendix 2a). The British port range was dominated by London and Liverpool. London is the world's leading port in terms of tonnage handled. It is the port of the British capital, which is also the heart of world finance. Liverpool is the gateway to and from Lancashire, which was the world's largest cotton-producing area in the 19th century. The Cardiff hub is linked to the export of coal from Wales, which is one of the main coal-producing regions[31]. On the other side of the Atlantic, the north-eastern seaboard of the United States is dominated by New York, the major gateway to and from the American economy.

Three major routes shape the global maritime network (Fig. 2, 1880). Firstly, the North Atlantic route, which was the preferred location for steam navigation on the high seas and which linked the industrialized world (United States, United Kingdom, North-West Europe) at the end of the nineteenth century[32]. As part of the intensive trade in manufactured goods for raw materials, the Atlantic Ocean was crisscrossed, with cities such as Rio de Janeiro, Montevideo and Buenos Aires acting as southern termini. The second major route connects Oceania and Asia with north-west Europe, converging in the Indian Ocean to reach the Suez Canal. This route illustrates the intensity of imperial relations between the British metropolis, on the one hand, and India, Australasia and, secondarily, China, on the other. It is worth noting the importance of Colombo (Sri Lanka) as a bunkering station for all these links. Finally, a third major route is the South American route, which gives an important role to ports of call on the Pacific coast, such as Valparaiso, for South America, and San Francisco, for North America. All in all, the world maritime network is structured around the two logics of the first contemporary globalization: the intensity of relations between industrial powers, on the one hand, and imperial relations, on the other[33].

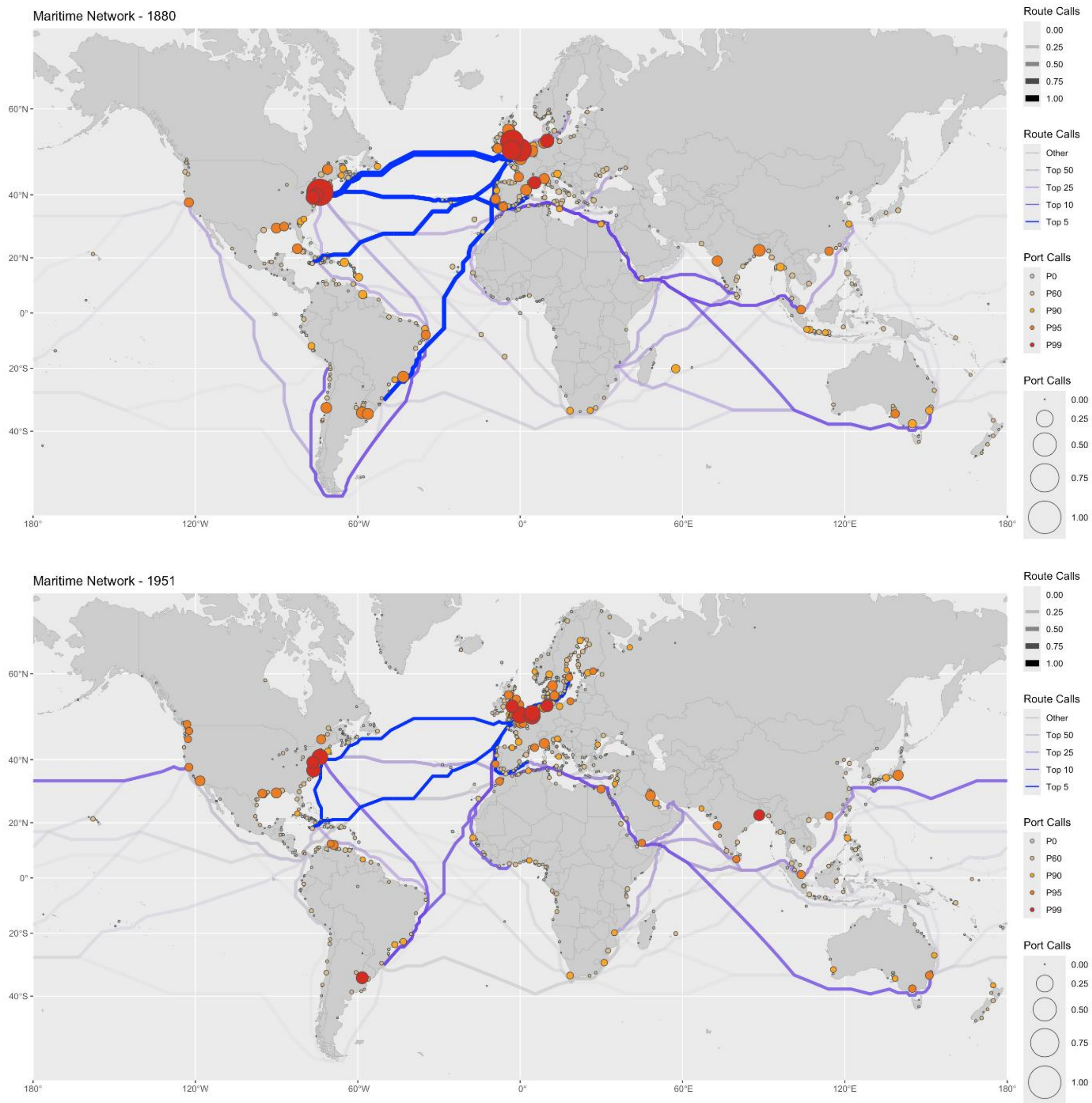

Figure 2. Cartography of the global maritime network at selected years

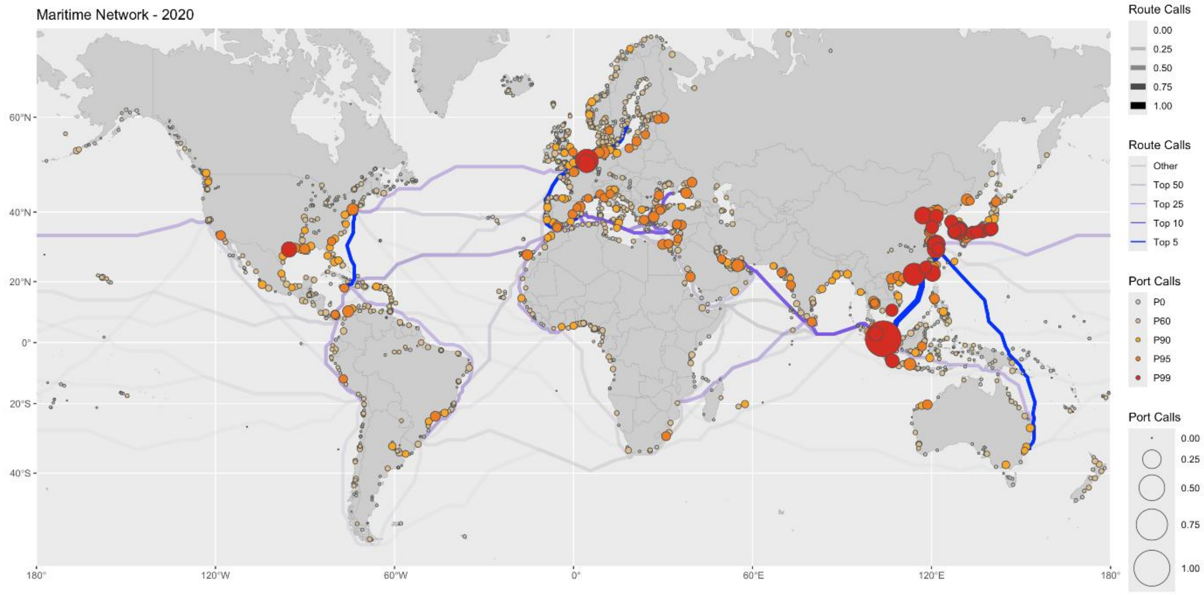

Figure 2 (continued)

In 1951, the increase in the number of well-equipped ports adapted to receive large cargo ships carrying heavy materials accentuated the polycentrism of the network (Appendix 2b). Four major hubs with an equivalent number of ports of call emerged. Alongside New York and London are Antwerp and Rotterdam. These are the two major ports on the Northern Range, which are the main gateways to Western Europe in the context of the continent's economic reconstruction[34]. Cardiff's disappearance as a hub was partly due to the switch from steam propulsion to engines running on petroleum-derived fuels (oil-fired boilers, diesel engines), which became widespread in the merchant fleet.

The second wave of globalization, initiated by the GATT agreements, was distinguished from the previous one by the development of the transpacific route (Fig. 2, 1951). Two routes became increasingly important. The first was the link between the Far East and the west coast of North America. Here too, the role of the United States in rebuilding the Japanese economy played a key role. On the other hand, the inter-oceanic route was established through the Panama Canal, which opened in 1914. The southern route via Cape Horn was marginalised. The same applied to the route linking Asia/Australasia to Western Europe, because the United States represented the new center of the world economy, or at least that of the free world. The United States is at the heart of transpacific and transatlantic relations. This pivotal role explains why New York's leadership was challenged both by the assertiveness of the ports on the Pacific coast (Los Angeles, San Francisco) and those to the south (New Orleans). The weight of the US economy is also reflected in the strengthening of the US-Latin America axis and the increased economic integration of the continent. However, connectivity is declining in Latin America and remaining stable in North America. While it remains strongest in Europe, it is tending to weaken slightly, while it is tending to strengthen in Africa and even more so in Asia (Fig. 3). This was the period of decolonization and the end of the privileged relations between the colonies and the European metropolises. Finally, the oil route linking the Middle East to Western Europe provided a new structural axis for the second wave of contemporary globalization.

The major feature of the third wave of globalization is the growing connectivity of Asia, while that of other continents is declining (Fig. 3). This reflects the rise of industrialization, first in the ‘four dragons’ (Hong Kong, South Korea, Singapore and Taiwan) and then in China, which has become the new ‘workshop of the world’. The top ten ports of call are mainly in the Far East, followed by North-West Europe. Appendix 2c shows the strong centrality of Singapore and Rotterdam, which are the mega-hubs of the world's two busiest straits (Malacca, English Channel). Each of these has a strong connection with a secondary hub: Hong Kong for Singapore, Antwerp for Rotterdam. Elsewhere, there is a constellation of micro-hubs, corresponding to the increase in the number of ports of call, which can be attributed mainly to the concentration of the general cargo transport sector and the very rapid increase in the size of container ships over the last twenty years. This practice has led to the equipping of coastal areas to encourage the practice of redistributing boxes (feedering).

The Asia-Europe route remains one of the main routes structuring world maritime trade (Fig. 2, 2020), but the nature of trade has changed. Asia has gone from being a buyer of European manufactured goods in the days of the empires to a producer and seller, as shown by the development of a powerful port front in the Far East. This is also reflected in the growing trade between China and Australia, which supplies the latter with raw materials and foodstuffs. Australia's main trading partner is no longer the United Kingdom, but China. We are witnessing the formation of a network highly concentrated on a few main routes, which ultimately receive few but very large ships, and at local/regional level, a sharp increase in the frequency of flows between hubs and spokes.

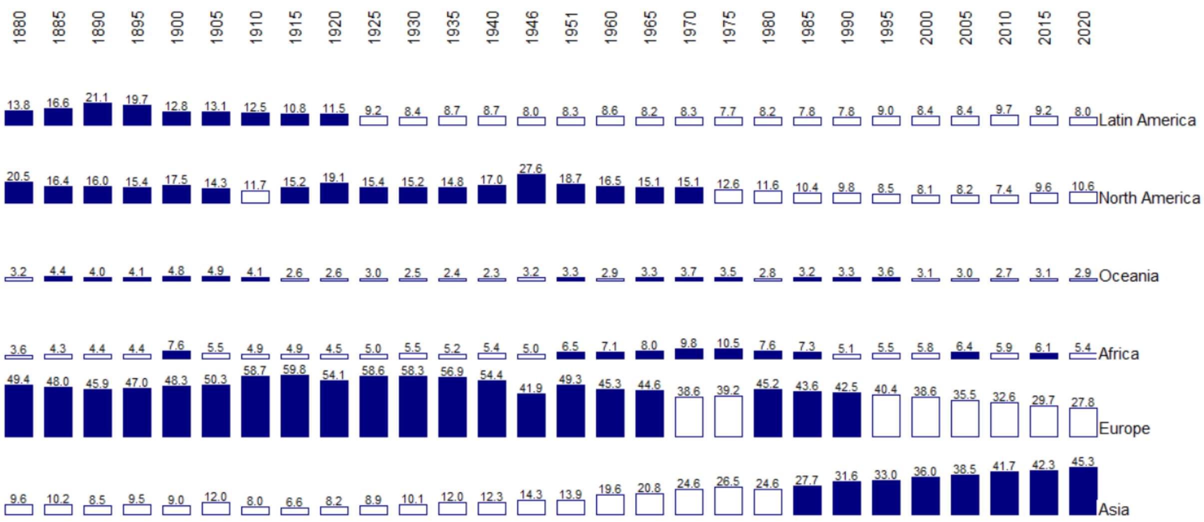

Figure 3. Geographic evolution of world maritime traffic

N.B. dark bars correspond to values higher than rows' average (Unit: % of world port calls)

GLOBAL CONNECTIVITY

Network measures confirm the evolution towards a centralized structure. Average clustering coefficient and density both regularly declined over the period, supporting the fact that the network had become sparser (Fig. 4). This evolution is more regular and clear for density. In the colonial era, different core-peripheries coexisted in the form of empires, having their own economic and geographic logics, and their own fleets. An analysis of ship logbooks from the British, Dutch, Spanish and French fleets between 1662 and 1855 demonstrated the regional specialization of major powers[35] and the strong influence of wind patterns. The observed transformation thus illustrates the impact of globalization, namely an increasing integration of maritime networks at the global scale, supported by the rationalization of links[36].

This ongoing rationalization questions the commonly accepted view that containerization is the origin of current changes. Our findings, instead, support the idea that containerization prolonged rather than initiated the rationalization of the global maritime network. This is explained by two concomitant forces. First, a strong path- and place-dependent process motivated technological (r)evolutions to occur at the same nodes, thereby reinforcing the existing port hierarchy, as suggested by the *preferential attachment process* in scale-free networks[37]. In a port context, such a phenomenon may come from a wide variety of factors, such as geography (site and situation), market size (most of the world's largest cities are port cities), economies of scale (infrastructures, port services, industries), and efficiency (reliability, productivity, reputation, and know-how). The overlap of different layers (e.g., sail, steam, breakbulk, tanker, container, cruise, etc.) makes the network extremely vulnerable to targeted attacks and cascading failures, what was coined "the fragility of interdependency"[38]. Just like cities[39], larger ports (by their traffic) are more diversified[40], while larger port cities (by their population) handle a wider variety of commodities[41]. Pure oil or container terminals are in fact relatively rare compared with large general cargo ports having become heavy industrial ports and later container hubs. Second, modern port infrastructures frequently developed at deep-water sites outside inner port cities, to gain space and welcome larger ships. These terminals were often deployed along major trunk lines connecting the largest markets, allowing a minimum deviation distance. Compared with the colonial era, multifunctional hubs have emerged serving a wider variety of markets through the concentration of major routes at key nodes.

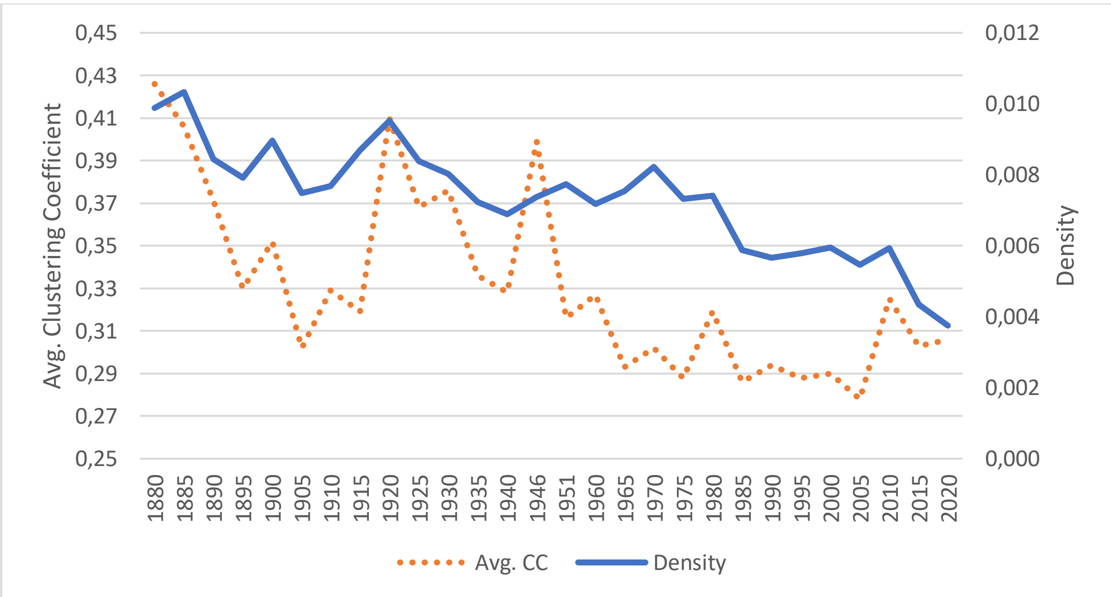

Figure 4. Evolution of network density and average clustering coefficient

In addition, we observe a convergence of density loss across specific regions (Fig. 5 and Appendix 3). These regions have been the most exposed to centralization along the period, especially around particular hubs, such as Rotterdam for British Isles and Hamburg for Scandinavia in North Europe, the most centralized region; Dubai and Abu Dhabi in the Middle East; Kobe, Busan, Hong Kong, Kaohsiung, and Shanghai in Northeast Asia;

Singapore, Port Klang, and Tanjung Pelepas in Southeast Asia. Such a transformation of the network is only visible on the long-term, which explains why previous attempts to measure and observe it over shorter and more recent periods have been unsuccessful, such as for the North Atlantic[42], Caribbean[43], and Mediterranean[44] areas. The two latter regions are more polycentric and therefore did not show any particular trend in terms of density.

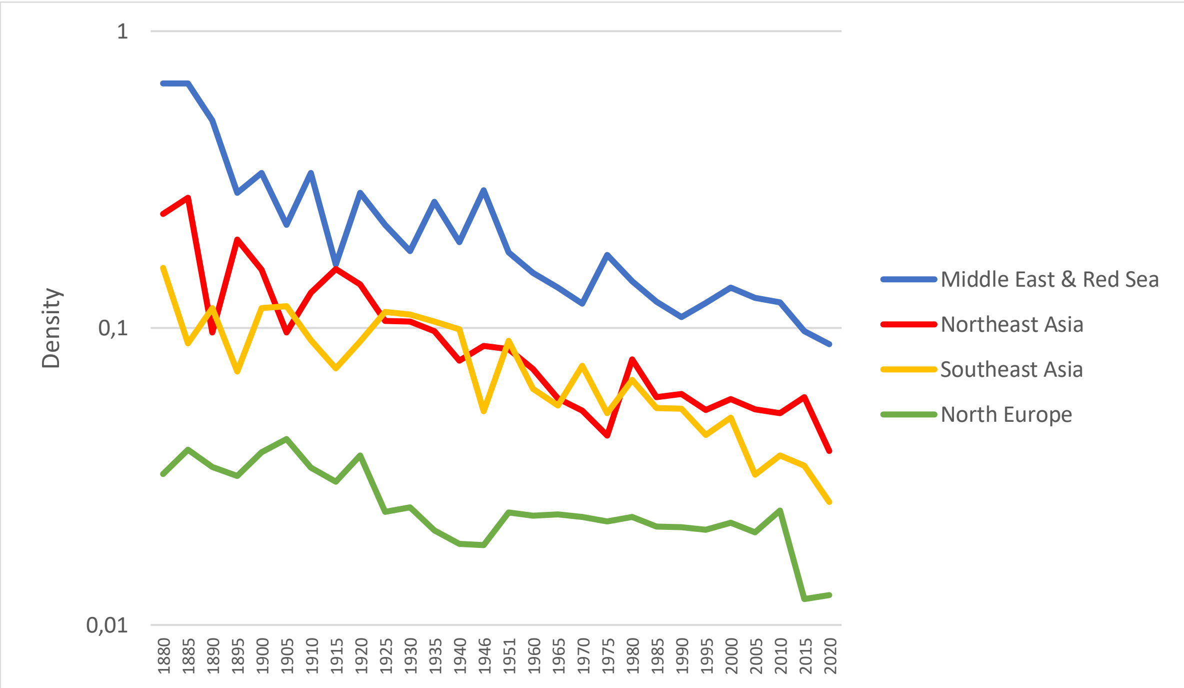

Figure 5. Density evolution in selected maritime regions

The scale-freeness of the network is relatively low overall (–1.5 to –1.4 in the initial period) and it decreases regularly over time (–1.2 to –1.1 in recent years), suggesting a transition towards a more polycentric structure (Fig. 6a). This is partly due to spatial frictions, such as the necessity to navigate through straits, interoceanic canals, and around coastlines[45], contrary to airline networks[46], which can develop as straight lines across oceans and land masses. This explains why the first-ever analysis of a maritime network by physicists[47] concluded that its topology is “somewhere between airline networks and railway networks”. The rich-club coefficient (Fig. 6b) also reduced over time, like the Gini coefficient and the Herfindhal index (Fig. 6c and Fig. 6d). The network as a whole witnessed a regular increase of the number of large nodes, connected by heavier but fewer connections. The evolution from disassortativity (negative degree correlation) to zero degree correlation (Fig. 6e) confirms the aforementioned results. The hub-and-spokes configuration suggested by declining density is blurred by the growing polycentricity of the network. Another possible explanation is the process of regional integration, which causes a growth of intraregional connectivity, without necessarily reinforcing the centralization of hubs.

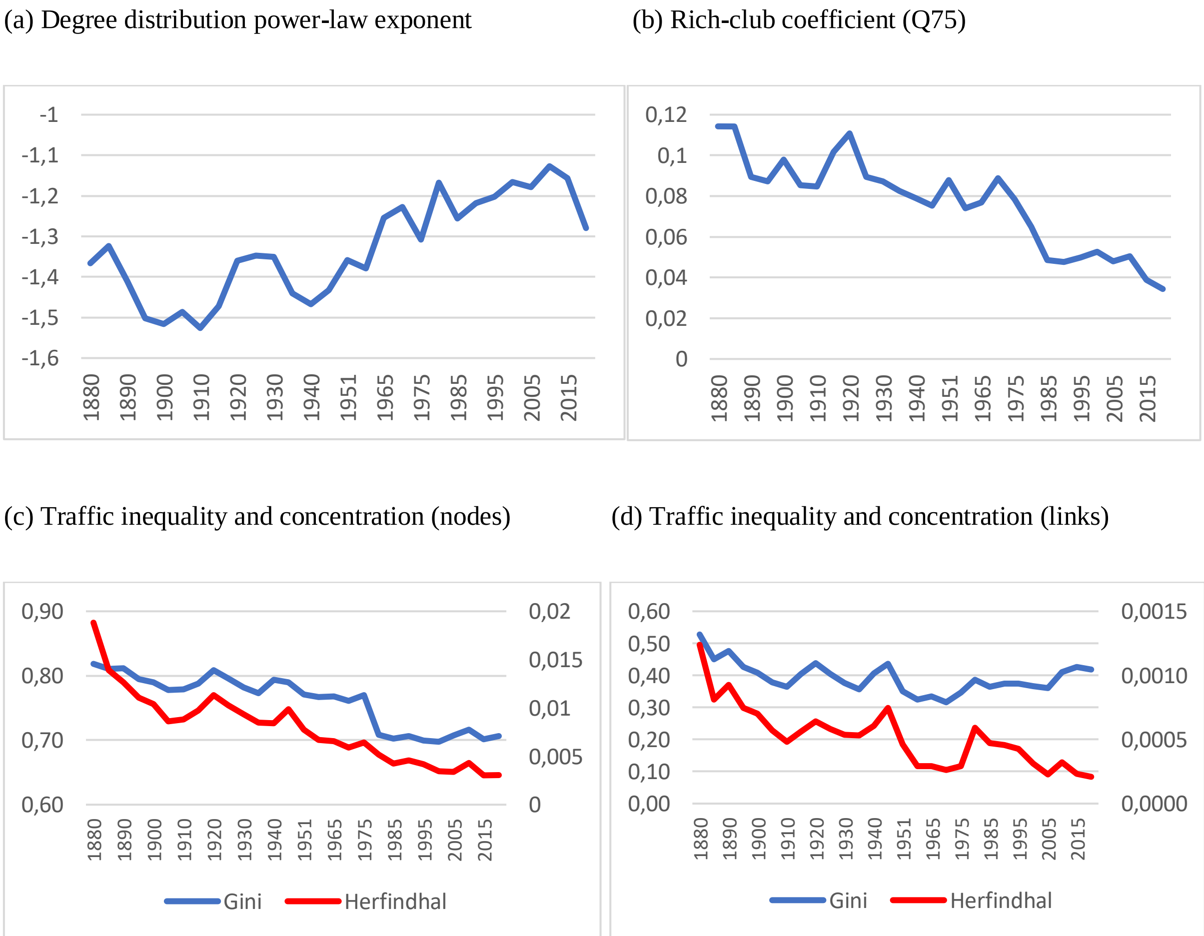

Figure 6. Hierarchical tendencies in the global maritime network

(e) Assortative mixing

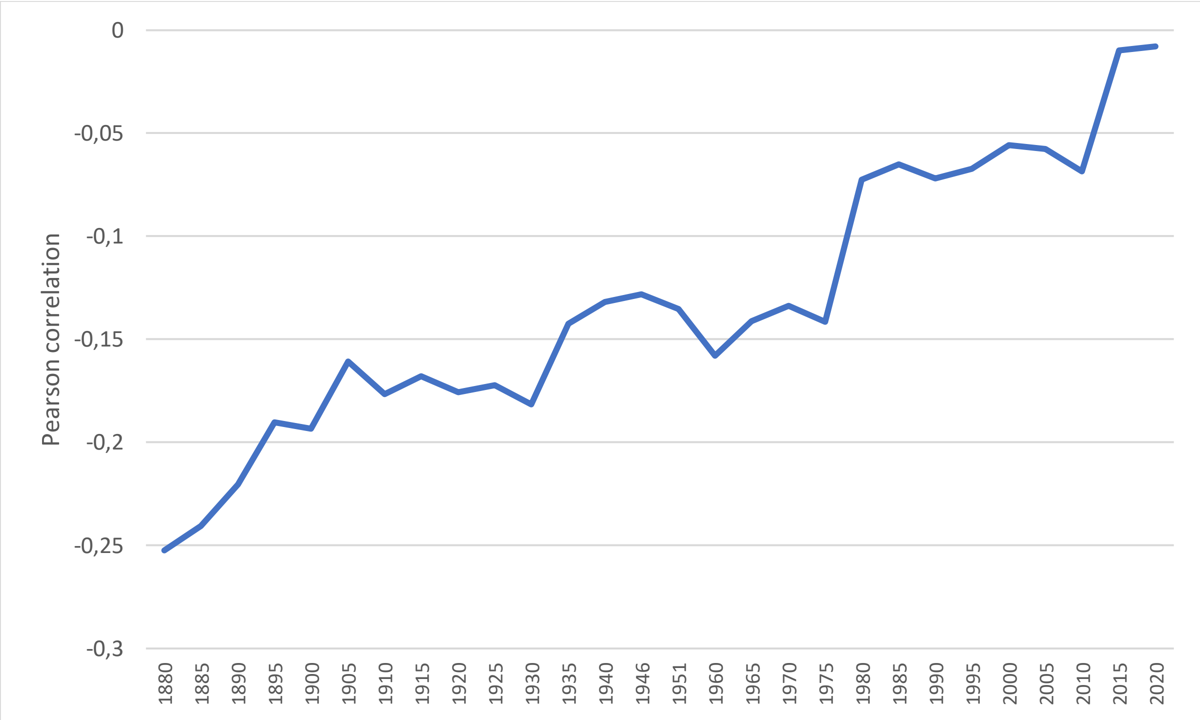

Figure 6 (continued)

The collective presentation of the available vindex's scores of the network generates the time series shown in Figure 7. As it can be observed, the overall vindex's performance can be described by a declining linear pattern under 73% level of determination. The positioning of some rebounds (nearby the beginning of Globalization waves and the WW2) that are visible in the time series compared its overall declining trend, indicate to further examine the network's performance against these externalities (therefore defining cutting points on the years 1915, 1940, and 1990). This observation interprets that the network becomes significantly more vulnerable regarding the major historical externalities of the period 1880-2020, therefore each historical milestone (although initially introduced some fluctuations) appears to have resulted in a more vulnerable network structure.

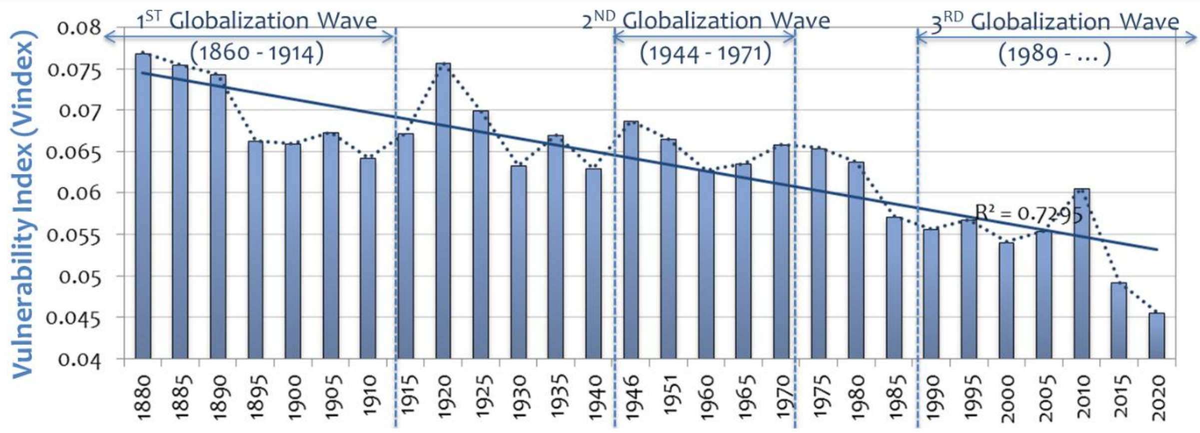

Figure 7. Evolution of the vulnerability index (vindex)

Thanks to increased maritime data availability, computational power, and renewed tools to study large graphs, empirical research on the structure and vulnerability of maritime networks has grown apace since the late 2000s. Our long-term and global analysis including most of the world fleet makes it possible to witness trends that remained so far unknown or only hypothetical. On the one hand, our results confirm well-known facts, such as major shifts of maritime connectivity across the globe and the growing concentration of the port and shipping industry, thereby ensuring that data is of trustful quality. On the other hand, we innovate by putting the current period into a new perspective, showing that the global maritime network went through structural changes since the 19th century. The three globalization waves motivated shipping actors to optimize their networks progressively at the expense of smaller port nodes, to save time and cost, in a context of growing global trade. Such results have many implications for policy. They illustrate how ongoing capitalistic forces foster the concentration of material flows across space, forcing public actors to compete and fund megaports. This has also important geopolitical consequences[48], as major hubs and gateways are not only trading places, but also command and control centers of the global economy and society through ever more sophisticated information systems. Without the intervention of governments and specialized organizations like the IMO, the reliance of global maritime connectivity on a handful of massive private actors and giant port infrastructures is likely to continue. Further research shall verify when the observed trends started, using Lloyd's data on the British fleet (1746-1879), and their continuation in the future.

ACKNOWLEDGEMENTS

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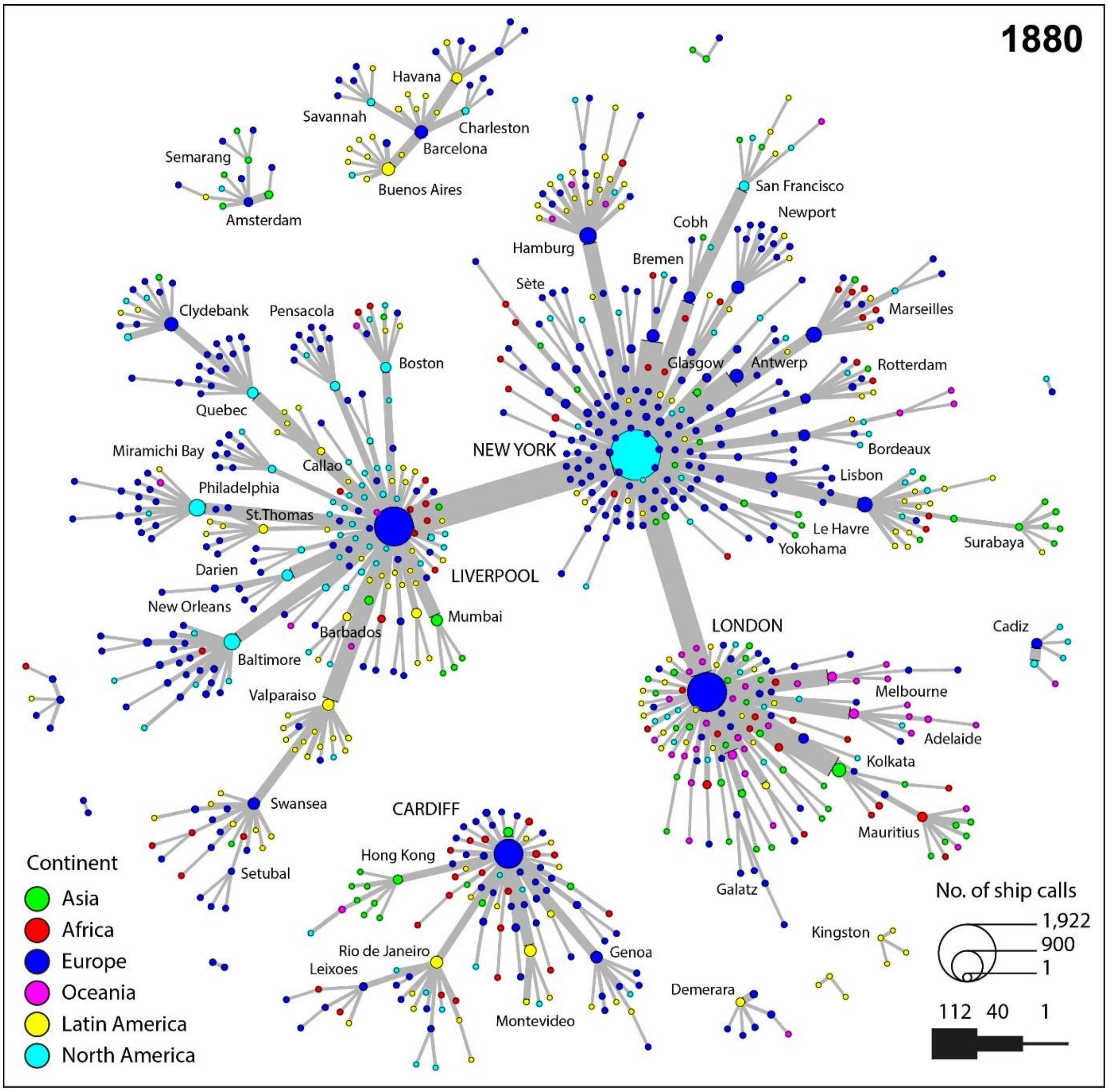
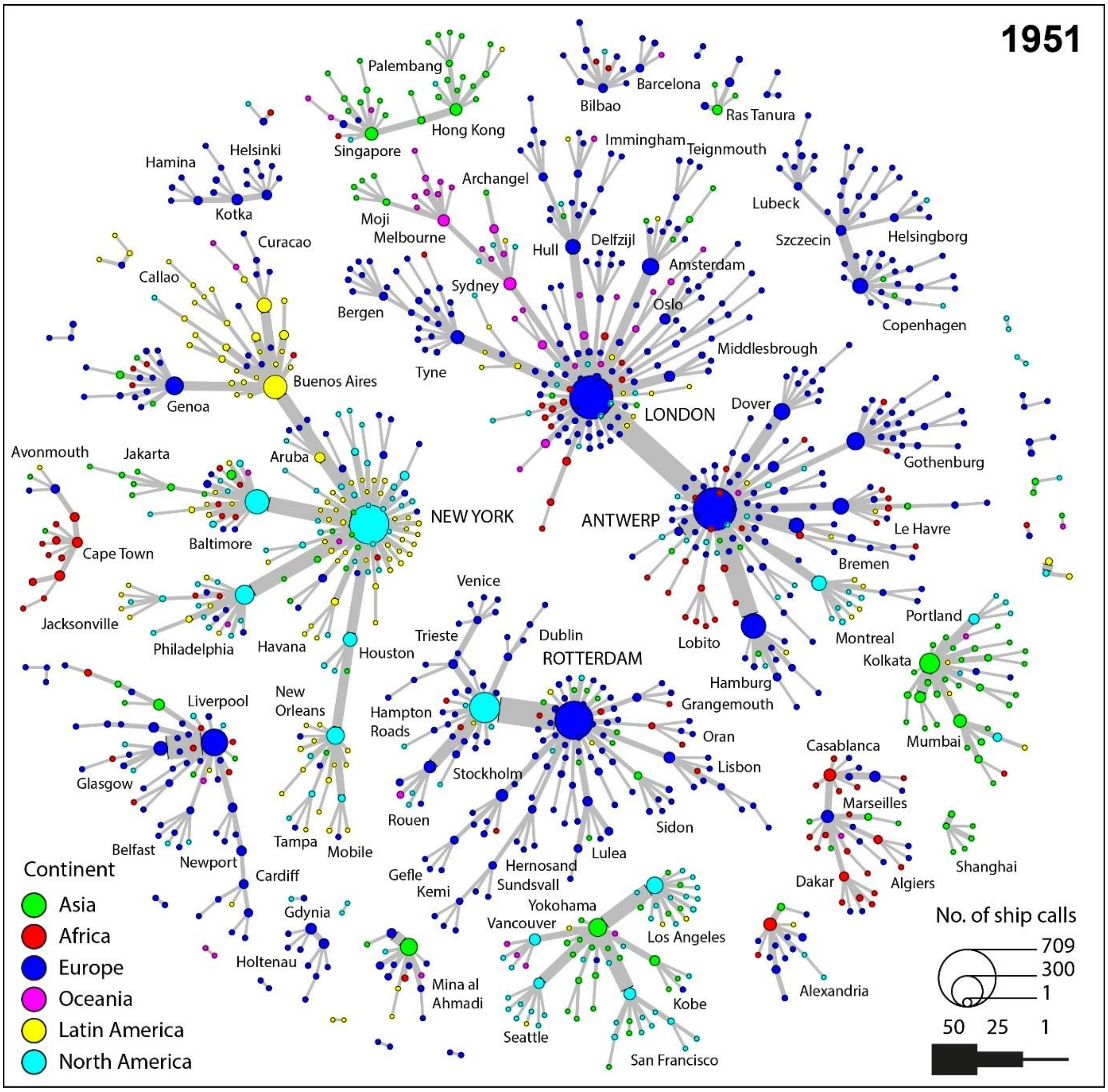
#	1880		1951		2020	
	Port	Calls	Port	Calls	Port	Calls
1	New York	1925	London	709	Singapore	2967
2	London	1421	Antwerp	699	Rotterdam	1154
3	Liverpool	1411	New York	645	Hong Kong	1077
4	Cardiff	983	Rotterdam	614	Busan	774
5	Philadelphia	480	Hampton Roads	478	Shanghai	718
6	Baltimore	457	Liverpool	399	Antwerp	679
7	Hamburg	454	Baltimore	365	Ningbo	677
8	Marseilles	387	Hamburg	359	Tianjin	612
9	Le Havre	374	Buenos Aires	356	Kaohsiung	538
10	Kolkata	347	Kolkata	287	Houston	489
11	Buenos Aires	324	Philadelphia	268	Ulsan	430
12	Clydebank	317	Yokohama	249	Port Klang	418
13	Antwerp	306	New Orleans	244	Yosu	418
14	Rio de Janeiro	297	Genoa	235	Nagoya	400
15	Montevideo	294	Mina al Ahmadi	231	Jakarta	384
16	Barcelona	286	Gothenburg	228	Dalian	383
17	Newport	277	Los Angeles	226	Yokohama	379
18	Bremen	275	Amsterdam	212	Taicang	378
19	Valparaiso	273	Le Havre	196	Incheon	352
20	Mumbai	248	Montreal	189	Onsan	340
21	Genoa	243	Curacao	188	Chiba	338
22	Swansea	240	Copenhagen	186	Qianwan	331
23	New Orleans	236	Bremen	179	Mizushima	329
24	Quebec	235	Hull	178	Gwangyang	313
25	Havana	227	Houston	172	Kobe	305
26	Cobh	225	Glasgow	161	Ho Chi Minh City	297
27	Boston(USA)	217	Singapore	151	Xiamen	293
28	Bordeaux	214	Mumbai	150	Zhoushan	293
29	Lisbon	202	Tyne	146	Hamburg	292
30	San Francisco	195	Alexandria	145	Pyeongtaek	287

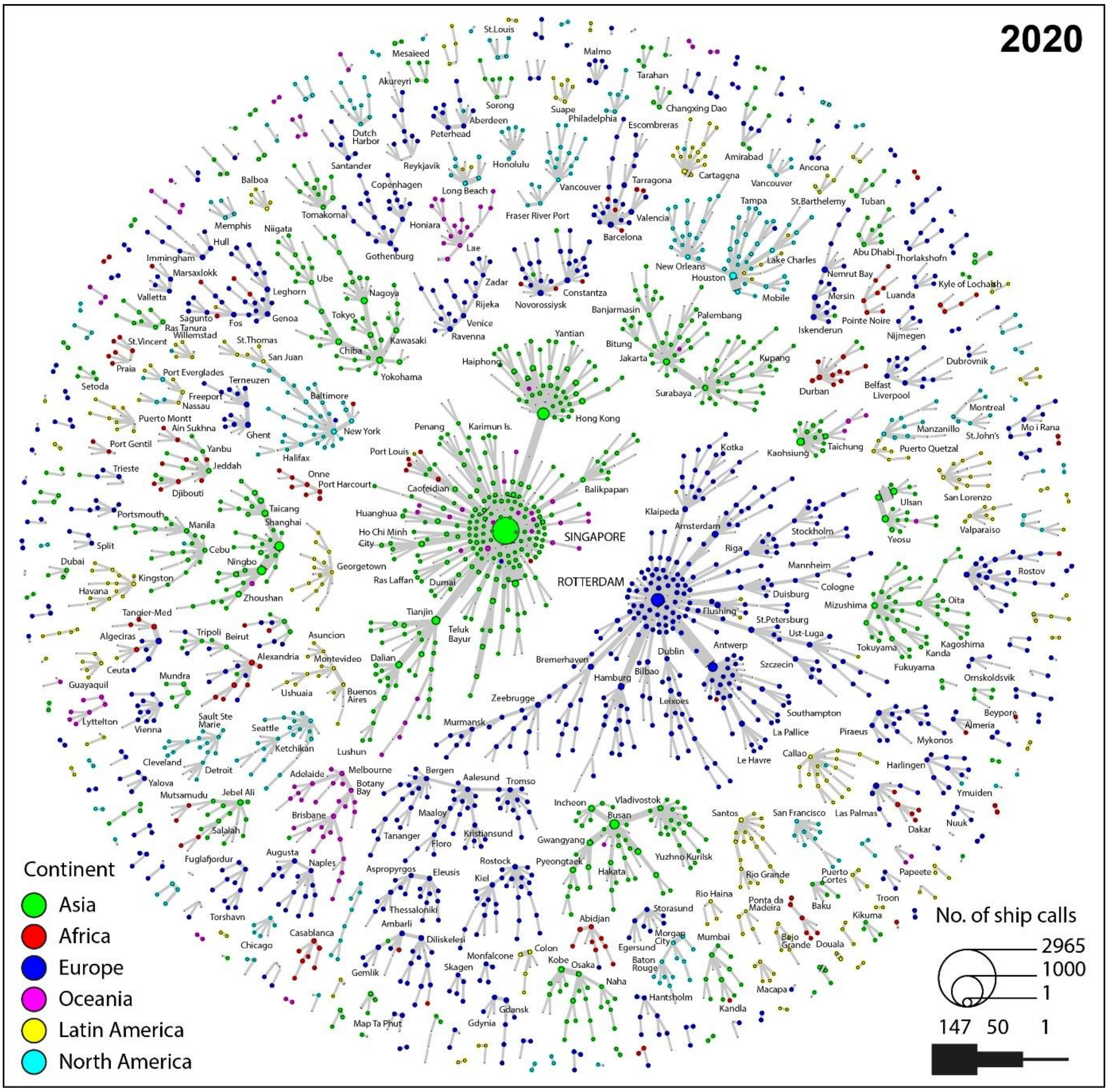
Appendix 1: Top 30 ports by the number of vessel calls at selected years



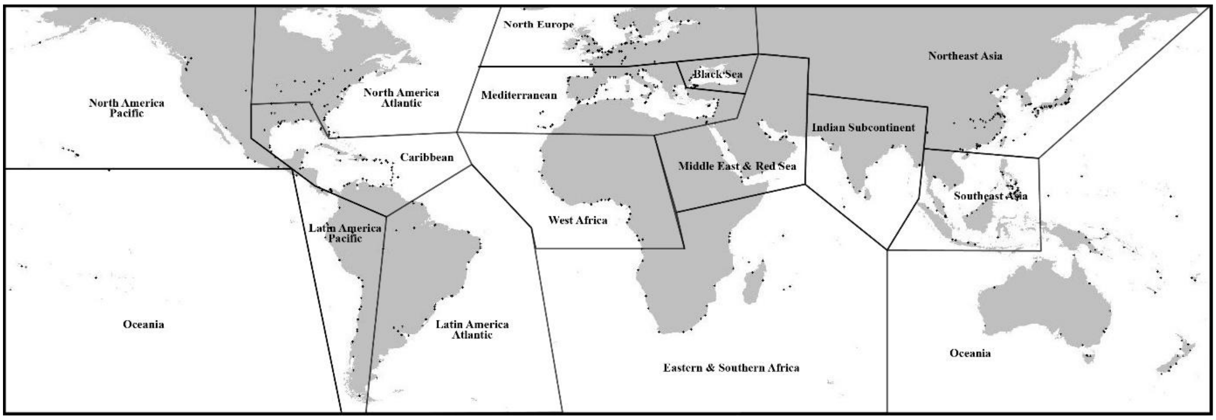
Appendix 2a: Hubs and nodal regions in the world maritime network, 1880



Appendix 2b: Hubs and nodal regions in the world maritime network, 1951



Appendix 2c: Hubs and nodal regions in the world maritime network, 2020



Appendix 3: Maritime subregions of the world

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