Norwegian port connectivity and its policy implications

Haiying Jia[a]*, Ove Daae Lampe[b], Veronika Solteszova[c], Siri P. Strandenes[d]

[a]* Center for Applied Research (SNF) at NHH, Norwegian School of Economics, Helleveien 30, 5045 Bergen, Norway. Corresponding author: E-mail: haiying.jia@snf.no

[b] Christian Michelsen Research AS, P.O.Box 6031, 5892 Bergen, Norway. odl@cmr.no

[c] Christian Michelsen Research AS, P.O.Box 6031, 5892 Bergen, Norway. veronika.solteszova@cmr.no

[d] Department of Economics, Norwegian School of Economics, Helleveien 30, 5045 Bergen, Norway. Siri.Strandenes@nhh.no

Abstract

The importance of a seaport depends on how well it is connected in a transportation network. A port's connectivity is therefore one of the key issues in determining its competitiveness and developments in regions and countries. We construct a port connectivity index for major Norwegian ports based on a unique dataset derived from the Automated Identification System (AIS) for multiple vessel types over a seven-year period. Port connectivity is evaluated empirically by the number of unique vessel visits, vessel sizes and cargo sizes. The research has implications for port authorities and policy makers in the areas of port planning, infrastructure investment, Short Sea Shipping promotion and environmental policies. The contributions of this research are twofold. Firstly, the methodology linking the AIS vessel tracking system with port connectivity is a pioneering empirical application of maritime big data. Secondly, the port connectivity index is constructed for multiple vessel types and regional port groups, which is an improvement from the current literature where conceptual measures are constructed based on hypothetical and usually too simple optimisation rules. The methodology can be easily expanded to other regions in the world.

Keywords: port connectivity; AIS; big data; short sea shipping; port planning

1. Introduction

Seaports play an important role in facilitating countries' external trade and internal market exchange. They are the key points of logistic chains for many industrial products and are essential for economic growth for countries and regions. As Smith (1776) already pointed out: ‘As by means of water-carriage, a more extensive market is opened to every sort of industry than what land-carriage alone can afford it, so it is upon the sea-coast, and along the banks of navigable rivers, that industry of every kind naturally begins to subdivide and improve itself ...’. According to the European Commission, 90% of total trade volume is transported via seaports in the European Union (europa.eu). Port performance and the position of ports in the global logistic chain reflect a country's trade competitiveness. Goss (1990) stresses how ports drive the economic development as they increase competition through enlargement of the market areas of firms ‘through providing increments to consumers' and producers' surpluses’. In line with global economic growth and increase in maritime transportation, the competition among ports has grown and so does the academic research in the area. Several measures have been identified as import in the port competiveness literature: price and service (Slack,1985; Cullinane and Toy, 2000); frequency (Bird and Bland, 1988); transit time and reliability (Cullinane and Toy, 2000); and efficiency Tongzon (2009). Tiwari, Itoh and Dio (2003) and Malchow and Kanafani (2004) suggest that port location is one of the most significant factors.

The perspective of a sea port has been developed from being regarded as ‘standalone transport nodes’ (Button 1993; Charlier and Ridolfi 1994; Cooper 1994; Goss 1990; Robinson 2002) to being viewed as an independent yet interdependent ‘port cluster element’ (Haezendonck 2001; Lambrou, Pallis and Nikitakos 2008; Musso ang Ghiara 2008; Roh, Lalwani and Naim 2007; Brett and Roe 2010). In the recent literature, a port is evaluated as an element in trade routing and logistics networks (Wang and Yeo, 2017; Du, Meng and Wang, 2017; Lau *et al.* 2017; Meng, Zhang and Xu, 2016; and Shi and Li, 2017). Port connectivity fits into this line of research and refers to how well one port connects to others in the maritime transportation network. In general, the higher the connectivity level of a port, the more attractive it will be in terms of facilitating the transportation of cargo and reducing transportation cost and time, which will result in it being more competitive than others (Jiang, Chew and Lee 2015). Port connectivity is essential for competitive ports as the concept is closely correlated to the frequency of shipping services. If sufficient volume is shipped between these ports, a higher frequency of shipping services and, thus, greater reliability can be guaranteed. Low, Lam and Tang (2009) propose a measure of port connectivity by developing a network-based hub port assessment model where a connectivity index for each port is based on the counts of origin and destination pairs. However, as pointed out by Jiang, Chew and Lee (2015), the simplistic method of counting the number of direct connections leave out some important factors for port connectivity, namely responsiveness, capacity and network structure. Jiang et al. (2015) outline a methodology to quantify port connectivity from the container transshipment port angle in an operational research framework, with objectives being to minimize transportation time or to maximize transportation capacity in a single-factor setting. However, their study is based on a simplified conceptual model rather than on the actual transportation flow. Also, the two criteria, time and capacity, are treated independently when measuring the port connectivity so that one port (e.g. Shanghai) may end up with different connectivity ranking under different measurements. Jiang, Chew and Lee (2015) point out that even though 'it is not immediately evident how to determine a port's connectivity as it is a concept that can have different interpretations and meanings in different cases, a more realistic methodology is desired in the literature'.

The United Nations Conference on Trade and Development (UNCTAD) has developed the Liner shipping connectivity index (LSCI), which in the authors' view provides a very good framework for measuring country connectivity both practically and empirically. The LSCI aims at capturing a country's level of integration into global liner shipping networks, in other words how well countries are connected to global shipping networks (Hoffmann, 2005). The index takes into consideration five elements: number of ships, their cargo-carrying capacity, maximum vessel size, number of services, and the number of companies that deploy ships in a country's ports. Whereas the LSCI is calculated at the country level on an annual basis, we adapt this concept to measure individual port's connectivity at smaller time intervals. Moreover, we broaden the scope from solely container shipping to include other shipping segments, namely passenger, tanker and dry cargo transportation.

Norway has historically been a strong shipping nation due to its geographical location and long coastline. Being the tenth largest shipowning country (UNCTAD 2015), the Norwegian fleet plays an important role in the international maritime industry. Domestic transportation along the coast is also a prerequisite, for instance, ferry services for passengers and cargo. However, perhaps because Norway is not in the European Union, studies on Norwegian ports have been limited. This is despite the fact that, according to the UNCTAD Port database, there are over one thousand ports in Norway, which is a large number for a country with such a small population. The Oslo region has typically been viewed as the representative port for Norwegian port connectivity, see for instance, Newton et al. (2010). Research on the overall Norwegian port connectivity is non-existent.

The objective of this research is to use Automatic Information System (AIS) data to evaluate Norwegian port connectivity by cargo type, vessel specifications and by port regions. The research differs from the literature where conceptual models are usually deployed (Low, Lam and Tang 2009; Jiang et al. 2015) by using actual vessel movement data to assess how well ports are connected to each other. In other words, the port connectivity measure is based on the actual transportation network between individual ports in a country based on real vessel shipment data. The remainder of the paper is organized as follows: section II describes the data and methodology, section III presents the port connectivity measurement, section IV presents the results for major Norwegian ports, Section V outlines the applications of this research and section VI concludes.

2. Data and Methodology

2.1 The Automatic Identification System (AIS) derived data

The Automatic Identification System (AIS) is an automatic vessel tracking system originally designed for anti-collision and port security purposes. Observations of AIS vessel traffic information enables us to assess the past sailing pattern of vessels, i.e. sailing speed and routing, as well as the level of connectivity for a particular port or region for particular ship types and cargo sizes/types. AIS data has previously been used to examine international trade (see, for instance, Adland, Jia and Strandenes (2017) for a study on global crude oil exports) We here utilize high-frequency satellite AIS data received between January 2009 and December 2015 along the Norwegian coast. AIS position reports that are sent every few seconds to five minutes at major Norwegian ports are extracted and stored. The information includes vessel ID (name and IMO), vessel type, length, draught and sometimes calling port name, speed when approaching ports (SOG) and so on. The time of arrival and departure at port is computed from the AIS data. This computation also requires the filtering of noise in AIS positions (for instance, a vessel that is close to the Norwegian border suddenly appears close to the North Pole, or any random positions).

The Norwegian territorial border is defined as the polygon that is close enough to the Norwegian mainland so that we do not lose the terrestrial-AIS signals (as opposed to satellite-AIS signals) before the vessels exit the Norwegian waters. To identify if a vessel is anchored in port, we create a subset of anchored vessels (SOG less than 1.0 knot) and that are close to a terminal/port (less than 1.0km). To efficiently identify the closest port, we first create a k-dimensional tree based on the ports' geographical locations. Each port is represented as one node of the KD-tree. Nodes that are geographically near each other are also closer to each other in the data structure, which makes the spatial search in the data structure very fast, i.e., we can efficiently identify the closest port based on a given position of a vessel. We record the time when a vessel is found anchored in a port for the first time as the time of arrival. The first time we find it moving at a distance greater or equal 1.0 km to the same port, we record the time as the time of departure from the port.

Based on AIS vessel positions obtained from the Norwegian Coastal Authority (Kystverket), we identify 577 terminals. Many of the major ports have multiple terminals or locations, therefore we group the 577 ports/terminals by geographic coordinates and municipal structure into the 43 major port areas that are listed as top Norwegian ports by total inbound and outbound traffic volume according to Statistics Norway (SSB, Statistisk Sentralbyrå).

For each port, we count the number of distinct vessel visits for a given ship type. We also record maximum, minimum, average and median of the observed draught as well as the length of each vessel. The draught is an indication of the loading condition of a vessel and, thus, requires particular attention. For each vessel we distinguish between two types of draught: the maximum possible draught (the maximum of all draught records for the vessel in the sample period) and the current draught before arrival to a port. This gives us some information about the load of the vessel arriving to a port. However, because draught information is updated by the crew and the updates do not always happen instantly, we therefore track all draught information from AIS records after departure from the last port (departure port) and before arrival to the next port (arrival port). Then we calculate the median draught as the draught of the respective voyage.

To detect voyages abroad, when a record shows that the vessel has left Norwegian port A and re-entered Norwegian water arriving port B after time length T, the vessel position during T is checked to confirm whether she has been abroad or not. In the occasional cases of missing position data during time T where no voyages are observed, a 'normal' journey length T_0 between port A and B is calculated. The 'normal' journey length T_0 is defined as the great circle distance between port A and B divided by the observed AIS median SOG during time T. If the time length is greater than twice the calculated normal length ($T > 2T_0$), a third port C is inserted, and this port is considered as 'abroad'.

These measures are counted on a monthly basis. Table 1 summarizes the main statistics of the data that are the components in the connectivity index.

Table 1. Main statistics of index components for the major ports 2009-2015

Port name	Total number of visits	Visits abroad	Domestic visits	Vessel length max (meter)	Reported draught ratio
Ålesund	4601	266	4335	290	72.5%
Alta	293	8	285	103	47.3%
Arendal	89	12	77	230	86.6%
Bergen	43818	5990	37828	345	64.7%
Bodø	23968	142	23826	238	71.8%
Borg	1003	295	708	181	96.8%
Bremanger	2649	270	2379	150	96.4%
Brønnøy	605	0	605	80	74.0%
Drammen	4669	1368	3301	225	80.8%
Eigersund	550	55	495	95	100.0%
Farsund	199	11	188	292	88.5%
Florø	7200	953	6247	241	67.2%
Hadsel	1844	26	1818	205	88.3%
Halden	1068	221	847	144	70.9%
Hammerfest	9753	299	9454	300	74.2%
Harstad	9607	54	9553	205	79.0%
Honningsvåg	5962	183	5779	345	71.7%
Karmsund	28433	3155	25278	330	69.5%
Kirkenes	3408	162	3246	257	55.2%
Kragerø	128	6	122	117	79.1%
Kristiansand	2320	403	1917	264	85.5%
Kristiansund	6749	1872	4877	276	60.3%
Kvinesdal	1326	177	1149	225	66.8%
Larvik	302	93	209	212	83.3%
Måløy	8460	161	8299	327	69.5%
Molde	5720	255	5465	334	59.5%
Moss	104373	1176	103197	200	71.2%
Narvik	1927	32	1895	300	79.4%
Oslo	7619	2417	5202	345	87.1%
Porsgrunn	8462	1650	6812	230	77.7%
Sauda	561	95	466	225	67.6%
Sortland	7510	16	7494	230	76.0%
Stavanger	91967	12230	79737	345	61.0%
Tønsberg	3334	777	2557	285	90.0%
Tromsø	11887	262	11625	221	81.4%
Trondheim	10801	236	10565	345	81.1%

We disregard fishing boats, tugs, military vessels, dredgers and other miscellaneous vessel types and only include passenger (AIS ship type code 60-69), cargo (70-79) and tanker vessels (80-89) in this research. For each port, we record and calculate port connectivity statistics per month and per type (passenger, cargo or tanker). The following section explains how the port connectivity index is constructed, based on which a matrix for major Norwegian ports connectivity is presented.

2.2. Port Connectivity index

UNCTAD developed the Liner Shipping Connectivity Index (LSCI) to measure how countries are connected in the liner-shipping segment (Hoffmann 2005). The index is calculated based on five components: number of ships, the container carrying capacity of those ships, the number of companies, the number of services, and the maximum ship size. Fugazza and Hoffmann (2015) extended this work by including the number of transshipments required between bilateral countries to reflect specifically the liner shipping connectivity between pairs of countries. To accommodate what is available and can be extracted in AIS, we construct the port connectivity index based on four of these components: total number of unique vessel visits from Norwegian ports, total number of unique vessels visits from abroad, maximum vessel size (represented as the product of max length and max draught), cargo loads (represented as the product of reported draught ratio and max vessel size). For each component a port's value is scaled by dividing it with the maximum value for all the ports in a given year. The four components are then averaged for each port, and the average is again divided by the maximum average for all the ports at the given year. Finally, the value is multiplied by 100 to obtain the final port connectivity index. This is also the way that the LSCI is constructed. The detailed formulas are presented below.

Let $x_{k,t}^{c}$ be the value of individual component k (k=4, in this case) for port c at time t. To be more specific, let $x_{1,c}^{t}$ represent the total number of unique vessel visits from abroad and $x_{2,c}^{t}$ represent the total number of domestic visits by unique vessels. Therefore, a frequent ferry service calling a port by one passenger vessel is only counted once during the time period (per month). Let $x_{3,c}^{t}$ represent the maximum vessel size, both from international and domestic visits. Here, we use the maximum of the product of vessel length and its reported max draught as a proxy.

$$x_{3,t}^{c} = \max_{t}\{LOA\_max_{v,t}^{c} * D\_max_{v}\} \tag{1}$$

Where, $LOA\_max_{v,t}^{c}$ is the maximum vessel length calling at port c during period t, $D\_max_{v,t}^{c}$ is the corresponding reported maximum draught for that vessel (v) over the entire sample period.

Let $x_{4,c}^{t}$ represent the maximum cargo load which is taken as the product of $x_{3,c}^{t}$ (max vessel size) and draught ratio. Draught ratio is the ratio between the reported median draught measure for the vessel before arrival of the port and its reported maximum draught over the sample period.

$$x_{4,c}^{t} = x_{3,c}^{t} * D\_median_{v,t}^{c} / D\_max_{v} \quad (2)$$

Where, $D\_median_{v,t}^{c}$ is the reported median draught for vessel *v* prior to calling at port *c*.

Each of the four components for port *c* at time t ($x_{k,c}^{t}$) are scaled by dividing the maximum value of that component among the ports. Then the average of the components is calculated for port *c*.

$$w_{c}^{t} = \sum_{1}^{K} \frac{x_{k,c}^{t}}{\max(x_{k,1}^{t}, x_{k,2}^{t}, \ldots, x_{k,C}^{t})} / K \quad (3)$$

Where, w_{c}^{t} is the averaged normalized value of all the *K* components for port *c* at time *t*;

The final port connectivity index (I_{c}^{t}) is then calculated as:

$$I_{c}^{t} = \frac{w_{c}^{t}}{\max_{C}(w_{1}^{t}, w_{2}^{t}, \ldots, w_{C}^{t})} \times 100 \quad (4)$$

As a demonstration of the index composition, Figure 1 shows the (scaled) components at the aggregate level, i.e. for all three types of vessels (cargo, tanker and passenger) from 2009 to 2015. The values for the four components, i.e. vessel visits from abroad, domestic vessel visits from, maximum vessel size and cargo size, are scaled based on equation (3). Figure 2 shows the overall port connectivity index for the ports, as well as breakdown by vessel types. It is worth to point out that Figure 1 presents the aggregated level with equal weight for three types of vessels. There exist variations at the vessel type level as shown in Figure 2. For instance, Stavanger has the highest connectivity overall, mainly driven by high passenger vessel visits (both domestic and international), however it is a minor port in terms of dry cargo. Bergen port is the second most connected port overall, however for the passenger vessel segment it is number four in the ranking. Narvik, being the main dry bulk port for iron ore exports, has the fifth highest connectivity in the cargo segment but it is really a small port in terms of passenger and tanker vessels. Nevertheless, the ports belonging to the largest cities of Norway, such as Stavanger, Bergen and Oslo, are also the top three ports in terms of connectivity.

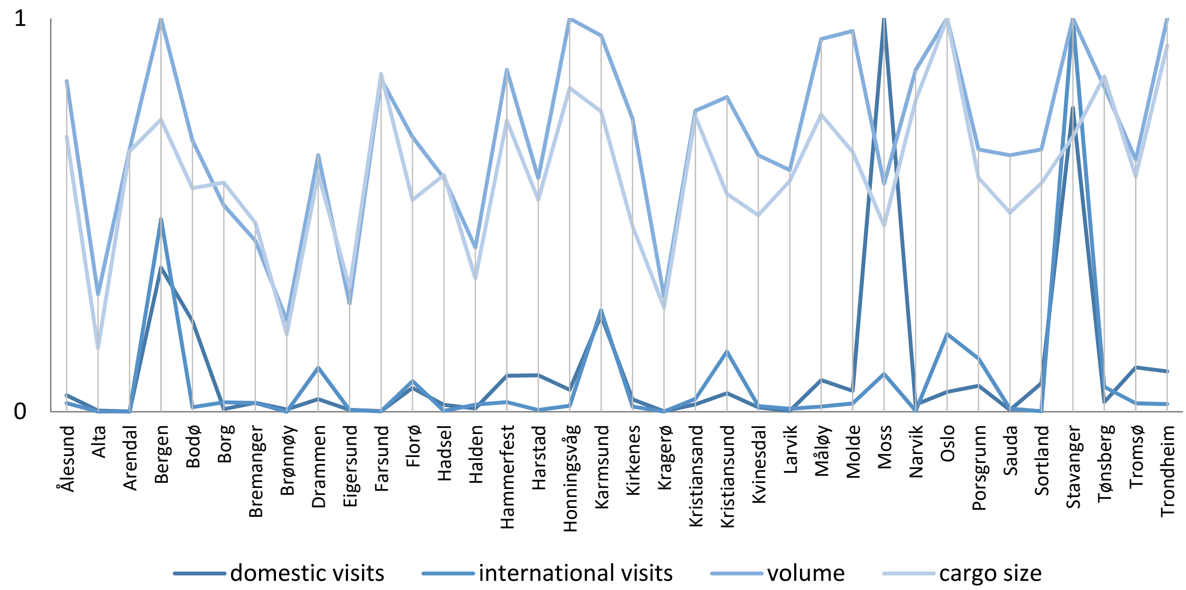

Figure 1. Port connectivity index components - aggregate level

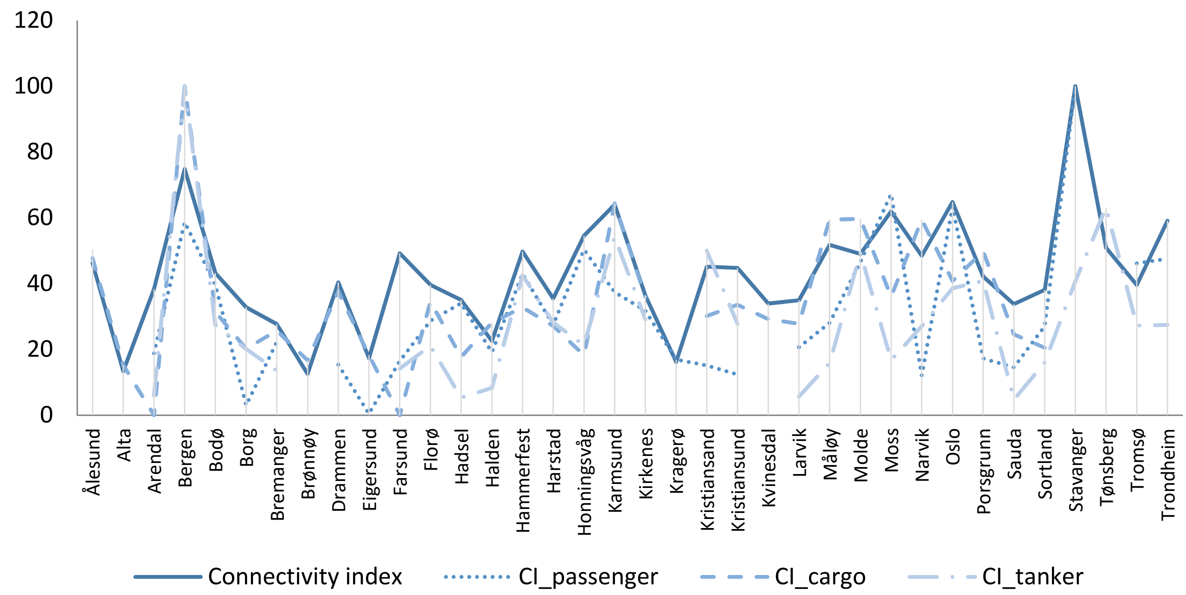

Figure 2. Port connectivity index - aggregate level

In order to show variation in the ports' connectivity over time, Figure 4, Figure 5 and Figure 3 add the time dimension for the passenger, cargo and tanker segments, respectively. Overall, the connectivity index value is consistent for the majority of the ports during the seven-year sample period. However, there are a few exceptions. In particular, in the passenger segment the port of

Oslo showed declining connectivity throughout the years and so does Honningsvåg (the northernmost city) since 2012. Importantly, we note that this change in index value only represents the relative connectivity position of that particular port in relation to other ports during that year, and it does not necessarily mean that the absolute measurement values change. Stavanger port has witnessed a strong increase in international passenger vessel visits in recent years and this contributes to the decreasing relative connectivity score for other ports. In the cargo segment, Narvik and Molde shows increasing connectivity, especially after 2011, but the absolute values of the four measures do not differ much. In the tanker segment, there is no obvious trend.

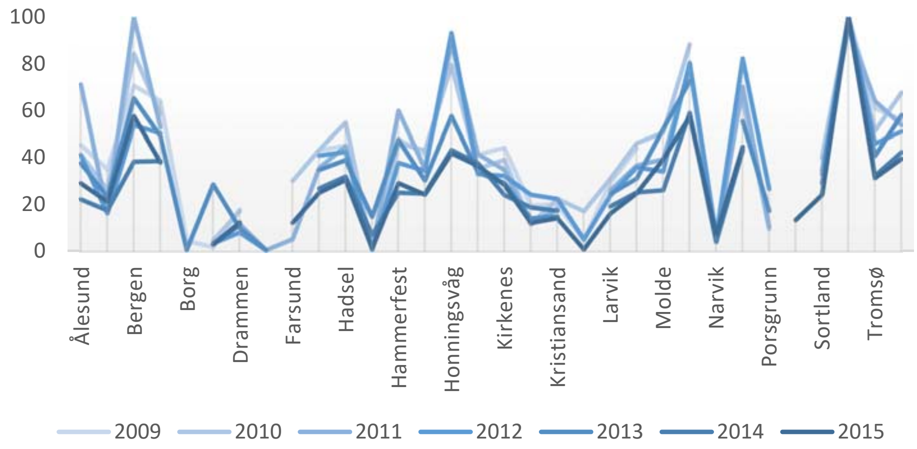

Figure 3. Norwegian port connectivity index - Passenger

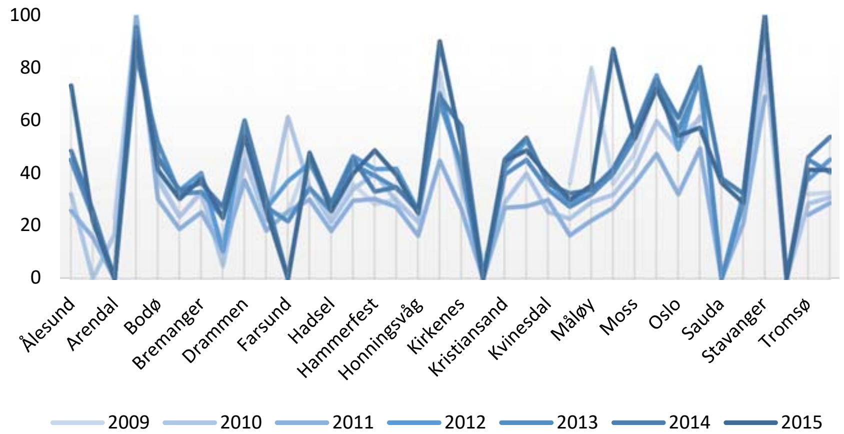

Figure 4. Norwegian port connectivity index – Cargo

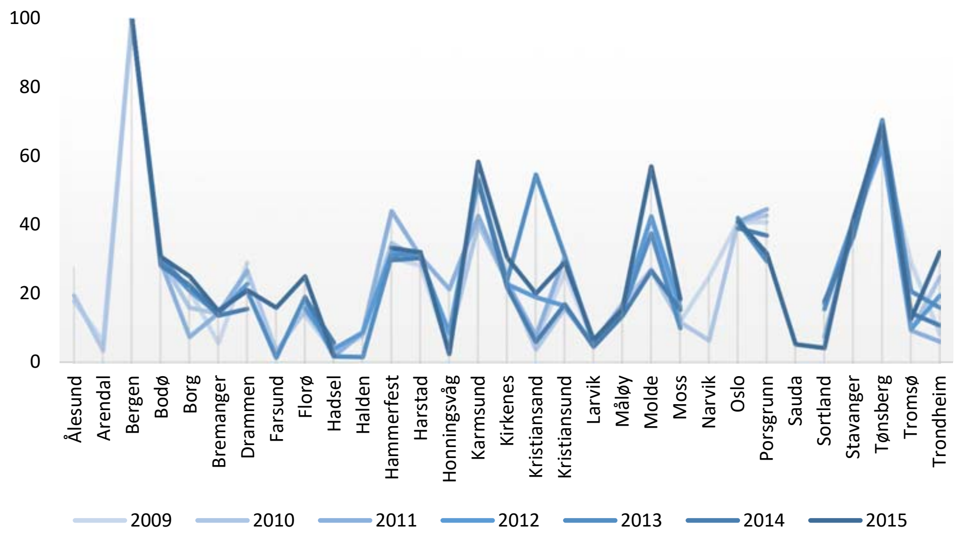

Figure 5. Norwegian port connectivity index - Tanker

3. Policy implications

This research has implications for port authorities and policy makers in the areas of port planning, infrastructure investment, environmental policies and Short Sea Shipping (SSS) promotion.

Our research provides the ability to drill down to the individual port level in terms of traffic flows across time and differentiate by cargo types and vessel sizes. More importantly, we assess the connectivity performance of individual ports in comparison to its peers during different time periods. This high level of detail is essential for investors and management in terms of transparency and can guide actions to drive continuous improvement in the port development. Ports are increasingly competing not as stand-alone focal points handling ships but as crucial links within supply chains. With increased awareness of the port's position in the network in terms of connectivity, productivity and capacity considerations, port authorities are better placed to make infrastructure investments and follow sustainable growth strategies. This is also crucial in the era when ports and their related manufacturing and services are being moved away from cities for practical and environmental reasons (for example, Singapore and Antwerp).

The constructed port connectivity index takes into account vessel visits from international and domestic ports separately. Some of the most prominent environmental issues that ports are focusing on are water, noise, and air emissions. Ships typically carry ballast water to provide stability and enhance voyage safety when they are less than fully loaded and discharge the ballast water when they reach the destination port. The ballast water contains organisms and pathogens that are present in the aquatic environment from where it originated. Vessels also carry marine organisms across aquatic environments on the hulls, i.e. hull fouling. These organisms – referred to as exotic, non-native, non-indigenous, alien, or invasive – may not only survive in the new environments but also out-compete native aquatic species. For instance, the Chinese mitten crab has been found to have devastating impacts on Scottish fish (Guardian, 2014). Therefore, the number of vessels visits, especially from international waters, is a good measure for monitoring and assessing the environmental risk of a port. Accordingly, port and municipality policies regarding the aquatic environment can be adjusted based on the proposed methodology in this research.

A good understanding of regional ports' connectivity also provides policy makers with knowledge in helping them to plan individual ports as well as maritime cluster development. The European Commission has emphasized the importance of blue economy growth through maritime clusters and cooperation with regional authorities (European Commission, 2017). Geographically adjacent ports with similar profiles yet detached traffic flows may consider to develop as a cluster as opposed to separate port areas. This falls well under the umbrella policy of Maritime Spatial Planning in Europe starting in 2014, in which the European Commission calls for concurrent uses of maritime space – economic, environmental and others – to be managed in a coherent way whilst minimizing competition with other activities or negative impacts on the environment. An aggregated view of the regional port network can improve the system efficiency by avoiding duplicated investment plans.

The assessment of reliability and connectivity along the Norwegian coast gives shippers essential knowledge in choosing transportation mode and route. This, in sequence, can direct maritime carriers, port authorities and related parties to promote more environmentally friendly transportation modes. In general, shipping has been regarded as 'the green mode' of freight transport – often substantiated by empirical data on average energy use per tonne-kilometer and corresponding emission figures. Such figures would typically show that shipping is 10-20 times more energy efficient than relevant road transport alternatives (Buhaug *et al.* 2009). (We acknowledge the potential effects from technology advancement towards greener transportation, such as LNG powered ships and electric trucks. However, the rollout is yet to be seen and this is beyond the scope of the current research.) The Norwegian government is promoting transferring freight from road to sea as a measure to develop environmentally friendly freight transport (Kystverket, 2017). Because not all ports have the required characteristics to achieve a hub role within the maritime transportation system, it could be an advantageous strategy for port authorities to develop Short Sea Shipping types of ports, rather than compete as hubs (Medda and Trujillo 2010). Merk and Notteboom (2015) point out that the SSS market in the EU is generally fragmented and underdeveloped. Though there exist many practical obstacles in SSS development, for example, insufficient volumes to achieve high service frequency, and the lack of consortiums or alliances among shipping/logistics companies who provide SSS services (Casaca and Marlow, 2002), research on regional port connectivity can provide some direction for port authorities towards SSS development. Also one needs to realize that the competitiveness of a seaport does not only depend on how well the port is connected with other ports, but also depends on the extent the cargo can reach its hinterland destination (e.g. Acciaro and McKinnon 2013).

4. Concluding Remarks

This research proposes an efficient yet empirically applicable methodology to measure port connectivity. We utilize AIS messages on ship positioning and extract information on when passenger, tanker and cargo vessels are calling at Norwegian ports. The high frequency AIS data is aggregated to construct statistical measures related to port connectivity such as the number of port calls as per port, the proportion of international traffic, and vessel- and voyage specifications (size, loading condition etc.). A port connectivity index, based on the principles of the UNCTAD LSCI, is calculated for the top 43 Norwegian ports. In comparison to measurement of cargo volume, the connectivity index proposed in this research gives a more comprehensive picture of a port's importance in the maritime transportation network.

This methodology can be applied to any regions and global ports for a wide range of cargo types. The algorithms developed for AIS data handling enables such a time consuming yet informative task to be accomplished, which is a big step up from the traditional conceptual modeling of port connectivity. Future research should include a more detailed analysis of the dataset from a 'complex network' point of view, such as how ports are connected to neighboring ports and internationally.

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