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► **To cite this version:**

Nikola Kutin, Marie-Sabine Saget, Thomas Vallée. Container Port Hierarchy and Connectivity based on Network Analysis. 2018. halshs-01828656

HAL Id: halshs-01828656

<https://shs.hal.science/halshs-01828656>

Preprint submitted on 3 Jul 2018

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2018/10

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CONTAINER PORT HIERARCHY AND CONNECTIVITY BASED ON NETWORK ANALYSIS

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This work was supported by the European Union's Erasmus+ Programme, Key Action 2, Capacity building in the field of higher education under DOCKSIDE Project (www.dockside-kh.eu), Grant number 573790-EPP-1-2016-1-FR-EPPKA2-CBHE-SP.

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Abstract

This study aims to analyze port hierarchy between 153 container ports. For this purpose, a network analysis was conducted. Particular attention was paid to 68 ports from the ASEAN+3¹ community. We have created five director weighted networks at both port and country levels. Results reveal that the prevailing structure of the global maritime network is hub and spoke, and that the port rankings change according to different centrality measures. Regarding the intra-ASEAN+3 connectivity, ASEAN member states form a cluster of interconnected ports. A comparative analysis shows that both the Export and Maritime connectivity networks have similar patterns, which indicates that the containerized trade within ASEAN+3 has the same features as the intra-regional exports.

Keywords: Network, ASEAN, Trade, Shipping, Connectivity, Centrality

¹ Member States of the Association of Southeast Asian Nations (ASEAN), the People's Republic of China, Japan, and the Republic of Korea.

1. Introduction

Maritime transport is the cheapest and most efficient way to transport goods in large quantities. According to data from Clarkson Research, containerized trade has increased by more than 600% since 1990. This has dramatically changed the character of ports' infrastructure. Due to the expansion of ports' hinterlands, shipping lines have been able to streamline their itineraries by reducing the number of ports of call, creating load-centre ports (hub ports). It also induced a further increase in vessel size, along with a growth in terminal area (Midoro, Musso, and Parola 2005). Indeed, Notteboom (2010) stated that 'the success of the port is strongly affected by the ability of the port community to fully exploit synergies with other transport nodes.'

Furthermore, the maritime network is a complex subject due to the fact that its prevailing structure is 'hub and spoke'. Asgari, Farahani, and Goh (2013) define a hub port as a port that connects regional ports (feeder lines) to other hub ports (global network). Such hub ports might exhibit different purposes or importance within a network. Some ports such as Singapore and Hong Kong have a strategic geographical position and play an important intermediate role in connecting other regional ports to major sea trade routes, while others like Shenzhen are a gateway to large manufacturing centres situated in the hinterland (Wang and Cullinane 2016). Therefore, analysing the position and the purpose of a port within a network is essential to understanding the nature of the liner shipping network.

According to the International Maritime Organization, over 90% of the world's trade is carried out via sea. Hence, it is interesting to analyze whether a network based on the maritime connectivity has similar features to the network related to the value of countries' total exports. An

interesting case study is the ASEAN+3² community which aims to promote regional economic integration in Eastern and South-Eastern Asia. According to Tongzon and Lee (2015) this integration may result in lower shipping costs and improved quality of shipping throughout the region, and thus contribute to an improvement in the ASEAN members' trade performance and international competitiveness.

This research aims to determine the characteristics of the maritime and trade networks at port and country levels by using the graph theory and centrality measures. For this purpose, a dataset of 153 ports from 50 countries, including statistics for 6,410 maritime routes in the year 2014, was used. Particular attention was paid to a subset of 68 ASEAN+3 ports, including 38 designated ports of the ASEAN Single Shipping Market (ASSM). This paper attempts to answer the following research questions: What are the characteristics of the global maritime shipping network? What are the key ports in the network and what is their main purpose (transshipment port, gateway port, regional port, etc.)? What is the position of the ASEAN community in the global shipping network? How are the regional maritime connectivity networks at port and country levels organized within the ASEAN+3 community? Are there any fundamental differences between maritime connectivity and countries' exports of all goods?

The remainder of this paper is as follows: Section 2 discusses the literature related to ports' connectivity and maritime trade. Section 3 explains the methodology related to the Network Analysis and the dataset used in the study. All results are depicted in Section 4. Lastly, a discussion on the outcomes of the study is provided in the final section.

² ASEAN+3 community includes all member states of the Association of Southeast Asian Nations (ASEAN), the People's Republic of China, Japan, and the Republic of Korea.

2. Review of the literature

2.1. Network Analysis in the context of maritime transport

While the main ports and shipping routes have been described in a number of studies, the structure and evolution of the global maritime network, as well as some crucial issues such as unequal traffic distribution and port hierarchies, has not been fully documented (Ducruet and Notteboom 2012; Ducruet 2013). It is important to analyze the ports' connectivity because even a small change in the network can cause shipping carriers to modify their shipping routes in order to meet the demands of the shipping markets (Peng et al. 2016). A suitable method to measure the connectivity of container ports is Network Analysis. It allows for the identification of port clusters, which may result in agglomeration economies and a strengthened bond between individual and organizational linkage networks (Yang, Wang, and Li 2016). Such an analysis is a good complement to traditional measures of individual throughput (Ducruet, Rozenblat, and Zaidi 2010).

The cost effectiveness and production efficiency of ports are closely linked to the optimization of their networks. John et al. (2016) applied Bayesian belief networks to identify various influencing variables related to different risk factors in a seaport system. Peng et al. (2016) used a mixed-integer nonlinear stochastic programming model and showed that the deployment of the containers handled at each seaport was not directly related to its throughput capacity. In a study conducted by Wang and Cullinane (2016), Freeman's centrality measures were estimated in order to determine the importance of a given port at both regional and global levels. The degree centrality

measures revealed that the key port in the network was Shenzhen. In terms of closeness centrality, which is related to the number of connections with diverse ports, Shanghai, Hong Kong and Singapore had the highest scores. In addition, the betweenness centrality measures pointed out that Hong Kong and Singapore are also hubs connecting different clusters of tightly connected ports.

Notteboom (2010) conducted a detailed container traffic analysis for the period 1985–2008 for 78 ports. His study showed that the performance of European ports was related to their position within supply chains and networks. There is also a gradual deconcentration process in the container handling market, though it remains more concentrated than other cargo handling segments. Ducruet (2013) applied network simplification techniques based on linkage analysis which removes from each port all its links except the largest one. His study revealed that the most diversified ports have a high level of centrality and dominance in the network. They are also connected with more ports situated at a longer physical distance. On the other hand, the most specialized ports capture the majority of global traffic, although their average connection distance is lower due to their distribution role at the intra-regional level.

2.2. Maritime and Trade networks in ASEAN+3 community

Since the establishment of ASEAN maritime transport cooperation, ASEAN Member States have been working to promote the progressive liberalization of maritime transport to improve the region's maritime performance and international competitiveness (ASEAN 2017). Regarding the development of the ASEAN transport network, Banomyong (2015) applied the Geographical Simulation Model (GSM) to analyze the effects of the implementation of The Master Plan on ASEAN Connectivity (MPAC) by the member states. The study shows that port

development is mostly concentrated in specific locations and in countries with better trade facilitation, and that the positive effect it entails could spread to non-ASEAN member states such as Japan, China and India which have a better trade facilitation environment. According to the Liner Shipping Index, computed by UNCTAD, the ASEAN community has had steady progress in terms of integration into the global network. However, the index varies across countries and additional efforts are needed to strengthen the maritime connectivity in order to realize the ASEAN Single Shipping Market (ASEAN 2017). Therefore it is necessary to analyze ASEAN port integration within the regional and global networks, and the relations with ASEAN's closest trade partners: People's Republic of China, Japan, and the Republic of Korea.

There have been a few case studies regarding the countries in the ASEAN+3 community. Sutomo and Soemardjito (2012) applied Multi-criteria Analysis, Analytical Hierarchy Process and Graph Theory to detect the most efficient ports in Indonesia. Their analysis was conducted with a sample of 18 ports with respect of the density of the transportation infrastructure, the capacity of the port, and the speed of goods movement to ports. Zaman, Vanany, and Awaluddin (2015) used the Gravity Model to analyze the connectivity of 12 Indonesian ports. By taking into account the ports' facilities, the size of the regional economies, supporting infrastructure (highways, roads, import and export zones, etc.) and connectivity (global, regional and national), the study identified the ports which could play the role of hub under various scenarios. A recent study from Fahmiasari and Parikesit (2017) assessed the efficiency of two plans used for the creation of an integrated container shipping network in Indonesia. They used a few network efficiency indices by taking into account the demand (TEU per year) at the port's origin and destination, ocean freight rates, and the port's connectivity. They concluded that the government should develop the least important ports in the network in order to improve the efficiency of intra-national trade and avoid

empty return containers. Lam and Yap (2011) analyzed slot capacity in terms of TEUs – i.e. vessel capacity based on 3000 container shipping services from 1995 to 2006 for the Eastern Asian ports of Shanghai, Ningbo, Busan and Kaohsiung. The study found that inter-container port complementarity accounted for a significant share of changes to shipping capacity and that the ports periodically restructured their networks to adjust to the demands of the market.

Similar to shipping networks where we see flows of containers between ports of origin and destination, trade flows of goods and services between countries can be represented by directed graphs where all edges are potentially bidirected, as long as exports and imports between two countries are of nonzero values (Nguyen, Pham, and Vallée 2016). An analysis of both trade flows and FDI flows within ASEAN+3 countries was recently conducted by Nguyen, Pham, and Vallée (2017). They concluded that during the 1990-2012 period, the degree of trade and FDI integration varied among the ASEAN+3 member states. Furthermore, ASEAN+3's intra-regional trade network seemed to be more densely connected than its intra-regional FDI network, and large or advanced countries tend to be better linked and form a sub-regional bloc of tightly connected economies.

2.3. Adding value to the literature

We have not found any studies in the literature comparing the trade and maritime networks. We expect some similarities between the two networks since 90% of exchanged goods are carried via sea (Ducruet 2013). The position of the ASEAN community within the global shipping network, as well as the connectivity of the designated ASEAN container ports, are topics which

also require additional research. Furthermore, most of the studies analysing the importance of various ports use a very limited sample size.

This research adds value to the literature by providing a comprehensive analysis of different types of networks at port and country levels using a sample of 6,410 maritime routes connecting 153 major ports around the world. Since we have almost all the major ports in the ASEAN+3 community, we can conduct an analysis on their intra-regional maritime and trade connectivity. The Network Analysis involves the computation of different centrality measures, allowing us to identify different clusters of tightly linked ports/countries. The method also detects nodes having the highest connectivity, good strategic location, and important intermediate connections. We also identify hub ports, which concentrate most of the maritime traffic or trade of goods between highly connected ports in the network. The findings of this study provide a foundation for understanding the typology of the global shipping industry, as well as the role of different ports/countries and communities within the network.

3. Methodology and data

Network analysis is the process of investigating complex structures through the use of graph theory (Otte and Rousseau 2002). It has been used in a variety of studies, with the nodes representing individuals, organizations, or even countries, and the ties can refer to communication, cooperation, friendship, or trade. Ties can be differentiated in most settings (Opsahl, Agneessens, and Skvoretz 2010). Freeman (1978) developed the well-known centrality measures such as Degree, Closeness and Betweenness for binary directed and undirected networks. Degree centrality assesses the number of connections of a node with the other individuals in the network.

Closeness centrality shows how easily a node can be reached by other nodes, and betweenness centrality describes how important a node is in terms of connecting other clusters of individuals (Jackson 2010). These measures have been conceptualized for weighted networks (Newman 2001; Borgatti 2005; Brandes 2001; Barrat, Barthélemy, and Vespignani 2004; Opsahl, Agneessens, and Skvoretz 2010).

3.1. Network Analysis based on centrality measures in the context of maritime trade

Maritime transport, and containerized trade in particular, consists of carriers transporting goods from port of origin to a given destination. Network analysis has been used by Wang and Cullinane (2016) and Ducruet (2013) to analyze port hierarchy and connectivity. We use directed weighted graphs, where the importance of the flow between the nodes depends on the edges' weights which can be represented by the value of exports, or, the average size of ships multiplied by the number of trips. In this study, the nodes are either a port or a country.

3.2. Variables and data

Data on port connectivity was obtained from Lloyd's Marine Intelligence Unit. It contains information about port to port connectivity in 2014, and consists of 153 ports from 51 countries, including 79 ports in Asia, 27 in North America, 20 in Europe, 19 in Africa and 8 in Latin America and the Caribbean. There are 6,410 direct maritime routes connecting the ports in the sample:

Container port of origin (Source, port i)

Container port of destination (Target, port j)

Average size of the ships in TEU going from port i to port j ($AvgTEU_{ij}$)

Number of trips from port i to port j ($NbTrips_{ij}$)

Data were also aggregated at a country level in order to analyze the interactions between the states in the sample:

Country of departure, Source (country a)

Country of arrival, Target (country b)

Average size of the ships in TEU going from country a to port b ($AvgTEU_{ab}$)

Number of trips from port A to port B ($NbTrips_{ab}$)

The export dataset was collected from UN ComTrade³ commodity databases in the Standard International Trade Classification (SITC) Revision 3. It contains the exports in USD for ASEAN + 3 states (EXP_{ab}).

3.3. Networks

Recall that each maritime route connects a port of origin and a port of destination. In order to analyze the global shipping network as well as the regional networks of the ASEAN+3 community, we built five directed weighted networks named the following: ‘Maritime Port Network’, ‘Maritime Country Network’, ‘ASEAN+3 Maritime Port Network’, ‘ASEAN+3 Maritime Country Network’ and ‘ASEAN+3 Export Country Network’.

³ <https://comtrade.un.org/>

In the case of maritime networks at port and country levels, the links between each pair of ports/countries are weighted according to the number of trips multiplied by the average size of the vessels operating on a maritime route. This indicator not only shows the frequency of the services (*NbTrips*) but also the relative importance of the container trade flows on the maritime routes *AvgTEU*.

Type of network	Type of nodes	No of nodes	No of edges	Weight of edges
Maritime Port Network	Ports	153	6410	$w_{ij} = AvgTEU_{ij} * NbTrips_{ij}$
Maritime Country network	Countries	51	2490	$w_{ab} = AvgTEU_{ab} * NbTrips_{ab}$
ASEAN+3 Maritime Port Network	Ports	68	1745	$w_{ij} = AvgTEU_{ij} * NbTrips_{ij}$
ASEAN+3 Maritime Country Network	Countries	13	135	$w_{ab} = AvgTEU_{ab} * NbTrips_{ab}$
ASEAN+3 Export Country Network	Countries	13	156	$w_{ab} = EXP_{ab}$

Table 1. Type of networks and weighting

Table 1 depicts some basic features of the networks at port and at country levels. In the maritime network ‘ASEAN+3 Export Country Network’, the edges are weighted according to the value of exports in USD (*EXP*). This indicator allows us to assess the importance of the trade between countries for all goods. Appendix 1 shows additional descriptive statistics about the variables that we used in this study.

3.4. Centrality measures used in this study

In order to analyze the different types of networks, and the hierarchy of ports or countries within them, we have computed a set of centrality measures for weighted directed graphs. The weight of the edges are according to the type of network and nodes (Table 1).

3.4.1. Weighted degree Centralities

In the case of directed graphs, there are two types of degree centralities, Indegree and Outdegree. The former shows the sum of all edges that are directed (pointing in) to node i while the latter depicts all edges that are going out from the node i . Mathematically, both measures can be represented by equations 1 and 2.

$$ws_i^{out} = \sum_j w_{ij} \quad (1) \quad ws_i^{in} = \sum_j w_{ji} \quad (2)$$

ws_i^{out} and ws_i^{in} refers to the weighted Outdegree and Indegree centralities of node i , which are the sum of the weights of the edges w_{ij} of all nodes N which have a direct incoming or outgoing connection with node i . Nodes i and j are connected when $w_{ij} > 0$. Ports having many connections with others and accommodating large ships have high Indegree coefficients, while ports which are a point of departure of a considerable number of vessels have high Outdegree scores. The same logic applies to the analysis of the interaction at a country level as well as in the case of the countries' exports where the weights of the edges are according to the value of exported goods.

3.4.2. Weighted Betweenness and Closeness Centralities

Betweenness and closeness centralities in weighted networks are based on the Dijkstra's algorithm (Dijkstra 1959). The Newman (2001) and Brandes (2001) algorithm to estimate the shortest path between two nodes in a weighted network is as follows:

$$d^w(i, j) = \min \left(\frac{1}{w_{ih}} + \dots + \frac{1}{x_{hj}} \right) \quad (4)$$

$d^w(i, j)$ refers to the weighted distance between node i and node j , while h is an intermediate node situated on the shortest path between i and j . Therefore, weighted closeness centrality of node i (wC_i) can be depicted by equation 5.

$$wC_i = \left[\sum_j^N d^w(i, j) \right] \quad (5)$$

In the context of containerized trade, a port with high weighed closeness centrality refers to a port with the possibility of reaching all other ports in the network by passing through not so many intermediate nodes.

Weighted Betweenness centrality (wB_i) is based on a combination of the number of intermediary nodes and tie weights (Opsahl, Agneessens, and Skvoretz 2010). It can be represented by the following equation:

$$wB_i = \frac{b_{jk}^w(i)}{b_{jk}^w} \quad (6)$$

$b_{jk}^w(i)$ refers to the number of times that node i is an intermediate passage for node j to reach all k nodes in the network, as well as the associated weighs to the links. Ports with high

weighted betweenness have a strategic position in the network, and might play a role as an important hub port or an obligatory passage to reach other ports.

3.4.3. Hub Coefficient

There are two main types of network configurations in the maritime trade: the hub and spoke network and the multi-port network (Figure 3). The first one is a system of connections where all traffic moves along spokes connected to the hub at the centre. By contrast, the multi-port calling configuration is characterized by direct trajectories of any given vessel between the ports. Such structure is used in the case of relatively small container port networks.

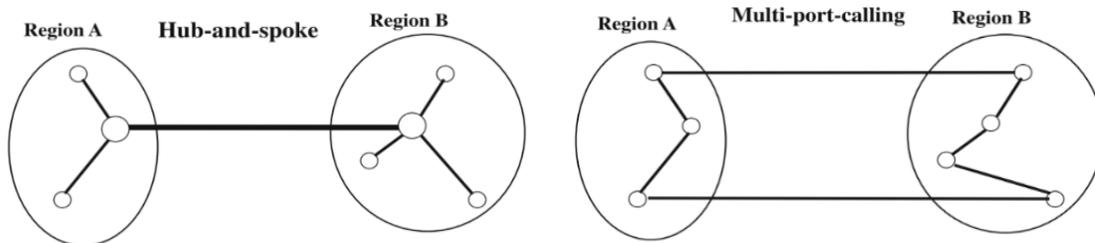


Figure 1 Hub and Spoke versus Multi-Port Calling configuration. Source: (Imai et al., 2009)

We used the algorithm of Kleinberg (1999) to detect hub ports, which was applied in the context of online queries and analysis of the hyperlink structure among 'www' pages. This algorithm identifies authoritative 'www' pages (authorities) for broad search topics. Pages that connect a number of authorities are called hubs.

Regarding maritime transport, ports having high Hub coefficients are connected to ports with high Indegree centrality. This algorithm allows us to identify ports which are mainly connected to other major ports in the network.

3.4.5. Identification of clusters

A related question of interest is to know if one port belongs to a particular community of ports, and if yes, how this community is defined? As stated by Pons (2005) and Pons and Latapy (2006), the concept of community in graph theory is not clearly defined. However, it is possible to define a community as a set of vertices (nodes) where the density of internal connections is greater than the density of connections to the outside (Pons 2005). Accordingly, to calculate the potential communities within a given network, one should split the network into a given number of groups. In order to determine different groups of ports or countries, we use the modularity algorithm for weighted directed networks applied by Blondel et al. (2008).

In summary, by applying Network Analysis and Graph Theory we can identify the ports/countries (i) with the most outgoing and incoming connections (degree centrality), (ii) which have diverse connections and are easily reachable by other nodes in the network (closeness centrality), (iii) which are intermediate links ‘bridges’ connecting different clusters or peripheral nodes (betweenness centrality) and (iv) which play the role of hub in regional and global shipping networks. In addition, this methodology allows us to discern tightly connected clusters of ports/countries.

4. Results

The networks analyses were conducted using Gephi software (version 0.9.2) and R software (Package ‘tnet’⁴).

4.1. Maritime Port Network (153 nodes)

4.1.1. Typology of the global ‘Maritime Port Network’

As shown in Appendix 1, the descriptive statistics of the nodes and the link attributes reveal a significant dispersion around the mean, as the studied sample consists of highly heterogeneous ports and maritime routes. The network has a high degree of connectivity (Table 2). On average, the bivariate distance between any two connected nodes is 1.809 edges and each interacts with approximately 48 other ports in the sample.

Clustering Coefficient	0.695
Diameter	4
Average Path Length	1.809
Average bivariate Degree	47.81699346
Average Weighted degree	16,409,626.386
Node Count	153
Density	0.276

Table 2. Characteristics of the Maritime Port Network

⁴ <https://cran.r-project.org/web/packages/tnet/tnet.pdf>

The clustering coefficient reflects the probability of being connected to other nodes in the network. It is relatively significant (0.69), as should be expected, considering the average number of neighbours of each node. It is also observed that the network density is small (0.276). The Graph Density measures how complete the network is (Bastian, Heymann, and Jacomy 2009). A complete network contains all possible edges and has a density of 1.

These results indicate that the network has a scale-free configuration. Such networks, introduced by Barabási and Albert (1999), are mainly characterized by a degree of distribution that follows a power law, with a few highly-connected nodes and a majority of nodes with lower degrees of centralities.

4.1.2. Ranking of ports in the Global Maritime network based on centrality measures

When we look at the rankings of the 153 ports in the ‘Maritime Port Network’ (Appendix 2), we observe that ports change their position according to different centrality measures. Recall that the weight of the links between the ports is according to the Number of Trips multiplied by the average size of the vessels operating between each pair of ports.

Table 3 depicts the top 20 ports ranked in terms of the selected network indicators. The most important port in Europe is the port of Rotterdam, as it has the highest Outdegree score. This means that the frequency and the size of the ships departing from this port of origin are substantial. In terms of Indegree centrality, Singapore has the highest score and Rotterdam ranks second.

No	Rank Outdegree (weighted)	Rank Indegree (weighted)	Rank Closeness (weighted)	Rank Betweenness (weighted)	Rank Hub
1	Rotterdam	Singapore	Port Said	Singapore	Singapore
2	Singapore	Rotterdam	Singapore	Port Said	Hong Kong
3	Shanghai	Port Said	Shanghai	Shanghai	Ningbo-Zhoushan
4	Hong Kong	Shanghai	Rotterdam	Rotterdam	Shanghai
5	Ningbo-Zhoushan	Hong Kong	Ningbo-Zhoushan	Hong Kong	Shenzhen
6	Port Said	Antwerp	Hamburg	Balboa	Port Klang
7	Hamburg	Hamburg	Hong Kong	Valencia	Rotterdam
8	Shenzhen	Ningbo-Zhoushan	Shenzhen	New York	Tanjung Pelepas
9	Antwerp	Bremen/Bremer haven	Antwerp	Tokyo	Kaohsiung
10	Bremen/Bremer haven	Shenzhen	Bremen/Bremer haven	Belawan	Port Said
11	Tokyo	Le Havre	Valencia	Port Klang	Hamburg
12	Le Havre	Valencia	Felixstowe	Marsaxlokk	Antwerp
13	Valencia	Tokyo	Yokohama	Tanjung Priok (Jakarta)	Algeciras
14	Felixstowe	Yokohama	Tokyo	Antwerp	Jebel Ali (Dubai)
15	Yokohama	New York	Algeciras	Yokohama	Le Havre
16	New York	Felixstowe	Tanjung Pelepas	Tanjung Perak (Surabaya)	Valencia
17	Algeciras	Nagoya	Port Klang	Shenzhen	New York
18	Nagoya	Algeciras	Le Havre	Ningbo-Zhoushan	Norfolk (USA)
19	Kaohsiung	Jebel Ali (Dubai)	Southampton	Port Everglades	Balboa
20	Port Klang	Kaohsiung	Keelung	Algeciras	Bremen/Bremer haven

Table 3. Ranking of top 20 ports according to different centrality measures

Although Port Said had an annual throughput of only 3.96 million TEU in 2014, it has the highest closeness coefficient due to its unique geographical location. The port is located at the north gate of the Suez Canal, a 200 km-long canal that connects the Mediterranean with the Red Sea (El-bastawisy and Abd-al-whab Helmy 2006), and is at a strategic position easily reachable by many ports in the sample. Singapore is ranked second due to its role as a major hub port

connecting Southeast Asia with Western Asia, Europe and Africa. Similar to the findings of Wang and Cullinane (2016), the Chinese ports of Shanghai, Shenzhen and Hong Kong have very high weighted closeness scores and rank 3rd, 7th and 8th respectively. Ningbo-Zhoushan is another Chinese container port which is ranked 5th and is situated in the Yangtze River Delta, a large industrial and logistics area.

Similar to closeness centrality, the betweenness measures show that the ports serving as the most important intermediate passages are Singapore, Port Said and Shanghai. It is interesting to highlight that the port of Balboa is in 6th place. It is an important hub connecting Far East and North America to the West Coast of South America, Central America and the Caribbean. Like Port Said in Egypt, the Panamanian port has a strategic location on the Panama Canal which makes it a compulsory intermediate node for the majority of traffic in Latin and Central America. Although weighted betweenness centrality identifies major hubs of the global network, Belawan with an annual throughput of 600,000 TEUs is ranked 10th. This means that the port is not a hub, but is compulsory passage for many smaller regional ports (feeder ports). Other Indonesian ports such as Port Klang, Tanjung Priok and Tanjung Perak (Surabaya) also play a key role in connecting the ASEAN community to the global shipping network.

In order to detect major hub ports in the global 'Maritime Port Network' we look at the Hub Coefficient. Unsurprisingly, the most important hub ports are identified as Singapore, Hong Kong, Ningbo-Zhoushan, Shanghai, Shenzhen, Port Klang and Rotterdam. These ports have very strong links between them as well as with other major ports in the network.

When we look at the correlation coefficients of the centrality measures and the annual throughput in 2014 (Table 4), there is very strong correlation between Outdegree and Indegree centralities (0.99) not surprisingly. It means that ports which are major points of departure for

many ships are also major destinations. In addition, indegree and outdegree are both positively correlated to Hub, Betweenness and Container Throughput. Thus, ports with high hub coefficients are intermediate links with a capacity to handle many containers and, due to their geographical locations, are easily reachable by other ports in the network.

	Outdegree	Indegree	Closeness	Betweenness	Hub	Container Throughput
Outdegree	1					
Indegree	0.99	1				
Closeness	0.34	0.35	1			
Betweenness	0.74	0.74	0.18	1		
Hub	0.80	0.81	0.61	0.47	1	
Container Throughput	0.72	0.68	0.22	0.63	0.62	1

Table 4. Correlation matrix between weighted centrality measures for the Maritime Port Network

The existence of hub ports in the ‘Maritime Port Network’ reveals that any dysfunction or removal of one hub can lead to the separation of different clusters or communities, and to a larger extent, the destabilization of the logistics chain (Xu et al. 2015).

Appendix 3 shows a graphical representation of the Maritime Port Network where we see that five communities have been identified. The first community consists of ports belonging to eleven countries from North and South America (see last column of the table in Appendix 2). In the second cluster there are 10 European, 1 Canadian and 1 Moroccan ports. The third community is formed by 51 ports from Europe, Asia, the Middle East and Africa. The fourth group of closely connected ports is dominated by ports from China, Taiwan, the U.S. and the Philippines. In this group we also have a few ports from Mexico. The last community only contains ports from Indonesia. These results reveal that the geographical location of a port is not enough by itself to explain the connections with other ports.

4.2. Maritime Country Network

At a country level, the maritime network is a polarized or scale-free structure with a high level of connectivity. It is a core-periphery structure where the most important countries are the world's main importers and exporters. Japan, Egypt and Spain have very high closeness coefficients, which means that they have strategic locations in the network. In terms of intermediate nodes, Spain, Japan, Germany and Malaysia are found to be the most important nodes. We have not estimated the hub coefficient due to the high level of density of the network and the fact that almost all countries in the sample are interconnected.

Clustering Coefficient	0.792
Diameter	3
Average Path Length	1.408
Average Bivariate Degree	29.784
Average Weighted degree	42,509,324.093
Node Count	51
Graph Density	0.596

Table 5. Characteristics of the Maritime Country Network

Unsurprisingly, at the country level the clustering coefficient and the graph density are higher than in the Maritime Port Network (Table 5).

When we compare the countries in the sample, we observe that China and the U.S. are the most connected nodes according to all centrality measures (Table 6). In terms of Indegree and

Outdegree centralities, Germany has the highest connectivity in Europe, followed by Spain and the Netherlands.

	Outdegree	Ranking Indegree (weighed)	Ranking closeness (weighted)	Ranking betweenness (weighted)
1	China	China	China	China
2	USA	USA	USA	USA
3	Germany	Germany	Japan	Spain
4	Singapore	Spain	Egypt	Japan
5	Netherlands	Singapore	Spain	Germany
6	Spain	Belgium	Germany	Malaysia
7	Japan	Netherlands	Hong Kong	Singapore
8	Hong Kong	Japan	Singapore	Egypt
9	Belgium	Egypt	Netherlands	Belgium
10	Egypt	Hong Kong	Taiwan	Taiwan

Table 6. Ranking of top 10 countries according to different centrality measures

We have identified four clusters of tightly connected countries (see the last column of the table in Appendix 4). The first one is constituted by only European countries. The second cluster includes 21 nodes mainly from Asia and the Middle East. The third cluster is the most diverse with countries from Europe, Asia, South America and Africa. Finally, similar to the port network, North and South American countries form a community.

4.3. ASEAN+3 Maritime Port Network

In this section we analyze the ports belonging to the ASEAN+3 community, which includes China, Hong Kong, Taiwan, South Korea, Japan, Singapore, Thailand, Vietnam, Indonesia,

Malaysia, Cambodia, the Philippines and Brunei. We did not include Myanmar due to the lack of data, and we did not include Laos since it is a land locked country.

Clustering Coefficient	0.741
Diameter	4
Average Path Length	1.677
Average Bivariate Degree	25.662
Average Weighted degree	7,332,918
Node Count	68
Graph Density	0.383

Table 7. Characteristics of the ASEAN+3 Maritime Port Network

The low graph density (0.383) and the average path length of 1.677 suggest that the ports are well connected and that on average they interact with 25.7 nodes in the sample (Table 7). The good connectivity between the ASEAN+3 ports is confirmed by the high clustering coefficient (0.741).

In contrast with the global ‘Maritime Port Network’, within ‘The ASEAN+3 Ports Network’ Singapore is ranked 5th and 7th in terms of Outdegree and indegree respectively. In terms of intra-ASEAN outgoing and incoming traffic, the Japanese ports and Honk Kong are the most important ones (Table 8). However, Singapore is the gateway port of ASEAN+3 to the global shipping market. It has many direct connections with smaller (feeder) ports and its role as a major transshipment centre for Eastern and South-Eastern Asia is confirmed by its high closeness and betweenness coefficients. Shanghai, Hong Kong and Shenzhen are also important intermediate ports. The high hub coefficients of Hong Kong, Singapore, Shanghai, Shenzhen and Kaohsiung show that these ports are mainly connected with other hubs of the ‘ASEAN+3 Maritime Port Network’. Appendix 6 shows detailed centrality measures for all ports in the sample.

	Outdegree	Indegree	Closeness	Betweenness	Hub
1	Tokyo	Tokyo	Singapore	Singapore	Hong Kong
2	Yokohama	Yokohama	Tokyo	Shanghai	Singapore
3	Nagoya	Nagoya	Yokohama	Hong Kong	Shanghai
4	Hong Kong	Hong Kong	Hong Kong	Shenzhen	Shenzhen
5	Singapore	Shenzhen	Shenzhen	Tokyo	Kaohsiung
6	Shenzhen	Shanghai	Shanghai	Yokohama	Port Klang
7	Shanghai	Singapore	Nagoya	Tanjung Priok (Jakarta)	Ningbo-Zhoushan
8	Keelung	Ningbo-Zhoushan	Ningbo-Zhoushan	Port Klang	Nagoya
9	Ningbo-Zhoushan	Keelung	Keelung	Tanjung Perak (Surabaya)	Laem Chabang
10	Kaohsiung	Kaohsiung	Hanshin Ports	Belawan	Tanjung Priok (Jakarta)
11	Hanshin Ports	Hanshin Ports	Kaohsiung	Bangkok	Hanshin Ports
12	Bangkok	Bangkok	Penang	Manila	Tokyo
13	Port Klang	Busan	Port Klang	Ningbo-Zhoushan	Yokohama
14	Laem Chabang	Port Klang	Bangkok	Kota Kinabalu	Penang
15	Busan	Laem Chabang	Laem Chabang	Kaohsiung	Tanjung Pelepas
16	Penang	Tanjung Pelepas	Busan	Tanjung Mas (Semarang)	Xiamen
17	Lianyungang	Penang	Belawan	Laem Chabang	Busan
18	Xiamen	Lianyungang	Lianyungang	Zhanjiang	Manila
19	Tanjung Priok (Jakarta)	Xiamen	Xiamen	Ho Chi Minh City	Keelung
20	Tokyo	Tanjung Priok (Jakarta)	Tanjung Mas (Semarang)	Nantong	Bangkok

Table 8. Ranking of top 20 ASEAN+3 ports according to different centrality measures

The correlation matrix between the centrality measures of the ‘ASEAN+3 Maritime Port Network’ is similar to that of the maritime port network. However, it should be noted that the correlation between Outdegree and hub, as well as indegree and hub, is lower in this network with

0.68 and 0.69 respectively. This is normal since we observe a regional network of well interconnected ports.

	Outdegree	Indegree	Closeness	Betweenness	Hub	Container Throughput
Outdegree	1					
Indegree	0.9971	1				
Closeness	0.3418	0.3446	1			
Betweenness	0.7032	0.7	0.2583	1		
Hub	0.6798	0.6875	0.6614	0.5346	1	
Container Throughput	0.5678	0.5839	0.2286	0.7652	0.57	1

Table 9. Correlation matrix between weighted centrality measures for the ‘ASEAN+3 Maritime Port Network’

Container throughput is highly correlated with betweenness centrality. Therefore, ports with high betweenness in the ASEAN+3 network also constitute an important part of the intra-ASEAN+3 maritime traffic.

As we can see in Appendix 7, three communities have been identified in this network. The first one includes 8 ports from Japan, Korea, and China. The second one includes 29 ports exclusively from ASEAN. The only ASEAN country we studied which does not have any ports in this cluster is the Philippines. The last cluster is the biggest one and has 31 ports from China, Hong Kong, Taiwan and the Philippines. These results suggest that the ASEAN ports have a strong maritime intra-regional integration. As a corollary, it means that the ASEAN Single Shipping Market and its designated ports maintain close ties. In addition, there is also a high level of connectivity between Chinese ports and Hong Kong.

4.5. Comparison between ASEAN+3 Maritime Country Network and ASEAN+3 Export Country Network

Since the dataset includes almost all major ports situated in ASEAN+3 nations, we focus our analysis on the particular case of the maritime and export networks at a country level in this community. Recall that in the former network weights of edges are based on the Number of Trips multiplied by the average size of the containerships in TEUs, while in the latter, weights correspond to country Exports in USD.

	ASEAN+3 Maritime Country Network	ASEAN+3 Export Country Network
Clustering Coefficient	0.909	1
Diameter	2	1
Average Path Length	1.135	1
Average Bivariate Degree	10.385	12
Average Weighted degree	25,181,747	224,695,259
Node Count	13	13
Graph Density	0.865	1

Table 10. Characteristics of ASEAN+3 Maritime Country Network and ASEAN+3 Export Country Networks

Unsurprisingly, the ‘Export Country Network’ is denser, since it takes into account all exported goods. On the other hand, ASEAN+3 countries have 10.38 maritime country connections on average.

At first glance we can see that major economies such as China, Japan and Hong Kong, which act as bridges toward Europe and North America, play a substantial role in both networks (Table 11). In the case of the ASEAN+3 Maritime Country Network, we have identified two clusters. The first one includes all ASEAN states except the Philippines, while the second is

constituted of China, Philippines, Japan, South Korea, Hong Kong and Taiwan. It confirms our previous finding that ASEAN countries form a well-connected community where the dominant port is Singapore (being both a port and a country).

Node	ASEAN+3 Maritime Country Network				ASEAN+3 Export Country Network			
	Outdegree	Indegree	Closeness	Betweenness	Outdegree	Indegree	Closeness	Betweenness
Brunei	12	12	12	6	13	12	13	5
Cambodia	13	13	13	6	12	13	11	5
China	2	2	2	5	1	1	1	1
Hong Kong	3	3	4	6	2	2	3	5
Indonesia	9	9	9	6	9	9	9	5
Japan	1	1	1	1	3	3	2	2
Malaysia	6	6	6	2	6	7	7	5
Philippines	10	10	10	6	11	11	12	5
Singapore	5	5	3	3	5	5	6	3
South Korea	8	8	8	6	4	4	4	5
Taiwan	4	4	5	4	7	6	8	5
Thailand	7	7	7	6	10	8	10	4
Vietnam	11	11	11	6	8	10	5	5

Table 11. Rankings of the ASEAN+3 countries in the Export and Maritime Network according to different weighted centrality measures

In the case of the Export Country Network (Appendix 11), we have identified two clusters of countries. The most dominant nodes are China and Hong Kong, and they form the first community. These results are consistent with the outcomes of the modularity analysis of the third network, ‘ASEAN+3 Port Network’, where Chinese ports and Hong Kong form the third cluster. The other states belong to the second community which is dominated by Japan and South Korea.

In both observed networks Japan, China and Hong Kong have the highest scores. In addition, the rankings of Cambodia, Brunei, Philippines and Thailand are very similar. Vietnam has low Outdegree and Indegree centralities while its betweenness scores are higher in the two networks. It should be highlighted that in the Maritime as well as the Export network, Singapore plays an important role as a bridging organization (high betweenness centrality). These results suggest that in the context of ASEAN+3, the development of the port infrastructure and the connectivity has a substantial impact on the overall trade performance. When we look at the structure of the Trade and Maritime Networks of ASEAN+3, we observe similar features not only at the country level but also at port level.

5. Conclusion

Network Analysis is a suitable method to investigate the structure of the maritime transport system as well as the hierarchy of the ports/countries at global and regional levels according to different centrality measures. We have analyzed five types of directed weighted networks. The weights of the links between nodes are according to the number of trips and the size of the containership vessels operating between the origin and destination ports, or, the value of countries' exports.

The first network consists of 153 ports from all around the world. Our findings confirm the hub and spoke structure of the Global Maritime Network. As major hubs have been identified Singapore, Hong Kong, Ningbo-Zhoushan, Shanghai and Shenzhen. Ports with relatively low Indegree and Outdegree centralities, such as Port Said, Balboa and Belawan, have very high betweenness centralities which indicates their strategic geographical position and connections with

ports which are situated at the periphery of the global network. When we aggregate the data at the country level, the ‘Maritime Country Network’ shows a similar pattern. The European states as well as North and South America form linked communities. China, the U.S., the Netherlands, and Japan are intermediate passages.

We have also analyzed the intra-maritime connectivity between ports situated in the ASEAN+3 countries. The Japanese ports and Hong Kong play the most important roles in terms of outgoing and incoming traffic. However, Shanghai and Singapore are found to have the highest betweenness scores which make them important intermediate points connecting many ports in the network. Furthermore, modularity analysis identifies a community of ports from exclusively ASEAN member states except the Philippines. This finding reveals that ASEAN states had a good intra-regional connectivity in 2014.

A comparative analysis was conducted between the maritime and trade integration of ASEAN+3 countries. In the case of maritime connectivity, all ASEAN member states form the first cluster, while China, Taiwan, Hong Kong, Republic of Korea and Japan are associated with the second cluster. When we weight the links between countries according to the exports, the ‘ASEAN+3 Export Country Network’ has similar features as the ‘ASEAN+3 Maritime Country Network’, even though the rankings for some countries was slightly different. Similar to the Ports Network, China and Hong Kong form one community, while Singapore plays an important intermediate role in both networks. These findings confirm the comparable pattern of countries’ exports and their maritime connectivities.

Potential future research could be conducted by analysing competition in the liner shipping sector by taking into account the number of carriers operating on different maritime routes. In the context of ongoing investments in port infrastructure and Climate Change, the sustainability of the

supply chain network is a hot topic. Network analysis could be a useful tool to detect ports which are important in the network and to assess their resilience to different disturbances such as natural and man-made disasters. A similar analysis for a longer period of time with dynamic graphs could be also conducted in order to observe how containerized transport has evolved throughout the years. In the near future, data availability should increase and similar analyses might be possible for a bigger sample.

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Acknowledgments

We would like to thank Ms. Kerry Slattery, International Programme Director, National University of Management, Phnom Penh, Cambodia, for reviewing this paper and providing us with valuable feedback.

Appendices:

Appendix 1: Descriptive statistics of different type of networks

Type of network	Nodes	Edges	Variables	Mean	Std. Dev.	Min	Max
Maritime Port Network	153	6410	AvgTEU	4299.762	3015.468	80	18270
			NoTrips	99.69938	277.1175	1	5510
Maritime Country network	51	1,519	AvgTEU	4911.418	2861.2	142	18270
			NoTrips	328.6866	912.2704	1	16872
ASEAN+3 Maritime Port Network	68	1745	AvgTEU	2022.986	1574.131	80	14080
			NoTrips	144.4292	412.3873	1	5510
ASEAN+3 Maritime Country Network	13	135	AvgTEU	1797.992	1205.591	608	6191
			NoTrips	1002.66	2233.5	1	16872
ASEAN+3 Export Country Network	13	156	Exports in '000 USD	1.87E+07	4.32E+07	39.708	3.63E+08

Appendix 2: Main weighted centralities measures for the ‘Maritime Port Network’

Weighted centrality measures for the ‘Maritime Port Network’ as well as the modularity class to which every port belongs.

Port	Country	Throughput '000 TEUs	Outdegree	Indegree	Closeness	Between ness	Hub	Modular ity Class
Singapore	Singapore	33900	118149	117755	0.000255259	8203	0.160737	2
Hong Kong	Hong Kong	22300	100390	89205	0.000254923	3860	0.160206	3
Ningbo- Zhoushan	China	19500	95592	76385	0.000254973	823	0.159628	3
Shanghai	China	35300	111663	92816	0.000255128	6105	0.159469	3
Shenzhen	China	24037	77508	63956	0.00025485	956	0.155226	3
Port Klang	Malaysia	10946	44367	40504	0.000254438	1241	0.14527	2
Rotterdam	Netherlan ds	12298	120562	116484	0.000255121	4417	0.143447	1
Tanjung Pelepas	Malaysia	8232	39650	28106	0.000254462	306	0.137985	2
Kaohsiung	Taiwan	10593	44712	44255	0.000253711	450	0.137476	3
Port Said	Egypt	3959	90325	99082	0.000255347	8093	0.13576	2
Hamburg	Germany	9775	86048	83600	0.000254961	283	0.135682	1
Antwerp	Belgium	8812	76157	85000	0.000254677	1134	0.135152	1
Algeciras	Spain	4555	46702	44956	0.0002545	749	0.134779	2
Jebel Ali (Dubai)	United Arab Emirates	15249	25922	44475	0.000253838	262	0.133776	2
Le Havre	France	2433	56095	62756	0.000254403	0	0.132202	1
Valencia	Spain	4442	55294	61160	0.000254583	1864	0.131433	2
New York	United States of America	5772	51713	50009	0.000253931	1729	0.131198	0
Norfolk (USA)	United States of America	2393	38504	43175	0.00025394	531	0.130281	0
Balboa	Panama	3468	36170	41370	0.000253911	1996	0.129293	0
Bremen/Breme rhaven	Germany	5731	64158	64553	0.000254651	549	0.128586	1
Hanshin Ports	Japan	2049	27443	31177	0.000253895	185	0.120247	3
Tangier- Mediterranee	Morocco	3070	37267	36626	0.000253716	274	0.120123	2
Felixstowe	United Kingdom	4072	52585	49102	0.000254574	164	0.119642	1
Barcelona	Spain	1893	34409	37668	0.000254259	373	0.118934	2
Genoa	Italy	2014	29392	30303	0.000254165	130	0.117121	2
La Spezia	Italy	1262	23890	22454	0.000253506	0	0.114949	2

Yokohama	Japan	2880	52289	50985	0.000254568	1091	0.113957	3
Busan	South Korea	18700	15141	16012	0.00025229	2	0.113493	3
Charleston	United States of America	1792	25453	27114	0.000252707	444	0.113109	0
Colombo	Sri Lanka	4908	7170	8296	0.000248966	302	0.111225	2
Nagoya	Japan	2569	46574	46271	0.00025424	147	0.108821	3
Tokyo	Japan	4894	58732	56035	0.000254508	1493	0.108662	3
Jawaharlal Nehru	India	4467	18054	16653	0.000252713	151	0.107663	2
Qingdao	China	16660	2356	1837	0.000244394	0	0.106445	3
Durban	South Africa	2644	16968	17701	0.000253876	0	0.106099	2
Oakland	United States of America	2394	33909	36491	0.000254214	267	0.105143	3
Laem Chabang	Thailand	6583	14955	13708	0.000252549	311	0.104848	3
Southampton	United Kingdom	1894	31915	34905	0.000254315	0	0.102741	1
Marsaxlokk	Malta	2869	27905	28793	0.000254144	1196	0.101823	2
Kingston(JAM)	Jamaica	1638	10960	12271	0.000251084	0	0.100984	0
Sines	Portugal	1228	20466	21944	0.000252418	0	0.100806	1
Houston	United States of America	1951	16012	16519	0.000251315	146	0.099833	0
Salalah	Oman	3000	18014	17289	0.000253146	0	0.098151	2
Zeebrugge	Belgium	2047	20222	22386	0.000253375	0	0.09733	2
Baltimore	United States of America	779	10009	10970	0.000251097	151	0.097192	0
Manzanillo (MEX)	Mexico	2355	17426	19414	0.000253276	5	0.096894	3
Xiamen	China	8600	11107	9573	0.000251503	0	0.096749	3
Gioia Tauro	Italy	3708	22955	24927	0.000253446	151	0.096483	2
Santos	Brazil	3685	38882	43005	0.000254199	561	0.096142	0
Long Beach	United States of America	6817	20971	20111	0.00025395	154	0.096018	3
Seattle/Tacoma	United States of America	3616	25629	24840	0.000253948	115	0.091343	3
Djibouti	Djibouti	736	10038	11075	0.000252094	0	0.087437	2
Miami	United States of America	877	8732	9619	0.000249325	0	0.086973	0
Jeddah	Saudi Arabia	4218	11088	15221	0.000252586	0	0.085954	2
Chennai	India	1552	3112	2750	0.000250227	0	0.084233	2
Halifax	Canada	400	8196	7880	0.000251291	0	0.082308	0

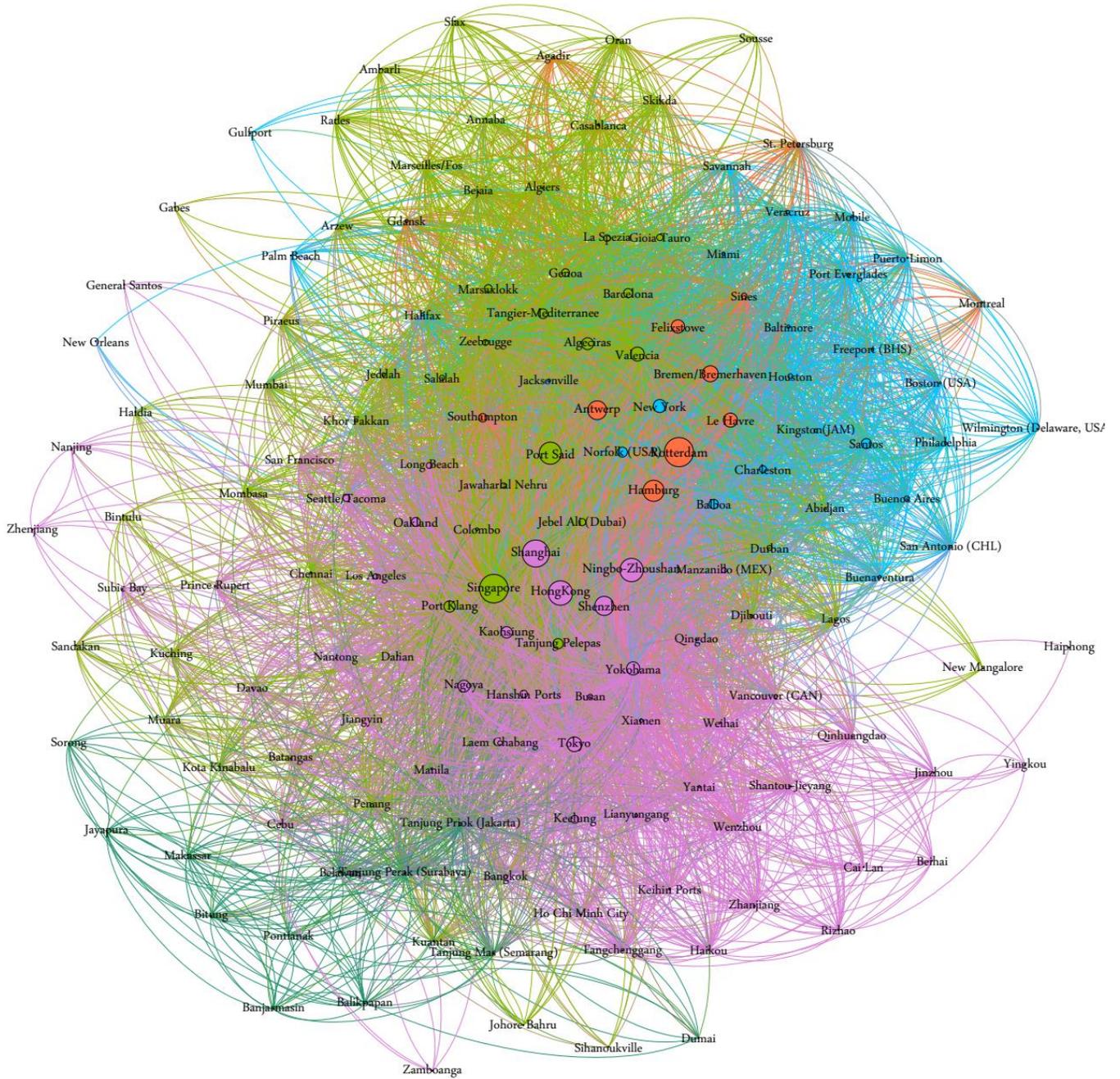
Jacksonville	United States of America	937	8132	9325	0.000249328	4	0.081441	0
Keelung	Taiwan	1686	28954	26053	0.000254266	236	0.080437	3
Abidjan	Ivory Coast	600	5053	4741	0.000250195	0	0.079872	2
Weihai	China	650	3148	3126	0.00024222	0	0.079158	3
Los Angeles	United States of America	8340	17781	16221	0.000253337	0	0.078246	3
Dalian	China	10128	938	674	0.000228621	0	0.078074	3
Buenos Aires	Argentina	1429	17610	21395	0.000253437	0	0.077169	0
Lianyungang	China	5005	9610	8830	0.000251928	22	0.07702	3
Freeport (BHS)	Bahamas	1400	6427	8069	0.000244959	0	0.075492	0
Manila	Philippines	3673	4628	4377	0.000247809	608	0.074503	3
Port Everglades	United States of America	1013	9927	10293	0.000249366	783	0.073943	0
Khor Fakkan	United Arab Emirates	3800	11116	11501	0.000252345	0	0.073812	2
Buenaventura	Colombia	855	7587	10541	0.000252342	0	0.073494	0
Yantai	China	2361	5269	5350	0.00024841	0	0.073099	3
Tanjung Priok (Jakarta)	Indonesia	6053	7121	7009	0.000249099	1178	0.070122	4
Algiers	Algeria	857	2720	2778	0.000248438	302	0.069246	2
Vancouver (CAN)	Canada	2913	11515	12198	0.000252746	0	0.068731	3
Shantou-Jieyang	China	1199	2294	2233	0.000247459	0	0.067891	3
Bejaia	Algeria	190	1246	1203	0.000238532	0	0.065856	2
Veracruz	Mexico	847	11508	11045	0.0002506	116	0.064379	0
Wenzhou	China	604	1093	1111	0.000238647	0	0.064046	3
Mobile	United States of America	237	5247	5620	0.000247758	0	0.063708	0
Lagos	Nigeria	1600	3015	4571	0.000249129	0	0.062854	2
Penang	Malaysia	1266	9563	9529	0.00025398	0	0.062227	2
Jiangyin	China	1000	569	269	0.000236921	0	0.060859	3
San Antonio (CHL)	Chile	1094	6523	8342	0.000250022	0	0.059194	0
Boston (USA)	United States of America	214	4787	4689	0.000249234	0	0.058282	0
Bangkok	Thailand	1536	13202	12600	0.000253203	743	0.057877	3
Philadelphia	United States of America	449	5566	4833	0.000247664	0	0.05588	0
Savannah	United States of America	3136	184	224	0.000158629	0	0.055857	0
St. Petersburg	Russia	2375	10036	10080	0.00025349	0	0.055675	1

Keihin Ports	Japan	#N/A	4045	3691	0.000249746	0	0.054855	3
Puerto Limon	Costa Rica	1090	1398	1775	0.000234897	0	0.052443	0
Tanjung Perak (Surabaya)	Indonesia	3128	3571	4453	0.000244101	1036	0.050822	4
San Francisco	United States of America	N/A	436	529	0.000200135	0	0.049688	3
Nantong	China	550	509	285	0.000229959	302	0.049605	3
Casablanca	Morocco	846	5534	5574	0.000249785	151	0.049558	2
Marseilles/Fos	France	1190	1851	1857	0.000243723	0	0.04887	2
Arzew	Algeria	0	160	194	0.000170751	0	0.047689	2
Batangas	Philippines	135	1234	1238	0.000236612	0	0.047307	3
Fangchenggan	China	N/A	1736	1722	0.000248573	0	0.045709	3
Skikda	Algeria	148	827	850	0.000233944	0	0.044804	2
Belawan	Indonesia	600	4295	4341	0.000251909	1285	0.043679	4
Annaba	Algeria	N/A	286	293	0.000213042	0	0.043332	2
Qinhuangdao	China	414	1034	1018	0.000235558	0	0.043277	3
Davao	Philippines	612	1863	1757	0.000242613	148	0.041973	3
Kuantan	Malaysia	131	1826	1809	0.000248985	0	0.041701	2
Mumbai	India	40	167	233	0.000165669	0	0.041363	2
Gdansk	Poland	1232	9378	10841	0.000253178	0	0.041259	1
Tanjung Mas (Semarang)	Indonesia	576	3979	3996	0.000250889	429	0.041223	4
Zhanjiang	China	581	2442	2451	0.000247578	302	0.040844	3
Haikou	China	1347	474	467	0.000219647	0	0.040763	3
Ho Chi Minh City	Vietnam	6515	982	895	0.000238771	302	0.037804	3
Piraeus	Greece	3585	238	284	0.000187533	0	0.03722	2
Mombasa	Kenya	1012	1016	1376	0.000233887	0	0.037172	2
Cebu	Philippines	708	1998	2074	0.000248501	0	0.036493	3
Oran	Algeria	201	1225	1230	0.000244109	0	0.034695	2
Kota Kinabalu	Malaysia	261	594	531	0.000226559	453	0.033889	2
Rades	Tunisia	311	566	418	0.000232525	0	0.032997	2
Montreal	Canada	1402	1763	1783	0.000245472	0	0.030655	1
Agadir	Morocco	159	995	965	0.00023294	0	0.030014	1
Kuching	Malaysia	228	119	104	0.000154045	0	0.028115	2
Ambarli	Turkey	3445	176	40	0.000174184	0	0.028031	2
Prince Rupert	Canada	618	3876	3365	0.000250295	0	0.027622	3
Wilmington (Delaware, USA)	United States of America	339	247	283	0.000222991	0	0.027387	0
Muara	Brunei	90	181	169	0.000181483	0	0.026533	2
Jinzhou	China	879	454	410	0.000222258	0	0.025778	3

Palm Beach	United States of America	263	61	53	8.72308E-05	0	0.025472	0
Sfax	Tunisia	84	371	316	0.000238652	0	0.024959	2
Rizhao	China	2420	1008	953	0.000237045	0	0.023722	3
Cai Lan	Vietnam	49	80	96	0.000145689	0	0.021967	3
Sandakan	Malaysia	275	174	164	0.000216514	0	0.017747	2
Beihai	China	85	53	54	0.000117595	0	0.016874	3
Pontianak	Indonesia	198	251	244	0.000229153	0	0.016138	4
Bintulu	Malaysia	258	65	66	0.000113534	0	0.014011	2
Haldia	India	102	44	40	0.000137418	0	0.013704	2
Sihanoukville	Cambodia	342	20	9	8.50579E-05	0	0.01345	2
Makassar	Indonesia	560	1934	1996	0.000242631	9	0.013276	4
Balikpapan	Indonesia	76	203	188	0.000203726	0	0.012641	4
Johore Bahru	Malaysia	793	69	78	0.000173205	0	0.012236	2
Subic Bay	Philippines	77	34	59	0.000125828	0	0.010446	3
Sousse	Tunisia	32	32	20	0.000148266	0	0.010005	2
Nanjing	China	2760	9	7	4.06656E-05	0	0.009943	3
Bitung	Indonesia	115	821	854	0.000238555	0	0.009602	4
Dumai	Indonesia	N/A	9	20	3.92993E-05	0	0.0075	4
New Mangalore	India	63	57	66	0.000191924	0	0.007331	2
Banjarmasin	Indonesia	404	587	610	0.000235175	0	0.007054	4
Jayapura	Indonesia	45	462	527	0.00022708	0	0.006889	4
Sorong	Indonesia	44	420	433	0.000223372	0	0.006405	4
Zhenjiang	China	385	20	20	0.000119423	0	0.006106	3
Gulfport	United States of America	188	61	54	0.000197569	0	0.005735	0
General Santos	Philippines	183	8	3	3.88156E-05	0	0.005725	3
Yingkou	China	5768	3	3	2.02369E-05	0	0.005317	3
Gabes	Tunisia	N/A	2	3	1.54084E-05	0	0.003331	2
Zamboanga	Philippines	79	63	71	0.000165775	0	0.002779	3
New Orleans	United States of America	491	1	3	1.19181E-05	0	0.001566	0
Haiphong	Vietnam	2131	0	0	4.31659E-06	0	0.000835	3

Note: Ports for which we do not have data for the container throughput, in the first column is written 'N/A'.

Appendix 3: Graphical representation of the ‘Maritime Port Network’



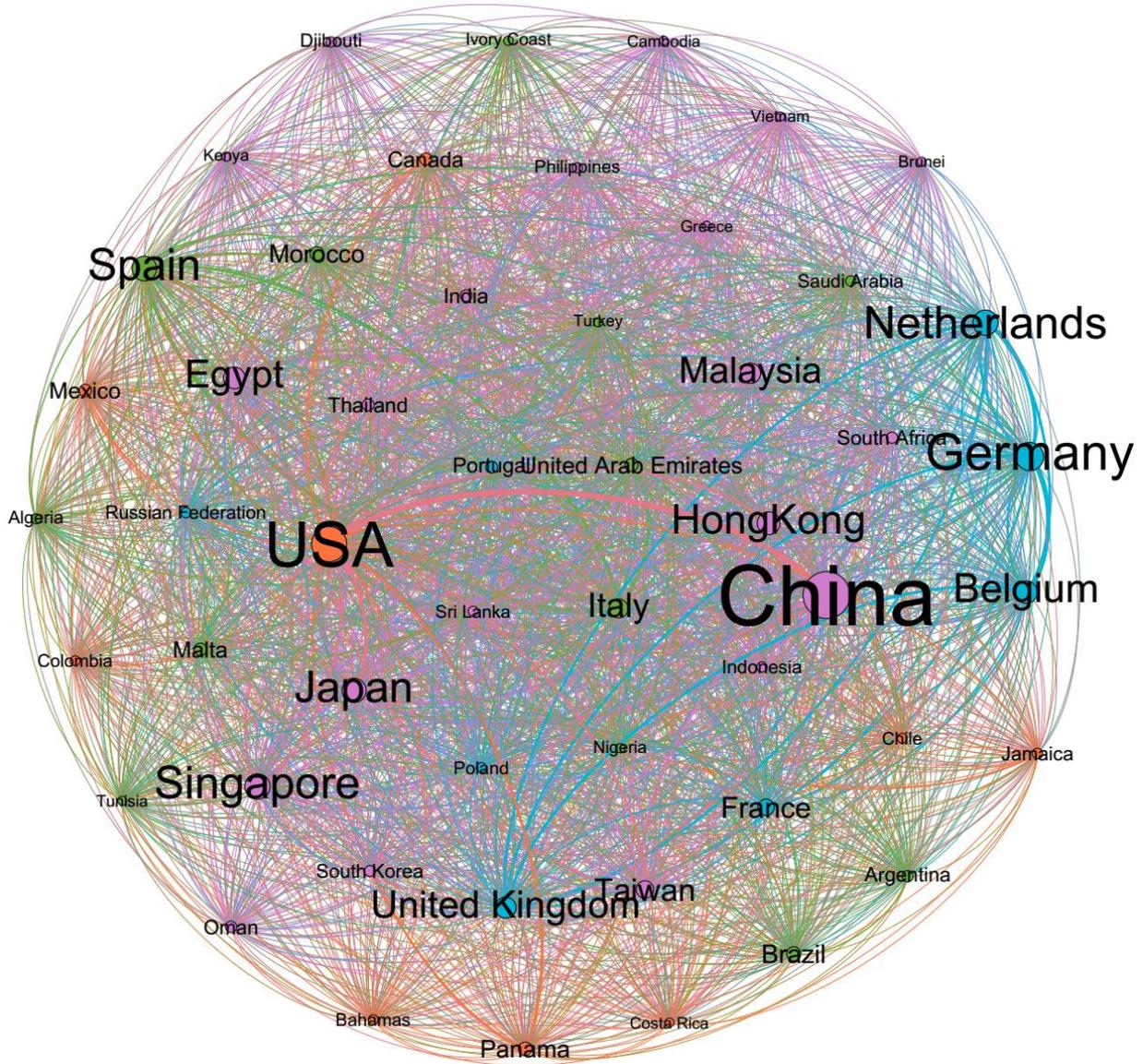
Maritime Network of 153 ports in the sample. The size of the nodes corresponds to their outdegree weighted centrality. The weight of the links is $w_{ij} = AvgTEU_{ij} * NbTrips$. The different colours of edges and nodes correspond to the modularity classes (closely linked nodes).

Appendix 4. Main centralities measures for the ‘Maritime Country Network’

	Outdegree (weighted)	Indegree (weighted)	Closeness (weighted)	Betweenness (weighted)	Modularity class
China	274245.9349	214893.3266	0.001476585	1340	1
USA	189447.0602	198563.4553	0.001473832	907	3
Germany	138943.6659	132126.0366	0.001467422	283	0
Singapore	118439.5886	116885.4411	0.001466241	175	1
Netherlands	117762.6223	111116.5104	0.001465357	0	0
Spain	113742.9457	120195.603	0.001467584	517	2
Japan	110083.7562	110874.2683	0.001472465	302	1
Hong Kong	100215.6263	90127.35064	0.001466468	0	1
Belgium	97922.95869	115112.6899	0.001461832	112	0
Egypt	91756.90448	98788.85722	0.001472406	134	1
United Kingdom	86829.98145	86888.5614	0.001461372	0	0
Malaysia	81789.48812	65233.56405	0.001457743	185	1
Italy	72755.63338	72661.93602	0.001461525	49	2
Taiwan	62205.8106	59135.69895	0.001464884	98	1
France	53911.22997	56846.53733	0.001449089	0	0
Brazil	38064.80367	42023.31767	0.001447278	72	2
Morocco	35319.87228	35687.98169	0.001448902	0	2
Panama	34123.72181	40126.30958	0.001460087	98	3
United Arab Emirates	29833.27757	52413.19357	0.00143046	49	2
Malta	26547.3555	28325.43968	0.00143489	98	2
Mexico	25933.92338	29697.44283	0.001439135	0	3
Canada	23713.61258	23523.62632	0.001451423	0	3
Portugal	21729.69064	23018.96137	0.001430386	0	0
Thailand	20795.08862	19675.28744	0.001444595	0	1
India	18897.93228	18218.72608	0.001394731	0	1
Oman	18159.4615	16604.92881	0.001430872	0	1
Argentina	17427.35967	21111.75727	0.001418548	0	2
South Africa	16104.84046	16364.69071	0.00141785	0	1
South Korea	14628.41699	16895.96553	0.001437067	0	1
Jamaica	12513.44473	13633.36596	0.001448754	0	3
Saudi Arabia	11015.93787	14866.82175	0.001412726	0	2
Russian Federation	10201.34583	10213.12975	0.001437509	0	0
Indonesia	9580.712991	10552.96713	0.001408387	0	1
Djibouti	9429.537833	10869.15225	0.001399613	0	1

Poland	8417.0845	10629.5575	0.001399373	0	0
Philippines	7930.561252	8263.025147	0.001404214	0	1
Algeria	7814.442874	7664.00515	0.001431827	0	2
Sri Lanka	7308.548	8071.568875	0.00134095	0	1
Colombia	7049.846135	9961.630901	0.001400785	0	3
Bahamas	6568.56575	7485.537381	0.001411229	0	3
Chile	6279.103708	8356.0399	0.001378792	0	3
Ivory Coast	4752.393333	4562.753	0.001304529	0	2
Nigeria	2790.3435	4504.5505	0.001261346	0	2
Costa Rica	1376.884833	1627.843071	0.001238829	0	3
Kenya	1012.167	1369.598	0.000903352	0	1
Vietnam	1009.076071	951.3793333	0.001184533	0	1
Tunisia	974.8014047	744.4635615	0.001142024	0	2
Greece	227.7643333	289.8393333	0.000595443	0	1
Brunei	190.17	170.6823333	0.000697308	0	1
Turkey	180.596	41.1145	0.000377861	0	2
Cambodia	19.637	9.038	0.000102614	0	1

Appendix 5 Graphical Representation of the Maritime Country Network



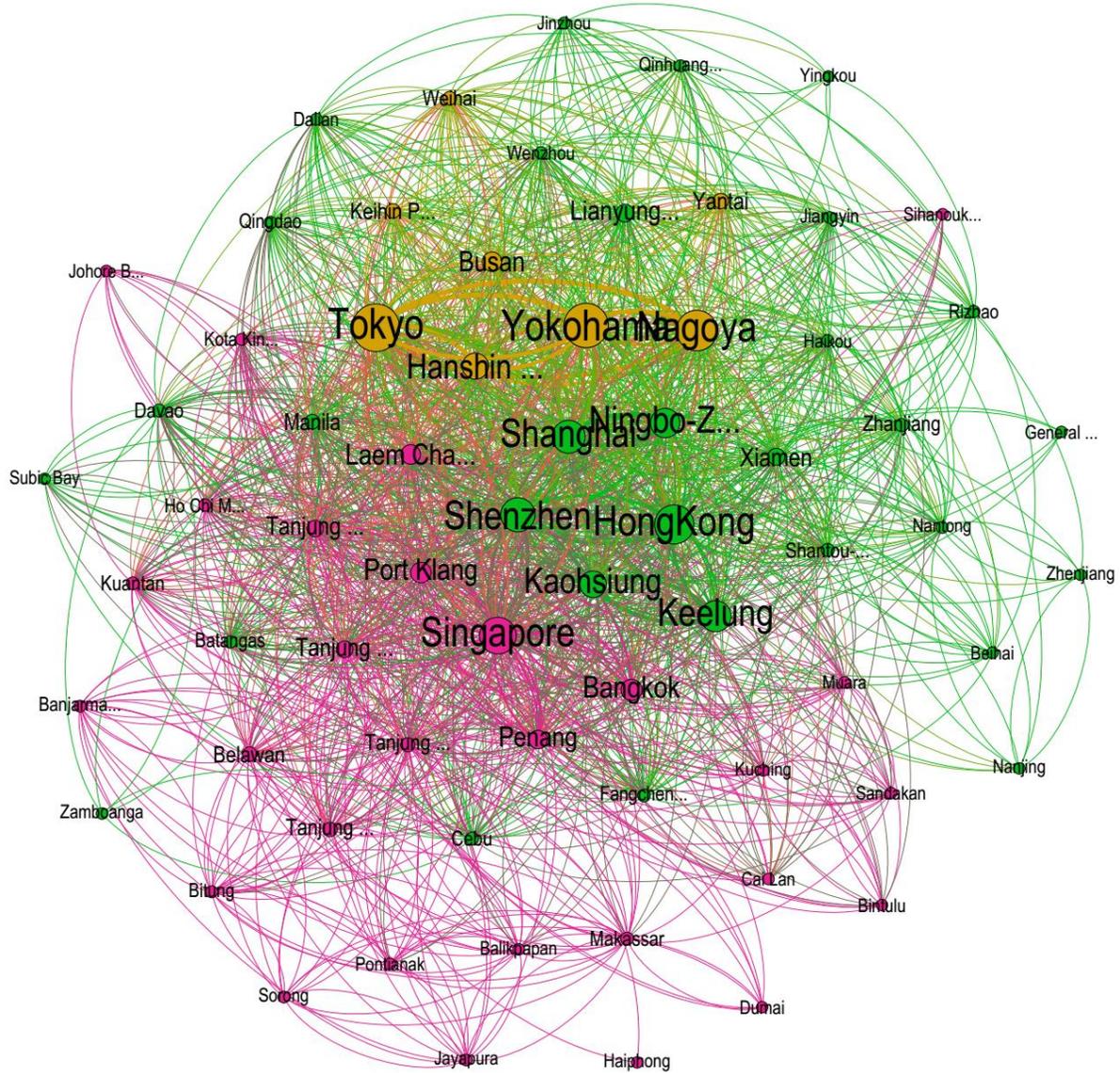
Maritime Network of 51 countries in the sample. The size of the nodes corresponds to their outdegree weighted centrality. The weight of the links is $w_{ab} = AvgTEU_{ab} * NbTrips_{ab}$. The different colours of edges and nodes correspond to the modularity classes (closely linked nodes).

Appendix 6 Main centralities measures for the 'ASEAN+3 Maritime Port Network'

	Outdegree (weighted)	Indegree (weighted)	Closeness (weighed)	Betweenness (weighted)	Hub	Modularity class
Tokyo	49119.811	46318.16	0.00050424	753	0.172171	0
Yokohama	44580.529	44385.518	0.00050421	691	0.171899	0
Nagoya	39489.751	38961.453	0.00050389	62	0.174722	0
Hong Kong	37752.444	38192.85	0.00050417	1021	0.198175	2
Singapore	34270.252	31123.216	0.00050438	1922	0.197974	1
Shenzhen	30783.731	33489.861	0.00050407	868	0.188277	2
Shanghai	29211.148	31193.976	0.00050402	1383	0.191338	2
Keelung	26650.695	23864.959	0.00050358	124	0.16422	2
Ningbo-Zhoushan	24251.828	25510.307	0.00050389	220	0.180556	2
Kaohsiung	20460.397	21458.386	0.00050303	194	0.188148	2
Hanshin Ports	19962.309	21359.149	0.00050351	89	0.172841	0
Bangkok	13191.611	12584.185	0.00050204	268	0.159568	1
Port Klang	12400.297	11351.893	0.00050266	442	0.181426	1
Laem Chabang	10932.673	11200.227	0.0005019	141	0.174055	1
Busan	10819.218	11583.462	0.00050153	2	0.165258	0
Penang	9480.783	9389.609	0.00050293	0	0.169541	1
Lianyungang	8637.937	8021.87	0.00050023	14	0.153506	2
Xiamen	7579.1	7357.996	0.00050017	0	0.166509	2
Tanjung Priok (Jakarta)	7063.208	6907.406	0.00049804	562	0.173976	1
Tanjung Pelepas	6898.514	10347.44	0.00049803	131	0.169408	1
Yantai	5198.723	5180.446	0.00049666	0	0.143925	0
Manila	4390.887	4047.275	0.00049628	268	0.164934	2
Belawan	4267.08	4308.74	0.0005007	404	0.109855	1
Keihin Ports	4038.396	3671.607	0.0004983	0	0.15233	0
Tanjung Mas (Semarang)	3977.09	3989.372	0.00049972	177	0.112376	1
Tanjung Perak (Surabaya)	3549.345	4441.804	0.00049185	438	0.139004	1
Weihai	2867.379	2752.191	0.00048866	0	0.138798	0
Zhanjiang	2442.11	2451.399	0.00049522	132	0.116075	2
Shantou-Jieyang	2160.844	2184.55	0.00049476	0	0.144317	2
Cebu	1998.429	2039.835	0.00049666	0	0.101664	2
Makassar	1933.587	1995.592	0.00049021	9	0.042231	1
Davao	1825.59	1708.268	0.00048898	63	0.108711	2
Kuantan	1820.187	1809.408	0.0004965	0	0.103511	1
Fangchenggang	1735.105	1720.914	0.00049617	0	0.126141	2

Qingdao	1384.061	948.521	0.00049058	0	0.128494	2
Batangas	1137.65	1141.526	0.00048176	0	0.118669	2
Rizhao	1008.275	952.762	0.00048163	0	0.067906	2
Ho Chi Minh City	982.453	890.3	0.00048463	132	0.103761	1
Wenzhou	960.566	1000.182	0.00048299	0	0.135263	2
Qinhuangdao	825.349	848.993	0.00047893	0	0.090689	2
Bitung	820.913	854.208	0.00048473	0	0.032146	1
Kota Kinabalu	592.913	530.902	0.00046846	198	0.092254	1
Banjarmasin	587.105	609.736	0.00048036	0	0.024995	1
Jiangyin	510.166	259.495	0.00048078	0	0.105093	2
Dalian	504.319	277.357	0.00047084	0	0.10489	2
Haikou	473.86	467.08	0.00045791	0	0.117169	2
Jayapura	462.342	527.098	0.00046923	0	0.024342	1
Jinzhou	444.249	410.351	0.00046109	0	0.061534	2
Nantong	439.876	248.783	0.00047243	132	0.093807	2
Sorong	420.308	433.052	0.00046421	0	0.021769	1
Pontianak	241.217	234.329	0.00047187	0	0.039264	1
Balikpapan	202.74	188.267	0.00043624	0	0.042295	1
Muara	179.989	169.156	0.00040324	0	0.068501	1
Sandakan	174.314	164.176	0.00045274	0	0.050555	1
Kuching	119.111	102.494	0.00035821	0	0.080139	1
Cai Lan	79.846	96.27	0.00034197	0	0.059348	1
Johore Bahru	68.269	69.799	0.00038845	0	0.028937	1
Bintulu	65.343	66.116	0.00028237	0	0.038965	1
Zamboanga	63.108	71.218	0.00037702	0	0.01042	2
Beihai	53.294	54.396	0.00029055	0	0.047079	2
Subic Bay	32.136	57.469	0.00030667	0	0.026543	2
Zhenjiang	20.349	20.2	0.00029374	0	0.016134	2
Sihanoukville	19.637	9.038	0.00022367	0	0.034609	1
Nanjing	8.55	6.318	0.00011661	0	0.026157	2
General Santos	8.07	2.69	0.00011253	0	0.013949	2
Dumai	3.906	20.024	9.4755E-05	0	0.010836	1
Yingkou	2.908	2.55	6.0473E-05	0	0.014053	2
Haiphong	0.26	0.26	1.3405E-05	0	0.003656	1

Appendix 7. Graphical representation of the ASEAN+3 Maritime Port Network



Maritime Network of the 68 ports in the sample which are associated with ASEAN+3 community. The size of the nodes corresponds to their outdegree weighted centrality. The weight of the links is $w_{ij} = AvgTEU_{ij} * NbTrips_{ij}$. The different colours of edges and nodes correspond to the modularity classes (closely linked nodes).

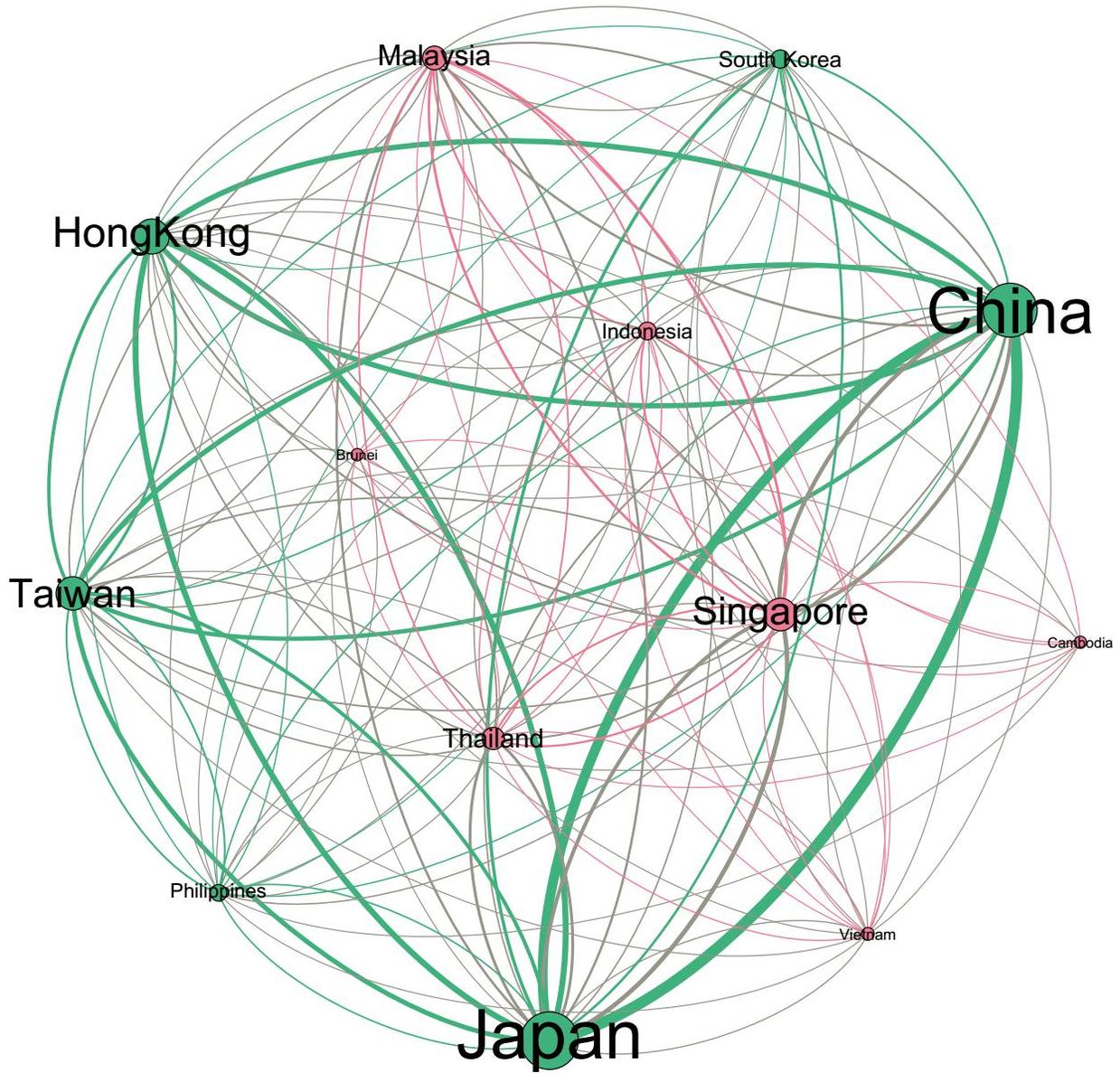
Appendix 8. Main centralities measures for the ‘ASEAN+3 Maritime Country Network’

Node	Outdegree (Weighted)	Indegree (weighed)	Closeness (weighted)	Betweenness (weighed)	Hub	Modularity Class
Brunei	188.682	170.6823	0.000873	0	0.198899	1
Cambodia	19.637	9.038	0.000254	0	0.199081	1
China	72001.16	70907.82	0.001167	20	0.293203	0
Hong Kong	39415.85	41034.54	0.001165	0	0.302092	0
Indonesia	9457.76	10398.21	0.001153	0	0.272449	1
Japan	78216.16	78690.86	0.001168	83	0.294955	0
Malaysia	19874.3	20767.24	0.001163	33	0.302092	1
Philippines	7604.649	7739.231	0.00115	0	0.268245	0
Singapore	35240.5	30512.55	0.001167	24	0.302092	1
South Korea	10449.38	12686.64	0.001159	0	0.274202	0
Taiwan	36636.58	36165.08	0.001165	22	0.302092	0
Thailand	17248.96	17334.35	0.001161	0	0.291449	1
Vietnam	1009.076	946.4733	0.001088	0	0.276565	1

Appendix 9. Main centralities measures for the ‘ASEAN+3 Export Country Network’

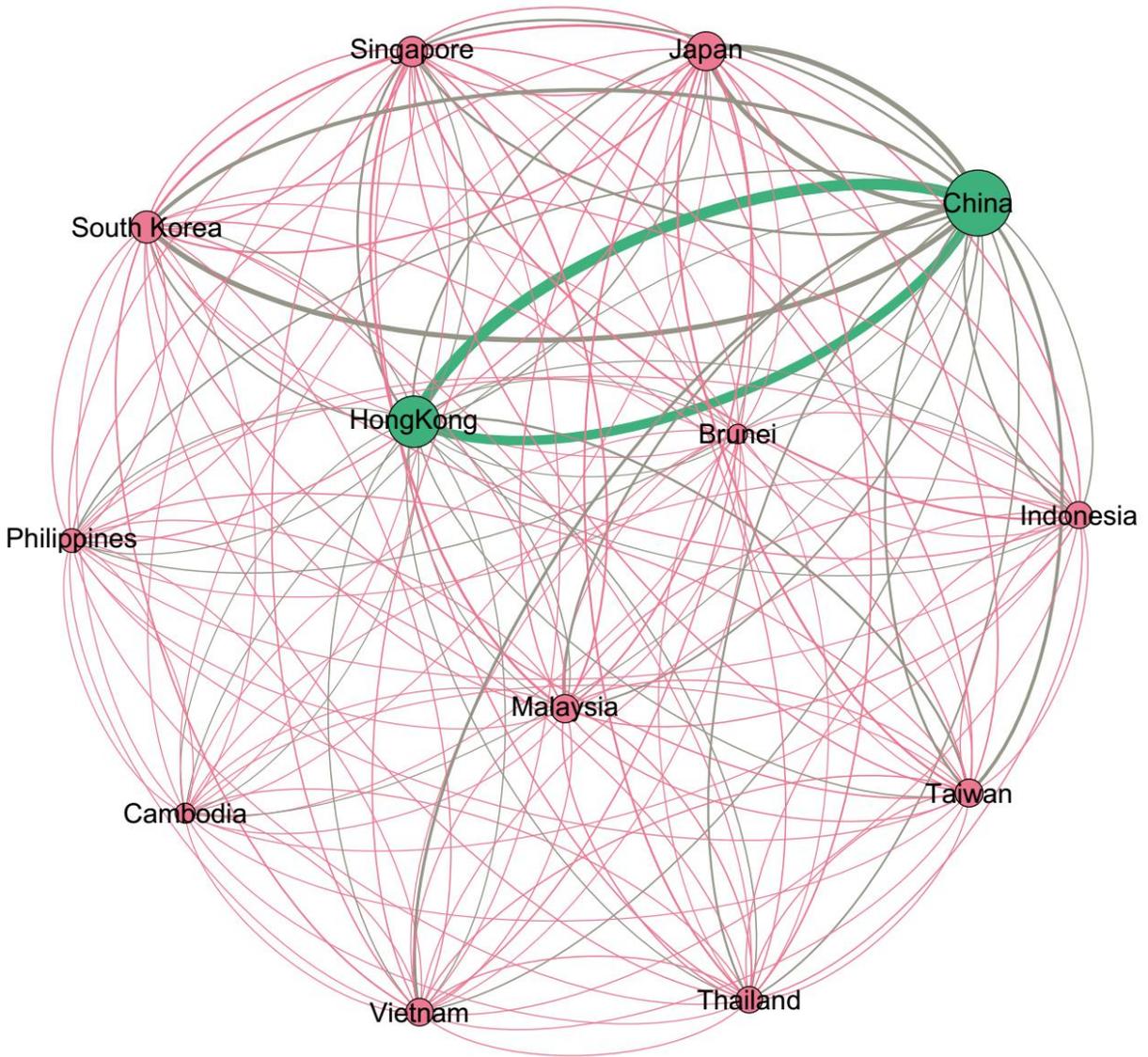
Node	Outdegree (weighted)	Indegree (weighted)	Closeness (Weighed)	Betweenness (Weighted)	Modularity Class
Brunei	5252.399	7946.597	0.005739	0	0
Cambodia	14838.35	1704.748	0.015294	0	0
China	800010.4	919958.9	0.017397	101	1
Hong Kong	553798.3	371891.2	0.01723	0	1
Indonesia	133570.8	99665.92	0.016174	0	0
Japan	338632	359284.8	0.017368	42	0
Malaysia	157607.7	145422.8	0.016319	0	0
Philippines	78707.57	41717.35	0.015253	0	0
Singapore	190761.7	271385.6	0.016392	12	0
South Korea	224272.7	303784.8	0.016781	0	0
Taiwan	151726.5	216453.9	0.016211	0	0
Thailand	126921.3	119201.9	0.015923	11	0
Vietnam	144938.6	62619.71	0.016736	0	0

Appendix 10. Graphical representation of the ASEAN+3 Maritime Country Network



Maritime Network of the 13 countries belonging to ASEAN+3 community. The size of the nodes corresponds to their Outdegree weighted centralities. The weight of the links is $w_{ab} = AvgTEU_{ab} * NbTrips_{ab}$. The different colours of edges and nodes correspond to the modularity classes (closely linked nodes).

Appendix 11. Graphical representation of the ASEAN+3 Export Country Network



Export Trade Network of the 13 countries belonging to ASEAN+3 community. The size of the nodes corresponds to their Outdegree weighted centralities. The weight of the links is $w_{ab} = EXP_{ab}$. The different colours of edges and nodes correspond to the modularity classes (closely linked nodes).

