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Urban gravity in the global container shipping network

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ABSTRACT

While the spatial and functional relationships between ports and cities have been put in question in the last decades, the continued importance of urbanization and maritime transport in global socio-economic development motivates deeper research on their interaction. The global trade network is often studied at the country level and all transport modes included, concluding that distance remains a strong counterforce to exchange. This article wishes to detect whether the global container shipping network obeys similar properties at the city level. More than 2 million inter-port vessel movements between 1977 and 2016 are assigned to about 9000 ports and 4600 cities to run a gravity model on two different network topologies. Gravitational properties are found, as larger cities connect more with each other but less at distance. The degree of distance effects negatively expanded in 40 years, confirming the "puzzling" or reinforcing effect of distance, yet it varies greatly depending on node aggregation and network topology. We conclude that ports and cities continue to share important interdependencies, but these often rest on a detrimental physical transformation. A discussion is proposed about the underlying operational and theoretical mechanisms at stake. Keywords container shipping; gravity model; maritime trade; port cities; spatial interaction; world city networks.

« *What goods could bear the expense of land carriage between London and Calcutta? Those two cities, however, at present carry on a very considerable commerce with each other* ». Adam Smith (1776)

1. Introduction

Numerous scholars concentrated their efforts on explaining the pattern of international trade flows, concluding that larger economies trade more with each other but less at distance, in accordance with the Newton's law of gravity. This crucial finding implies that geography plays a vital role in the development of interactions, up to nowadays, despite the various technical and organizational facilitations of the last decades. The applicability of such a framework to maritime networks and at the city level remains, however, challenging. In the last 50 years or so, the spatial characteristics of maritime networks changed tremendously, with an increasing power of global transport actors in designing their services (Rodrigue and Notteboom, 2009). Shipping sector liberalization motivated the rationalization of port-to-port routes to save time and cost, resulting in evermore traffic concentration at large hubs and gateways (Rodrigue and Notteboom, 2010). In parallel, the "world city network" became an entity on its own, cities being less reliant upon maritime transport for their development compared with aviation and more immaterial exchanges (Bretagnolle, 2015).

Port cities thus have an ambiguous status in the academic literature. It had become widely accepted that port-city relationships declined both spatially and functionally (Bird, 1963; Hoyle, 1989), urban growth and port growth becoming mutually incompatible. Another view is that ports and cities maintain close links (Hall and Jacobs, 2012) which intensity may vary overtime (Ducruet and Lee, 2006) and across the world (Lee et al., 2008). Such discrepancies would imply that global maritime networks and world city networks are two different entities. Nevertheless, international trade remains dominated by maritime transport (UNCTAD, 2019) and world population and economic growth keep concentrating in coastal areas (Adomaitis, 2014; United Nations, 2017). It is therefore the goal of this paper to investigate more in-depth the changing interplay between urban networks and shipping networks. A case study of container shipping is proposed at the global level over the last 40 years as a means discussing the influence of economic, spatial, and technological changes. The main hypothesis is that shipping networks remain constrained by distance due to their spatial nature (Barthelemy, 2015) and, at the same time, remain tied to urban regularities given the fact that cities are the main engines of trade flows. It assumes that port cities and shipping networks are in fact part of the same global trading system, beyond the local divergence felt at

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particular places. Testing such a hypothesis necessitates a comparison between different network topologies and city definitions.

The remainders of the article are organized as follows. The next section reviews how gravity models have been applied in bilateral trade studies and maritime studies, while detailing our hypothesis about the existence of gravitational rules in the "world maritime city network". Section 3 explains the combination of shipping and urban data under different network topologies and node aggregation levels. Section 4 constitutes the core of the article as it delivers main results for the period 1977–2016 and concludes about how much gravity can be found in the global maritime system of world cities. Lastly, the conclusion provides insights for further research and interprets the results for possible policy implications.

2. Literature review

2.1. The gravity of international trade flows

Studies seeking to explain the distribution of trade flows using geographic distance as a key parameter in a gravity model are numerous. Based on what is known as one of the most important findings in economics, or the fact that distance negatively affects trade, Disdier and Head (2008) reviewed no less than 1467 distance effects in 103 papers. There is a puzzling evidence that trade costs, of which transport costs (and of which geographic distance) continued to be a friction despite the integration of the world economy (Carrère and Schiff, 2005) and the lowering effect of borders (Head and Mayer, 2011). A good example is the study by Limao and Venables (2001) looking at the effect of common borders, landlocked, islands, distance, in addition to the average density of the road network, the paved road and railway network, and the telephone main lines per inhabitant all turned into a composite infrastructure quality index. Other studies also tried to search for other effects than pure distance to explain bilateral trade flows, such as the value of commodities and trade direction (Geraci and Prewo, 1977), the disentangling of different transport modes and uncertainty in delivery times (Nordas and Piermartini, 2004), developed and developing countries (Carrère and Schiff, 2005), product differentiation (Anderson and van Wincoop, 2004), trade facilitation (Wilson et al., 2005; Egger, 2008), logistics improvement (Behar et al., 2009), unfamiliarity in information flows (Huang, 2007), income growth (Irwin and Terviö, 2002), common language, colonial links, currency union, and WTO membership (Bougheas et al., 2009; Head and Mayer, 2011).

Another way of improvement has been to use nautical distances for countries trading by sea, as "great-circle routes often differ substantially from actual cargo routes", but no clear effect was found using either parameters (Disdier and Head, 2008). Other studies went deeper in the qualification of maritime routes and ports. For instance, Wilmsmeier et al. (2006) used port infrastructure efficiency, port privatization, general transport infrastructure, customs delay, and port connectivity in their study of bilateral trade among Latin American countries. Although the introduction of containers is believed to have lowered distance impacts after 1980 (Hummels, 2001), the dispersion of economic mass is seen as a counterforce as well as the changing composition of trade (Brun et al., 2005), as well as the inclusion of bulks in trade flow measures in most gravity models. The growth of China is by no means exemplary of such trends, as the world's top importer and exporter of certain bulky commodities (e.g. coal, oil) and the factory of the world for containers, serving very distant markets such as Europe and North America.

Although Limao and Venables (2001) mention the "structure of the shipping industry" as one important factor influencing transport costs, this variable is not well explained by the authors. Seamless multimodal transport is mentioned by Nordas and Piermartini (2004), in relation with containerization, but the island effect in countries like Japan and Taiwan is seen as going against intermodal performance. Nevertheless, and echoing Clark et al. (2004), Nordas and Piermartini (2004) conclude that port efficiency has a strong impact, if not the largest, on trade flows. Although they discuss the growing containerization of goods, the lack of data on what is "inside the box" could not allow for an assessment of the true importance of containers in total trade (Rodrigue and Notteboom, 2015), as bulks and perishable goods are increasingly put in standard boxes. Korinek and Sourdin (2010) acknowledge that containers have a cheaper cost but a higher value per unit contrary to bulks, although "distance therefore does not fully explain differences in the shipping rates charged to exporters". The authors also underline that "time may be increasingly important due to just-in-time production and fragmentation of production". It is thus clear that the economic literature on trade is not well connected with the literature on global production networks, global commodity chains, and global maritime networks (see Jacobs et al., 2010).

2.2. Are maritime networks gravitational?

Except from the discussion by Clark et al. (2004) on the impact of economies of scales on trade, rare studies questioned the gravity of maritime networks per se. The reliance on the national level is one main reason, preventing scholars to focus on specific nodes at the subnational level. The lack of trade data at the local level is another reason, despite the fact that Limao and Venables (2001) studied the particular case of Baltimore – acknowledging the difficulty to make comparisons. More likely are studies of other communication networks such as telecommunication flows in Belgium (Krings et al., 2009), airline flows (Grosche et al., 2007), the Korean highway network (Jung et al., 2008), and intermodal transport networks in Southeast Asia (Dai et al., 2016). Despite their huge importance for carrying trade, maritime networks – and especially container shipping – are more the expression of liner service schedules, thus creating spatial gaps between shipping flows distribution and trade flows distribution.

The search for gravitational properties in maritime networks do exist but are relatively few and use the port rather the city as the unit of analysis. McCalla (2004) referred to the central place theory in his analysis of the Caribbean liner shipping network, concluding that "defining hierarchical structure is elusive". Physicists and archaeologists did use gravity equations to model interactions among Aegean Bronze Age ports (Rivers et al., 2015) while the global cargo-ship network was analyzed in such ways for recent years (Kaluza et al., 2010), conducting to a lack of explanation power. Another example is Guerrero et al. (2015) who demonstrated that international trade flows of containerized commodities are better explained by inter-country vessel calls as distance metric than by crow's fly distances. Bensassi et al. (2015) applied a gravity model to Spanish export data to explain the variability of maritime freight rates and quantify the impact of maritime freight rates on maritime trade. Lastly, Fugazza and Hoffmann (2017) concluded that direct maritime connections, additional transshipment, and container vessel sizes influence bilateral exports, so that "the impact of distance on bilateral exports in classical gravity models is likely to be overestimated".

Other studies not using gravity models can shed light on the importance, still, of geography in the structure of maritime networks. For instance, it was showed that shorter maritime links carry the most diversified and voluminous traffic (Ducruet and Notteboom, 2012), while the global network is regionally organized based on nodal structures where a hub dominates its geographical port neighbors. Long-distance linkages are constrained by spatial friction (e.g. coastline) so that transport operators develop intermediate stops to expand their market (Fleming and Hayuth, 1994; Rodrigue and Notteboom, 2010). In addition, interactions among world ports create regional delineations showing a strong influence of physical geography with the emergence of seas and basins as dense communities (see Kaluza et al., 2010). Some studies even showed that the emergence of communities was not only based on geographic proximity but also culture and long-term historical ties (Ducruet et al., 2010; Ducruet and Zaidi, 2012). Last but not least, Ducruet et al. (2018) demonstrated that larger cities connect over longer distances on average than smaller cities in the global maritime network.

When it comes to cities (or port cities) as the unit of analysis in a maritime network, no previous study can be used as a reference. We thus hypothesize that gravitational rules may best apply based on three ideal-typical elements. First, port hinterlands should be coastal and captive. This situation would be possible only if each city was an island, preventing itself from port competition. In reality however, hinterlands may reach further inland, beyond the port city itself, and part of them may be contestable, in the case of competition. Second, maritime transport should play a dominant role in intercity exchanges. In the absence of modal information, except for specific regions such as Southeast Asia (Dai et al., 2016), analyses of urban networks often rely on one single layer of information. This explains why road network accessibility could not be fully correlated with port throughput in Europe (Chapelon, 2006) and, conversely, why sea-land connectivity was more in line with the urban hierarchy than single connectivity in Australia (Berli et al., 2018). Third, maritime flows should not be rerouted via transshipment hubs. Economies of scale in liner shipping had the effect of concentrating traffic at fewer ports but without creating equivalent urban growth (Slack and Gouvernal, 2015), accentuating the gap between urban network and shipping network pattern. The emergence of transshipment ports is also favored by discrepancies in terms of port efficiency and economic vitality (Mohamed-Chérif and Ducruet, 2016) as well as coastal shipping regulation (e.g. the Jones' Act in USA).

3. Methodological specifications

3.1. World maritime grid and shipping distances

First of all, the calculation of inter-port distances was made possible by using a world maritime grid, the latter consisting in “an approximation of paths taken by ship movements while respecting the geographic constraints of coastlines” (Berli et al., 2018). The global oceanic space had been partitioned using a new methodology, namely a regular meshing of eight squares subsequently divided through an iterative process, except for those squares fully included within land or sea. As the iteration progressed the number of squares grew, especially along coastlines, which originated from Natural Earth. Ulterior steps consisted in building maritime trajectories using the Moore neighborhood to connect squares' centroids. Finally, each port was connected to the closest node of the grid without intersecting continents, and based on the calculating an approximation of the shortest maritime path between all pairs of ports (Fig. 1).

Inter-city maritime traffic is measured in this paper using the *Lloyd's List* database on global containership movements. This database details the arrival and departures of all the world's containership fleet and is thus highly representative of this shipping segment. Traffic is measured in deadweight tons (DWTs) and its volume at cities and between them equals the sum of vessel capacities during four complete months of circulation each year, between 1977 and 2016 (i.e. March, June, September, and December). Such a time period of 40 years enables questioning the aforementioned changes taking place in liner shipping, especially in terms of network patterns. The choice of DWT rather than the number of movements makes the analysis more in line with actual trade flows and port throughputs, as the carrying capacity of vessels may vary greatly between links of same frequency. Deadweight tons shall also better reflect the increase in vessel sizes overtime, especially since the introduction of post-panamax vessels and later mega-ships on the market. One flaw of this data is the risk of overestimating the amount of traffic handled at the ports since all vessels are supposed to travel fully loaded, the occupancy rate being unknown as well as the share of empty containers. We lowered this risk by excluding other moves than cargo handling such as arrest, conversion, break up, lay-up, launch, repair, passage, anchor, and sheltering. A careful selection of port nodes was also made since the original database comprised straits, countries, offshore platforms, canals, and other sorts of non-cargo ports.

The shipping network was constructed by the aggregation of all vessel movements into an intercity matrix using two different topologies (Fig. 2), with reference to the pioneering work of Hu and Zhu (2009). The space-L definition refers to direct inter-port calls only along the sequence of vessel movements, while the space-P definition adds to them indirect linkages. The space-P is an interesting topology as it indicates how far ships can travel in one stop only. There are concrete implications of shifting from one configuration to the other. In the case of ports situated at both ends of a pendulum route, such as Hamburg and Shanghai, those are separated by numerous stops in between. The two ports remain separated in space-L but are connected in space-P, where all ports served by the same vessel belong to a complete subgraph. Thus, the space-P configuration allows more distant links to occur, being more in line with trade patterns. Yet, the risk of space-P is to overestimate the traffic intensity of indirect links (Fig. 2) due to the fact that ship rotations are not origin-destination flows. While vessel movement data is useful to grasp the influence of shipping actors on network structure, customs data is closer to trade patterns and could serve, for instance, the analysis and mapping of US international seaborne trade flows (Shen, 2017). In turn, space-L is a better footprint to depict how ports connect each other in proximity. This network structure is closer to shipping line logics and will be more suited to detect transshipment nodes doing hub-and-spokes and/or interlining activities. In any case, space-L and space-P are two facets of the same container shipping network but they cannot be fully representative of real trade flows among locations as *Lloyd's List* tracks vessels rather than individual containers and their merchandise.

3.2. From ports to gateway cities and city-regions

Considering city size as an important determinant of maritime flow distribution motivates a more in-depth examination of their spatial structure than at the country level. In addition to the fact that population as a proxy does not always account for total urban mass, should it be from a spatial or economic viewpoint (Jung et al., 2008), two major obstacles had to be overcome in order to further proceed, however. First, the absence of a universal definition of the (port) city has the risk of considering various objects across countries, from the administrative area to the metropolitan area. Certain organizations like the OECD and Eurostat do provide information about OECD and European cities but it is confined to a certain part of the world, and does not go beneath 250,000 inhabitants. Second, and related with the first, the absence of global data about the economy of cities, such as Gross Domestic Product or employment, could not be found equally across countries, due to different definitions of such variables and of the city itself.

For such reasons, it was decided to collect population data from one of the first harmonized databases ever made, the *Geopolis* database (Moriconi-Ebrard, 1994). Geopolis has the enormous advantage of being built upon the same definition of the city – the morphological extent of the built-up area around the city's core. It includes all the world's cities having at least 100,000 inhabitants in 1990 while going back to 1950. Based on the same definition, it was possible to update this database (and complement its lacks) up to 2015 using two other sources, namely *Population Statistics* and *World Gazetteer*. After assembling and harmonizing the database on a 5-year basis, intermediate years were estimated using quotients. A total of 9396 ports was assigned to 4621 cities (Fig. 3), each city hosting more or less ports, the city population ranging from a few hundred inhabitants to megacities comprising more than 30 million (e.g. Tokyo). Ports with zero population, either due to the true locational factor or to the absence of data, were excluded from the analysis or incorporated when located near a city.

Ports were assigned to cities in two ways, gateways and city-regions

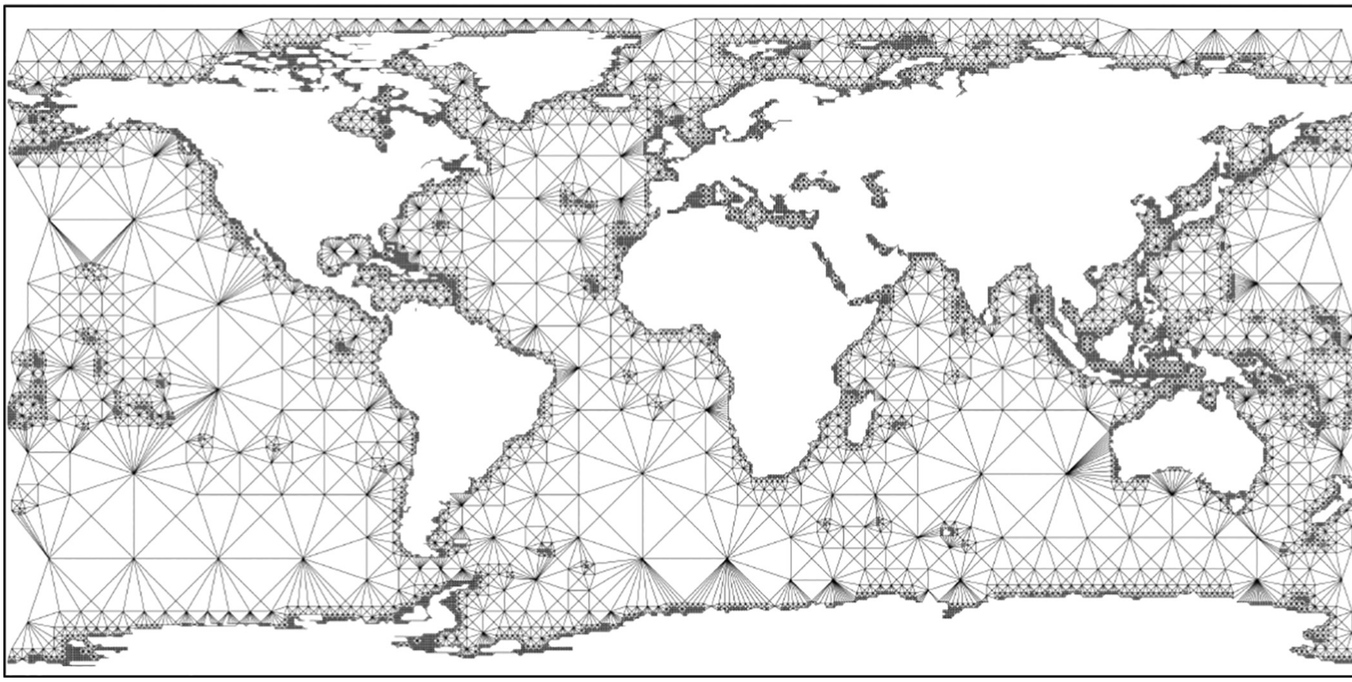


Fig. 1. The world maritime grid.
Source: modified from Bunel et al. (2017)

(Fig. 4). Gateways refer to cities hosting ports and with no or limited competition with other cities within a range of about 200 km maximum, depending on the spatial extent of urbanization, the configuration of land transport, and other elements such as national borders, elevation, etc. City-regions include more diverse cases as it considers the dominant urban center near the port as the reference city. They may include non-port cities connected to the port by land and/or river transport, multiple cities, and multiple ports should they be coastal or inland. It implies that the city hosting the port may not always be the catalyzer of port activity, so that land distance between place of transit (port) and place of production/consumption (city-region) matters. The widespread development of land transport, and especially trucking, was seen by early geographers as one crucial factor in the weakening ties between ports and hinterlands (Hoare, 1986). This methodology also makes it possible that a gateway may also be a central place depending on the level of aggregation and observation (Bird, 1977). For instance, Tokyo as a gateway only comprises Tokyo port, while as a city-region it includes all Tokyo bay ports and cities such as Yokohama, Chiba, and Kawasaki. Los Angeles and Long Beach are two separate gateways but constitute only one city-region (Los Angeles). The shift from one case to the other for the same city may also be time-related according to various phases of port migration (Bird, 1963) outside the original urban core, which is captured by the amount of maritime flows. This methodology responds to the need for taking into account the role of node aggregation in maritime network analysis (Ducruet et al., 2017; Tsiotas and Polyzos, 2018). The traffic of outer ports (or *outports*) and new ports, located away from their original urban core, is ignored at the level of gateways but is integrated at the one of city-regions. At the level of city-regions, the larger city in terms of population takes precedence over other cities including gateways.

Cities were also classified according to their locational characteristics to be tested in subsequent analyses: coastal, island, upstream, downstream, and national capital. It is hypothesized that location type may influence cities' connectivity (Ducruet et al., 2018), with for instance upstream gateways being increasingly disadvantaged for the handling of larger vessels compared with other cities. Shifting the analysis from gateway to city-region allows for the indirect analysis of road transport effects, especially for upstream cities like Guangzhou and London, which perform traffic at both inner ports and outer ports. This also applies to non-port cities, coastal or inland, serving as a regional economic cores for smaller and neighboring port locations, so that the latter are not considered at the gateway level. They include cities having lost their port functions through migration such as lack of space, congestion (e.g. Istanbul, San Francisco, The Hague) or having developed more inland with single or multiple access to maritime trade (e.g. Berlin, Caracas, Beijing, Rabat, Tel-Aviv), sometimes to such an extent that city-region and gateway form only one single entity (e.g. Kuala Lumpur/Port Klang, Lima/Callao, Seoul/Incheon). Gateways and city-regions are thus not mutually exclusive; they are two geographic levels of observation of the port-city relationship.

4. Main results

4.1. Port-city relationships

First, the correlation coefficient (Pearson) between cities' population and their traffic (Deadweight Tons, DWTs) was tested under different topologies (Fig. 5), confirming that "communication intensities scales linearly with city size" (Krings et al., 2009). Yet, they are moderately correlated (between mostly 0.35 and 0.50) but remain lower for gateways than for city-regions. This means that gateway cities are insufficient in explaining traffic volume, due to their limited share in the extended hinterland economy. A slight growth of the correlation coefficients is observed since the late 1990s however in the space-P network for gateways that takes into account more distant linkages. This would mean that larger port cities tend to handle more traffic as the network grows in size and in density in the second half of the study period. Yet, the coefficient is much higher when considering city-regions. Space-L city-regions enjoyed the highest significance (about 0.55) in the early period but declined in ways comparable with space-P gateways, while space-P city-regions maintained a coefficient between 0.45 and 0.50 in the late period. This confirms that the extended definition of cities as city-regions is more relevant than the port city or gateway definition in explaining the amount of maritime flows handled at ports. Port activities, i.e. container handling, have shifted away from original urban cores, while connecting with other ports at distance. This level of

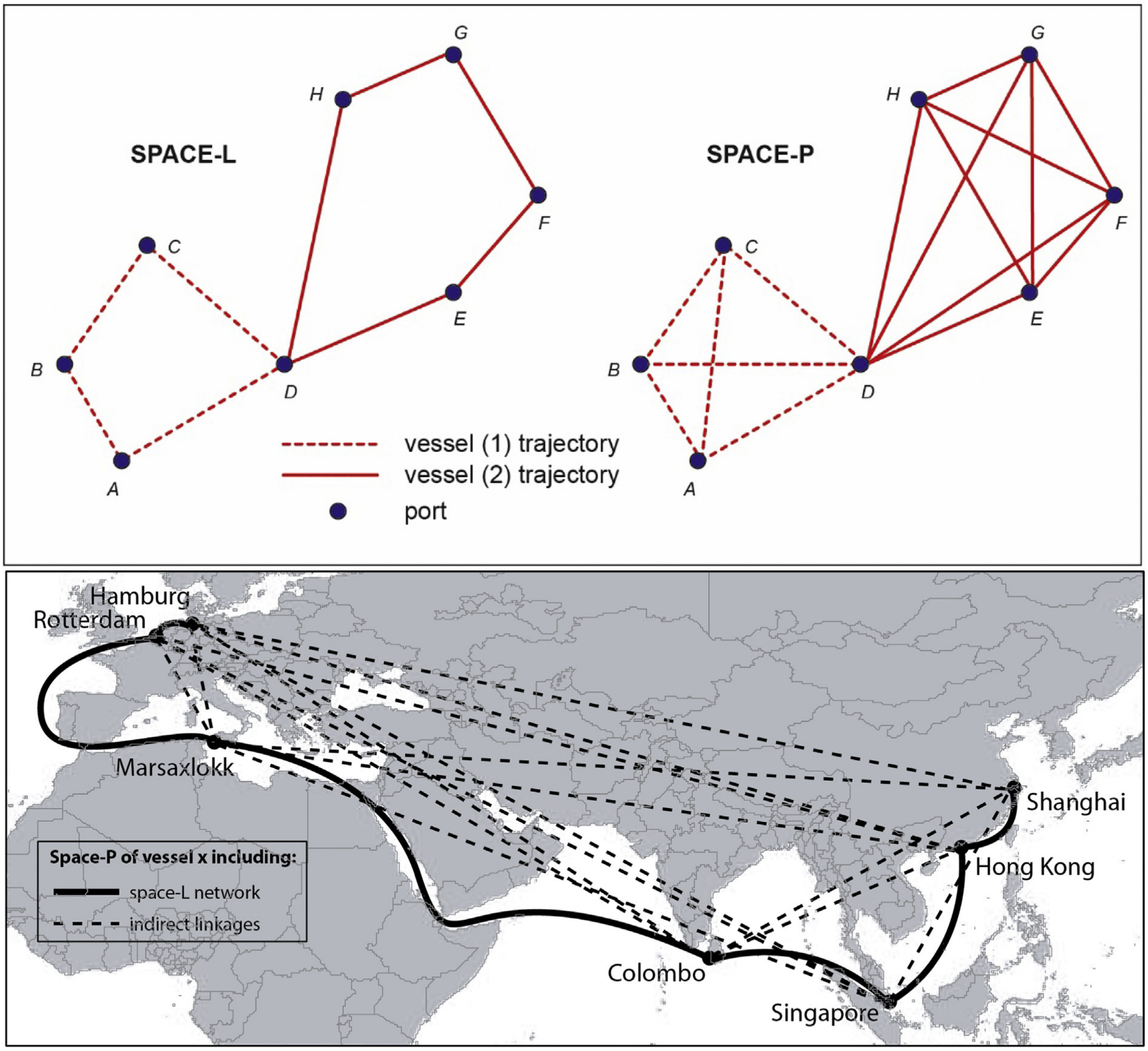


Fig. 2. Topologies of the liner shipping network.
Source: modified from Hu and Zhu (2009)

observation shall have strong impacts on how the gravity model applies to the distribution of container flows among the world's cities.

Second, we test the relationship between cities' population and the average distance of their shipping links with other ports. The yearly correlation coefficient (Pearson) on cross-sectional data (Fig. 6a) shows that as the network is more aggregated (city-regions) and denser (space-P), the coefficient slightly increases due to the expansion of the global economy (larger and longer links). This stands in contrast with the findings of Tsiotas and Polyzos (2018) where "the lowering data resolution causes loss of information" although "the socioeconomic predictors of network connectivity showed consistency", mainly due to the fact that the authors study a domestic maritime network. Despite the lower correlation (between mostly 0.10 and 0.35) but positive for all network configurations and all years, we observe a growing tendency for larger cities to connect, on average, at longer distances. The four configurations show similar and balanced trends on the study period. One interpretation is the similarity with complex network studies looking at ports and distance in liner shipping networks (Ducruet and Zaidi, 2012) but also airline networks (Guimera et al., 2005), where nodes with high degree centrality (i.e. number of adjacently connected neighbors) connect over farther distances as a result of their stronger reachability and connectivity. This would suggest that not only larger cities trade more with each other (Fig. 5) but they also interact via more distance, but these combined effects shall be more fully understood in the analyses by multiple regression as in the next part and gravity equation as in the next section.

Third, multiple regression analysis (see details for the functions estimated on Appendix 2a) considering eight continents and four locational differences, which is standardized on "Europe" and "coastal", on panel data in 40 years sheds more light on the various effects of urban characteristics on traffic generation dynamics (Table 1) in addition to "average" distance of their shipping links with other cities at cities. Population, average distance of links, the dummies of island, and downstream have positive signs, indicating that larger cities that are geographically favored generate more traffic than cities located inland or upstream, the latter being constrained to receive larger ships. Average distance with trade partners has positive signs for DWTs because of the wider trade opportunities with remote larger cities having trunk services. Cities in North and Latin America handle more DWTs than European ones, if other factors are same, because of their geographical characteristics as large continents and less shortsea shipping services with neighboring ports, or relatively longer traffic by bigger ships. Results show more fitted (see Adj. R-square) in the space-P than in the space-L and are more consistent for city-regions than for

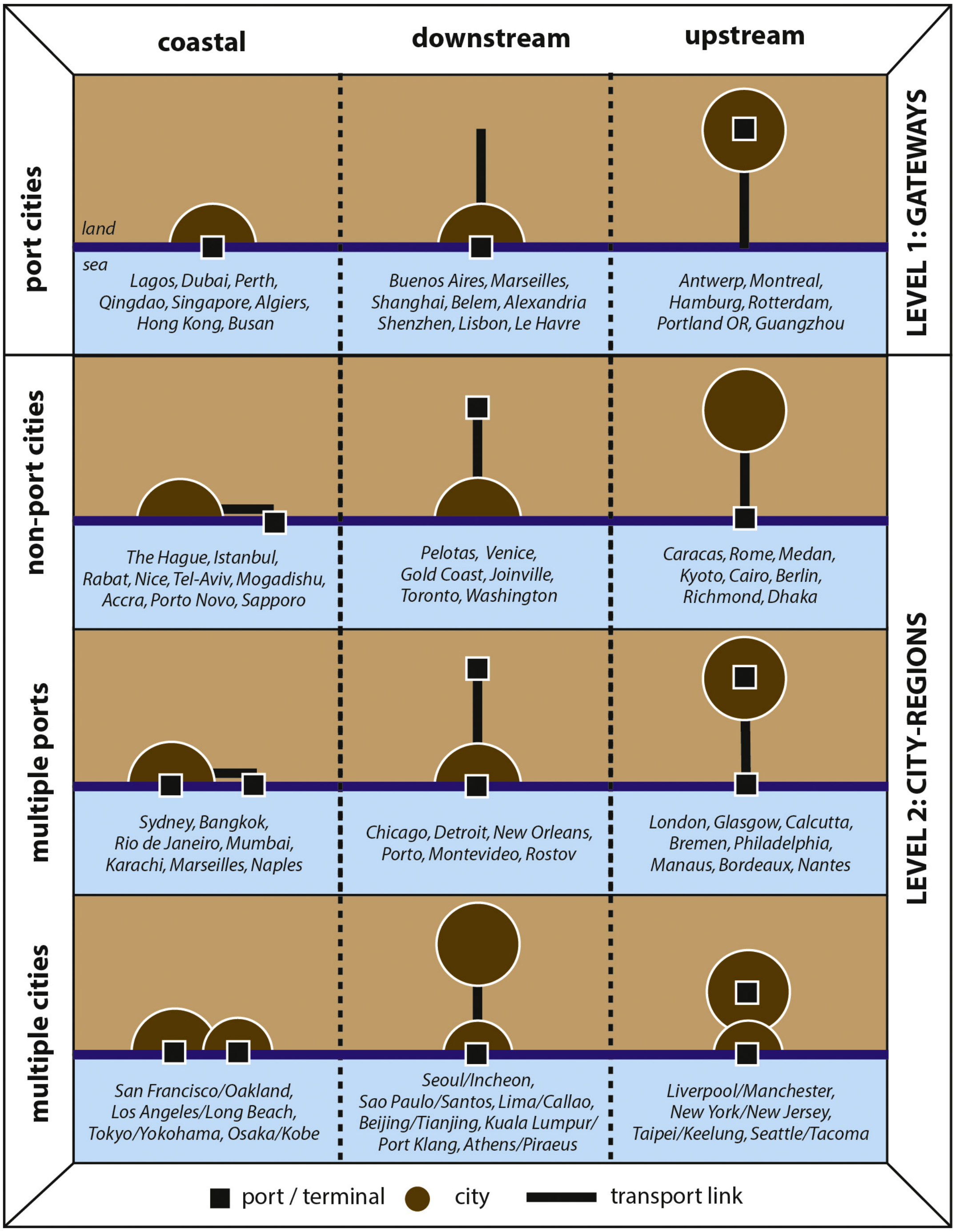


Fig. 3. Port-city matching and typology.
(Source: own elaboration)

gateways as in the previous results. This is in line with the fact that space-P better reflects trade (indirect) patterns than shipping (direct) patterns and city-regions better reflect extended hinterlands than sole port cities. We also observe that national capital cities generate more traffic than other cities because they are often larger and due to their need for more diverse goods delivered by containerships, except for gateways in the space-L network. This helps to conclude that traffic is far from being randomly distributed and urban characteristics are very influential in explaining its volume and growth.

Lastly, in addition to the above multiple regression analysis, we estimate the yearly parameters of their average distance for global average distance (see Appendix 2a). The parameters show the changes of effects of relative longer shipping links (i.e. more than 1.0) to their traffic (Fig. 6b). The results suggest that cities' traffic had been more explained by long-distance interactions until the middle of the period, or positive until 2007, but the standardized value has been declining since the mid-1990s already. It is in accordance with the fact that long-distance, direct port-to-port shipping routes were gradually replaced by shorter, pendulum and hub-and-spokes connections in a context of rationalization (Cullinane and Khanna, 2000). The expansion of inter-regional trade for international horizontal specialization within global supply network, like electric and automotive parts' procurement inside East and Southeast Asia, constitutes relatively shorter traffic network. Large cities keep connecting at farther distances due to their market size

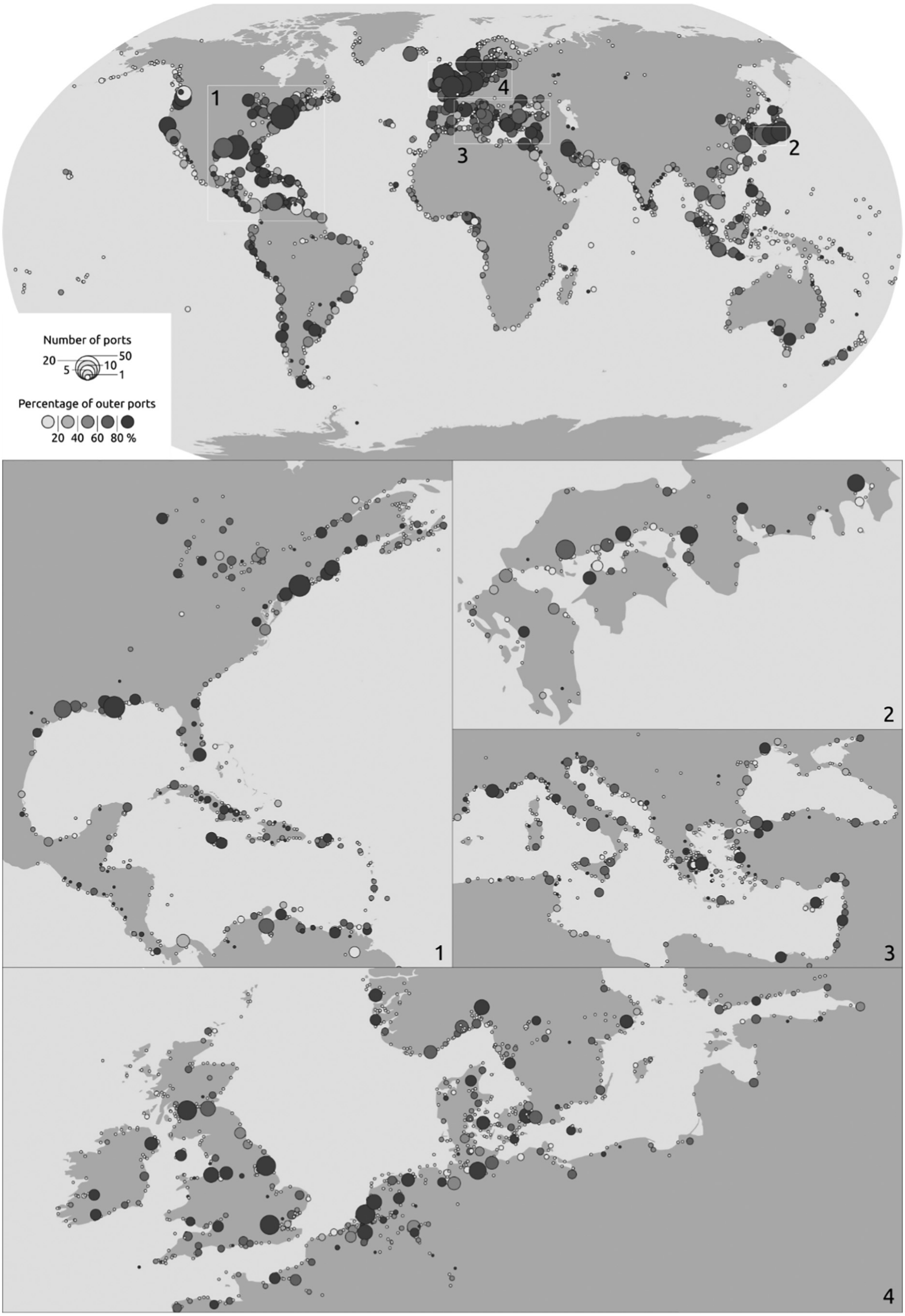


Fig. 4. Distribution of cities and their number of ports.
(Source: own realization)

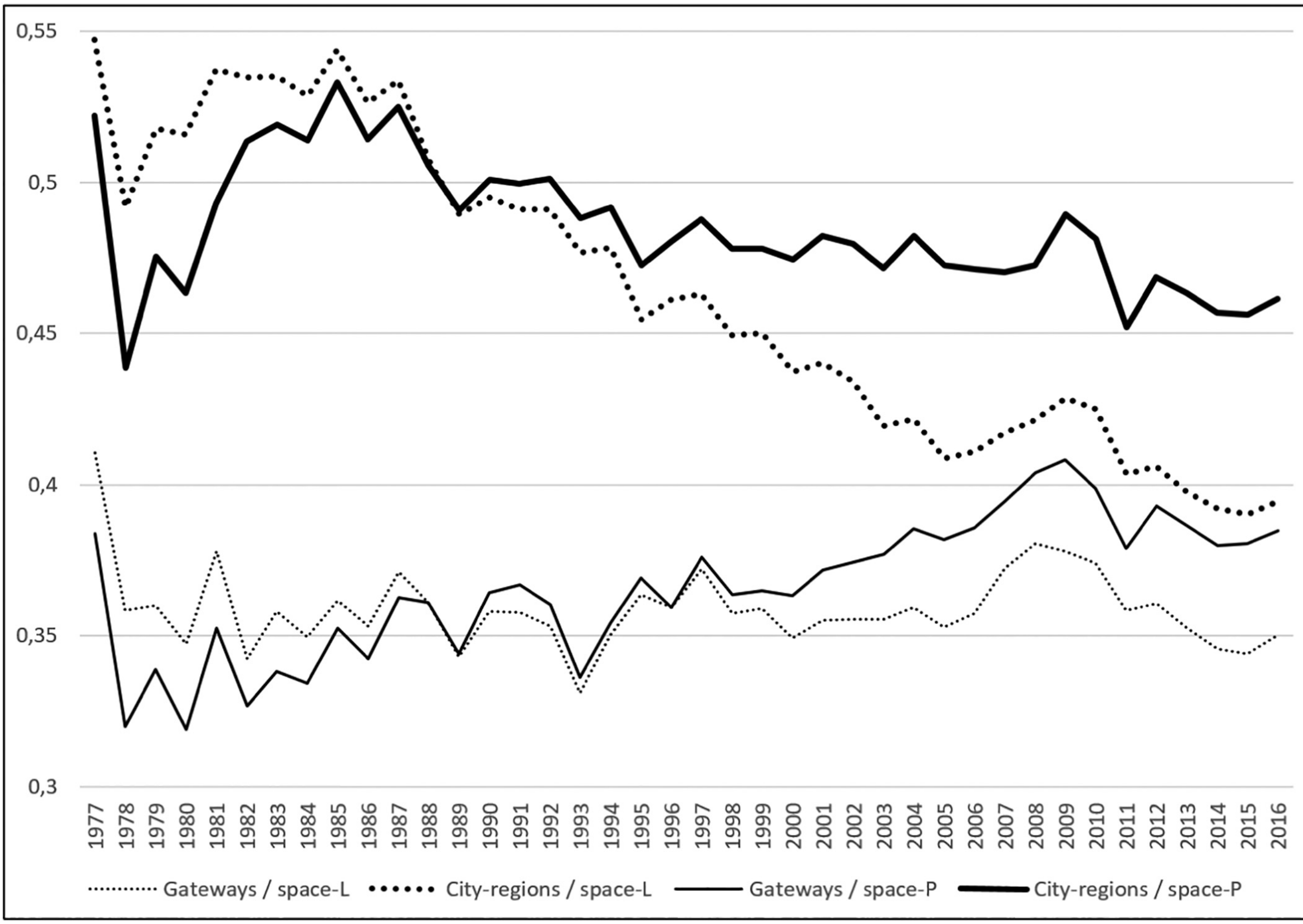


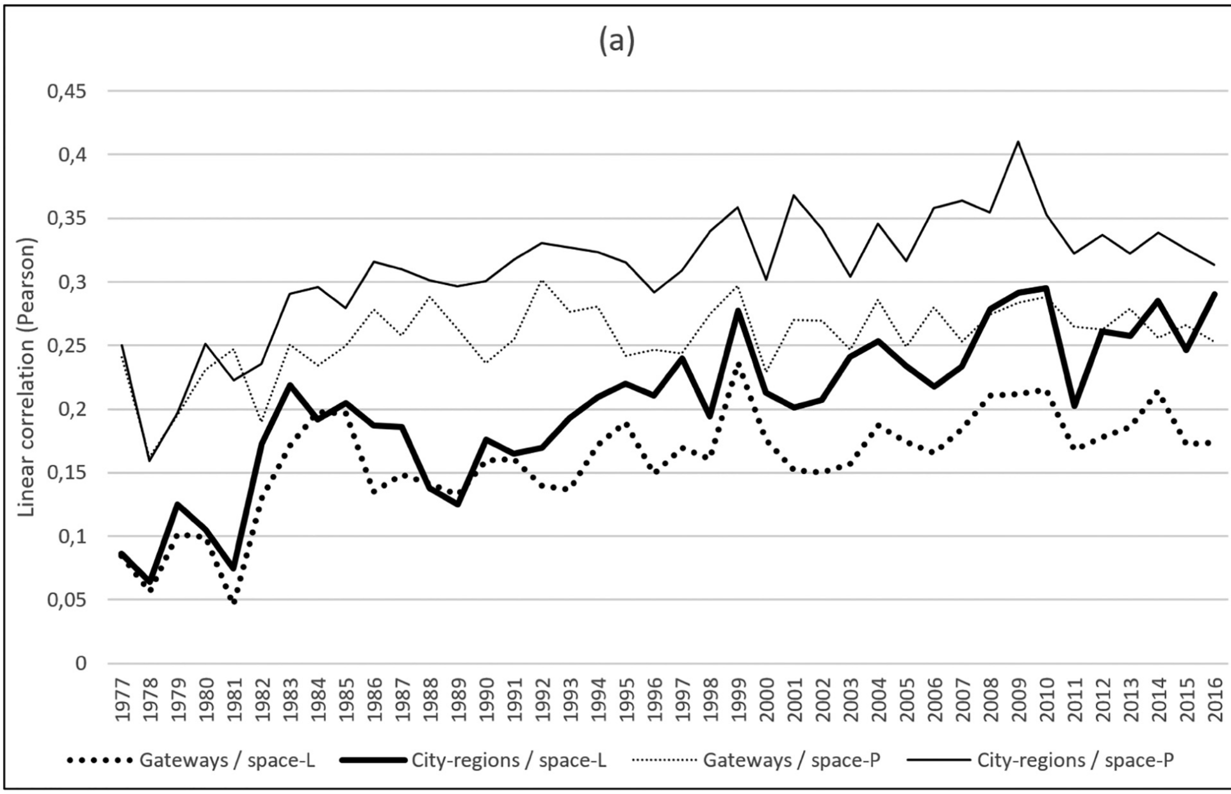
Fig. 5. Port-city correlation under different network topologies, 1977–2016.
(Source: own realization)

(Fig. 6a) but at the same time, traffic becomes increasingly explained by short-distance interactions (Fig. 6b). The emergence of transshipment hubs drastically modified the shape of port systems, centralizing flows within and between regions in the form of high-frequency hub-feeder flows. Values were initially higher for space-P compared with space-L due to the inclusion of long-distance linkages, before their convergence in the second half of the study period. This explains why the coefficients at space-P/city-regions have been sharply decreasing in the study period. In addition, just after the bankruptcy of Lehman Brothers in 2008, the parameters became almost zero from negative value for the restructuring of their service routes, or reducing the number of ship calls at trunk lines, and the demand decreasing for high-speed services (i.e. load factor's improvement).

4.2. Gravitational properties of the networks

The results obtained from the application of the gravity model, which has eight continental dummies on origin and destination, and are standardizes on "Europe", are summarized in Table 2 (see details for the functions estimated in Appendix 2b). They confirm that the maritime distance of intercity links has a negative influence on shipping flows among cities, and this effect negatively increases with node aggregation and network density, namely from gateway to city-region, and from space-L to space-P as in the results in section 4.1. The year dummy (linear variable) is positive meaning that constant term's effect also increased over time between 1977 and 2016 for the expansion of containerization and the improvement of maritime transport technology. As in section 4.1, while the continental dummies while the continental dummies for North and Latin America are positive for DWTs, the one of Africa is negative due to fewer liner services and insufficient container terminal development. Population has the expected positive sign, with an increase from gateway/space-L to city-region/space-P, thus confirming as in Fig. 5 that larger cities connect more with each other. Last but not least, we observe that city-region/space-P has a higher Adj. R-square than gateway/space-P so that central places take the lead in explaining maritime flows compared with gateways because they are a more suitable definition reflecting extended hinterlands and complex shipping structures. Those results mean that the global container shipping network is highly gravitational and thus can be considered as a coherent system where flows, nodes, and geography are mutually interdependent.

The time variation of the distance effect, which is estimated by interaction term for distance on panel data in 40 years, is best captured by Fig. 7 (see Appendix 2b). As a matter of fact, and echoing the aforementioned "puzzling effect" found in most studies of international trade, distance has had an increasingly negative influence on interurban shipping flows because of the progress of containerization such as hub-and-spokes networks and interregional trade for global supply chains. But this effect is found here to highly depend on node aggregation and network topology. The latter has the least felt the friction of distance, given that it better reflects shipping line logics than trade logics. The negative influence of distance is then more apparent in the space-P network, where trading ports are more represented than in the space-L. However, a huge and growing gap can be seen gradually between gateways and city-regions after the late 1990s because of the progress of their specialization on container traffic. This is because among space-



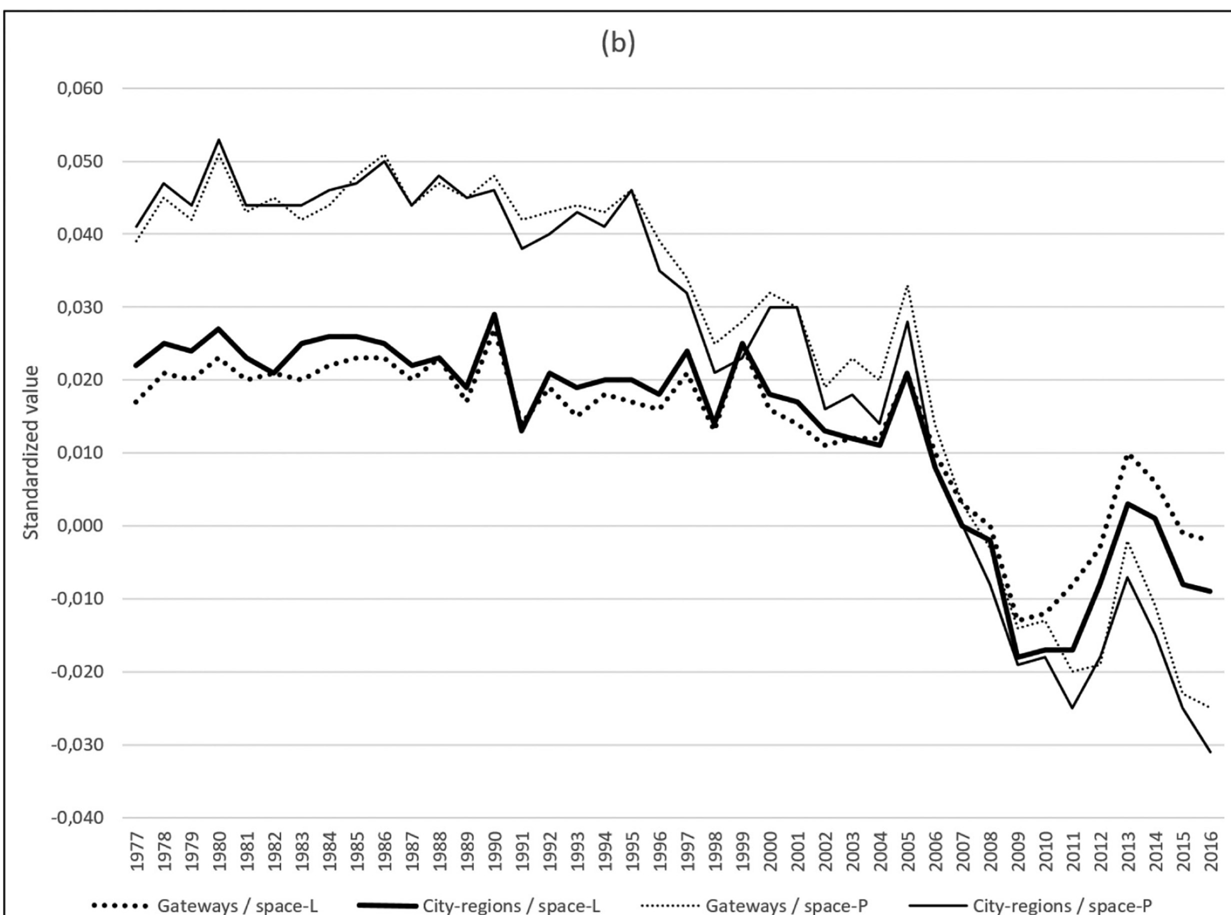


Fig. 6. City size (a), city traffic (b) and connection length, 1977–2016.
(Source: own realization)

Table 1
Multiple regression estimated.
(Source: own realization)

	Space-L		Space-P	
	Gateways	City-regions	Gateways	City-regions
Population	0.218 ***	0.242 ***	0.095 ***	0.111 ***
Distance	0.138 ***	0.137 ***	0.112 ***	0.102 ***
Year dummy	0.200 ***	0.215 ***	0.158 ***	0.175 ***
Degree centrality	0.571 ***	0.558 ***	0.663 ***	0.664 ***
City dummy				
Island	0.028 ***	0.028 ***	0.074 ***	0.072 ***
Capital	−0.001	0.007	0.030 ***	0.028 ***
Location dummy				
Downstream	0.013 **	0.026 ***	0.009 *	0.011 **
Inland	−0.044 ***	−0.022 ***	−0.042 ***	−0.023 ***
Upstream	−0.063 ***	−0.051 ***	−0.052 ***	−0.043 ***
Continental dummy				
Africa	−0.010 *	−0.019 ***	−0.028 ***	−0.037 ***
East Asia	−0.020 ***	−0.030 ***	0.030 ***	0.015 **
Latin America	0.061 ***	0.034 ***	0.030 ***	0.017 ***
Mediterranean	−0.003	−0.006	0.000	−0.001
North America	0.117 ***	0.099 ***	0.088 ***	0.073 ***
Oceania	0.059 ***	0.061 ***	0.004	0.001
West Asia	0.046 ***	0.040 ***	0.041 ***	0.037 ***
Adjusted R-square	0.670	0.692	0.692	0.714

Note: The numbers are standardized coefficients for comparison on typologies. DWTs, population, and distance are natural logarithm. Location dummy are standardized on “Costal”. Continental dummies' coefficients are standardized on “Europe”. *$p < .1$, **$p < .01$, ***$p < .001$.

Table 2
Gravity model estimated.
Source: own realization.

	Space-L		Space-P	
	Gateways	City-regions	Gateways	City-regions
Population at origin	0.207 ***	0.221 ***	0.214 ***	0.239 ***
Population at destination	0.209 ***	0.226 ***	0.206 ***	0.229 ***
Distance	−0.122 ***	−0.154 ***	−0.137 ***	−0.176 ***
Year dummy	0.252 ***	0.257 ***	0.239 ***	0.242 ***
Continental dummy				
Origin				
Africa	−0.033 ***	−0.035 ***	−0.066 ***	−0.075 ***
East Asia	0.001	0.007 *	0.026 ***	0.015 ***
Latin America	0.039 ***	0.011 ***	0.039 ***	−0.001
Mediterranean	−0.007 **	−0.012 ***	−0.007 ***	−0.011 ***
North America	0.114 ***	0.116 ***	0.087 ***	0.081 ***
Oceania	0.039 ***	0.048 ***	0.026 ***	0.028 ***
West Asia	0.032 ***	0.034 ***	0.013 ***	0.005 ***
Destination				
Africa	−0.016 ***	−0.015 ***	−0.062 ***	−0.071 ***
East Asia	−0.005	−0.006	0.028 ***	0.019 ***
Latin America	0.050 ***	0.019 ***	0.038 ***	0.000
Mediterranean	−0.008 ***	−0.013 ***	−0.007 ***	−0.012 ***
North America	0.109 ***	0.102 ***	0.085 ***	0.080 ***
Oceania	0.044 ***	0.049 ***	0.022 ***	0.025 ***
West Asia	0.039 ***	0.036 ***	0.013 ***	0.005 ***
Adjusted R-square	0.160	0.178	0.158	0.184

Note: The numbers are standardized coefficients for comparison on typologies. DWTs, population, and distance are natural logarithm. Continental dummies' coefficients are standardized on “Europe”. *$p < .1$, **$p < .01$, ***$p < .001$.

P cities, those with a large economic base (here population) are more central and connected as seen in the previous analyses, given their wide connectivity when considering outer ports or “indirect connectivity” of regional economic centers. In turn, this would imply that port traffic is increasingly handled at ports away from the larger economic centers they serve, so that such ports have limited developmental effects locally (Fujita and Mori, 1996; Slack and Gouvernal, 2015) as their economic development would remain in the non-port regional core. In the case of a subcategory that could be entitled “core gateways”, i.e. when a port city is already the main market and maintained / developed inner port and outer port like many of the world's global cities, there is a convergence between port and urban functions both spatially and functionally as the urban settlement pattern overlaps the port system hierarchy.

5. Conclusion

This paper demonstrated that maritime flows form a world city network where geography and urban characteristics remain highly influential, despite all the contemporary economic and technological changes in the ports and maritime sector. This is not to say that the container shipping industry had no effect on the way ports and cities interact with each other. Scholars focusing on the port-city interface converge in a sense that most of the world's port cities had been through a deep rethinking of their functional and spatial mechanisms internally (Hall and Clark, 2010). But when taking some distance, namely adopting a global network perspective using various topologies, and extending the definition of the city beyond the port itself, the macro-structure of the system remains relatively unchanged. Cities continue to be important engines of traffic generation, and maritime flows continue to connect them according to simple parameters of which distance but also other locational characteristics.

The deepest change is indirectly revealed by our results, when shifting from port city to city-region. It is, however, rarely considered in either urban or transport studies, as it relates to the fact that cities increasingly use distant port terminals to access maritime trade. Thus land-based transport, mainly trucking, becomes an inevitable tool between ports and city-regions, thereby posing important issues in terms of environmental impacts. Ironically, port-city separation was seen, in the 1960s and 1970s, as the only solution to save cities from many disturbances and to let the port grow on its own. Nowadays, however, extensive trucking in the form of corridors between remotely located ports and major cities are being re-examined, and it has become frequent to see ports returning within cities (El Hosni, 2017). Cities such as London, Tokyo, and Taipei recently invested in a new port near the urban core. While Taipei and Tokyo's initiatives comes from the central and metropolitan governments, the London case is more driven by Dubai Port World's slogan “ship closer, save money” in its competition with Hutchinson Whampoa, which operates the distant gateway of Felixstowe, 250 km away from the capital city. In addition, shortsea shipping is seen as a favorable candidate to lower dominant truck-based transport systems, but its bargaining power remains low, after decades of laissez-faire.

This research thus contributes to promote a better interconnection between port and city, as decades of separation did not eliminate their mutual dependence. The applicability of gravitational rules to the world maritime city network is an important finding for two main reasons. First in urban studies, it confirms that material flows remain essential to urban development, contrary to the belief that cities' growth now only depends on telecommunications and virtual connectivity. Second, in the wider field of network analysis, it provides an additional clue that the study of spatial networks should integrate temporal change and node characteristics, to avoid the risk of drawing conclusions solely based on the pure topological architecture of real-world systems.

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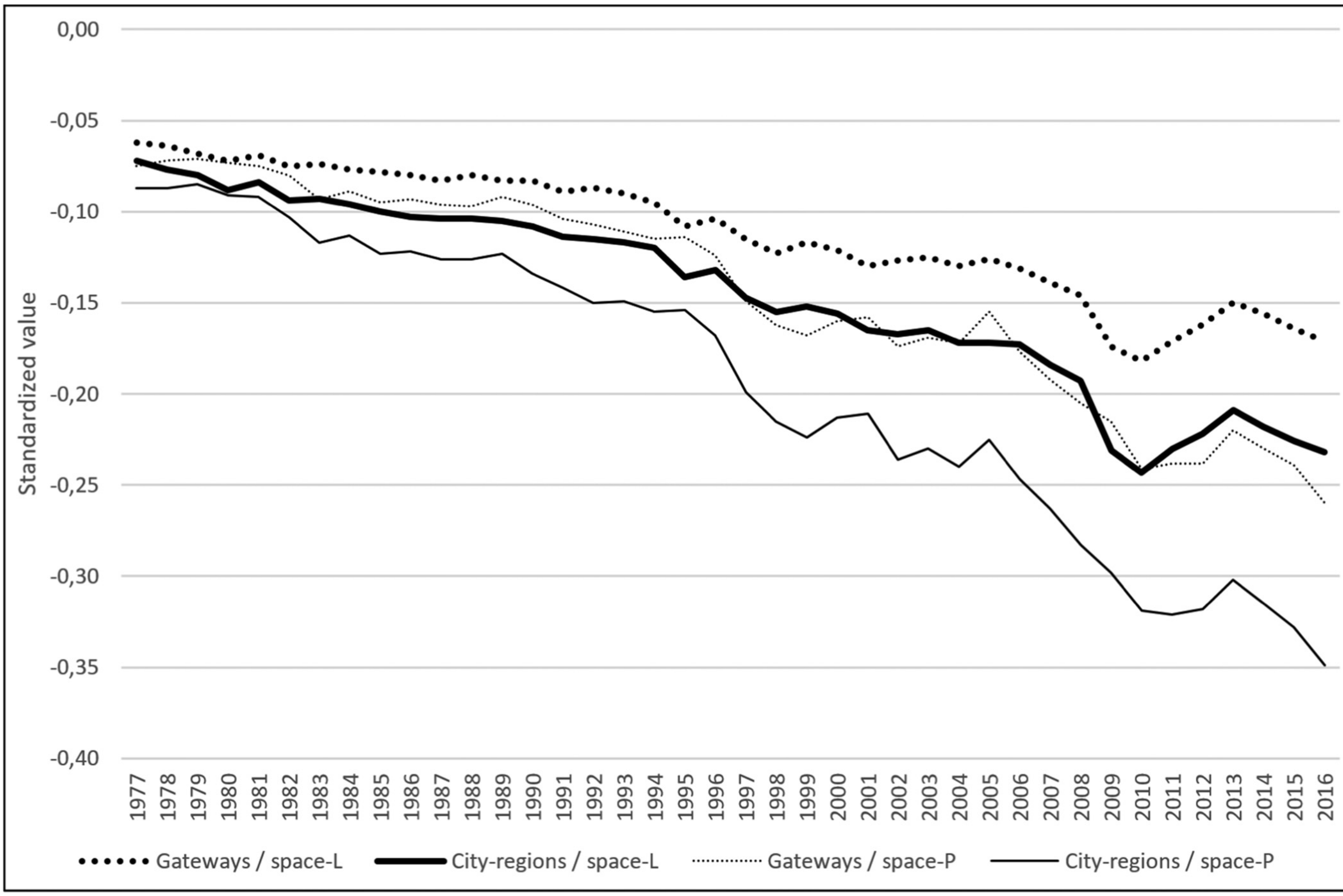

Fig. 7. Distance effect in the gravity model.
(Source: own realization)

17KK0058 and 18KK0051.

Appendix A. Descriptive statistics for database

(a) Multiple regression for Port-city connection

Variables		Space-L		Space-P	
		Gateways	City-regions	Gateways	City-regions
DWT at ports (*1000)	Ave.	4809.44	5687.97	134,050.21	160,112.00
	S.D	21,565.88	24,917.22	567,748.54	663,636.41
	Min	0.94	0.94	1.54	0.94
	Max	516,724.99	529,087.77	13,232,154.05	13,667,231.53
Population	Ave.	928.71	1184.38	937.75	1173.15
	S.D	2370.31	2712.14	2413.18	2698.37
	Min	0.32	0.32	0.32	0.32
	Max	36,933.00	36,933.00	36,933.00	36,933.00
Ave. Distance at ports	Ave.	2426.41	2560.65	5523.36	5743.96
	S.D	2201.05	2215.94	3561.96	3561.96
	Min	1.85	5.89	30.74	30.74
	Max	24,254.76	24,271.92	23,151.68	23,139.36

Note: Only for the samples without missing value.

A.1. Descriptive statistics for multiple regression.

Source: own realization.

(b) Gravity model for gravitational property

Variables		Space-L		Space-P	
		Gateways	City-regions	Gateways	City-regions
DWT on links (*1000)	Ave.	483.31	551.67	2332.98	2826.89
	S.D	2473.04	2894.16	13,519.18	17,049.33
	Min	0.94	0.94	0.94	0.94
	Max	193,713.35	193,713.35	1,374,517.91	1,374,517.91
Population, origin (i)	Ave.	2063.94	2582.21	1882.68	2393.22
	S.D	3922.96	4483.39	3711.13	4249.77
	Min	0.43	1.00	0.32	0.32
	Max	36,933.00	36,933.00	36,933.00	36,933.00
Population, destination (j)	Ave.	2209.44	2758.01	1903.78	2417.88
	S.D	4174.19	4731.54	3738.47	4272.53
	Min	0.43	1.00	0.32	0.32
	Max	36,933.00	36,933.00	36,933.00	36,933.00
Distance between links	Ave.	3512.90	3744.12	7702.22	7955.64
	S.D	4242.40	4348.69	6326.65	6265.05
	Min	1.85	7.81	1.85	7.81
	Max	24,643.72	24,643.72	25,730.41	25,730.41

Note: Only for the samples without missing value.

A.2. Descriptive statistics for gravity model.

Source: own realization.

Appendix B. Functions estimated

(a) The equation of multiple regression analysis is as follows.

$$\ln(dwt_i^t) = \alpha + \beta\bullet\ln(pop_i^t) + \gamma\bullet\ln(ave\_dist_i^t) + \theta\bullet centrality_i^t + \delta\bullet year\_dummy^t + \sum \mu_k\bullet city\_dummy_{i,k} + \sum \pi_l\bullet location\_dummy_{i,l} + \sum \rho_m \bullet continental\_dummy_{i,m} + \varepsilon_{it}$$

Here, dwt_i^t is the capacity of ship calls at the port(s) in a port city i at time t, pop_i^t is the number of inhabitants at the port city i, for the 40 years' sample (between 1977 and 2016). And, $ave\_dist_i^t$ is the "average" distance of their maritime traffic. $centrality_i^t$ is the degree of centrality (number of adjacently connected neighbors). In addition, we apply for dummy variables representing the characteristics of port cites and maritime industry; 1) $year\_dummy^t$ is linear variable from 1977 to 2016 (1977 = zero, 1978 = 1, and 2016 = 39) for capturing the technology change on maritime industries; like ship size expansion and handling ability, 2) $city\_dummy_{i,k}$ is binary variable for three categories (island, capital, and others = zero) for capturing port city function, 3) $location\_dummy_{i,l}$ is binary variable for four categories (downstream, inland, upstream, and coastal = zero) for representing ports' location in the outlying region, and 4) $continental\_dummy_{i,m}$ is eight groups (Africa, East Asia, Latin America, Mediterranean, North America, Oceania, West Asia, and Europe = zero) for reflecting the regional characteristics. The estimated results are listed on Table 1.

Furthermore, by discussing the change of distance effects (r), we introduce separate interaction terms between the ration of $ave\_dist_i^t$ for the global average of their average distance and the individual years ($year_p$, p = 1 to 40) on following equation. Then, we can capture the relevant distance effects by year. Fig. 6(a) shows the change of estimated parameters of interaction terms (r_p).

$$\ln(dwt_i^t) = \alpha + \beta\bullet\ln(pop_i^t) + \sum_{p=1}^{40} \gamma_p\bullet\frac{ave\_dist_i^t}{\overline{ave\_dist_i^t}}\bullet year_p + \theta\bullet centrality_i^t + \delta\bullet year\_dummy^t + \sum \mu_k\bullet city\_dummy_{i,k} + \sum \pi_l\bullet location\_dummy_{i,l} + \sum \rho_m \bullet continental\_dummy_{i,m} + \varepsilon_{it}$$

(b) The equation of (basic) gravity model is as follows.

$$\ln(dwt_{ij}^t) = \alpha + \beta_i\bullet\ln(pop_i^t) + \beta_j\bullet\ln(pop_j^t) + \gamma\bullet\ln(dist_{ij}) + \delta\bullet year\_dummy^t + \sum \rho_{i,m}\bullet continental\_dummy_{i,m} + \sum \rho_{j,m}\bullet continental\_dummy_{j,m} + \varepsilon_{ijt}$$

Here, dwt_{ij}^t is the capacity of maritime links between two port cities; i (origin) and j (destination), pop_i^t and pop_j^t are the amount of population at the origin and the destination of the link respectively. And, $dist_{ij}$ is the maritime distance of the link between two port cities. As with (a), we apply for the dummies of year and continental. About continental dummy, they are constructed by two variables on origin and destination of port cities respectively. The estimated results are listed on Table 2.

Furthermore, as with (a), we introduce separate interaction terms for capturing the relevant distance effect by year. Fig. 7 shows the change of estimated parameters of interaction terms (r_p).

$$\ln(dwt_{ij}^t) = \alpha + \beta_i\bullet\ln(pop_i^t) + \beta_j\bullet\ln(pop_j^t) + \sum_{p=1}^{40} \gamma_p\bullet\ln(dist_{ij})\bullet year_p + \delta\bullet year\_dummy^t + \sum \rho_{i,m}\bullet continental\_dummy_{i,m} + \sum \rho_{j,m}\bullet continental\_dummy_{j,m} + \varepsilon_{ijt}$$

References

Adomaitis, K., 2014. World's major port cities are growing faster than inland cities. Euromonitor International publication date: May 31th. https://blog.euromonitor.com.

Anderson, J.E., van Wincoop, E., 2004. Trade costs. J. Econ. Lit. 42, 691–751.

Barthelemy, M., 2015. Spatial networks: tools and perspectives. In: Ducruet, C. (Ed.), Maritime Networks: Spatial Structures and Time Dynamics. Routledge studies in transport analysis, pp. 50–60.

Behar, A., Manners, P., Nelson, B.D., 2009. Exports and logistics. In: Discussion Papers Series No. 439, Oxford. University of Oxford.

Bensassi, S., Marquez-Ramos, L., Martinez-Zarzoso, I., Suarez-Burguet, C., 2015. Relationship between logistics infrastructure and trade: evidence from Spanish regional exports. Transp. Res. A 72, 47–61.

Berli, J., Bunel, M., Ducruet, C., 2018. Sea-land interdependence in the global maritime network: the case of Australian port cities. Netw. Spat. Econ. 18 (3), 467–471.

Bird, J., 1963. The Major Seaports of the United Kingdom. Hutchinson, London.

Bird, J., 1977. Centrality and Cities. Routledge & Kegan Paul, London.

Bretagnolle, A., 2015. City-systems and maritime transport in the long term. In: Ducruet, C. (Ed.), Maritime Networks: Spatial Structures and Time Dynamics. Routledge Studies in Transport Analysis, pp. 27–36.

Brun, J.F., Carrère, C., Guillaumont, P., de Melo, J., 2005. Has distance died? Evidence from a panel gravity model. World Bank Econ. Rev. 19 (1), 99–120.

Bunel, M., Bahoken, F., Ducruet, C., Lagesse, C., Marnot, B., Mermet, E., Petit, S., 2017. Geovisualizing the sail-to-steam transition through vessel movement data. In: Ducruet, C. (Ed.), *Advances in Shipping Data Analysis and Modeling. Tracking and Mapping Maritime Flows in the Age of Big Data*. London and New York: Routledge, pp. 189–205.

Carrère, C., Schiff, M., 2005. On the geography of trade. Distance is alive and well. Revue Economique 6 (56), 1249–1274.

Chapelon, L., 2006. L'accessibilité, marqueur des inégalités de rayonnement des villes portuaires en Europe. Cybergeo 345. https://journals.openedition.org/cybergeo/2463.

Clark, X., Dollar, D., Micco, A., 2004. Port efficiency, maritime transports, and bilateral trade. J. Dev. Econ. 75, 417–450.

Cullinane, K.P.B., Khanna, M., 2000. Economies of scale in large containerships: optimal size and geographical implications. J. Transp. Geogr. 8 (3), 181–195.

Dai, L., Derudder, B., Liu, X., 2016. Generative network models for simulating urban networks, the case of inter-city transport network in Southeast Asia. Cybergeo 786. https://journals.openedition.org/cybergeo/27734.

Disdier, A.C., Head, K., 2008. The puzzling persistence of the distance effect on bilateral trade. Rev. Econ. Stat. 90 (1), 37–48.

Ducruet, C., Lee, S.W., 2006. Frontline soldiers of globalisation: port-city evolution and regional competition. Geojournal 67 (2), 107–122.

Ducruet, C., Notteboom, T.E., 2012. The worldwide maritime network of container shipping: spatial structure and regional dynamics. Global Networks 12 (3), 395–423.

Ducruet, C., Zaidi, F., 2012. Maritime constellations: a complex network approach to shipping and ports. Maritime Policy and Management 39 (2), 151–168.

Ducruet, C., Rozenblat, C., Zaidi, F., 2010. Ports in multi-level maritime networks: evidence from the Atlantic (1996-2006). J. Transp. Geogr. 18 (4), 508–518.

Ducruet, C., Ferrari, C., Itoh, H., Tei, A., 2017. The local determinants of interregional shipping flows. In: Ducruet, C. (Ed.), *Advances in Shipping Data Analysis and Modelling. Tracking and Maritime Flows in the Age of Big Data*. London & new York: Routledge, pp. 233–250.

Ducruet, C., Cuyala, S., El Hosni, A., 2018. Maritime networks as systems of cities: the long-term interdependencies between global shipping flows and urban development (1890-2010). J. Transp. Geogr. 66, 340–355.

Egger, P., 2008. On the role of distance for bilateral trade. World Econ. 31 (5), 653–662.

Fleming, D.K., Hayuth, Y., 1994. Spatial characteristics of transportation hubs: centrality and intermediacy. J. Transp. Geogr. 2 (1), 3–18.

Fugazza, M., Hoffmann, J., 2017. Liner shipping connectivity as determinant of trade. Journal of Shipping and Trade 2 (1). https://doi.org/10.1186/s41072-017-0019-5.

Fujita, M., Mori, T., 1996. The role of ports in the making of major cities: self-agglomeration and hub-effect. J. Dev. Econ. 49 (1), 93–120.

Geraci, V.J., Prewo, W., 1977. Bilateral trade flows and transport costs. Rev. Econ. Stat. 59 (1), 67–74.

Grosche, T., Rothlauf, F., Heinzl, A., 2007. Gravity models for airline passenger volume estimation. J. Air Transp. Manag. 13 (4), 175–183.

Guerrero, D., Grasland, C., Ducruet, C., 2015. Explaining international trade flows with shipping-based distances. In: Ducruet, C. (Ed.), *Maritime Networks: Spatial Structures and Time Dynamics*, Routledge studies in transport analysis, pp. 303–321.

Guimera, R., Mossa, S., Turtschi, A., Amaral, L.A., 2005. The worldwide air transportation network: anomalous centrality, community structure, and cities' global roles. Proceedings of the National Academy of Sciences USA 102 (22), 7794–7799.

Hall, P.V., Clark, A., 2010. Maritime ports and the politics of reconnection. In: Desfor, G., Laidley, J., Schubert, D., Stevens, Q. (Eds.), Transforming Urban Waterfronts: Fixity and Flow. Routledge, Abingdon, pp. 17–34.

Hall, P.V., Jacobs, W., 2012. Why are maritime ports (still) urban, and why should policy makers care? Maritime Policy and Management 39 (2), 189–206.

Head, K., Mayer, T., 2011. Gravity, market potential and economic development. J. Econ. Geogr. 11 (2), 281–294.

Hoare, A.G., 1986. British ports and their export hinterlands: a rapidly changing geography. Geografiska Annaler B 68 (1), 29–40.

Hoyle, B.S., 1989. The port-city interface: trends, problems, and examples. Geoforum 20 (4), 429–435.

Hu, Y., Zhu, D., 2009. Empirical analysis of the worldwide maritime transportation network. Physica A 388 (10), 2061–2071.

Huang, R.R., 2007. Distance and trade: disentangling unfamiliarity effects and transport cost effects. Eur. Econ. Rev. 51, 161–181.

Hummels, D., 2001. Time as a Trade Barrier. Center for Global Trade Analysis, Purdue University, GTAP Working Paper: No. 1152.

Irwin, D.A., Terviö, M., 2002. Does trade raise income? Evidence from the twentieth century. J. Int. Econ. 58, 1–18.

Jacobs, W., Ducruet, C., De Langen, P.W., 2010. Integrating world cities into production networks: the case of port cities. Global Networks 10 (1), 92–113.

Jung, W.S., Wang, F., Stanley, H.E., 2008. Gravity model in the Korean highway. Europhysics Letters Association 81 (4), 48005.

Kaluza, P., Kölzsch, A., Gastner, M.T., Blasius, B., 2010. The complex network of global cargo ship movements. J. R. Soc. Interface 7 (48), 1093–1103.

Korinek, J., Sourdin, P., 2010. Clarifying trade costs: maritime transport and its effect on agricultural trade. Applied Economic Perspectives and Policy 32 (3), 417–435.

Krings, G., Calabrese, F., Ratti, C., Blondel, V.D., 2009. Urban gravity: a model for intercity telecommunication flows. Journal of Statistical Mechanics: Theory and Experiment 7, L07003.

Lee, S.W., Song, D.W., Ducruet, C., 2008. A tale of Asia's world ports: the spatial evolution in global hub port cities. Geoforum 39 (1), 372–385.

Limao, N., Venables, A.J., 2001. Infrastructure, geographical disadvantage, transport costs, and trade. World Bank Econ. Rev. 15 (3), 461–479.

McCalla, R.J., 2004. Hierarchical network structure as seen in container shipping liner services in the Caribbean Basin. Belgeo 4, 407–418.

Mohamed-Chérif, F.Z., Ducruet, C., 2016. Regional integration and maritime connectivity across the Maghreb seaport system. J. Transp. Geogr. 51, 280–293.

Moriconi-Ebrard, F., 1994. Geopolis : pour comparer les villes du monde. Economica, Paris.

Nordas, H.K., Piermartini, R., 2004. Infrastructure and trade. In: WTO Staff Working Paper No. ERSD-2004-04, Geneva, https://doi.org/10.30875/471105a9-en.

Rivers, R., Evans, T., Knappett, C., 2015. From oar to sail. The role of technology and geography in the evolution of Bronze Age Mediterranean networks. In: Ducruet, C. (Ed.), *Maritime Networks: Spatial Structures and Time Dynamics*, Routledge Studies in Transport Analysis, pp. 63–76.

Rodrigue, J.P., Notteboom, T.E., 2009. The geography of containerization: half a century of revolution, adaptation and diffusion. Geojournal 74, 1–5.

Rodrigue, J.P., Notteboom, T.E., 2010. Foreland-based regionalization: integrating intermediate hubs with port hinterlands. Res. Transp. Econ. 27 (1), 19–29.

Rodrigue, J.P., Notteboom, T.E., 2015. Looking inside the box: evidence from the containerization of commodities and the cold chain. Maritime Policy and Management 42 (3), 207–227.

Shen, G., 2017. GIS-based analysis of US international seaborne trade flows. In: Ducruet, C. (Ed.), *Advances in Shipping Data Analysis and Modeling. Tracking and Mapping Maritime Flows in the Age of Big Data*. London and New York: Routledge, pp. 147–172.

Slack, B., Gouvernal, E., 2015. Container transshipment and logistics in the context of urban economic development. Growth Chang. 47 (3), 406–415.

Tsiotas, D., Polyzos, S., 2018. Effects in the network topology due to node aggregation: empirical evidence from the domestic maritime transportation in Greece. Physica A. 491, 71–88.

UNCTAD, 2019. Review of Maritime Transport. United Nations, Geneva.

United Nations, 2017. The Ocean Conference. United Nations, New York.

Wilmsmeier, G., Hoffmann, J., Sanchez, R.J., 2006. The impact of port characteristics on international maritime transport costs. Res. Transp. Econ. 16, 117–140.

Wilson, J.S., Mann, C.L., Otsuki, T., 2005. Assessing the benefits of trade facilitation: a global perspective. World Econ. 28 (6), 841–871.