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Revisiting port system delineation through an analysis of maritime interdependencies among seaports

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ABSTRACT

A port system is a system of two or more ports, located in proximity within a given area. In literature, various geographical and functional scales have been identified ranging from complete coastlines to the notions of a ‘range’ and a ‘multi-port gateway region’. Not only does the spatial scale create confusion on the true functional delineation of port systems, but it also complicates a clear understanding of the relational mechanisms at stake within these port systems. This paper revisits existing approaches to and empirical delineations of port systems. Maritime network analysis techniques are deployed to understand hierarchies and interdependencies among nodes of container port systems and sub-systems in North Europe and Northeast Asia. The results provide additional insights on how ports interact from a maritime services’ perspectives and demonstrate whether or not ports which are traditionally considered as belonging to the same port system can in reality be considered forming a fully integrated port system.

Keywords: *connectivity; port geography, port system, maritime network*

1. Introduction

In transport geography and beyond, the analysis of ports has long resulted in scattered monographs interested in the morphological evolution of their infrastructure and outlying territory (for a review of port geography research see Ng and Ducruet, 2014 and Ng et al., 2014). Model-based approaches were soon proposed to grasp ideal-typical sequences of port development, not only at the level of the port itself but more transnational in scope, as in the famous corridor development model of Taaffe et al. (1963) that pioneered the study of what would become the concept of a “port system”. While this model was greatly inspired from the formation of urban primacy in developing economies, other works on coastal corridor development were highly influential for subsequent research on ports, such as on the Northeastern U.S. megalopolis from Boston to Washington (Gottmann, 1961) and the North European port range from Le Havre to Hamburg (Vigarié, 1964). Those studies had in common that they considered port development from a strict land-based perspective. This was criticized at the same period by Rimmer (1967) in his study of Oceania, calling for the inclusion of maritime linkages in the study of port systems. This posture was only adopted by Robinson (1968) in his PhD dissertation on Vancouver and British Columbia ports, before maritime network analysis started to receive foremost attention from the 2000s onwards (see Ducruet, 2020 for a recent review).

Another characteristic of port system analysis was its preoccupation with small sets of ports within national boundaries (see a review by Ducruet et al., 2009a). This dominant approach illustrated the belief that port systems mainly rest on geographic proximity and political borders. The definition – and thus the delineation – of port systems varies greatly across the academic spectrum, and is often confounded with a coast, a country, a range or maritime façade, and to a wider entity from seas and basins to the entire world port system. In a review of no less than 399 port geography papers, Marei and Ducruet (2015) concluded that a majority (48%) of this corpus studied a single port, 22% focused at the country level, 10.3% at the subnational scale, 13.5 % opted for a transnational approach, and less than 1% concerned the level of entire basins, while the world level only occupied 5.5% of all papers.

Not only does the spatial scale create confusion on the true functional delineation of port systems, but it also complicates a clear understanding of the relational mechanisms at stake within the port system itself. It is a fact that the prime interest of scholars studying port systems is the way ports dominate each other. Methodologically, such analyses look at the distribution of port throughputs and its evolution through markets shares or more advanced statistical methods like the application of the Gini coefficient or the Herfindahl index. Yet and as underlined long ago by Rimmer (1967), the relational approach is ignored in classical studies of port systems, or the way ports are actually linked with each other through the maritime

network, as highlighted by Robinson (1968, pp. 95-97): *“it is possible to define the spatial patterns of functional relationships between ports by examining the linkages which are sustained by the inter-port shipping movements of foreign trade vessels. Such an analysis provides not only an accurate measure of the linkages themselves but also clarifies the relationships between ports, the spatial organization of port functions and the functional status of individual ports within the total group (...) The system of ports operating interdependently may now be regarded in abstract form as a set of points or nodes in a network, a transportation network in which the lines or links in the network are in fact ‘imaginary routes’”*. The relational perspective thus serves to identify not only hierarchies but functions within the port system.

Much later, the further integration of graph theory and complex network methods into port geography shall revive Robinson’s legacy (but without reference to it). Concepts of hub, bridge and community gradually became rather common in maritime network studies, benefitting from increasingly available shipping data on inter-port flows and improved computational power. New models of network development were proposed in maritime studies, exactly by Robinson (1998) three decades later, proposing to consider the multilayered nature of hub hierarchies in Asia and elsewhere.

At present, an important number of port system studies is in hand to attempt a review of the field. This paper wishes to examine how existing delineations of port systems correspond to the pattern of maritime flows, based on the case of container shipping. We compare the distribution of port hierarchies and inter-port maritime flows within two regions, namely North Europe and Northeast Asia, for the years 1996, 2006, and 2016. These two regions with cargo-rich hinterlands are among the most important port areas in the world in volume terms. For example, eight of the ten largest container ports in the world (in TEU terms) are located in Northeast Asia, while 6 of the top 10 container ports in Europe are located in North Europe, including the top 3, i.e. Rotterdam, Antwerp and Hamburg. Furthermore, many of these ports are leading the way in terms of port business innovation (Merk, 2013), green port development (Lam and Notteboom, 2014) and efficient and effective port governance (see e.g. the edited volume by Brooks et al., 2017). Given their status at the global port scene, their highly dynamic development paths and observed dynamics in inter-port competition and co-operation, these regions have attracted considerable attention from transport specialists willing to study port systems, should it be at the level of the entire regions or at thinner geographic levels. Despite extensive studies on these port regions or parts thereof, some key questions related to the spatiotemporal dynamics in port systems remain underexplored. How are existing definitions / visions of port systems reflected in the actual pattern of maritime flows and ship calling patterns? What are the implications of matches or gaps between the two for research and practice/policy? Our main hypothesis is that ports should be coupled/strongly interconnected

based on carrier choices but also other factors (geography, range effects, hubs and spokes), resulting in possible discrepancies between commonly accepted port systems and actual ones.

This paper thus revisits existing approaches to and empirical delineations of port systems. In particular, maritime network analysis techniques are deployed to understand hierarchies and interdependencies among nodes of container port systems and sub-systems in North Europe and Northeast Asia. As such, it is close to existing graph-theoretical works willing to test the overlap between a system of flows and given borders. The work of Blondel et al. (2010) on mobile phone telecommunications in Belgium, for instance, can be seen as a pioneering experiment of the kind, revealing the extent to which such communications are influenced by cultural and administrative borders. The results provide additional insights on how ports interact from a maritime services' perspective and demonstrate whether or not ports which are traditionally considered as belonging to the same port system can in reality be considered to be a fully integrated port system. We thus check how the decomposed maritime network corresponds to existing port system delineations, and discuss the factors causing gaps or overlaps.

The remainder of this paper is organized as follows. Section 2 reviews how port systems have been treated in the literature in general and more specifically about North Europe and Northeast Asia, providing a typology of existing studies. This literature review sets the background for a confrontation with our empirical results. Section 3 includes a quantitative analysis of vessel movement data in view of unravelling the maritime backbone and port communities of the two regions under examination in a comparative and dynamic perspective. We discuss in Section 4 the degree of overlap between our results and existing port system delineations and present conclusions about the lessons learned for further research in the field.

2. The concept 'port system' in literature

A port system can be defined as a system of two or more ports, located in proximity within a given area (Ducruet, 2009). In literature, various geographical and functional scales have been identified ranging from complete coastlines (e.g. the West coast of North America as one port system) to the notion of a 'range' (Vigarié, 1964) and a 'multi-port gateway region'. A *port range* can be defined as a group of container ports situated along the same seashore and sharing

more or less the inland service area (i.e. a shared or overlapping hinterland). A commonly used example is the Hamburg-Le Havre range in Europe. Within container port ranges one can generally observe fierce intra-range competition. A *multi-port gateway region* refers to a smaller geographical scale than a container port range. The term was first coined by Notteboom (2009a; 2010) and later also applied by e.g. Feng and Notteboom (2013) and Liu et al (2013). The locational relationship to nearby identical traffic hinterlands is one of the criteria that can be used to group adjacent container ports into the same multi-port gateway region. Also, the port calling patterns in the liner service networks of shipping and hinterland connectivity profile can help to group ports to a multi-port gateway region (Notteboom, 2009). Typical examples include the Rhine-Scheldt Delta (Belgium and the Netherlands) and the Yangtze River Delta and Pearl River Delta in China. A container port range can be home to several multi-port gateway regions. For example, the Hamburg-Le Havre range includes the multi-port gateway regions of North-Germany, the Rhine-Scheldt Delta and the Seine Estuary in France.

Tables 1 and 2 provide an overview of studies focusing on different scales of container port systems (i.e. continent-wide port systems, ranges and multi-port gateway regions) in respectively North Europe and East Asia. Next to the identification of the container port systems analysed, the tables also classify extant literature based on the main methodological approaches deployed by the respective authors. Thereby, a distinction is made between the following research dimensions:

- Studies focusing on the *analysis of container traffic volumes and related market shares* within the given port systems;
- Studies using measures to analyse *container traffic (de)concentration patterns* in port systems. Most of these port geography papers rely on measures of concentration or inequality such as the Gini coefficient (including Lorenz curves and Gini decomposition analysis) and the Herfindahl–Hirschman Index (HHI);
- Studies relying on *maritime network analysis* deploying a wide range of network indicators and measures linked to the centrality and connectivity of nodes within a maritime network consisting of container liner services;
- *Port choice and port competitiveness* studies. Here, logit models, decision making models (such as Analytical Hierarchy Process - AHP), factor analysis, principal component analysis or other statistical techniques are used to analyse the relative competitiveness of a

node within a given container port system or to model route and port choice through a port system;

- *Analysis of complementarity vs. substitutability between ports.* Here, the focus is on assessing whether nodes of the same port system act as substitutes to each other (implying competition) or complements (pointing to a high level of interdependence among the nodes);
- Determination of the ‘*relevant geographic market*’ (RGM). The term RGM typically is used by competition authorities to assess changes in the power of market actors in case of a merger or acquisition. The RGM can be defined as a geographical territory in which competition conditions in a relevant market of a product or service are sufficiently the same for all participants and therefore this territory can be separated from other territories. In a port context, the RGM concept has mainly been used to assess the impact of an M&A (mergers and acquisitions) activity in the container terminal operating business on the market positions of terminal operators. A well-known and pioneering EC competition case in the port sector was the take-over of ECT in Rotterdam by HutchisonPorts in the late 1990s;
- *Traffic forecasting studies* which deploy time series analysis and more advanced forecasting methods to develop scenarios and prognoses for the future traffic volumes and related market shares of nodes in a port system.

Table 1 Overview of port system studies focusing on container ports in North Europe

Table 2 Overview of port system studies focusing on container ports in East Asia

Tables 1 and 2 show that diverse delineations of container port systems have been used, while Figure 1 provides a cartography of the most recurrent configurations. The port range is the most common geographical scale of analysis. In North Europe, the Hamburg-Le Havre range is the most used port range, while the entire Scandinavia/Baltic region is typically considered as one port range. The same applies to the UK/Ireland. In East Asia, a much broader set of possible delineations of port ranges is used. Some of these delineations follow a country-based

approach (e.g. port systems in South Korea and Japan) while in other cases the considered range follows a more functional definition less based on administrative borders.

A limited number of studies focus on multi-port gateway regions. In East Asia, the Pearl River Delta and Yangtze River Delta are frequently examined multi-port gateway regions, although in other studies these deltas are considered as port ranges. The Bohai Rim in the northeast of China (also known as the Bohai Sea Economic Rim) is sometimes assessed as one port system at range or gateway region level, while in other studies the region is further decomposed in several sub-systems such as the Liaoning port system, Shandong port system and the Jin-Ji system (near Tianjin and Beijing). The most commonly used delineations of gateway regions in North Europe include the Rhine-Scheldt Delta, the Seine Estuary and the north German port system, all belonging to the Hamburg-Le Havre range. However, the ports included in these multi-port gateway regions might differ among the studies observed. For example, in Notteboom (2010), Dunkirk (France) and Amsterdam are included in the Rhine-Scheldt Delta while other studies follow a narrower delineation of this delta by only including ports which are located along or in the estuaries of the rivers Rhine/Meuse/Scheldt.

The reported studies each focus on specific functional interdependencies among nodes of the port systems under consideration which makes the delineation of relevant port systems and sub-systems more complex. In line with the work of Van Klink (1995), seaports can be subjected to three types of functional interdependencies with other nodes of the same port system:

- *Chain networks.* The output of one port in the system is the input for another. Trans-oceanic relations are an example of chain networks (e.g. relation Rotterdam - Singapore for deepsea liner services on the Europe-Far East trade);
- *Complex networks.* The nodes use each other's output. An example are the relations between ports in a hub-and-spoke network setting (e.g. South Korean container port Busan and smaller feeder ports in Northeast Asia).
- *Formation networks.* The formation network is based on pooled relations. The ports in the system make use of the same location factors. In these relations, competition but also complementarity/co-operation among ports can occur.

The vast majority of the studies mentioned in Tables 1 and 2 assess port systems by addressing competition and cargo concentration or deconcentration between nodes in the same formation network. Port choice and traffic forecasting studies (and related market shares) are also based on the interaction of ports in a formation network. The same applies to the notion of ‘relevant geographic market’ used by competition authorities.

Maritime network analyses, however, look at the interaction between nodes also in chain and complex networks. In fact, the study of maritime networks allows to develop a dual approach to the analysis and delineation of port systems. First, one can identify sub-systems of a large port system which basically act separately from each other (separate sub-markets from a maritime perspective). Second, one can identify sub-sets or groups of ports within a wider port system with a high complementarity and interdependence and which compete with other such groups.

The analysis of maritime networks thus allows to assess hierarchies and interdependencies among nodes in a port system. However, the position and function of a seaport in such a port system is only examined from the perspective of maritime liner services and related maritime connectivity without considering the spatial and functional ties seaports have with the land leg, i.e. potential overlaps or complementarity in hinterland coverage (i.e. shared / contestable / overlapping hinterland vs. captive hinterland). Thus, the delineations of port systems using maritime network analysis solely focus on maritime liner services. Still, such analysis can provide additional insights on the validity of the use of specific port system delineations used in literature while also adding chain and complex network dimensions to the more traditional formation network approach.

3. Maritime interdependencies among seaports in North Europe and Northeast Asia

3.1 Methodology

3.1.1 Data and network construction

In this paper, we use Lloyd’s List global database on vessel movements among ports of the world. This source has advantages and disadvantages for the analysis of maritime networks. On the one hand, it is highly representative of this particular shipping segment as it covers the entire fleet of containerships. It is also very detailed as it provides the carrying capacity, flag, operator, date of build, and the dates of arrival and departure of each vessel. On the other, what remains unknown is the true amount of cargo carried by vessels and therefore handled at the docks. In any case, it allows to construct a global, weighted origin-destination matrix of container flows following the methodology used by Hu and Zhu (2009) based on liner schedule and port call data. From this methodology, we opted for the space-P topology where all ports visited by the same vessel during a certain time period (here four complete months of circulation per year of observation, i.e. May-June and November-December) are connected within a complete subgraph. All subgraphs are combined to form the final network made of all vessel movements between all ports. It is believed that such a topology better embraces the complexity of shipping patterns than space-L where only direct inter-port stops are considered. The weight of nodes and links (or total traffic) equals the call frequency multiplied by vessel capacity measured in deadweight tonnage (DWT).

3.1.2 Graph partitioning

The main goal of this research is to confront the distribution and dynamics of maritime networks to the pre-established definition of port systems as units of references in the academic literature and beyond. Network analysis in general provides a wide variety of partitioning (or clustering) methods in order to reveal the main structure. Such methods have proved useful to test the relevance of borders of various kinds, such as cultural, political, and administrative borders, as in the case of mobile phone communications in Belgium for instance (Blondel et al., 2010).

Two main and complementary graph clustering methods are applied to the final network, namely single linkage analysis (SLA) and the Louvain algorithm. The single linkage analysis method is relatively straightforward, as it extracts the backbone of the network and its main hubs (if any), retaining for each node only its weightiest flow link in terms of total traffic (Nystuen and Dacey, 1961). Although the loss of information is huge by the deletion of many

other links, SLA allows to delineate so-called “nodal regions” defined by one independent node and its subordinates.. Such a method already proved to be useful to analyse the structure of many networks of which maritime systems at various scales and overtime (see Wang and Wang, 2011; Ducruet and Notteboom, 2012 for early applications to the global container shipping network). Nodal regions are the reflection not only of hierarchical tendencies but also of barrier effects of various kinds, from geographic distance (cf. remoteness) to the influence of physical geography (coastlines, basins, closed seas, islands) and territorial factors. The latter effects include political instability, war, blockade, and often result in the isolation of certain nodal regions from the core(s) of the network (see Ducruet et al., 2018).

Contrary to SLA, the Louvain algorithm is applied on all linkages and therefore does not suffer a loss of information (Blondel et al., 2008). It consists in calculating intra- and inter-cluster variance based on the sole topology of the network (binary graph with 0 value without link and 1 value if any), resulting in a relatively small number of clusters. The Louvain method is thus less reliant on hierarchical tendencies as it focuses on the density of linkages to detect hidden groups of nodes. Other clustering methods were applied to maritime networks, such as modularity (Kaluza et al., 2010) but it is believed that comparing SLA and Louvain is sufficient to grasp the underlying systemic nature of port systems in the regions under consideration. The combination of the two methods was judged necessary to fully embrace how port systems can be delineated from a full network.

3.1.3 Regional and temporal background

Two case studies were selected to apply our methodology, namely North Europe and Northeast Asia. Those two regions have in common to comprise large gateways and large hubs – those being sometimes the same nodes, transshipping containers through sea-land services to/from the hinterland and through sea-sea services in the form of hub-and-spokes systems, notwithstanding shortsea shipping and coastal shipping flows that may bypass such large hubs to connect smaller nodes with each other. North Europe and Northeast Asia have also in common to bear significant physical barriers, such as the impossibility to transfer flows from South Korea to the Eurasian hinterland (cf. North Korea), the islandic nature of the British Isles, Japan, and Taiwan, and the relative separation of Scandinavia from the European

mainland. Such barriers create both constraints and opportunities when it comes to connect the different parts of the two ensembles internally through shipping. Yet, the two regions are also very different in terms of their underlying territorial and economic functionality. North Europe is part of a wider commercial European Union where regional integration is high due to the low influence of national borders on intra-regional trade (note that our analysis only includes pre-Brexit data). In comparison, Northeast Asia is less integrated as it does not form a commercial union like the ASEAN in South Asia. Regional integration is an important factor in the establishment of coherent port systems as demonstrated by Lemarchand and Joly (2009) using port throughput as main variable. Northeast Asia was better seen by Rodrigue (1996) as a set of localized, subnational freight corridors rather than transnational ones due to such barrier effects and the fact that geographic distances are enormous compared with Europe.

In order to best compare the structure and evolution of port systems in the two regions under study, it was decided to run the analysis for three years with a ten-year interval, namely 1996, 2006, and 2016. Each selected year is a turning point for the maritime and ports sector, and especially for container shipping. The year 1996 marked the introduction of the first post-Panamax container vessel which triggered consecutive waves of scale increases in ship size (Cullinane and Khanna, 2000; Ge et al., 2019). The mid 1990s also gave birth to the first strategic alliances among container carriers on the main east-west trade lanes (Notteboom et al., 2017). Combined with increased globalisation and liberalization of trade, these developments supported a growing centralization of shipping routes around large ports having sufficient cargo handling capacity (Rodrigue and Notteboom, 2010; Ducruet and Berli, 2019). The year 2006 was the last year of a boom period in the container shipping industry, partly as a result of the strong emergence of China as a major trade centre in the wake of its accession to the WTO in 2001. The year 2016, on the other hand, was one of the most difficult years for the shipping industry in recent history with a market characterised by extremely low freight rates, overcapacity and a strong focus of carriers on cost control through consolidation (i.e. a wave of M&As), alliance formation and shipping network reconfigurations. It is our goal to study how port systems in those two regions adapted to such structural changes in the shipping industry, with the hypothesis that technological and operational changes may have either reinforced or altered the way ports connect each other through liner services.

Before diving into the network analysis of the two regions, it is necessary to provide a more classic concentration analysis using the Gini coefficient. Yet our approach is original as it applies Gini to the traffic not only on ports but also on inter-port links (Table 3). Results show that traffic is highly concentrated in both regions. While Northeast Asia is more concentrated than North Europe, the region followed a decreasing trend over time. North Europe witnessed a de-concentration only in 2006.

Table 3: Vessel traffic concentration in Europe and Asia based on the Gini coefficient, 1996-2016

3.2 Results

3.2.1 Hierarchical tendencies

The application of SLA reveals that North Europe (NE) and Northeast Asia (NA) share interesting similarities in terms of port system configuration. Both regions have evolved from a monocentric to a polycentric structure, NE and NA being polarized in 1996 by Rotterdam and Hong Kong, respectively. These two main hubs are also the largest by their total vessel traffic (DWT) and they dominate most of other ports in a direct or indirect way. The rest of the period is marked by a reinforcement of the geographic specialization of hub dominance and by the growing importance of formerly secondary hubs. One exception is Le Havre, which remains a domestic hub centralizing flows uniquely within the French territory (Figure 2). Despite their bigger size and huge traffic growth, mainland Chinese ports also remained bound to national connectivity, emerging as domestic hubs in 2016 such as Yangshan (the offshore port complex of Shanghai), Beilun, Bayuquan, and Shanghai. For dominant hubs, we observe that Rotterdam's domination extended across the whole region in 1996 but gradually shrank due to a growing divide between Northeast and Northwest Europe. The initial specialization of Bremerhaven (Denmark-Sweden) and Hamburg (Baltic) on Scandinavia became more and more apparent overtime, as Rotterdam kept dominating mostly the British Isles, including the large gateway of Felixstowe. Yet, the analysis confirms for NE that these hubs form one large

entity corresponding to the commonly used and cited Le Havre-Hamburg North European Range.

In Northeast Asia (Figure 3), the evolution of nodal regions followed a somewhat different path, shifting from a monocentric to a dual structure. Economic and logistics conditions fiercely impacted such a shift as seen with the growth of Busan (South Korea) from a secondary hub to a dominant hub and the decline of Japanese ports to such extent that they formed in 2006 and 2016 an isolated nodal region confined to the domestic level. One similarity however between north Europe and northeast Asia is the regional specialization of hubs. Busan's growth as a transshipment hub kept on polarizing adjacent secondary nodes in the Yellow Sea (i.e. North China, rest of Korea) and the East Sea (North Japan, Far East Russia), while Hong Kong's dominance became limited to the central and southern parts of mainland China. This reflects both the proactive strategy of South Korea to transform itself into an international logistics hub and the evolution of Hong Kong from a load centre to a financial hub doing less physical operations than supply chain management activities.

3.2.2 Cluster density

The application of the Louvain algorithm provides similarities and differences with SLA for the two regions under study. Antwerp and Le Havre belong to the same cluster in 1996 and 2016 together with numerous Scandinavian and British smaller ports (Figure 4). Bremerhaven stands apart in 1996 and 2006 and for the later year it includes a set of Norwegian ports as in the SLA. This is also the case of Hamburg for the three years under investigation. Rotterdam is part of the same cluster than Felixstowe in 1996, Antwerp in 2006, and Bremerhaven in 2016, making it difficult to establish a clear pattern. The geographic layout of clusters varies greatly overtime so that the delineation of port systems remains difficult. Two similarities with SLA however are the inclusion of French ports in the same cluster than Le Havre at all years and the inclusion of certain British ports in the same cluster than Rotterdam but only in 1996 and 2006.

In Northeast Asia (Figure 5), the geographic logic of clusters is much more apparent than for North Europe. While Hong Kong stands apart in 1996, it is included in the same cluster than

Shanghai and Ningbo in 1996, and shares the same cluster with most Taiwanese and mainland Chinese ports in 2016. The overall pattern in 2016 is thus highly similar to the one of SLA, with Hong Kong and Chinese ports being highly interdependent, Busan's influence extending across the Yellow and East seas, and Japanese main ports standing apart from the rest of the regional system. One exception with SLA is Osaka port belonging to the same cluster than Shanghai and Tianjin. Geographic proximity is also apparent with the cluster of northern Japanese small ports in 1996 and 2006, South Korean (e.g. Gwangyang, Busan) and Japanese south-western ports in 1996 and 2006. One special case is the cluster comprising main Japanese ports and Taiwanese ports in 1996 and 2006.

The discrepancy of cluster formation between Europe and Asia can be explained by the stronger importance of sea transport for Asian economies than for European ones. Asian port systems are more easily explained by geographic factors, notwithstanding certain exceptions, whereas for North Europe, the pattern is marked by greater volatility and complexity. In other words, carrier choices and shipping line logics that underlie port selection and network formation are more in line with geography in Asia than in Europe, where hinterland imperatives prevail.

4. Discussion and conclusion

The network analysis of maritime container flows helps us to rethink the way port systems are commonly understood by scholars and practitioners. One crucial result is that port systems are not fixed in space, due to the volatility of maritime networks. Therefore, their delineation should not be taken for granted and is not set in stone. However, existing port system studies tend to select samples of ports based on the assumption that those function in a formation network setting within political (national) or physical (seas, basins) boundaries. In our results, we observe a subtle mix between such proximities and other linkages, principally due to the distortions caused by hub-and-spokes systems. This implies that the network analysis approach allows to reveal interdependencies in port systems that go beyond the formation network level. For instance, many port systems studied per se in the literature such as the Bohai Rim, mainland China, Scandinavia, and the Baltic are in fact subsystems depending on an external transshipment hub, such as Busan, Hong Kong, and Hamburg, respectively. The functioning of

these port systems can thus only be fully understood when adding chain and complex network attributes. Similarly, the British Isles as a port system would make no sense without considering the huge centralization power of Rotterdam on its external flows. Yet, large hubs taken altogether form transnational shipping corridors as already well depicted for decades in the literature, such as the Le Havre – Hamburg range that clearly appears in our results. National port systems are more subsystems away from the “core” of the network, such as Le Havre / France and Tokyo / Japan. For Japan, only the largest ports escape from the influence of Busan. For China, the centralization power of Busan in the North and Hong Kong in the South makes it difficult to speak of a comprehensive mainland Chinese port system, although the recent rise of Chinese domestic hubs seems to act as a counterforce against external polarization.

The findings of the presented analysis are a clear invitation to rethink the way port systems are usually considered at the local level. In a given region or range, the identification and inclusion of the dominant hub, should it be external to the region or part of it, seems to be a prerequisite of any analysis, to make the results closer to the reality of flows and to move beyond formation network aspects only. In highly centralized regions such as North Europe and Northeast Asia, but also others like the Caribbean, the Mediterranean and South Asia, such a shift of focus is necessary. Algeria’s flows highly rely on the Maltese hub, the same applies to numerous Indian ports dependent on Colombo (Sri Lanka) and even U.S. ports served by the offshore hubs of the Caribbean. Although the offshore hub became included in port system evolutionary models (Notteboom and Rodrigue, 2005; Rodrigue and Notteboom, 2010), empirical studies tended to neglect its importance by continuing to analyse port systems from a pure inter-port competition point of view (i.e. formation network) based on national borders and coastline continuity. This is particularly true when the offshore hub stands geographically away from the studied port system. But from a maritime perspective, distance does not hold the same functionality than on earth, as vessels may be deployed with high frequencies between hubs and spokes separated by hundreds or thousands of kilometres.

One difficulty however of a maritime-based approach to port system configuration is practical, as scientists and practitioners are not always in possession of relational data capable of measuring and mapping the extent to which ports are linked to each other. As most port system studies rely on port throughput analysis, delineating with precision the relevant scale of

analysis shall involve more efforts to discuss the definition of the chosen area and the nature of possible interdependencies among the nodes. Another difficulty is the probable mismatch between planning zones and maritime-based port systems, since the latter often extend beyond the authority of a given institution. This raises the question on how port systems could or should evolve if their configuration is left mainly in the hands of shipping lines. While traffic over-concentration in a few main ports might be against the EU objective of regional balance and distributional equity (Notteboom, 2009a), attempts to favour short-sea shipping and coastal shipping through, for instance, the EC Marco Polo initiatives fell short in shifting cargo flows from land to sea and from large to smaller ports.

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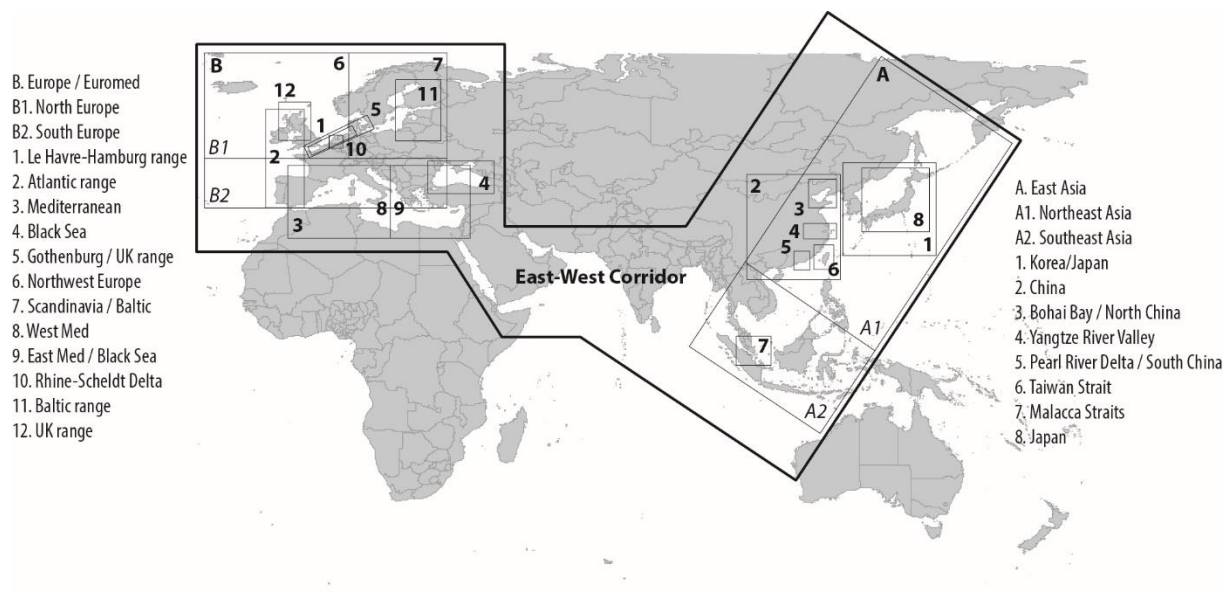


Figure 1: Cartography of recurrent maritime ranges

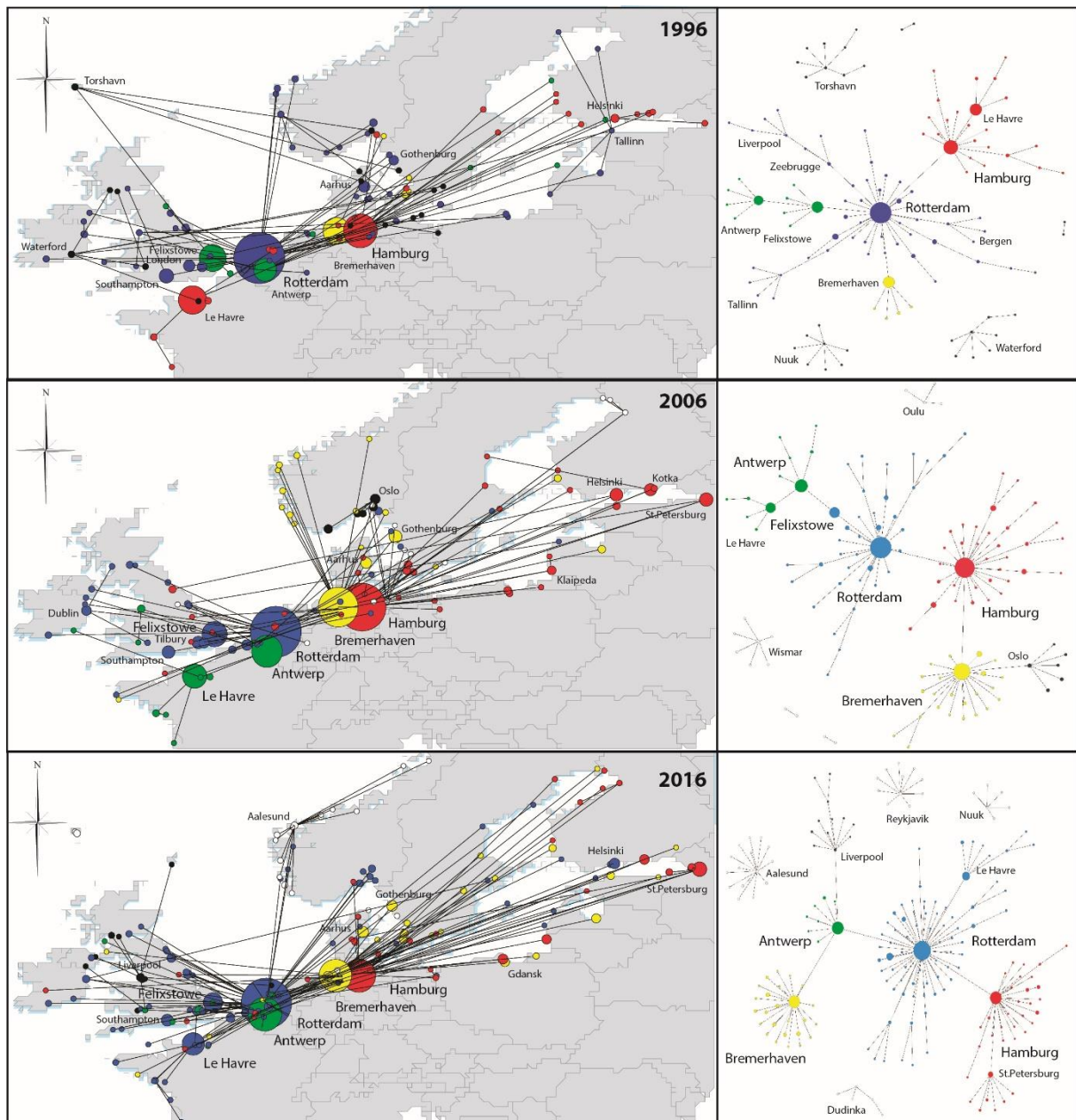


Figure 2: Single linkage analysis of North European container flows, 1996-2016

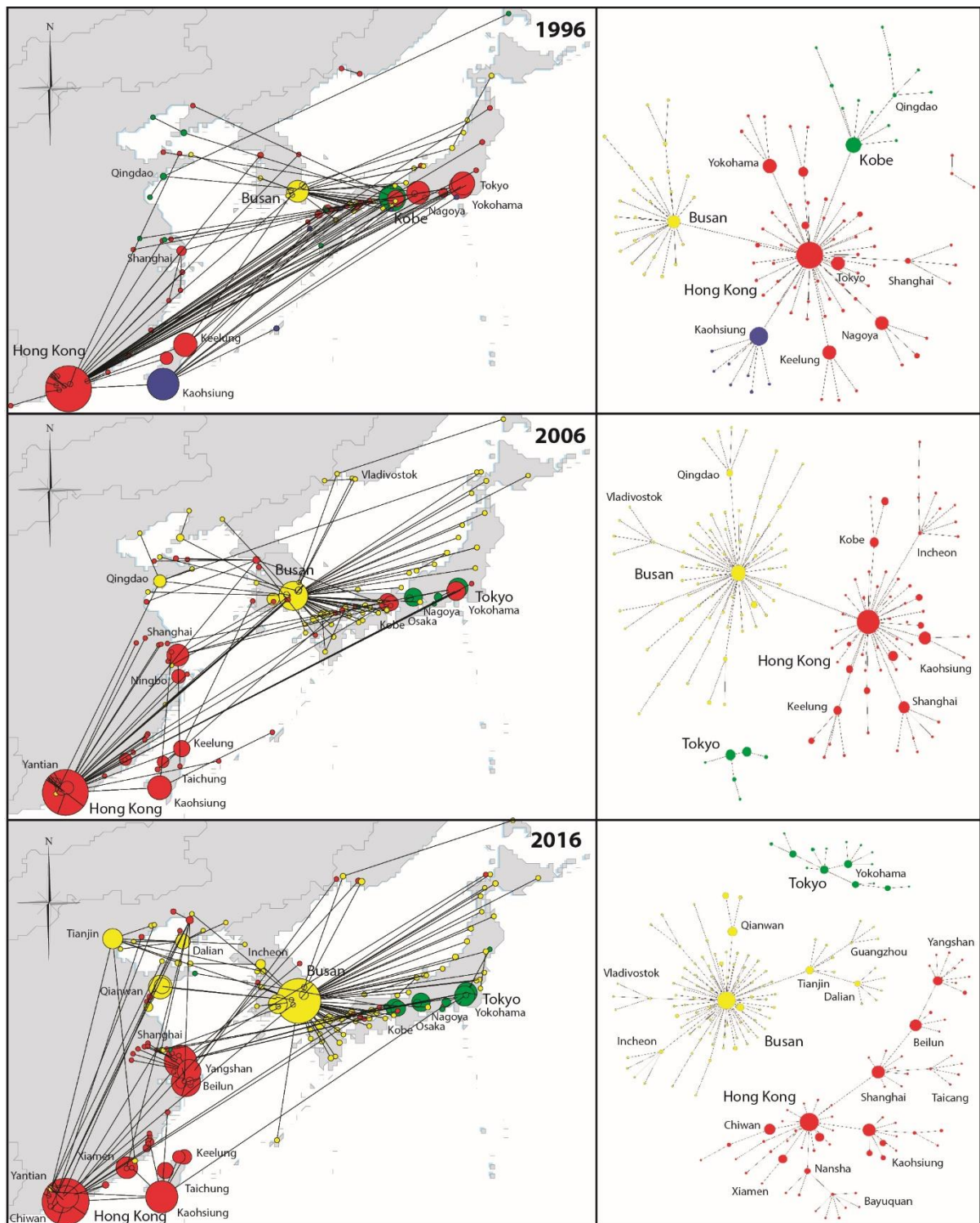


Figure 3: Single linkage analysis of Northeast Asian container flows, 1996-2016

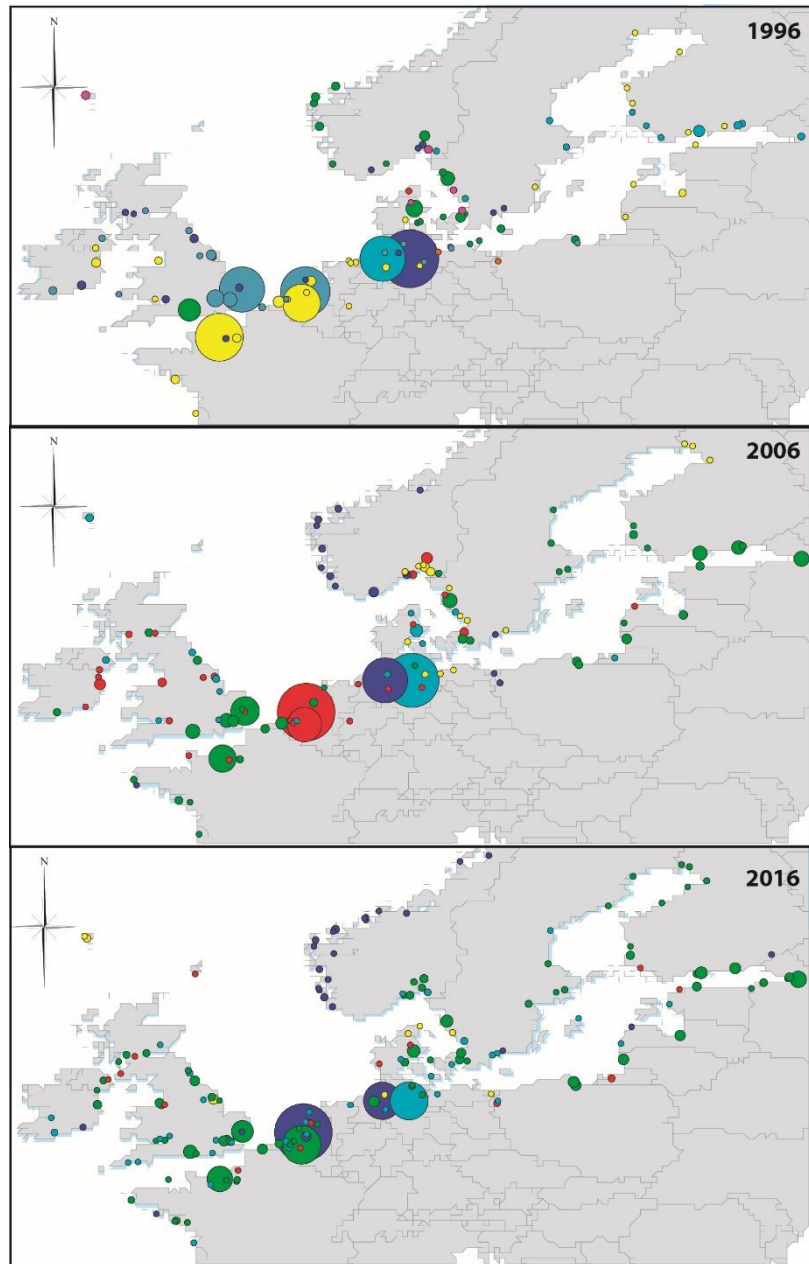


Figure 4: Cluster identification among North European container ports, 1996-2016

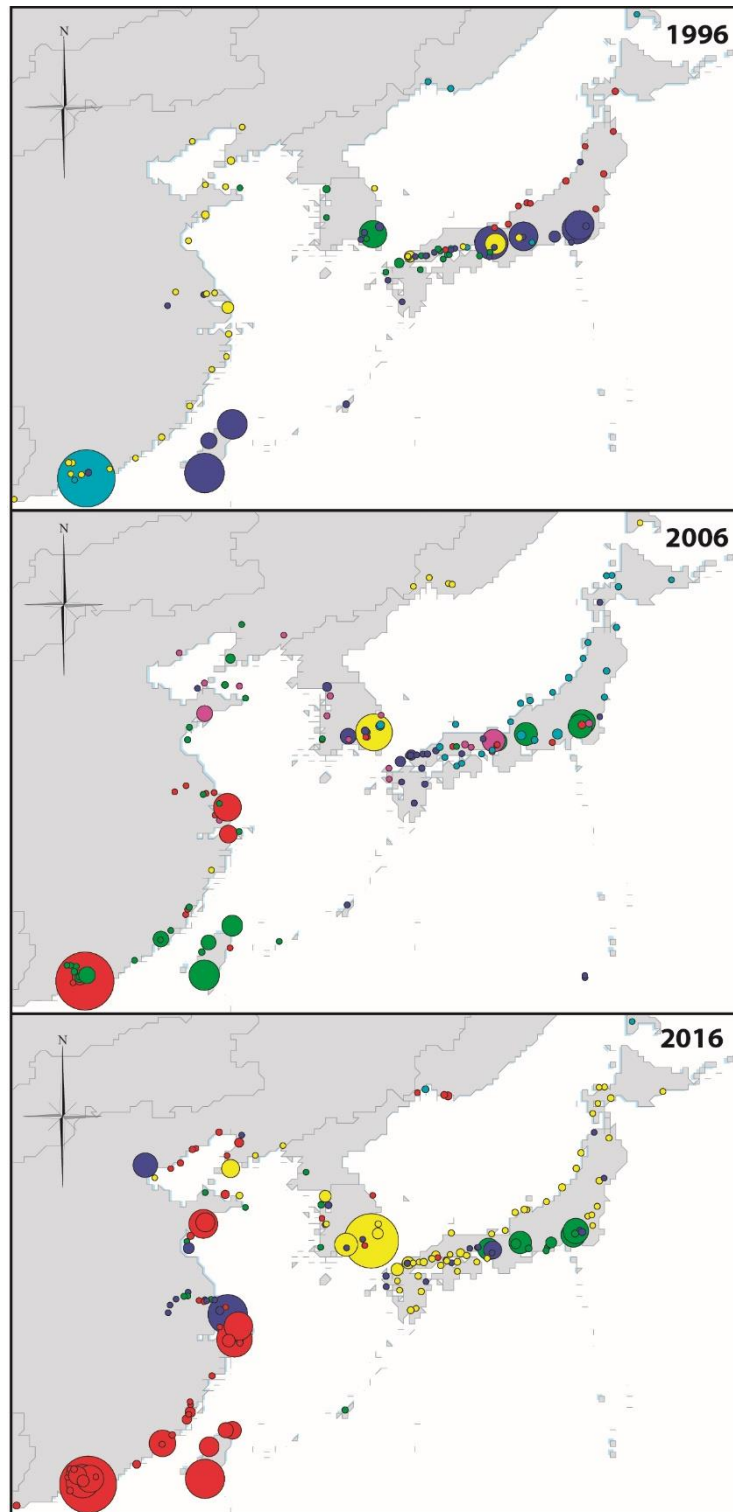


Figure 5: Cluster identification among Northeast Asian container ports, 1996-2016

	Cargo			Unit		Period	Main methodological focus								Interdependencies			Port system (no. of ports considered)		
					vessel calls (no. or capacities)		Traffic volumes and market shares	Port traffic (de)concentration	Maritime network analysis	Port choice and competitiveness	Complementarity vs. substitutability	Determination 'relevant geographic	Traffic forecasting	Main methodologies	Formation network	Chain network	Complex network	Continent	Range	Multi-port region
			All cargo	TEU	tons															
			Bulk																	
			Containers																	
Notteboom (1997)	x			x		1980-1994	x	x						Gini coefficient Net shift analysis	x			Europe (36)	Hamburg-Le Havre range (11) Atlantic range (9) Mediterranean - Europe (16)	nihil
Charlier (1998)	x			x		1980-1986	x								x					Benelux
Trotta (2000)	x			x		1997-2000	x			x					x			Europe	Northern ports (F, NL, BE, DE and PL) vs. Southern ports (ESP, F, I, SL, CRO, HE)	
Haezendonck et al (2000)	x		x	x	x	1980-1998	x			x				Statistical analysis of survey on competitive advantage	x				Antwerp within Hamburg-Le Havre range	
European Commission (2001) - Case No COMP/JV.56	x			x			x					x			x				For hinterland: RGM comprises continental Northern Europe For transshipment:	

- HUTCHISON / ECT (Rotterdam)																				RGM comprises the Gothenburg-Le Havre range (incl. UK)	
Veldman and Bückmann (2003)	x			x						x					Port Competition Logit Model (port choice linked to hinterland regions)	x				Antwerp-Hamburg range (4)	
Notteboom (2006a)	x			x			1975-2003	x	x						Gini Decomposition	x			Europe (47)	Hamburg-Le Havre range (14) Atlantic range (9) Mediterranean - Europe (20) UK range (4)	
Thorez and Olivier (2006)	x		x	x	x		1995-2004	x			x				Qualitative discussion of port competitiveness factors	x				Hamburg-Le Havre range	
Soppé and Frémont (2007)	x					x		x	x		x	x				x	x			North European range	
Notteboom (2007)	x			x		x	1975-2006	x	x	x					Gini coefficient Net shift analysis Distribution of vessel calls	x				Hamburg-Le Havre range	sub-division of H range per country (BE; DE; F and N) sub-division between upstream vs. coastal ports
Notteboom (2009b)	x			x		x		x		x	x	x			Analysis vessel calls + hinterland traffic + measures for level of substitutability between ports	x				Rhine-Scheldt D (here coined as "ZARA ports")	

Beresford and Pettitt (2009)	x		x	x	x		1999-2007	x			x					x				United Kingdom	Tyne Tees (2); Humber (5); East Anglia (3); South East (4); South Coast (2); Bristol Channel (6); Northwest/Mersey (4)
Garcia-Alonso & Sanchez-Soriano (2009)	x										x				Port choice from hinterland perspective using discrete choice model	x				Spain (with focus on Bilbao, Algeciras, Valencia and Barcelona)	
Ducruet et al. (2010a)	x					x	1996-2006			x					Bisecting K-means		x	x	Atlantic	functional Le Havre – Hamburg range	
Unicredit (2010) - Maritime Trend Barometer			x								x				Ranking of ports based on logistics performance	x				Selection of NW-European ports (Amsterdam, Felixstowe, Wilhelmshaven, Zeebrugge, Bremerhaven, Antwerpen, Rotterdam, Hamburg)	
NEA (2010)	x		x	x	x		2005-forecasts till 2030	x							Modelling the selection of core ports in TEN-T EU	x		x		TEN-Connect port grouping: Hamburg-Le Havre; GB/Ireland; Nordic/Baltic; Atlantic Arc; West-Med; East Med and Black Sea	

Notteboom (2010)	x			x			1985-2008	x	x	x					HHI-index Net shift analysis	x			Europe (75)	Hamburg-Le Havre range; Atlantic range; Mediterranean - Europe; UK range; Baltic range; Black Sea range - Europe	Rhine-Scheldt Delta, Helgoland Bay, UK South East Coast, Spanish Med, Ligurian range, Seine Estuary, Black Sea West, South Finland, Portuguese range, North Adriatic, Gdansk Bay, Kattegat/TH Sound
Wang and Wang (2011)	x					x	2008	x		x					Graph theory			x	World	Antwerp (37 ports) & Rotterdam (11 ports) hubs for North and West Europe	
Plasschaert et al. (2011)	x					x	2007			x					Degree and betweenness centrality; Clique analysis	x		x		Maritime range: Hamburg-Le Havre range (of which 6 central ports) + Tilbury and Felixstowe	
De Langen et al. (2012)			x		x		2011 + forecasts to 2030	x			x			x	Application of TRANS-TOOLS model	x				Hamburg-Le Havre range	

Ducruet and Notteboom (2012)	x					x	1996-2006		x	x					Single linkage analysis	x	x	x	Northwest Europe as independent nodal region + transatlantic tiny links		
Freire Seoane et al. (2013)	x		x			x	2007-2011			x					Complex networks			x	World	North European core	
Wiegman & Dekker (2014)	x		x	x	x			x							Data Envelopment Analysis	x				Hamburg-Le Havre range (11)	
Notteboom & De Langen (2015)	x			x			1985-2012	x					x			x			Europe (75)	same as Notteboom (2010)	same as Notteboom (2010)
Li et al. (2015)	x					x	2001-2012	x		x					Graph theory			x	World	Europe, Baltic	
Xu et al. (2015)	x					x	2001-2012	x		x					Graph theory			x	World - NW Europe as subregion		
Tran and Haasis (2015)	x					x	1995-2011	x		x							x		East-West corridor	Northern Europe	
Meersman et al. (2016)	x			x							x				Cost model for hinterland trucking with consideration of road pricing schemes	x				Hamburg-Le Havre range	
European Commission (2017) - Case M.8459 - TIL / PSA / PSA DGD (Antwerp)	x			x				x					x			x			For hinterland: RGM at least comprises the ports of Antwerp and Rotterdam and probably the entire Hamburg-Le Havre		

																				range. For transhipment: RGM comprises at the very least the Hamburg-Le Havre range.	
Kleman (2017)			x		x		1648- 2000	x			x				Long-term trends in inter-port competition	x				Hamburg-Le Havre range	
Merkel (2017)	x			x			2000- 2014	x				x			Spatial dependence model to measure complementarity/ competition between ports in the same region	x			Europe (92)	Hamburg-Le Havre region (17): characterized mostly by competition Mediterranean region (27): complementary with regard to demand. Atlantic region (10) Baltic/Scandinavian region (23) UK region (15)	Country level
Rashed et al (2018)	x			x			1995- 2007 + forecasts	x						x	Demand forecasting model for container throughput (incl. elasticity to trade indices)	x				Hamburg-Le Havre range	
Liu et al. (2018)	x						2014			x					Complex networks			x	World	Europe	
Marasco and Romano (2018)	x			x			1990- 2014 + forecasts till 2022	x			x	x		x	Scenario analysis based on Lotka Volterra model	x				Hamburg-Le Havre range (6)	Benelux ports: switching to 'mutualism' German ports: expected to

																					compete also in forecasted future
No. of occurrences							26	8	14	14	4	3	3		28	5	12				

Table 1: Typology of selected works on port systems in North Europe

Source: own elaboration

	Cargo			Unit	Period	Main methodological focus								Interdependencies			Port system (no. of ports considered)		
				vessel calls (no. or capacities)		Traffic volumes and market shares	Port traffic (de)concentration	Maritime network analysis	Port choice and competitiveness	Complementarity vs.	Determination 'relevant	Traffic forecasting	Main methodologies	Formation network	Chain network	Complex network	Continent	Range	Multi-port region
		All cargo												x					Pearl-River Delta
Wang and slack (2000)																			Pearl-River Delta;
Slack and Wang (2002)	x			x		1996-1999	x	x	x				Challenge of the periphery	x					Yangtze River Delta;
Song and Yeo (2004)	x			x		2001-2002	x		x				Competitive analysis using AHP				China (8)		Malacca Straits
Yanbing et al. (2005)	x			x			x		x				Model for port competition ability combined with AHP					Bohai Bay - China (5)	

Notteboom (2006b)	x			x			1980-2004	x	x						Gini Decomposition	x			East-Asia (27)	Bohai Bay (3) Yangtze River Delta (2) Taiwan (3) Trans-Taiwan (2) Pearl River Delta (5) Japan (8) South Korea (4)	
Comtois and Dong (2007)	x			x			1990-2005				x				Market quotient hinterland regions						Yangtze River Delta (Shanghai vs. Ningbo)
Wang and Cullinane (2008)	x					x				x					Multiple linkage analysis				East Asia (39)		
Ducruet et al. (2009)			x			x	1985-2005	x	x							x			Northeast Asia	North Korea	
Shinohara (2009)	x			x			1995-2008								Port policy discussion					Japan	<i>Super hub ports:</i> Kobe/Osaka; Nagoya/Yokkauchi; Tokyo/Yokohama
Ducruet et al. (2010b)	x					x	1996-2006	x		x					Single linkage analysis	x		x	Northeast Asia		Super hub ports Hong Kong and Busan
Lam and Yap (2011)	x					x	1995-2006	x		x	x	x			Schedule analysis				East Asia	Shanghai, Busan, Kaohsiung and Ningbo	
Wang and Wang (2011)	x					x	2008	x		x					Graph theory			x	World	Hong Kong hub for China/Korea/Japan (15 ports); Shenzhen hub for South China and Japan (9 ports); Shanghai hub for Yangtze River and	

																			North China (17 ports); Busan hub for Korea and Russian far east (14 ports); Tokyo hub for Japan (11 ports)	
Wang and Ng (2011)																	x	China	Three-tier port system among the 24 ports being investigated: 4 major hub ports, 15 feeder ports, and 5 (Dalian, Guangzhou, Qingdao, Tianjin, and Xiamen) as second-tier ports, i.e. neither major hub ports nor feeder ports.	
Ducruet and Notteboom (2012)	x					x	1996-2006		x	x				Single linkage analysis		x	x	East Asia as one nodal region extending across Africa and Pacific		
Low and Tang (2012)	x							x			x	x		4Cs index				East Asia		
Wang and Ducruet (2012)	x			x			1970-2010	x	x					Gini - Herfindahl	x				Yangtze River Valley	

Wang and Ducruet (2013)			x	x			1868-2010	x	x						Gini - Herfindahl ; rank-size	x			China	North, Yangtze/Centre, South	
Feng and Notteboom (2013)	x		x	x	x		2001-2010	x	x							x				Bohai Sea Economic Rim - BER (5)	
Liu, Wang and Yip (2013)	x			x			2003-2009	x	x												Pearl River Delta
Wang and Cullinane (2014)	x					x				x					Multiple linkage analysis				East Asia (39)		
Li et al. (2015)	x					x	2001-2012	x		x					Graph theory			x	Far East		
Tran and Haasis (2015)	x					x	1995-2011	x		x						x			East-West corridor	Northeast Asia	
Xu et al. (2015)																					
Mareš and Ducruet (2015)	x					x	1996-2011			x					Single linkage analysis			x	East Asia		
Notteboom & Yang (2017)	x			x			1985-2015	x								x			China (40)		Liaoning (5) Jin-Ji (4) Shandong (4) Yangtze River Delta (7) Taiwan straits (5) Pearl River Delta (9) Beibu (3)
Wang, Notteboom, Lau, Ng (2017)	x			x			2004-2012	x	x						HHI - Domestic vs. transshipment containers	x					5 adjacent port pairs: Daian/Yingkou; Qingdao/Yantai; Shanghai/Ningbo; Xiamen/Quanzhou; Shenzhen/Guangzhou

Liu et al. (2018)	x						2014			x					Complex networks			x	World - Asia as subregion		
Ducruet and Wang (2018)	x					x	1977-2016			x					Single linkage analysis	x		x	Northeast Asia	China	Main connections per subperiod within the region
No. of occurrences								19	11	15	6	2	0	0		12	3	12			

Table 2: Typology of selected works on port systems in Northeast Asia

Source: own elaboration

	Nodes			Links		
	1996	2006	2016	1996	2006	2016
North Europe	0.831	0.802	0.828	0.851	0.837	0.886
Northeast Asia	0.879	0.848	0.817	0.904	0.882	0.869

Table 3: Vessel traffic concentration in Europe and Asia based on the Gini coefficient, 1996-2016

Source: own elaboration based on Lloyd's List data