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Measuring Container Port Complementarity and Substitutability with Automatic Identification System (AIS) Data – Studying the Inter-port Relationships in the Oslo Fjord Multi-port Gateway Region

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ABSTRACT: This paper considers the degree of competition among small and medium-sized container ports located in a multi-port gateway region. The level of port competition is evaluated by means of an analysis of the revealed preferences in the port-calling pattern of container feeder vessels deployed on their various links and routes. Unit of analysis is feeder vessel sailing legs and ports stays at/between adjacent container ports. At these ports' terminals, ships are moored and loading and unloading of containers are performed. The vessel movement data is provided by the Automatic Identification System (AIS). A study of the principal container ports in the Oslo Fjord area is performed, measuring the actual container feeder traffic during the year of 2015. It is demonstrated to which extent ports in the Oslo Fjord region are acting as substitutes, and to which extent they are functioning more as a complement to each other.

1 INTRODUCTION

Among the objectives shared by countries within the European common market is the objective of improving the performance of their multimodal logistics chains. By 2030, 30% of goods (compared with 2005) transported by road freight over 300 km in Europe should shift to other transportation modes such as seaborne; by 2050 this percentage should increase to more than 50%, in order to achieve a more competitive, sustainable and resource-efficient transport system (European Commission, 2011). Therefore, knowledge on aspects of inter-port competition (Wang et al., 2005), particularly between comparable and adjacent ports located within a single gateway region (Notteboom, 2009, 2010) is essential in order for both economic and sustainable development reasons. Firstly, for a shipping liner to demand a port service and the port to supply that service, the provision of this service will ultimately be resource demanding for the actors involved. Secondly, ports' service availability and ship sailing routes and ports called influence carriers' operating costs, and may include both economic, environmental and societal aspects, for ships both at sea and in port. Therefore, from the perspective of both the shipping liner companies, port authorities and governors, the actual ship calls among the container ports in a gateway region need to be ascertained. The rationale for this study is that when conducting research on inter-port competition, port economic theory attests the concepts of complements and substitutes (see for example Wang et al., 2005).

The research question in this study is to which degree the container ports in the Norwegian Oslo Fjord are competing with each other in attracting shipping liners ship calls?

Unit of analysis is container feeder ships actual sailing routes and roundtrips between adjacent container gateway ports within the Oslo Fjord region.

To answer the research question the complementarity and substitutability among adjacent Oslo Fjord container ports is measured. The degree of substitutability from a shipping operator's standpoint is assessed by means of an analysis of revealed preferences in the Oslo Fjord container port-calling pattern of ships deployed on different trade routes.

The container ship identification and motion data in this study are provided by AIS. AIS is a telemetric system that automatically transmits a ship's information to ports and ships in the vicinity. To obtain reliable AIS results (Harati-Mokhtari et al., 2007) we use static and dynamic ship information from the AIS data. Static ship information include static data such as ship IMO number and name, while dynamic motion-related information include information such as GPS positions. AIS interconnected sensors repeatedly and automatically update dynamic information.

This study is - to our knowledge - the first to study the foreland dimension of complementarity and substitutability within a multiport gateway region with ship movement data from AIS.

The paper is organized as follows: The next section is a literature review of the previous studies on inter-port competition and the gauging of complementarity and substitutability among container ports in multi-port gateway regions. The subsequent sections outline the methodology used in the analysis, the data used and the results obtained. The concluding remarks are presented in the final section.

2 LITERATURE REVIEW

There is a vast literature considering the application of AIS data to measure ship and port economic performance or safety of operations, see for example Naus et al., 2007; Ni Ni et al., 2011; Chen et al., 2016. To achieve insight into the degree of port competition in general, and specifically neighbouring ports' competition, the theory of complementarity and substitutability among adjacent gateway ports, as presented by Notteboom (2009) will be described. The level of substitutability from a shipping line's perspective can be measured by means of an analysis of ship operators' revealed preferences in the port bundling and port-calling pattern of ships deployed on different trade routes. Notteboom (2009, p.745) asserts:

- 'Two load centres are perfect substitutes for a port user if that user is willing to substitute one load centre for another at a constant rate'
- 'Two load centres are perfect complements if they are always "consumed" together in fixed proportions by a port user'

Moreover, 'A high degree of substitutability between individual load centres is associated with fierce competition. In contrast, a high level of complementarity would create an environment in which mutual coordination prevails – at least for the container market segment considered' (Notteboom, 2009, p.745).

Next, as we in this paper investigate adjacent ports –or ports in proximity- what that means in our context needs to be clarified. This is not straightforward, as there are several dimensions of proximity; one example of dimensions of port proximity is geographical proximity (Hall & Jacobs, 2009), which is the spatial distance between actors and their activities. Another example of dimensions of port proximity is functional proximity. Our two main proximity dimensions, i.e. criteria, when sampling ports in this study, are: (1) geographical proximity; the ports are within the same geographical area; which is the Oslo Fjord region, and (2) service proximity; that ports provide the service of loading and unloading containers ship-to-shore, performed with either ports' quay cranes or the ships own cranes (lift-on lift-off, i.e. Lo-Lo). The Oslo Fjord region, which can be characterised as a multi-port gateway region (Notteboom (2010), includes seven container gateway ports within the Norwegian port trunk-network, see Figure 1. According to Berg and Schøyen (2014), these ports are either being owned by municipalities: Either as an inter-municipal company or as municipal businesses, and therefore ports compete on conditions similar to any private enterprise.

Figure 1. The principal container ports in the Oslo Fjord region. Compiled from Berg & Schøyen (2014).

Figure 1 shows the ports in the multi-port gateway of the Oslo Fjord region. Drammen and Oslo are in the northern end of the western and eastern fjord arm respectively. Moss and Borg are located on the eastern side of the Oslo Fjord. Kristiansand, Grenland, and Larvik are on the western side.

Foreland denotes the geographical area a port serves through networking with other feeder ports (Bichou, 2013), the foreland considered in this paper are the principal container ports in the Oslo Fjord region, as depicted in Figure 1, the feeder network between them, and with foreign ports, which are on European mainland and the UK, see Section 5.

3 METHOD

In this section, we first descript the method to ascertain ships' port calls, that is to detect where and when a ship is moored to a container quay. Thereafter we describe the method applied to define and measure port-calling patterns of ships linked to the sampled ports.

3.1 *Ship movement and port call data from AIS*

The unique ship identification identity known as IMO numbers of the ships and ships' movement data are based on Automatic Identification System (AIS) data which were delivered by the Norwegian Costal Administration, and are used to measure ship sailings between these ports and evaluate some implication on inter-port competition.

The AIS data (geographic positions in latitude (lat) and longitude (long), and time) was sorted in time per ship following Hjelmervik et al. (2017). The Universal Transverse Mercator (UTM) positions in zone 33 were calculated from the positions following the formulas originally derived by Krüger (1912). The speed of ship m at time step n is estimated by

$$SMG_m^n = \frac{\sqrt{\left(UTM_{x,m}^{n+1} - UTM_{x,m}^{n}\right)^2 + \left(UTM_{y,m}^{n+1} - UTM_{y,m}^{n}\right)^2}}{T_m^{n+1} - T_m^n} \quad (1)$$

where $\left(UTM_{x,m}^{n}, UTM_{y,m}^{n}\right)$ is the UTM position of ship m at time T_m^n. "A ship is defined as being berthed in port at time T_m^n if the speed of the ship is equal to zero and its position is inside one of the geographical boxes associated with the container terminals' berth(s). The time span the ship lies berthed at the terminal is the time from it arrived until it left the port" Hjelmervik et al. (2017).

3.2 *Measurement of port bundles for roundtrips to a gateway region*

Inter-port competition can be defined as the competition between (or among) different ports (Wang et al., 2005); within the context of the study reported in this paper the discussion is limited solely to container ports.

The ports included in a roundtrip are the ports a ship visit before leaving the multi-port gateway region. A ship is assumed to leave the gateway region if there is a time span of more than 48 hours between two subsequent berthings.

Reshuffling the order of the port calls or port swapping are common ways of handling ship delays in multi-port gateway regions, for the Oslo Fjord region see Hordnes (2016). Therefore, the sequence or logistical patterns (Bichou, 2013) the ports are called within one roundtrip are not taken into consideration.

Single-port roundtrips are when only one port is called in the gateway region for one and the same roundtrip. Multi-port roundtrips are when two or more ports are called in the gateway region for one and the same roundtrip.

Figure 2 illustrates a multi-port gateway region (Notteboom, 2010) with ship roundtrips to foreign ports outside the region.

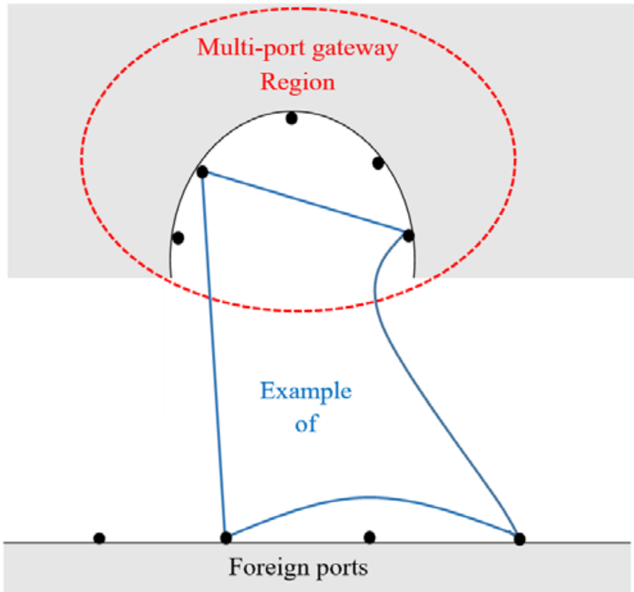

Figure 2. Schematic illustration of a multi-port gateway region with five ports, and a roundtrip that includes two ports in the multiport gateway region and two foreign ports.

4 DATA

The paper studies container Lo-Lo ship traffic between the Oslo Fjord ports during year 2015. The geographical location of these ports' container terminals and their nautical approaches were identified from digital coastal maps provided online by the Norwegian Coastal Administration. Seven container ports are identified and considered, consisting of eleven terminals. Each of those terminals are equipped with container handling cranes and yard stacking vehicles to load and discharge ungeared container ships (Schøyen and Odeck, 2017). Data on the individual Oslo Fjord port's annual container traffic, measured in Twenty feet Equivalent Unit (TEU), for the year of 2015, were collected from Statistics Norway. The dataset contains AIS static data, including IMO number and AIS dynamic data such as time and ship position coordinates (lat and long). More than 2.4 million AIS observations from 2 347 ships of different types are collected from 1 January 2015 to 31 December 2015. Using the geographical position of the container terminal(s) situated in each port, combined with the AIS data, 97 different container ships were identified as berthing at the aforementioned seven container ports. Table 1 depicts the sampled ports' ship calls and container traffic.

Note that missing AIS signals and possible errors when identifying container ship calls and container traffic flow, might introduce noise in the data set. The results should therefore be received with some caution.

Table 1. Ship traffic and container flow over the principal container ports in the Oslo Fjord area. Compiled from AIS and Statistics Norway.

Year 2015	Number of unique container ships Source: AIS < 5 calls	≥ 5 calls	Container traffic per port, TEUs Source: Statistics Norway
Oslo	5	8	195 466
Drammen	4	13	59 464
Moss	5	19	63 107
Borg	5	8	45 879
Larvik	12	11	61 807
Grenland	14	7	34 557
Kristiansand	19	11	51 460
Total			511 740

Table 1 shows that the definitive large load centre among the Oslo Fjord ports is the port of Oslo, with a container traffic equal to 195 466 TEU, which equals nearly 38% of the combined Oslo Fjord ports' container traffic.

5 RESULTS AND DISCUSSION

Figure 3 shows examples of typical container feeder pendulum services, illustrating some foreign container ports, which to the Oslo Fjord ones are connected.

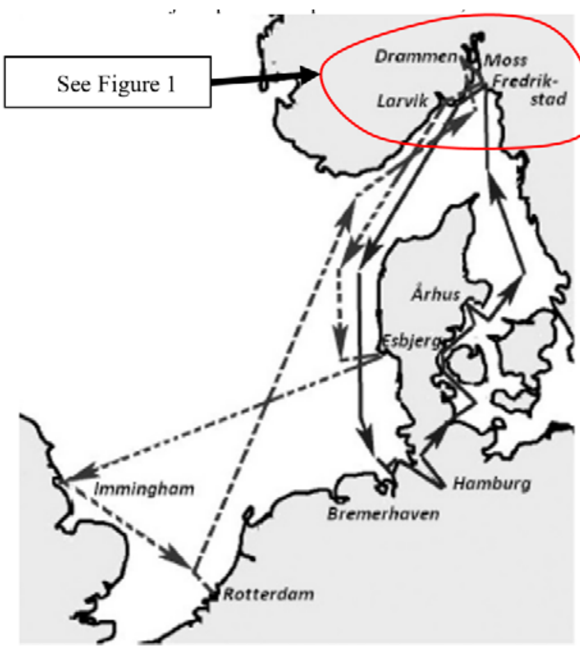

Figure 3. Examples of typical container feeder pendulum services. Compiled from Schøyen & Bråthen (2015). The continuous lines represent a typical feeder service between the Oslo Fjord ports and ports in Germany, Sweden and Denmark. The dashed lines represents an example of an intra-European service between Oslo Fjord ports and ports in the UK, the Netherlands, and Denmark.

The roles of feeders in supply chains – relative to the Oslo Fjord context – is explained in Schøyen & Bråthen (2015). Short sea container shipping in Europe can be divided into two market segments. The first segment serves pure intra-European transportation and is often referred to as short sea shipping. The second segment, feeder service, is an extension of the ocean liner market. A feeder service connects at least two ports in order for the containers to be redistributed to or from an ocean-service in one of these ports (UNECE, 2001). In this niche, feeders represent a link in global hub-and-spoke containerized networks. For feeder services, flexibility in routing and scheduling between ports and between terminals within a port area is imperative.

Totally 707 roundtrips with totally 1482 port calls were identified. An initial analysis gives that on average 2.1 ports were called per roundtrip.

Next, ships are frequently – and on the same roundtrip (time less than 48 hours)- moored to more than one berth during one port call; that means they are hauled from one terminal to another within the port area, or between different quays at one terminal within the port area. For port of Drammen, we find three weekly and regular container ship calls, a closer investigation shows that Drammen has only one container ship berth, therefore sometimes ships go to anchorage just outside the port after it has unloaded containers and then returns to the berth for loading after the other ship has finished its operation. If the anchorage operation and stay has a duration of less than 48 hours, that will be counted as one port call within one roundtrip.

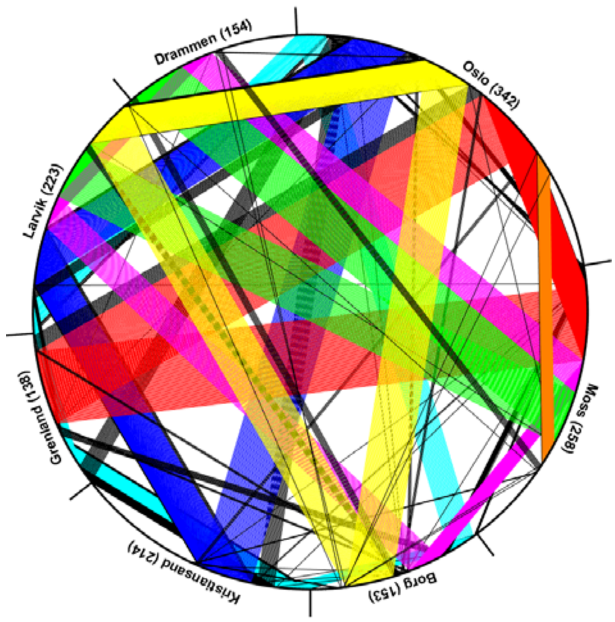

Figure 4. Illustration of roundtrips that includes Oslo Fjord container ports. The lines connect ports that a ship visits during a roundtrip.

To go in more details about the differences between port bundling per roundtrip among the seven ports, Figure 4 is developed. The colored lines in Figure 4 show the most common ship roundtrip patterns between Oslo Fjord container ports. As pointed out in Section 3, the sequence that the ports are called within one roundtrip are not taken into consideration. The widest lines between ports in Figure 4 are the most common ship roundtrip, i.e. port bundle, which are the red lines that are forming the triangle Grenland - Oslo - Moss.

Figure 4's labels on the circle's rim show that there were 154 different container ship roundtrips on

Drammen and 343 on Oslo. For each individual port, the circle's rim has a certain arc length, which denotes the combined number of roundtrip to that port. For the part of on port's arc length which have no lines attached, this denotes roundtrips with calls to only that port and no other Oslo Fjord port on that roundtrip; i.e. a single port roundtrip.

Figure 5 depicts number of container ship berthings at the two neighbouring ports located near the most dense population areas in the capital of Norway: Oslo and Drammen.

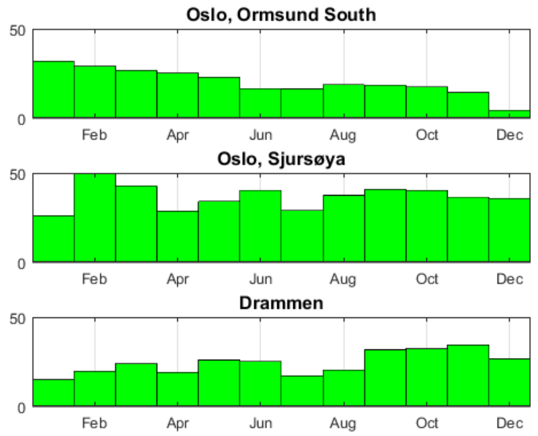

Figure 5. Number of berthings at three of the Oslo Fjord container quays.

During 2015, the number of berths at Oslo, Ormsund, was reduced until the container quay closed down on 1 January 2016. As illustrated in Figure 5, the other container terminal in Oslo: Sjursøya, did not increase accordingly. Drammen, however, experienced an increase, which indicates that Drammen and Oslo ports are competitors. Oslo and Drammen ports are located in the end of two different fjord arms, but have a largely overlapping foreland and hinterland. Figures 4 and 5 show that ship operators seldom decide to call on both Oslo and Drammen at the same roundtrip. Therefore, these two ports will typically be perceived as substitutes. Substitutes are characterized by fierce competition (Notteboom, 2009), and Figure 4 informs – as an example, that the ports of Oslo and Drammen were competitors in respect of container business.

Table 2 depicts –per individual port- number of single port calls versus number of multi-port calls. Figure 3 and Table 2 show that for many roundtrips to the Oslo Fjord region, only one port is called, i.e. single-port roundtrip. The column to the right in Table 2 shows that Drammen and Kristiansand were the port with the highest single-call ratio, with 42% and 50% respectively, i.e. they were the ports which faced the highest substitutability and foreland competition - measured in respect of attractiveness of shipping companies.

Table 2. Ratio of number of single-port calls versus number of multi-port calls for roundtrips on Oslo Fjord container ports.

	Port calls within a roundtrip [No.]	Single-port calls [No.]		Multi-port calls [No.]	
Oslo	342	83	(24%)	259	(76%)
Drammen	154	64	(42%)	90	(58%)
Moss	258	71	(28%)	187	(72%)
Borg	153	22	(14%)	131	(86%)
Larvik	223	3	(1%)	220	(99%)
Grenland	138	1	(1%)	137	(99%)
Kristiansand	214	106	(50%)	108	(50%)
Total no. of port calls	1482	350	(24%)	1132	(76%)
Total no. of regional calls	707	350	(50%)	357	(50%)

Table 3 shows the most common port bundles for roundtrips on the Oslo Fjord container ports. The most common port bundle is that -for one roundtrip- either three ports or one port is called. Notably, roundtrips with two port calls in the Oslo Fjord, are relatively rare.

Table 3. The seven most common port bundles for roundtrips on the Oslo Fjord container ports.

Port bundle	Ports per roundtrip [No.]	Roundtrips [No.]	Line colours in Figure 4
Grenland-Oslo-Moss	3	64	**Red**
Kristiansand-Larvik-Oslo	3	46	**Blue**
Larvik-Drammen-Moss	3	46	**Green**
Larvik-Oslo-Borg	3	41	**Yellow**
Larvik-Drammen-Moss-Borg	4	28	**Purple**
Kristiansand-Grenland-Larvik-Oslo-Borg	5	25	**Light blue**
Oslo-Moss	2	20	**Orange**

Table 3 shows that Oslo is included in five of the seven most common bundles. Among these five bundles, three (Grenland-Oslo-Moss, Larvik-Oslo-Borg and Kristiansand-Grenland-Larvik-Oslo-Borg) are ships calling ports on both wester side and eastern side of the Oslo fjord (confer Figure 1) and two are calling only ports on one side of the fjord (west: Kristiansand-Larvik-Oslo and east: Oslo-Moss). For the two bundles where Oslo are not included (Larvik-Drammen-Moss and Larvik-Drammen-Moss-Borg), the ships are calling ports both at the western side and eastern side of the Oslo Fjord.

6 CONCLUSION

The research question of this study is to which degree are the container ports in the Norwegian Oslo Fjord competing with each other in attracting shipping liners ship calls? The container ship calls to seven neighbouring ports in the Oslo Fjord were studied with AIS data, in an effort to investigate degree of substitutability and complementarity between them.

The theoretical contribution of this paper is that a framework for applying AIS data is developed and presented to analyse revealed preference of shipping liners when performing roundtrips on ports in the Oslo Fjord multi-port region.

Half of the feeder ship roundtrips between Oslo Fjord ports and foreign ports call one single port in the Oslo Fjord; for the other half they call multi-ports in the Oslo Fjord. Notably, for multi-port calls, three port calls are more common than two port calls: Feeder services frequently connect ports located at the western and eastern side of the Oslo Fjord. It is demonstrated to which extent some of the ports in the Oslo Fjord region are acting as substitutes, and to which extent some ports functions more as a complement to the largest load centre: Oslo.

The results presented should be relevant and useful for shipping companies, port and container terminal managers and policy makers both on port foreland development, for example nautical access, hinterland connections, for example road planning, and for researchers within the field of ship routing and port economics. The method and results provided are probably less valuable for each individual port manager and container terminal operator, as their ship traffic are known for them in their own collected statistics.

However, the results should be received with some caution, as there bound to be noise in the data and the presented results, due to missing AIS signals and possible errors when identifying container ship calls and container traffic flows. Regarding the former, the AIS data can be considered as fairly "clean", as they originated from automatically generated GPS-signals and not from human input into the AIS-system, which frequently contain errors in the given context. Thus, one future area of potential studies is to make a closer investigation on what is a container ship – in respect of ship design and freight capability- and what are the container traffic flows (in TEUs) and commodities transported between the ports considered. Another possible future extension in the container port competition and cooperation context is to apply different approaches to the same dataset, thus triangulating the findings and exploring the validity of the approaches.

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