Co-evolutionary dynamics of ports and cities in the global maritime network, 1950-90

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Port cities and maritime networks

Models and trends of port-city evolution

Much has been said about the evolution of port cities, from the perspectives of planners, architects, sociologists, economists, historians, and geographers alike, especially in terms of changing urban landscape, port morphology, and other interactions between port and city. Although the definition of the port city concept itself has remained blurred (Ducruet, 2011), most studies converged around the idea that large cities will ultimately get rid of their port activity so as to diversify their economy, prevent their citizens from environmental degradation, be more creative and knowledge-based. Various forms of waterfront redevelopment strategies emerged since the 1950s already to value the city's maritime culture and atmosphere for other uses than cargo handling operations and related industries. At the same time, transport chain actors of which the port increasingly saw the city as a constraint to infrastructure expansion for traffic growth and fluidity, as modern terminals were often develop outside of the city's jurisdiction to find available land and gain in both sea and land accessibility.

Port geography contributed to depict these trends by providing spatial models of port-city evolution organised around successive phases, as well as numerous port impact studies and in-depth investigation of particular ports and port cities (Ng et al., 2014). The Anyport model of James Bird (1963) provided a generalisation of the spatial shift of modern port terminals from the upstream city towards downstream deep-sea locations as a response to urban growth and port growth. Brian Hoyle (1989) later modelled the evolution of the port-city interface to explain how cities and ports grew increasingly apart due to technological change in port and shipping operations, favouring the rise of "placeless ports" and new urban challenges in a postmodern society (Norcliffe et al., 1996). Historians as well proposed a stage approach to port city diversification (Murphey, 1989).

Nevertheless and because cities remain more than ever essential consumption and production centres, there remains a debate on whether such a physical and functional separation process is truly universal (Lee et al., 2008) due to its regional diversity and varying intensity. Geographers also contributed to the debate by discussing the fundamentally urban dimension of commodity chains and the integration versus disintegration dynamics taking place in and around port cities (Hesse, 2010, 2013). Other scholars motivated policy-makers to maintain the benefits of port-city proximity due to the positive externalities provided by cities to ports (Hall and Jacobs, 2012), which was recently illustrated by the creation of new container terminals in the vicinity of certain global cities in order to reduce trucking to and from distant terminals (El Hosni, 2015), such as London, Taipei, Tokyo, and Yokohama. Such examples seem to question the validity of classic port-city evolutionary models.

Measuring port-city interdependence on a larger scale

Most of the time, empirical investigations of port-city evolution remained focused on specific places and projects, at the level of the urban waterfront. As already discussed by Ducruet and Itoh (2015), there are very scarce large-scale analyses of port-region and port-city interdependences (see also Chapter 16 by Ducruet and Itoh on port regions and material flows). Numerous analyses looked at the changing economic impact of ports on their local economy based on a variety of disaggregated data but in turn, these studies remained impossible to compare to one another and over time given the diversity of sources and methods to measure spillovers, related employment, and value added. Looking at the geographical determinants of the port and maritime industries, several works concluded to a stronger influence of urban size (often measured by the number of inhabitants) than port size (as measured by total tonnage or containerised cargo volume) on the distribution of port and maritime services in Australia (O'Connor, 1987, 1989), Canada (Slack, 1989), and at the world scale (Jacobs et al., 2010). Such results suggested that while physical cargo handling operations are more and more performed outside large cities, the latter keep concentrating more "white-collar" office-based activities such as brokers, insurers, and traders. More dynamic analyses came to the similar conclusion that the correlation between port and city was no longer relevant, given the lack of a significant statistical correlation between port traffic growth and urban population growth in France (Steck, 1995) and the decline of the linear correlation between port traffic volume and urban population in India (Kidwai, 1989). A more systematic, global measurement of the relationship between port and urban development was proposed by Ducruet and Lee (2006) over the period 1970-2005. It also confirmed the decreasing correlation between traffic and population, but was solely based on container throughput volumes.

Another drawback of the port-city literature is the rarity of a network approach. Jacobs et al. (2010) did provide a classification of port cities based on their situation in the global network of maritime advanced provider services and their port throughput, but it remained rather static and did not address the distribution of physical flows among port cities. More likely in geography and elsewhere are studies of cities in abstract models of urban interaction where actual flows are absent, or in other types of networks such as airlines, roads and railways, but no study has ever been done about the urban dimension of maritime networks (Ducruet and Lugo, 2013; Ducruet and Beauguitte, 2014). Graph-theoretical and statistical methods were used to explain, for instance, the accessibility and centrality of cities and regions in airline networks by their population and Gross Domestic Product (Choi et al., 2006; Neal, 2011; Wang et al., 2011; Dobruszkes et al., 2011). For other transport modes, Cattan (1995) analysed barrier effects in air and rail flows among European cities, and Guerrero and Proulhac (2014) revealed distinct relationships between the urban hierarchy and the spatial distribution of the respective export volumes of wholesalers and manufacturing companies in France. One aspect of maritime centrality for cities was explored, however, when investigating the respective role of maritime and airline networks in the combined air-sea centrality of cities, but without taking into account other urban data (Ducruet et al., 2011). The same applies to other types of inter-city linkages, which were analysed regardless of other urban attributes, such as those of multinational firms in various sectors (Rozenblat, 2010; Taylor, 2012). with the exception of Jacobs et al. (2011) showing the limited influence of container port traffic on the amount of maritime advanced producer services in world cities.

Reconciling port cities and maritime networks

This chapter proposes to palliate the aforementioned lack of a global and dynamic view by an analysis of combined maritime traffic and urban population data. This is the first-ever analysis of maritime flows in relation to cities based on rigourous harmonisation and manipulation of multiple historical data sources. It aims to measure the influence of urban demographic size on the distribution of global maritime flows, as a means to re-explore the existing literature on ports and cities. It also engages in a wider debate on whether urban development had become increasingly virtual, to such extent that material flows (and their related infrastructures) are increasingly disconnected from human settlements and planning/development priorities (Hall and Hesse, 2012). It gives paramount importance to the definition of the port city itself as a spatial unit, considering not only the locality of the port, but also the extended urban environment at a city-region (or urban area) level, which is more of a morphological nature and has the advantage of being comparable over time and across space. Another innovation compared with previous work is the application of a graph-theoretical framework thanks to the extraction of vessel movement data from the *Lloyd's List* corpus, in particular the *Lloyd's Shipping Index* providing information on the last known movement of each vessel recorded. For the first time, not only traffic and population weights are considered when statistically measuring port-city relationships, but also effective maritime linkages between port cities, here by the cumulated number of vessel calls.

Such a global and dynamic approach will test the extent to which the global maritime network is centralised by larger cities, and how has the correlation between maritime traffic and urban population evolved over time. This research has, therefore, wider implications than for the sole port-city issue. The topological features of spatial networks have rarely been confronted to the socio-characteristics of its nodes (Ducruet and Beauguitte, 2014). Providing a demographic weight to ports thus allows testing numerous ideas about the dependence of maritime networks upon a hierarchy of urban places rather than considering nodes only as ports or terminals. Because it is often the case that several ports belong to the same morphological urban area, the analysis is more compact and aggregated and thus may shed new light about port-city evolution in the last decades. For practical reason of data availability, and because the research is still in progress, the proposed analysis is limited to the period 1950-1990. One main hypothesis is based on the literature on port cities and maritime networks: the initially strong link between maritime flows and urban development has gradually declined. Yet, such a hypothesis might be questioned thanks to a renewed methodological framework where port cities and maritime flows are observed in a radically different way than in the past.

Data and methodology

First of all, this research was motivated by the availability of demographic data in the *Geopolis* database, which provides the number of inhabitants in urban areas based on morphological criteria over the period 1950-1990 (Moriconi-Ebrard, 1994). It was preferred to other possible sources, such as the United Nations, as *Geopolis* rests on a more robust definition of the city. It includes cities having at least 100,000 inhabitants in 1990. This database was completed by *Populstat* for the rest of the period (Lahmeyer, 2006) to zoom on specific port cities at the end of the chapter. Both databases have the advantage to be historical and to consider urban areas rather than sole administrative boundaries.

With reference to Figure 20.1, each port or terminal was associated to the nearest urban centre taking into account urbanization patterns, physical proximity, road accessibility, and urban system layout. This manual method was preferred to any automatic matching in a Geographical Information System (GIS) to avoid putting together cross-border locations belonging to radically different socio-economic contexts. More precisely, two levels of urban activity have been distinguished, city and urban area. The city level is the municipality where the port is located, i.e. the smallest administrative area that is often eponym of the port itself, but not in all cases. The urban area level is the agglomeration or urban morphological area, with two possibilities: the urban area to which the city belongs, or a more distant, inland urban area that connects by road the city, the latter being the maritime outlet of the former. Two or more cities may be included in the same urban area, such as Tokyo and Yokohama that are administratively distinct cities but belong to the same morphological entity. The same methodology applied to coastal and river port cities.

A third type occurred, that is the combination of coastal and inland, especially in the case Santos urban area (Brazil) being the gateway of Sao Paulo urban area, i.e. two urban areas next to each other.

[Figure 20.1 here]

As a result, it was possible to aggregate many ports and terminals altogether that in fact serve the same city, and gain in spatial coherence. For instance, we calculated that London port itself accounted for about 85-90% of the urban area's total vessels calls between 1890 and 1965, but it rapidly dropped since then until reaching 26% in 2008, with the gradual shift of terminals and traffic to deep-sea terminals along the Thames River and up to Felixstowe (Figure 20.2). Although the two curves went through similar evolutions over the whole period, the gap has widened following the shift of modern terminals towards suburban, deep-sea locations outside of the urban core. This is a typical example that confirms the accuracy of the Anyport model (Bird, 1963) in which such a trend was observed around the same period. Notably, Felixstowe set up Britain's first container terminal in 1967 and at the same time, between 1960 and 1980, the so-called London Docklands were gradually closed and the port activity relocated to Tilbury, Thamesport, and Felixstowe. This long-term view is currently in progress when it comes to the whole sample of ports worldwide. Port activity corresponds to the number of vessel calls calculated from the *Lloyd's Shipping Index*.

[Figure 20.2 here]

Because the population data was available only every decade, it was decided to calculate the year-on-year average for the intermediate years of 1965, 1975, and 1985, to better see a trend in the association between population and traffic. As a result and considering only the urban area level, the global port-urban database concentrates a noticeable proportion of world ports and population, with about 500 urban areas considered for this time period (Table 20.1). The share of ports included in urban areas has increased, but the share of population and vessel calls has decreased, which is mainly due to the exclusion of smaller cities by *Geopolis*. Nevertheless, this sample is very representative of global maritime activity, as it remains around 80% of total vessel calls over time. This is already in itself an indication that maritime traffic is more likely to concentrate in larger cities. In addition, the urban areas exerting maritime trade have always been three times larger on average than other cities in terms of demographic size. Although such evidences are insufficient to conclude to mutual port-city growth effects, it confirms the observation that port cities enjoyed stronger dynamics due to their direct access to international trade networks (Dogan, 1988).

[Table 20.1 here]

The changing correlation between traffic and population

One possible way to further check the respective influence of urban size and maritime traffic distribution is to look at the linear correlation among them and at the changing share of city size classes (quantiles) (Table 20.2). Despite certain fluctuations, maritime traffic is distributed hierarchically as its share increases along with population. The distribution among the six classes is relatively stable over time. Noticeable changes can be highlighted, however. For instance, the largest cities regularly dominate world traffic but their share has dropped from 59.4% to 49.7% between 1951 and 1990, while the share of the smallest cities has almost doubled, from 2.8% to 5.3%. In fact, traffic gradually shifted from the largest cities towards smaller ones, as each class gained around 2% over the period. This shift largely explains the decreasing concentration of maritime traffic among cities, as seen with the Gini coefficient (0.724 to 0.684) and the Herfindahl index, but the latter has been more stable than the first.

One very important result is the decreasing linear correlation between traffic and population. The linear function was in all cases the best fit between the two variables. Interestingly, the correlation coefficients obtained for port urban areas (i.e. the port city itself) are always lower than when including non-port urban areas (i.e. distant cities served by the port). Indeed, numerous inland cities are the true engines of port activity, despite road distance between port and city, and taking into account such an important aspect has been beneficial to the results[1]. Another results is that the correlation has somewhat stabilised, creating a widening gap with the one obtained based on coastal urban areas only. This directly relates to the «hinterland effect» by which ports situated in minor coastal cities may have handle traffic volumes far beyond the needs of their host city, so that considering the nearby inland urban area as the city of reference improved the coherence of the results. While the correlation coefficient for coastal cities dropped only by half, the one based on coastal and inland cities lost only one point.

[Table 20.2 here]

Urban centrality in the global maritime network

The relationship between centrality and demography

[1] The synthesis provided by the OECD (2014) on port-city development included a figure showing the relationship between inland cities and coastal ports, distinguishing amongst independent metropolis (large port city far away from an inland core), short-range corridor (coastal and inland cities belong to the same morphological area), long-range corridor (port city under the shadow of the inland city within a 200km radius), and dependent satellite (large inland city near a minor port city). The four possible types of spatial configuration were discussed in terms of self-agglomeration or lock-in effects based on the model of Fujita and Mori (1996) about the development of port cities.

Another important dimension of the research is the influence of demographic size on the centrality of cities in worldwide maritime flows. Commonly accepted measures of node centrality were calculated and compared (Table 20.3) so as to reveal their possible link with demographic size. Overall, all indicators exhibited a declining correlation with urban population, especially since 1960. Betweenness centrality, which corresponds to the number of occurrences of nodes on shortest paths in the entire graph, had the highest correlation in 1951, superseded by degree centrality, a more local measure (i.e. number of adjacent neighbours), since 1960. Eccentricity always had a lower correlation, while the clustering coefficient is negatively correlated and remains around -0.2. This negative score means that despite its low significance, the ability of nodes to be a star in the network (i.e. lower scores correspond to hubs with poorly connected neighbours) is more likely to apply to larger cities.

The latter evidence is confirmed when looking at the average clustering coefficient by classes of urban size (quantiles). While for all cities the clustering coefficient has regularly decreased, suggesting a general evolution of the network towards a hub-and-spokes or «scale-free» structure, the largest cities always score the lowest, as they tend to be the hubs for multiple, poorly connected and smaller cities. With a few exceptions, the average clustering coefficient increases from one class to another as population increases, which suggests that as cities get smaller, their ability to centralise maritime flows decreases. Yet, the gap between the average clustering coefficient of the smallest and the largest cities has narrowed over time, from 0.32 to 0.15, which means that the probability for hub functions to concentrate at larger cities has somewhat become more blurred than in the earlier decades. Lastly, the rich-club coefficient that divides the link density (or completeness) among larger cities by the link density among all cities shows that larger cities tended to be around five times better connected with each other. Thus, the urban hierarchy certainly influences, at least partly, the spatial distribution of the global maritime network, notwithstanding important changes. Yet, it is also important to address how hierarchically connected are cities of various size in the network.

[Table 20.3 here]

The analysis of priority linkages is a useful method to further understand the influence of urban hierarchies on the distribution of maritime flows. At the level of city size classes (Table 20.4), the share of vessel calls distributed between urban areas of similar size (intra-class) always remained lower than for the flows between other cities, and it has even decreased over time, from 48% in 1951 to about 38% in 1990. In comparison, the share of flows between adjacent classes oscillated around 20% of inter-class flows, while flows between demographically opposed cities (i.e. largest to/from smallest) increased from 0.9% to 13.8%. Overall, largest cities connect primarily with each other, as the two top classes (5 and 6) have a combined share of 82.7% of total intra-class flows in 1951, but this share dropped to 62.8% in 1990.

Such elements motivate the reference to the declining clustering coefficient on the level of the entire network, as one may conclude to the growing centralisation of network flows, especially around larger cities, which become more connected to smaller ones due their increasing role as intermediary hubs in the network.

[Table 20.4 here]

Additional evidence was obtained from the analysis of network assortativity (Table 20.5). As defined by Newman (2002), assortativity (or assortative mixing) is measured by the Pearson correlation coefficient of degree between pairs of linked nodes. It indicates whether nodes of similar (or dissimilar) size preferentially connect to each other in a network. Urban area population was preferred to degree in this chapter to elucidate whether city size plays a role in the distribution of maritime flows. Assortativity was calculated with Python NetworkX package based on real population numbers and their logarithm, and on binary or weighted city-to-city matrix. Results were insignificant when considering binary linkages (presence or absence of a link). Taking into account weighted edges provided a positive and growing assortativity of the network, especially between 1970 and 1990, and this was even truer with logs for urban population. Despite the growing centralisation of maritime flows by larger cities (towards smaller cities) and just like scale-free networks in general, large hubs strongly connect each other while multiplying links towards smaller nodes.

[Table 20.5 here]

Cities in nodal maritime regions

Priority linkages may also be mapped based on the nodal region algorithm (or single linkage analysis) by which only the largest flow link of each node is kept in the graph (see also Appendix 20.1). Such a method helps revealing which nodes centralise flows in a tree graph and eventually the hidden subsystems composing the network. In this analysis, urban area population is taken as the referent metric to map nodes (Figure 20.3), while nodal regions are positioned using a Gem-Frick visualisation algorithm in the TULIP software to put major nodes and components at the centre of the figure and less important ones at its periphery. One first observation is that the number of large connected components has decreased from seven in 1951 to two-three in 1990, which underlines both the growing integration of global trade (Feenstra, 1999) and centralisation of the global maritime network around fewer pivotal hubs – the latter being an illustration of the declining clustering coefficient observed in Table 20.3. A second observation is that the geographic dimension of the components has fundamentally changed through a reinforced regionalisation of maritime flows. The hubs of these components tend to gradually restrict their dominance towards geographically close port cities, whereas in the beginning of the period, it was often the case that port cities from different, distant continents were included in the same subgraph. This brings concrete evidence about the shift from a colonial, centre-periphery system to a more polycentric one based on intra-regional freight distribution where the logistical factor had become prominent.

The extent to which larger cities always dominate smaller cities can be discussed based on this analysis. In 1951, the central hubs of the three largest components are also the world's largest port cities, namely London, Tokyo, and New York. It is not a coincidence that exactly these three nodes are titled "global cities" by Sassen (1991) in the title of her masterpiece on the matter, although her essay did not pay much attention to the port and maritime function of these cities per se. These major maritime nodes dominate a large number of other ones through the principle of transitivity, not only in their close vicinity but also through long-distance trade exchanges, such as London directly or indirectly centralising flows connecting Europe with Africa, Australia, and the Americas.

However, the demographic size of certain port cities is not always reflected by an equivalent position in the maritime network. Some port cities have simply faced trade decline despite their demographic growth, such as Bombay and Calcutta following the demise of the British Empire and the 1947 independence, and Buenos Aires facing internal political tensions that gradually eroded its previous prosperity. The large, global city of Paris (France) being a river port 250 kilometres from the coast always appeared as a terminal node. This is also the case of Great Lakes cities such as Chicago, Toronto, and Detroit which maritime accessibility is hampered by the necessary passage through the St. Lawrence Seaway before reaching international sea routes. Conversely, port cities such as Al-Kuwait or Basrah in 1960 enjoyed a strong nodal position regardless of their smaller urban size mostly due to the boom of oil business in the Middle East. But the most impressive example of this gap is the outstanding centrality of Antwerp and Rotterdam in the European component, especially since 1970, despite a relatively minor urban dimension compared with other world port cities, as they became Europe's largest gateways and still occupy this role nowadays, together with Hamburg, the latter being three times larger by its population. The same phenomenon occurred in Asia, where Singapore and Hong Kong, which are still large cities, gradually became the major hub ports for a number of even larger cities such as Bangkok, Jakarta, Shanghai, and Karachi. The latter ports became constrained by urban growth as shipping lines centralised their networks upon a few, strategically located transhipment nodes. London and New York have become minor ports in the network in 1990, despite their urban size and the volume of their traffic, due to the reorientation of major trunk lines towards external hub ports in North Europe and the Caribbean, respectively. With the exception of Tokyo, Osaka, Sao Paulo and Los Angeles, most of the largest cities have become somewhat peripheral in the maritime network in 1990.

Another reason is the influence of political events and transitions, as seen with the isolation of the Barcelona, Bilbao, and Shanghai components in 1951, their respective governments having imposed trade barriers with the outside world at the time (i.e.

Franco and Mao rules). However, Shanghai integrated the larger Tokyo component through Singapore in 1960 and Hong Kong in 1970. Perhaps, the isolation of the Alexandria (Egypt) component can be explained by the imminent revolution officially dated in 1952. Other examples include the Kiel/Murmansk dyad in 1960 in a context of Cold War, and the Tel-Aviv/Haifa (Israel) component in 1970 and 1980 that did not include neighbouring ports until becoming part of the larger Venice component in 1980. This is also the case for Beirut/Lattakia in 1970 and 1980 before and during the civil war, and of Havana (Cuba) connecting principally Cuban ports, Rostock (East Germany), and Varna (Bulgaria) in 1970 also reflecting upon the Cold War era. In 1980, Havana still stands apart but has one connexion with Vigo in Spain, and although it integrated the larger Singapore component in 1990 it was through Odessa (Ukraine) as part of the USSR trading system.

Another observed factor is the persistence of specialised long-distance linkages such as those based on maintained colonial ties, as seen with the Dunkirk component in 1951 comprising Le Havre, Brest, Bordeaux together with colonial ports (Madagascar, Vietnam, Benin, Congo, and Senegal) and the Lisbon component in 1951, 1960 and 1970 including Porto, Angolese, and Guinea-Bissau ports. To some extent, the Marseilles component that remains isolated until 1990 may be placed in this category, since it has a relatively smaller size than the largest components and mostly includes French and African ports, reflecting upon the somewhat independent French trading system. Lastly, the isolation of certain smaller components from the larger ones may also be caused by coastal morphology and geographic proximity. It is the case of the North Adriatic component of Rijeka/Trieste/Venice in 1960, of the Southern African component Cape Town/Durban in 1951 and 1960. The Sydney/Melbourne component has always been apart from 1951 to 1990. Numerous other intra-European components fall in this category based on specialised intra-regional trades.

[Figure 20.3 here]

Port-urban trajectories

This research can potentially shed more light on the long-term evolution of port cities. The selection of a few examples is a first step in such a direction. The analysis benefited from the inclusion of additional urban data drawn from the *Populstat* database (Lahmeyer, 2006), still at the level of urban areas rather than the sole administrative unit. Comparing urban population and maritime traffic (Figure 20.4) shows that the number of vessel calls and of inhabitants for London have underwent two opposed trajectories over the period: a parallel growth (1890-1935) and decline (1951-2008). While vessel traffic is significantly and statistically explained by urban population in both cases, with about 88% and 67% for the determination coefficient on the power-law line, it remains only around 15% for the whole period. As mentioned in the methodological section, there has been a rapid traffic shift towards modern terminals situated outside the urban core alongside drastic waterfront redevelopments in the Dockland area. Nevertheless, welcoming ever-bigger ships had led to a decreasing number of port calls, due to increasing ship size, while a large proportion of UK traffic became rerouted via Benelux ports and notably Rotterdam, as seen in Figure 20.3. Such factors can explain at least partly London's traffic evolution. But at the same time, London's population has also shrunk over time, in similar ways than traffic, although the two evolutions may not be directly interdependent. Population stagnation or decline in large Western cities is a general phenomenon that is caused by wider demographic trends such as ageing and urban sprawl.

In the case of Shanghai, the determination coefficient over the whole period remains moderately significant (45%), but it is much higher when splitting the period in two, namely 1890-1946 (76%) and 1951-2008 (73%). In 1949, a major political change occurred, namely the proclamation of the People's Republic of China, causing a drastic traffic declining which had recovered in accordance with the urban system. Contrary to the general belief that China as a whole was closed to international trade under Mao rule, port activity resumed rather rapidly already in the 1960s, while the spatial distribution of maritime traffic overlapped again the urban hierarchy of coastal port cities. This was also demonstrated by Wang and Ducruet (2013) in their analysis of Chinese port tonnage over the period 1868-2010 based on customs and ministry data, concluding to a strong resilience of the port system to political disturbances. The direct impact of China's official opening to foreign investment and international trade in 1978, known as the Open Door Policy led by Deng Xiaoping, is clearly illustrated by rapid traffic growth between 1975 and 1980. Urban population, fed by massive in-migration from rural areas, grew steadily since then, backed by ongoing industrialisation (Wand and Ducruet, 2012).

[Figure 20.4 here]

Conclusion

The link between port and city had often been analysed at the intra-urban level in previous research, where the separation process, both physical and functional, had been most visible. Expanding the analysis at the urban area level for the period 1950-1990 through a systematic quantitative approach of hundreds of port cities allowed confirming a growing disarticulation between the global urban hierarchy and the global maritime network. Yet, the magnitude of urban development remains an essential factor to explain maritime traffic distribution across the globe, notwithstanding the rise of less-urbanised hub ports and the influence of other factors such as site constraints, political contexts, and the changing pattern of trade routes. This first-ever dynamic and global analysis of combined maritime and urban data from a network perspective could, at least, fill this lack in the related urban and transport literature, which was still very much monographic or focused on other types of networks.

Further research shall concentrate on refining the statistical approach to port-city evolution, by applying more sophisticated tests on maritime and urban time series data, especially to check the direction of their mutual influence, and the possible regional logic behind such an influence. This will necessitate to fully exploiting the potential of the *Populstat* database for all cities, which goes back to the nineteenth century and prolongs the time coverage up to the 2000s. Including more many smaller cities and urban areas will inevitably improve the results in terms of global port-city correlation, traffic distribution, and evolution. The analysis of port-urban trajectories should be expanded so as to check whether comparable trends can be extracted and compared. In particular, certain properties such as assortativity or clustering may translate subsequent industrial and regional changes, such as the emergence of hub-and-spokes systems in liner shipping and the prolonged Asian growth.

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		1951	1960	1965	1970	1975	1980	1985	1990
	No. urban areas	442	490	498	498	511	523	550	547
World share (%)	No. ports	50.9	42.5	46.8	51.7	54.6	57.1	59.3	62.8
	Urban population	52.9	51.5	50.9	50.4	48.5	47.1	46.8	46.7
	No. vessel calls	81.9	81.3	82.2	82.5	81.4	80.6	78.1	78.1
Average population (000s inhab.)	Port cities	418	538	616	687	765	847	932	1014
	Non-port cities	141	167	189	221	251	297	340	382

Table 20.1: Characteristics of the port-urban database, 1950-1990

	Quantiles	1951	1960	1965	1970	1975	1980	1985	1990
Share of world vessel calls (%)	6	59.4	59.4	56.9	56.8	56.9	49.2	49.7	49.7
	5	18.9	15.5	18.7	18.6	15.4	22.4	20.8	20.2
	4	8.3	10.6	10.8	10.1	11.3	11.7	10.1	11.1
	3	6.4	7.3	6.2	6.9	8.2	7.8	8.5	8.1
	2	4.1	3.8	4.6	4.6	5.6	5.2	6.3	5.6
	1	2.8	3.4	2.7	2.9	2.6	3.7	4.7	5.3
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Correlation (Pearson)	Coastal urban areas	0.521	0.485	0.404	0.408	0.326	0.315	0.338	0.288
	Coastal & inland urban areas	0.559	0.581	0.535	0.572	0.511	0.467	0.498	0.437
Traffic concentration	Gini coefficient	0.724	0.710	0.704	0.696	0.712	0.697	0.684	0.684
	Herfindahl index	0.012	0.011	0.010	0.009	0.011	0.010	0.009	0.011

Table 20.2: City sizes and traffic distribution, 1950-1990

	Quantiles	1951	1960	1970	1980	1990
Average clustering coefficient*	6	0.434	0.417	0.413	0.371	0.361
	5	0.532	0.539	0.457	0.398	0.377
	4	0.584	0.567	0.493	0.476	0.422
	3	0.580	0.562	0.547	0.488	0.512
	2	0.627	0.587	0.543	0.500	0.476
	1	0.756	0.663	0.676	0.560	0.515
	All	0.542	0.542	0.534	0.487	0.465
Correlation	Clustering coefficient*	-0.231	-0.251	-0.255	-0.202	-0.210
	Degree centrality	0.462	0.521	0.469	0.465	0.423
	Betweenness centrality*	0.507	0.494	0.449	0.452	0.344
	Eccentricity*	0.312	0.356	0.325	0.312	0.232
Rich-club coefficient		5.597	5.959	5.166	4.974	4.843

Table 20.3: City sizes and network measures, 1950-1990

N.B. zero values are excluded for variables marked with *

	Quantiles	1951	1960	1970	1980	1990
Intra-class (%)	6	67.5	63.8	50.3	44.4	45.3
	5	15.2	13.5	16.9	20.4	17.5
	4	11.9	12.5	12.6	11.0	12.3
	3	5.0	9.1	6.0	7.7	8.7
	2	3.8	3.5	3.1	4.5	5.8
	1	2.2	4.5	2.9	3.3	5.5
	All	48.0	43.9	39.0	34.7	37.8
Inter-class (%)	Opposed (1/6)	0.9	7.6	10.1	12.5	13.8
	Adjacent	22.5	19.7	21.4	22.1	20.6
	All	52.0	56.1	61.0	65.3	62.2

Table 20.4: Maritime flows and urban homophily, 1950-1990

Urban weight	Population (raw)		Population (log)	
Links weight	unweighted	weighted	unweighted	weighted
1951	-0.0297	0.0406	-0.0183	0.0974
p	0.0053	9.98E-10	0.0865	5.88E-49
1960	-0.0425	0.0029	-0.0420	0.0773
p	5.18E-06	0.6119	6.50E-06	7.39E-40
1970	-0.0278	0.0414	-0.0274	0.0814
p	0.0011	4.35E-14	0.0013	8.36E-50
1980	-0.0126	0.1024	-0.0108	0.1394
p	0.1601	4.57E-65	0.2310	1.81E-119
1990	-0.0117	0.1177	0.0041	0.2032
p	0.1587	9.08E-111	0.6215	0.0

Table 20.5: Evolution of network assortativity, 1950-1990

Rank	1951		1960		1970		1980		1990	
1	London	799	Hamburg	889	Rotterdam	941	Rotterdam	1,130	Singapour	1,718
2	Rotterdam	741	London	863	Hamburg	918	Singapour	993	Rotterdam	1,114
3	New York	698	Rotterdam	851	Tokyo	905	Hamburg	872	Tokyo	989
4	Antwerpen	633	New York	718	London	586	Tokyo	839	Antwerpen	758
5	Hampton Rds	520	Tokyo	599	New York	585	Antwerpen	772	Hamburg	644
6	Liverpool	517	Antwerpen	597	Antwerpen	582	New Orleans	748	Hong Kong	602
7	Hamburg	380	Liverpool	488	Osaka	555	Osaka	458	Osaka	593
8	Tokyo	379	Osaka	399	Singapour	445	New York	414	New Orleans	578
9	Baltimore	348	New Orleans	372	New Orleans	426	Jiddah	384	Los Angeles	456
10	Buenos Aires	338	Buenos Aires	351	Liverpool	390	Los Angeles	371	Houston	312
11	Calcutta	275	Houston	339	Houston	357	Hong Kong	362	Las Palmas	301
12	Portland	272	Hampton Rds	335	Hampton Rds	357	London	352	Bangkok	285
13	Houston	262	Al-Kuwayt	327	Genova	335	Houston	338	Odessa	284
14	Amsterdam	257	Genova	319	Hong Kong	311	Lagos	328	Vancouver	277
15	New Orleans	246	Calcutta	301	Vancouver	286	Marseille	321	London	273
16	Al-Kuwayt	235	Baltimore	278	Buenos Aires	276	Gdansk	301	Kaohsiung	268
17	Marseille	234	Bremen	277	San Francisco	276	Alexandrie	293	Nagoya	263
18	Los Angeles	229	Amsterdam	276	Marseille	274	Buenos Aires	292	Marseille	262
19	Genova	229	Singapour	270	Gdansk	272	Vancouver	290	Constanta	252
20	Le Havre	201	Montreal	267	Los Angeles	252	Bremen	276	Durban	242
21	Glasgow	199	Vancouver	245	Capetown	251	Basrah	275	New York	236
22	Tyneside	197	Los Angeles	239	Durban	250	Constanta	253	Bombay	226
23	Montreal	191	Kobenhavn	224	Lisboa	244	Lisboa	252	Hampton Rds	226
24	San Francisco	189	Glasgow	222	Al-Kuwayt	239	Las Palmas	243	Pusan	210
25	Kobenhavn	188	Hong Kong	216	Calcutta	233	Bombay	235	Gdansk	206
26	Hull	185	Portland	210	Bremen	230	Hampton Rds	234	Le Havre	204
27	Bremen	184	San Francisco	199	Las Palmas	225	Genova	231	Jiddah	197
28	Seattle	179	Gdansk	198	Portland	212	Odessa	224	San Francisco	188
29	Singapour	170	Hull	194	Kitakyushu	212	Le Havre	218	Shanghai	188
30	Sydney	168	Marseille	184	Baltimore	206	Durban	214	Alexandrie	185

Appendix 20.1: Top 30 urban areas by the number of vessel calls, 1950-1990

N.B. the following short names for urban areas are in parentheses: Norfolk/Portsmouth VA (Hampton Roads), Megalopolis Central (New York), Los Angeles/Riverside/Oxnard (Los Angeles), Megalopolis South (Washington/Baltimore), Liverpool/Birkenhead (Liverpool)

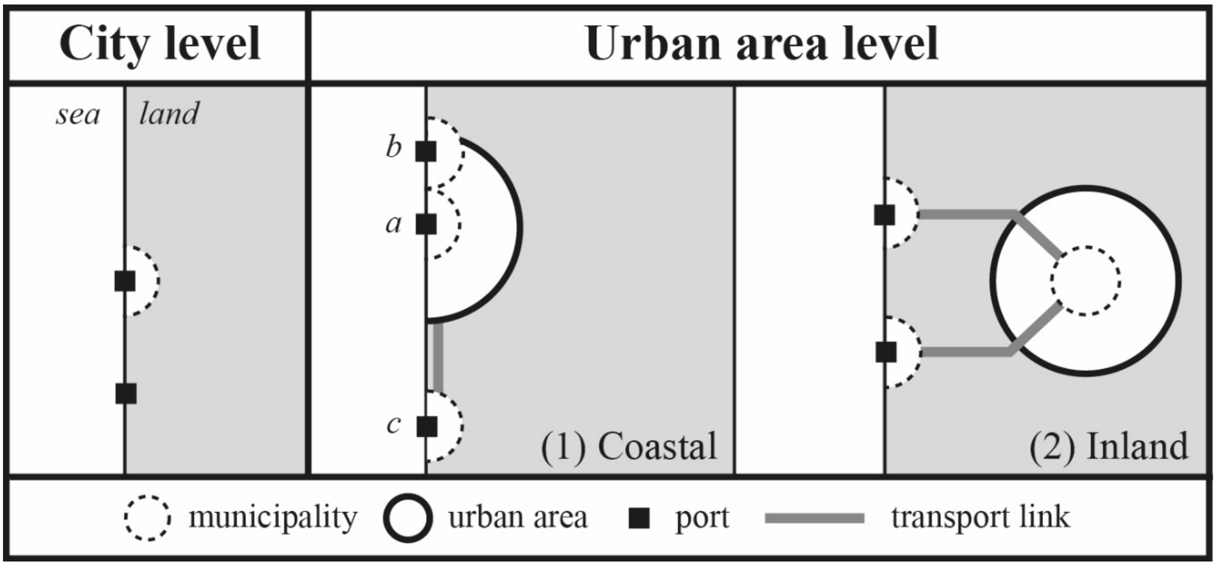


Figure 20.1: Methodology for port-city matching
Source: own realisation

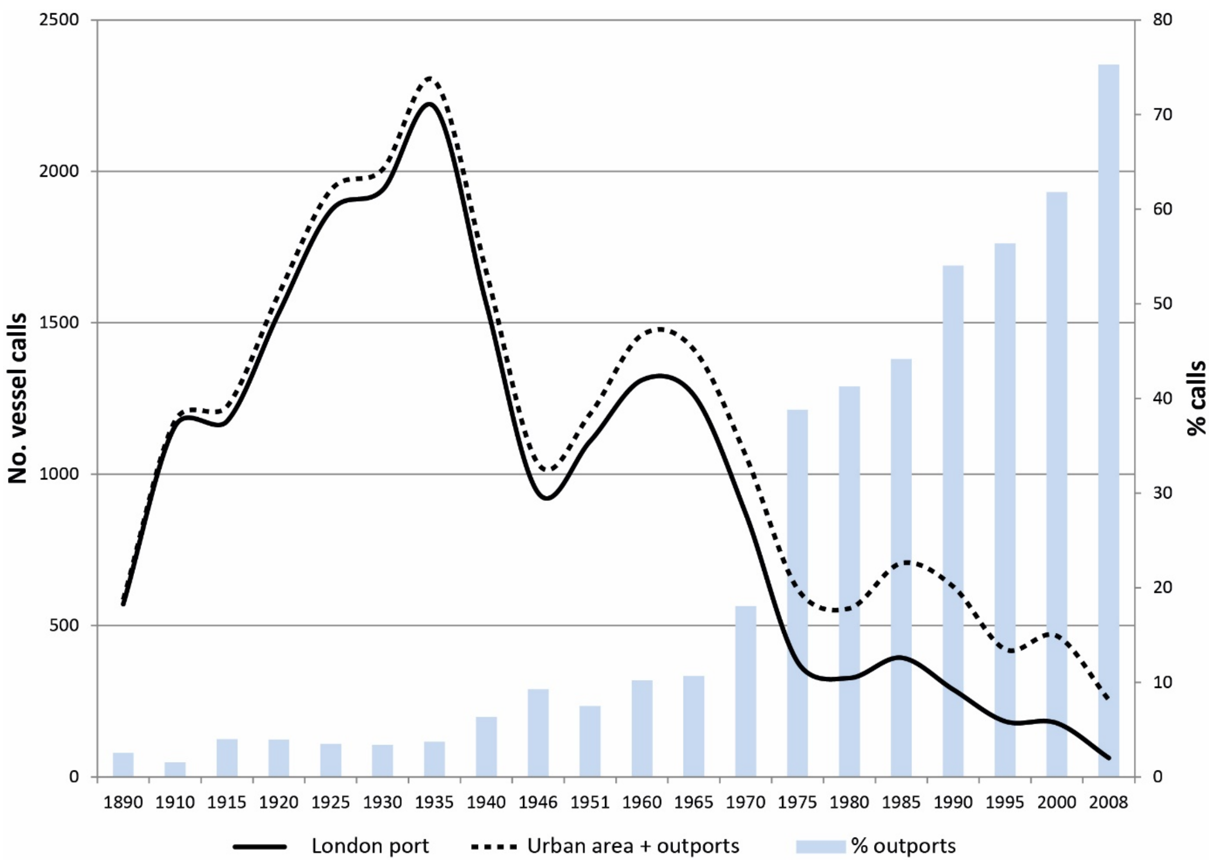
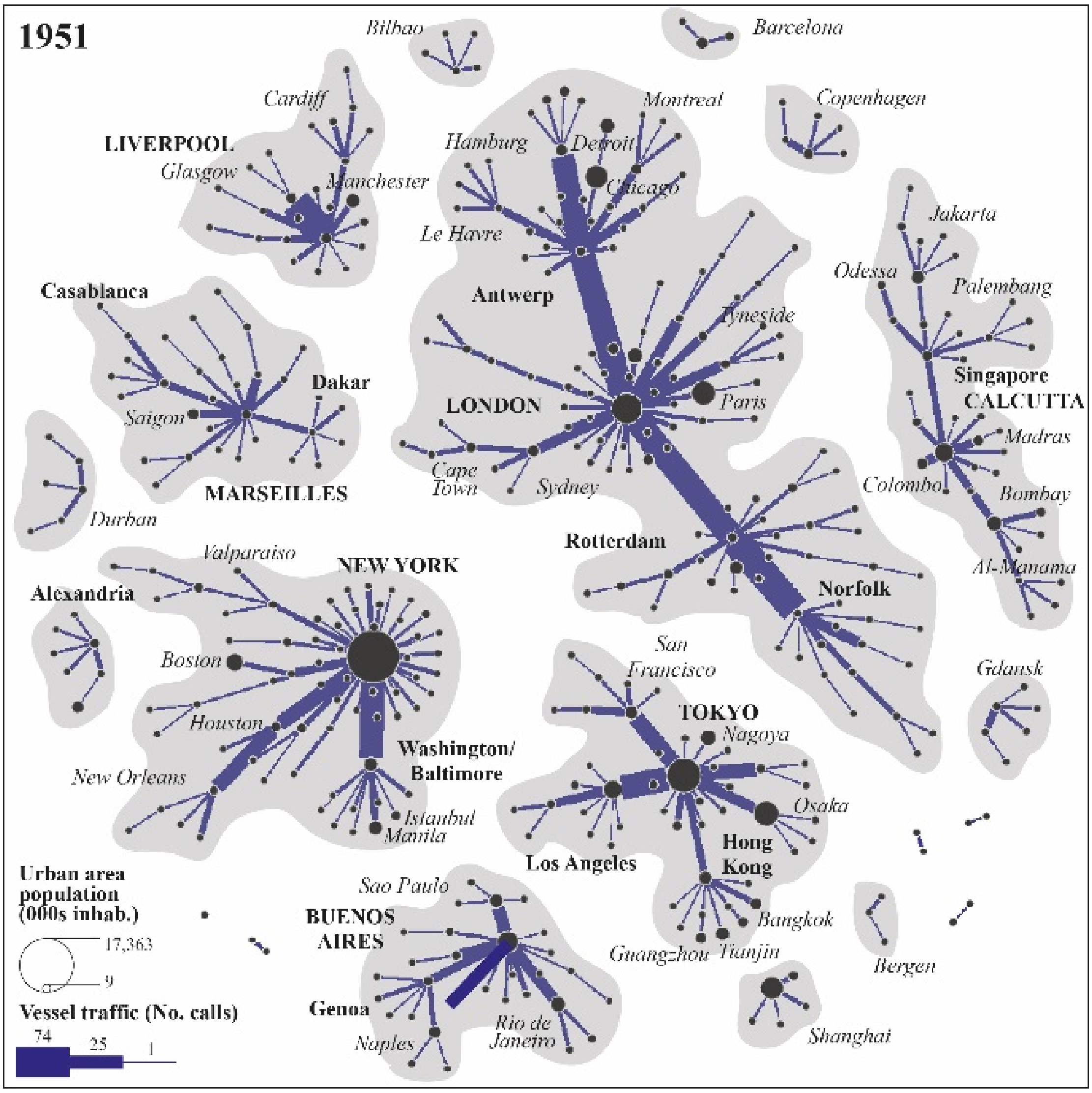
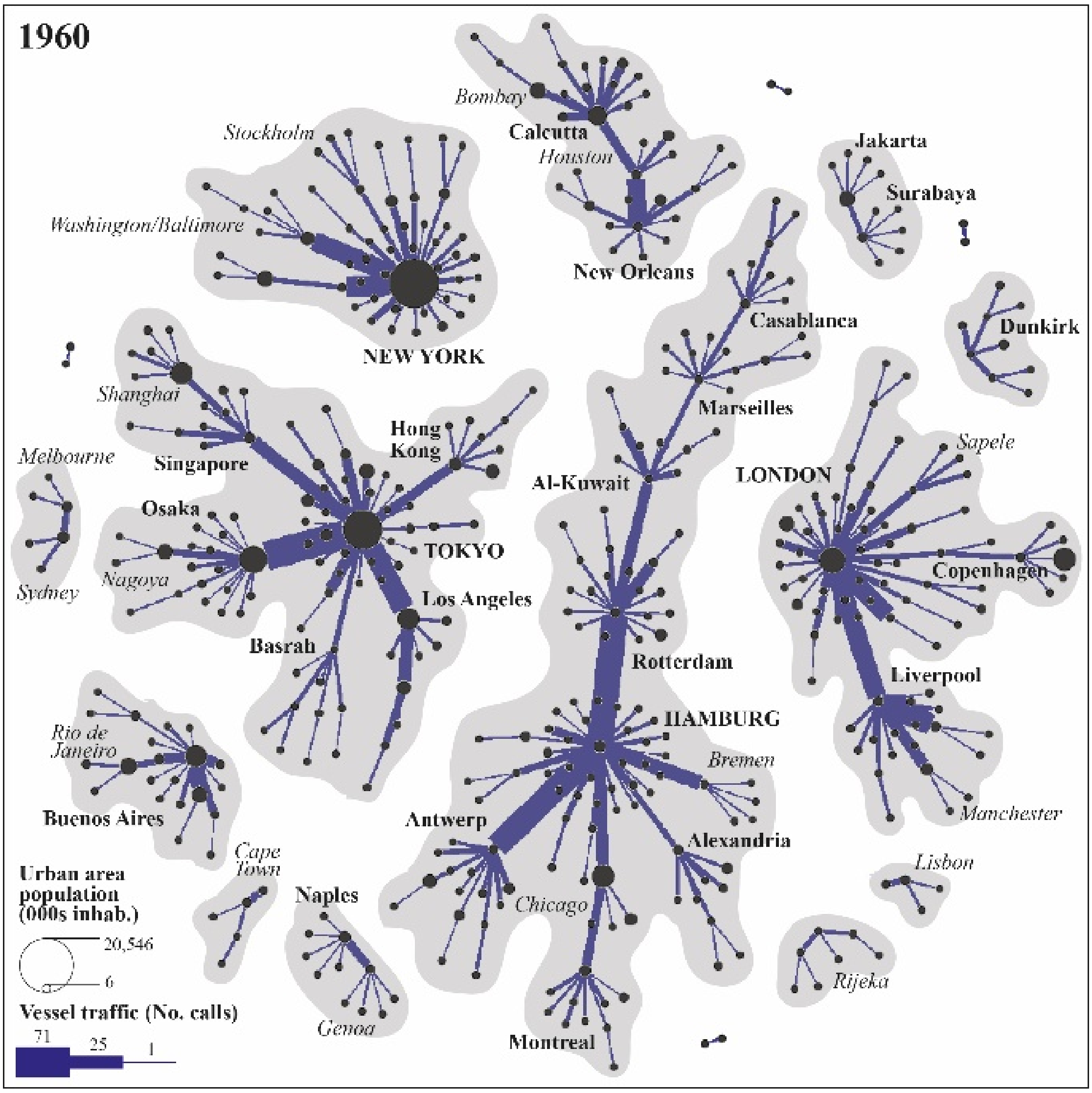
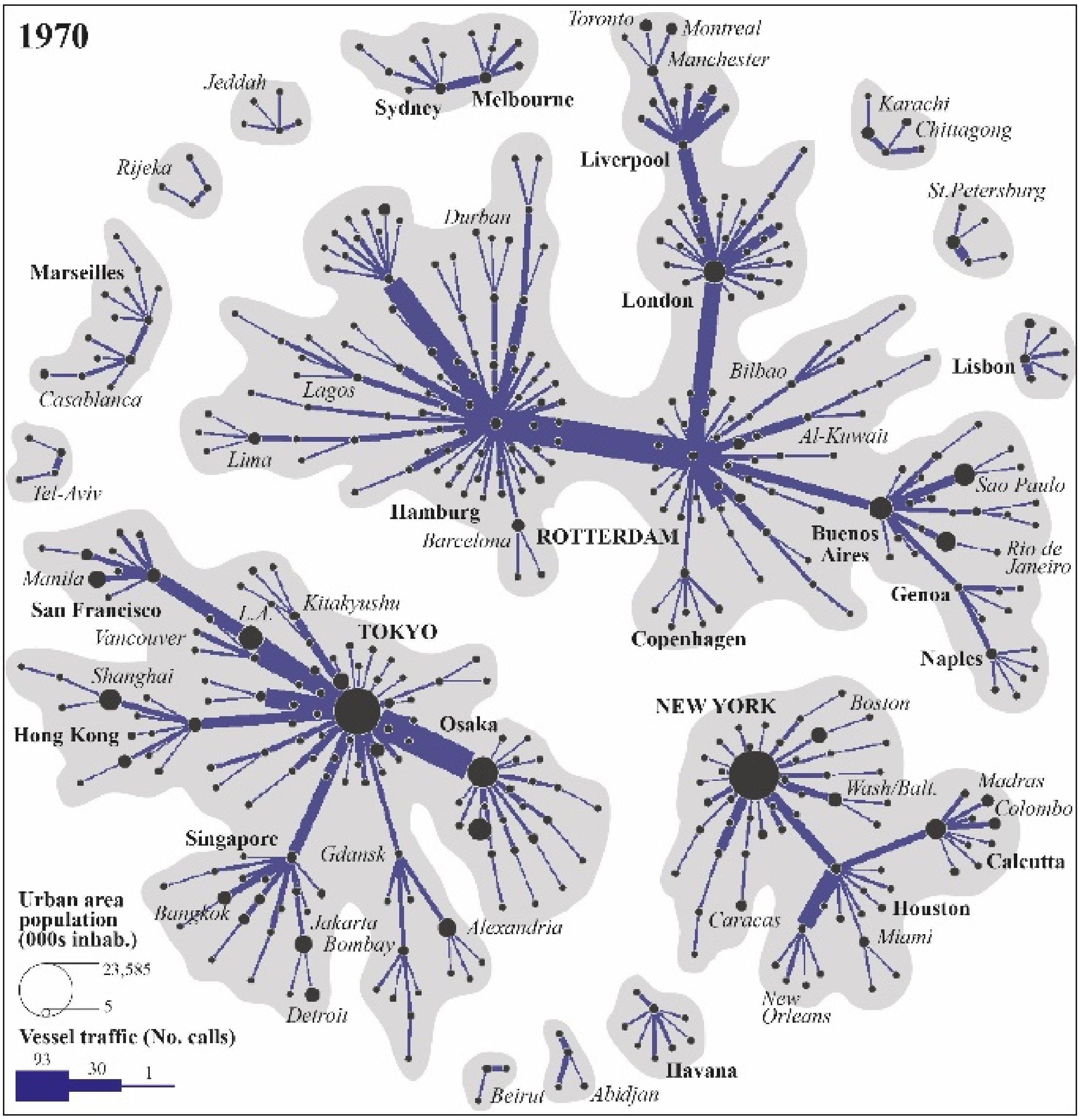


Figure 20.2: London's maritime traffic at port and urban area level, 1890-2008
Source: own realisation

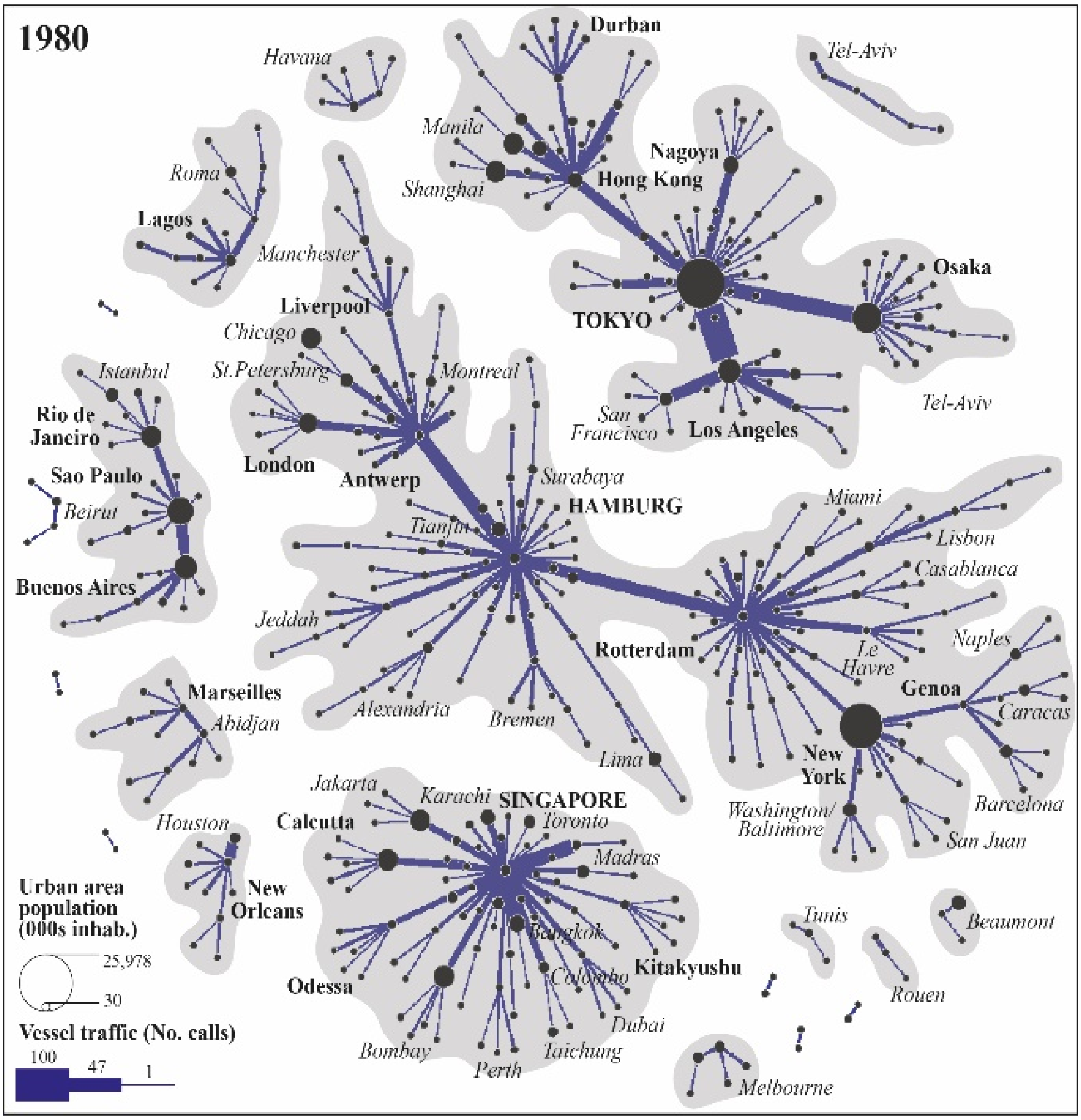


1951
Bilbao
Barcelona
Cardiff
Montreal
Copenhagen
LIVERPOOL
Hamburg
Detroit
Glasgow
Manchester
Chicago
Jakarta
Le Havre
Odessa
Palembang
Casablanca
Antwerp
Tyneside
Dakar
Singapore
CALCUTTA
Saigon
LONDON
Paris
Madras
Cape Town
Sydney
Colombo
MARSEILLES
Bombay
Durban
Rotterdam
Valparaiso
NEW YORK
Al-Manama
Alexandria
Norfolk
San Francisco
Boston
Gdansk
Houston
TOKYO
Nagoya
Washington/ Baltimore
New Orleans
Osaka
Istanbul
Manila
Hong Kong
Los Angeles
Urban area population (000s inhab.)
Sao Paulo
17,363
9
BUENOS AIRES
Bangkok
Guangzhou
Tianjin
Bergen
Vessel traffic (No. calls)
Genoa
74
25
1
Rio de Janeiro
Naples
Shanghai


1960
Bombay
Calcutta
Houston
Stockholm
Washington/Baltimore
New Orleans
NEW YORK
Jakarta
Surabaya
Dunkirk
Casablanca
Marseilles
Shanghai
Hong Kong
Melbourne
Singapore
Al-Kuwait
LONDON
Sapele
Osaka
TOKYO
Copenhagen
Nagoya
Sydney
Los Angeles
Basrah
Rotterdam
Liverpool
HAMBURG
Rio de Janeiro
Bremen
Buenos Aires
Antwerp
Manchester
Alexandria
Cape Town
Lisbon
Urban area population (000s inhab.)
Naples
Chicago
20,546
6
Rijeka
Vessel traffic (No. calls)
Genoa
Montreal
71
25
1



1970
Toronto
Montreal
Manchester
Jeddah
Sydney
Melbourne
Karachi
Chittagong
Liverpool
Rijeka
St.Petersburg
Durban
Marseilles
London
Lisbon
Bilbao
Lagos
Casablanca
Al-Kuwait
Lima
Sao Paulo
Tel-Aviv
Hamburg
Buenos Aires
Barcelona
ROTTERDAM
Rio de Janeiro
Manila
Genoa
San Francisco
Kitakyushu
L.A.
TOKYO
Copenhagen
Vancouver
Naples
Shanghai
NEW YORK
Boston
Hong Kong
Osaka
Madras
Wash/Balt.
Colombo
Singapore
Calcutta
Gdansk
Urban area population (000s inhab.)
Houston
Caracas
Bangkok
Jakarta
Alexandria
Miami
Bombay
23,585
5
New Orleans
Detroit
Vessel traffic (No. calls)
93
30
1
Havana
Beirut
Abidjan


1980
Durban
Havana
Tel-Aviv
Manila
Nagoya
Roma
Shanghai
Hong Kong
Lagos
Manchester
Osaka
Liverpool
TOKYO
Chicago
St.Petersburg
Montreal
Istanbul
Rio de Janeiro
San Francisco
Los Angeles
Tel-Aviv
London
Antwerp
Sao Paulo
Surabaya
HAMBURG
Beirut
Tianjin
Miami
Lisbon
Buenos Aires
Casablanca
Jeddah
Rotterdam
Naples
Le Havre
Marseilles
Genoa
Abidjan
Alexandria
Bremen
Caracas
Lima
New York
Jakarta
Karachi
SINGAPORE
Barcelona
Washington/ Baltimore
Houston
Calcutta
Toronto
San Juan
Madras
New Orleans
Tunis
Beaumont
Bangkok
Urban area population (000s inhab.)
25,978
30
Colombo
Kitakyushu
Odessa
Rouen
Dubai
Vessel traffic (No. calls)
100
47
1
Bombay
Taichung
Perth
Melbourne

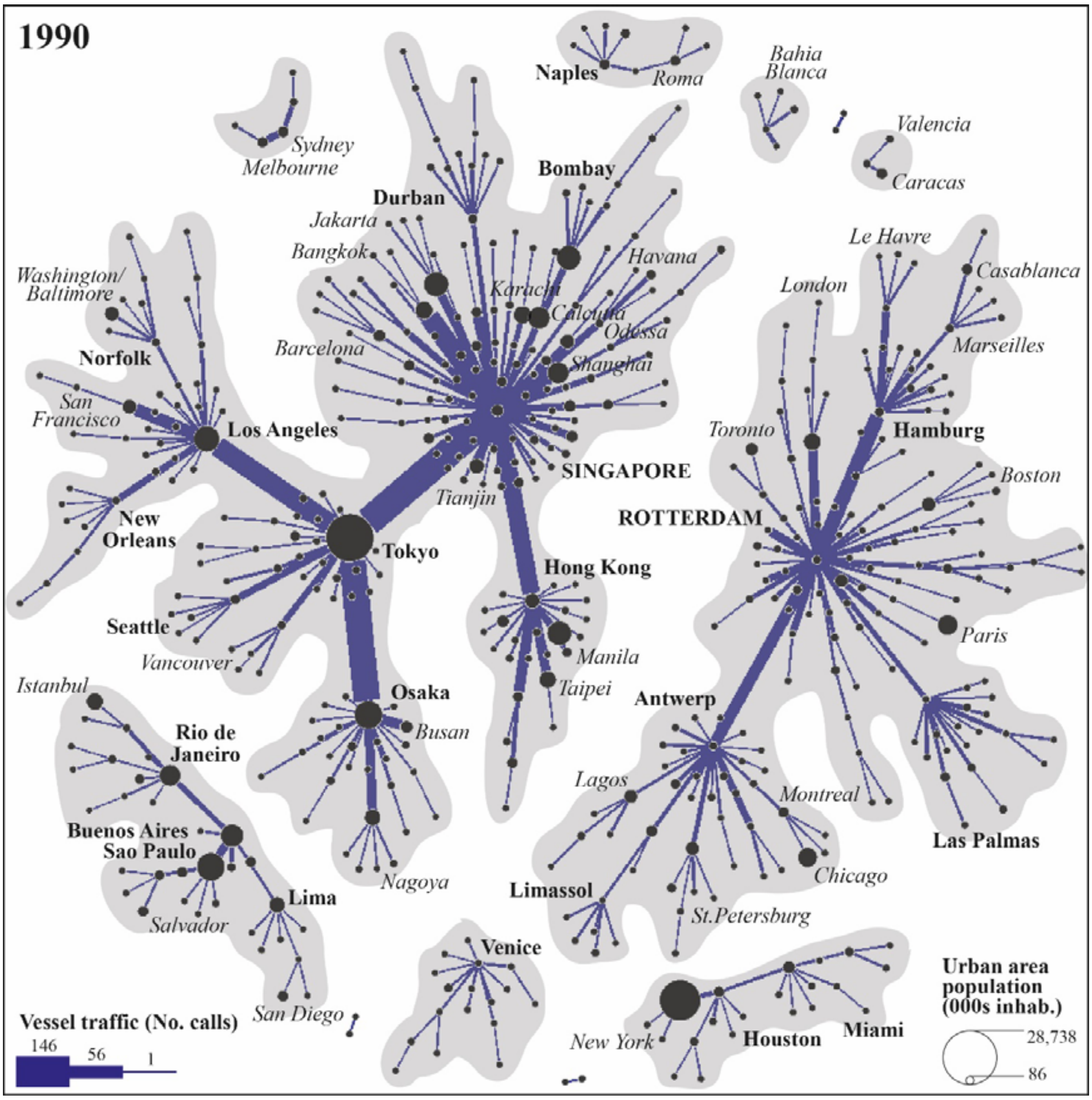


Figure 20.3: Urban centrality and nodal regions in the global maritime network, 1951-1990

Source: own realisation based on data from Geopolis and Lloyd's Shipping Index

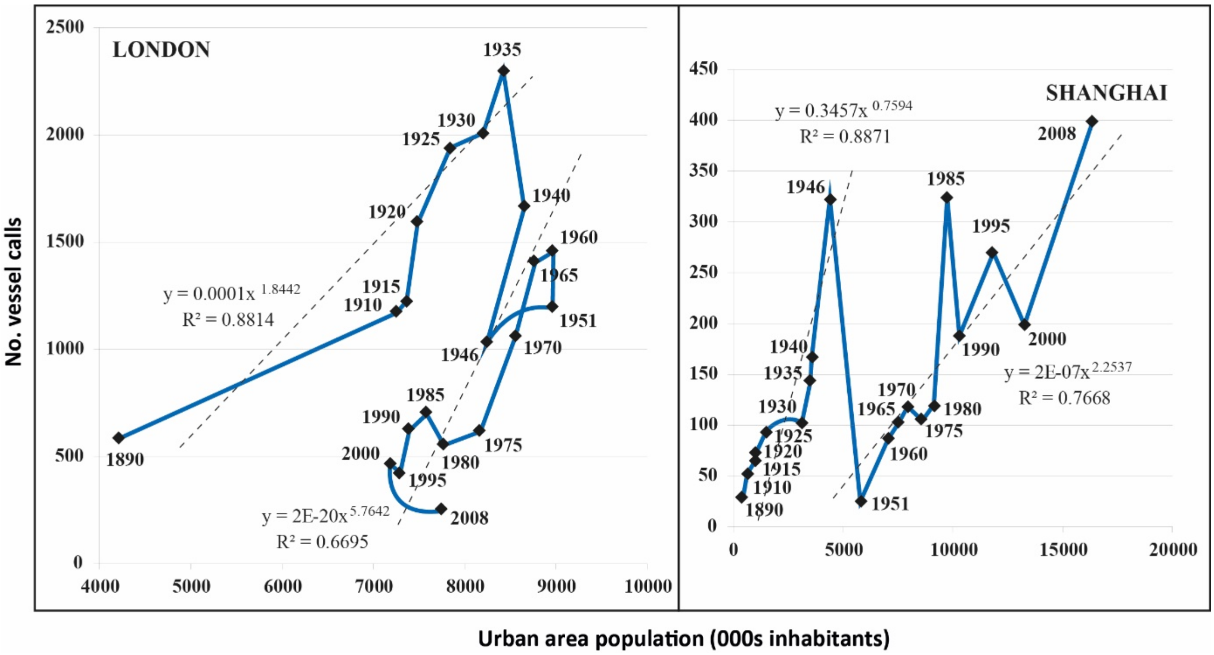


Figure 20.4: Port-urban trajectory of London and Shanghai, 1890-2008

Source: own elaboration