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Do Larger Ships Visit Fewer Regions/Ports?

An Empirical Analysis on Global Liners Serving China

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Abstract

We study empirically how global carriers determine the regions to serve and the number of port calls on the Chinese coast, based on service schedules in 2011–15. Increasing ship size, within a certain range, leads to more clusters/ports visited. Beyond that, container ships visit fewer clusters, not necessarily fewer ports. Therefore, even if two ports are very close, as long as they are efficient, they may both be called at in a service. This signifies the difference between the hub-and-spoke structure in liner shipping and that in aviation, where it is unnecessary to have two hubs in the same place.

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1.0 Introduction

Intuitively, larger vessels in an international shipping service should visit more regions or call at more ports, so as to fill up more space in the ships before sailing across the ocean. However, many academic studies have stated that when ships get bigger, liner shipping services will adopt a ‘hub and spoke’ (H&S) network, such as that in aviation, and only call at a few hub ports (Hayuth, 1981; Notteboom, 1997; Imai *et al*., 2009). So what really happens in practice?

A liner shipping service refers to a fleet of container vessels of similar capacity, operated by one or more liner shipping companies, carrying containerised cargoes through a predetermined sequence of ports in a fixed schedule. Due to global liners’ relentless pursuit of economies of scale, increasingly larger vessels are built and deployed in these services. In the past 50 years, the largest container ships in the water have increased from 1,530 to 19,870 TEUs, with even larger vessels of 20,988 TEUs already on the order books.[1] Concurrent with this trend is the continuous concentration occurring in liner shipping markets. As of 17 October 2015, the top three liner operators controlled 37.2 per cent of the world’s capacity, the top six controlled 50.8 per cent, and the top 20 had 84.9 per cent. The four major alliances, with members from the top 20 liner operators, operated 81.9 per cent of the world’s capacity. In addition, the recent mergers between COSCO and CSCL,[2] and between CMA CGM and NOL,[3] have accelerated the concentration process.

On the bright side, this trend of ships becoming larger enables the global liners to provide efficient and reliable services at a low cost, which allows multi-national businesses to implement efficient logistics management strategies, and also stimulates international trade. However, major port operators are concerned about the impacts of the H&S network structure in an increasingly concentrated liner market. They have to invest aggressively to expand or upgrade their facilities in order to reduce congestion at the hubs and compete for the hub position, which may result in overcapacity in port supply. In addition, the cost advantage of large ships can only be realised if it has a high loading factor. Facing a low demand, large shipping companies tend to form alliances to make full use of the large ships, which increases the possibility of collusion among major liner operators.

Therefore, ascertaining the status and trends in the liner network structure due to the increase of ship size can help different stakeholders in the shipping industry, as well as the policy makers at different levels, to understand the possible impacts of increasing ship size and market concentration, enabling them to take appropriate measures. However, as shown from the literature review below, most studies on H&S network structure in shipping are from a theoretical point of view. In reality, the design of liner shipping services has to consider the geographic condition of the ports, which are the main limiting factor for port accessibility, as well as the economic activity of a hinterland that determines the total demand for container shipping in the port cluster — a group of near-by ports serving the same hinterland. Consequently, the impacts of ship size on liner service decisions must be location specific.

As will be shown in Section 3, China is by far the largest country in containerised trade.

[1] www.alphaliner.com, accessed on 21 December 2015.

[2] www.wsj.com/articles/china-approves-merger-of-cosco-china-shipping-1449834748.

[3] www.wsj.com/articles/french-shipper-cma-cgm-to-make-offer-to-buy-neptune-orient-lines-1449454066.

Seven (mainland) Chinese ports are among the world's top 10 busiest container ports. There are more than 500 liner services to and from China, and all of the top 20 liner operators have services that call at Chinese ports in several port clusters. By observing the attributes of these liner services, the number of clusters visited and the number of port calls, the statistical evidence on the relationship between the number of clusters/ports visited and the liner attributes, including ship size, can be discovered. This evidence can provide a better understanding of the behaviour of liner shipping networks serving the Chinese trade.

Based on the data of liner services to and from China, this paper analyses the statistical relationship between the number of port clusters visited, as well as the number of port calls in each service, and various attributes of the services. We find that for the international liners serving China, if the ship is less than 12,000 TEUs, cluster/port visits will increase along with ship size. Beyond that limit, larger ships may visit fewer clusters, but not necessarily a smaller number of ports. This reveals the behaviour of H&S structures in liner shipping: super large container vessels may only choose to visit clusters with a higher demand. However, they may not limit the number of port calls in a cluster — if the ports have similar demand levels and operational efficiency. Therefore, for a hinterland with a high demand for shipping, there can be more than one hub in the same region.

The paper is organised as follows. Section 2 reviews existing literature regarding the impact of ship size on liner shipping networks. Section 3 describes the background to Chinese ports and port clusters, and the liner services to and from China. Then, in Section 4, the major factors affecting cluster/port visits are introduced, together with the description of the data. Section 5 applies an ordered logit model to cluster visits, and an Ordinary Least Square (OLS) model to port visits, and then presents the empirical results. Finally, Section 6 contains a summary of the results and discusses policy recommendations.

2.0 Literature Review

The behaviour of large container ships has been well studied in many diverse areas: the optimal ship size under economies of scale (Jansson and Shneerson, 1982; Lim, 1994, 1998; Cullinane and Khanna, 1999, 2000); H&S liner networks with large ships (Imai *et al.*, 2006, 2009; Chen and Zhang, 2008; Tran and Haasis, 2014), and liner operations research (Hsu and Hsieh, 2007).

Jansson and Shneerson (1982) analysed optimal ship size from the perspective of minimising the total cost per ton-mile for a given number of ports. Using comparative statistics, the optimal ship size was found to increase with shipping distance and port productivity. They further analysed economies of scale from the perspectives of both the liner operators and the shippers, which enables the identification of economies of trade density (Jansson and Shneerson, 1985). The research pointed out that for given trade volume, the greater the coast-to-coast distance, the more extensive will be the service range. This is similar to our empirical result that for the long-distance routes, such as Far East (FE)–North Europe (NEurope) route, liners will visit more clusters.

The economic viability of mega-container vessels and H&S network structures need to be considered in different trade routes. Imai *et al.* (2006) studied the viability of container mega-vessels in a competitive environment using game theory. They compared two strategies: Multi-Port Calling (MPC) of two port callings per week by 5,000 TEU ships, and H&S network of one port calling by a 10,000 TEU mega-ship. They found that mega-vessels are viable for the Asia–Europe route, but not for the Asia–North America route if freight rate and feeder costs are high. Chen and Zhang (2008) developed an integer programming model to compare the economic feasibility of an H&S network using mega-containerships, vs. that of an MPC network using conventional containerships, in the Asia–Europe and Asia–North America routes. The capacity of conventional ships is 6,500 TEUs, while that for mega vessels is 9,600 TEUs and above. In the H&S network, only one port was selected as the hub in Asia: Hong Kong port. They concluded that if the feeder cost is too high, the hub and spoke system using mega vessels may cost more per TEU than conventional vessels using MPC. Imai *et al*. (2009) found that taking into account empty container repositioning and container management costs, MPC is superior to the H&S structure. Most of the conclusions are made based on the assessment that the H&S structure only allows calling on one hub port in a region.

Lim (1994) evaluated the economies of container ship size using the operation performance data in earnings and costs of container service, and concluded that there is no generally applicable answer to the question of optimum vessel size. Later, Lim (1998) further pointed out that pursuing economies of scale cannot be a panacea to the profitability of carriers, and that cooperation is a more desirable method for better returns. This implies that alliances would have an impact on the optimal ship sizes.

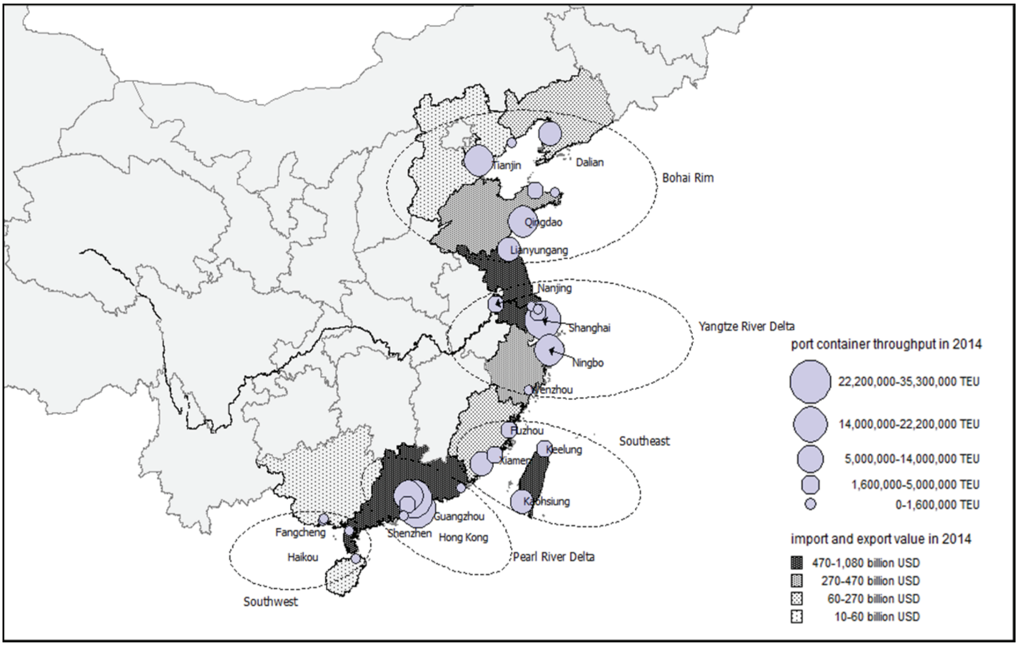
Tran and Haasis (2014) studied the liner shipping network structure on the east–west route, and used the degree of centrality to measure port strength. They found a process of port decentralisation from the data between 1995 and 2011, where secondary ports have grown and lowered the centrality of larger ones. As ship sizes are generally increasing over time, liners were calling at more secondary ports even as the ship size increases.

Wang and Wang (2011) studied the spatial pattern of the global shipping network and its H&S system using the liner schedule of 24 carriers during July 2008. By calculating the number of shipping lines to and from a port, the study identified regional hub ports with the number of feeder ports and its hinterland. The hub ports identified in the East Asia region are Hong Kong, Shenzhen, Shanghai, Pusan, Tokyo, Tianjin, Qingdao, and Kaohsiung. It revealed that two hub-ports can co-exist in very close proximity, such as Hong Kong and Shenzhen.

Considering the benefits to both shippers and carriers, Hsu and Hsieh (2007) developed a two-objective model to study the optimal routing, ship size, and sailing frequency in liner shipping by minimising shipping costs and inventory cost. The H&S structures were also predetermined in this model.

Existing studies have addressed many issues associated with the increase in containership size. The study of H&S in liner shipping, as one of the issues in the trend of increasing ship size, has also attracted much attention. However, there is no existing study on whether the increase in ship size will necessarily lead to reduced port visits, and whether it will also result in a reduced coverage of the service area — the hinterland. Compared with the existing studies, our research identifies the statistical relationship between clusters/ports visited and the attributes of liner services in a specific geographical region. The focus of our research is to investigate the current status of the application of H&S networks due to the increase in ship size, and how this will affect shipping liners' choices as to the regions to serve, and the number of port calls. Also, it points out that the formation of H&S

Figure 1
Distribution of Five Port Clusters and Container Ports in China



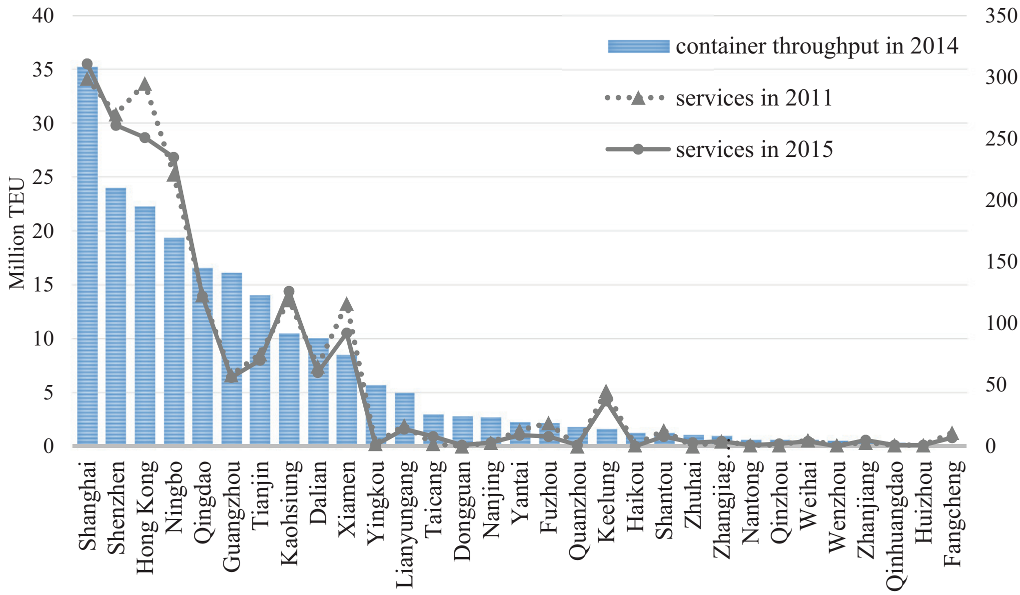
networks in liner shipping may not necessarily follow the same pattern as those in aviation (Zhang *et al*., 2011).

3.0 Liner Shipping Services Calling at Chinese Ports: 2011–15

This section introduces the economic activities in the coastal areas of China, the container ports and port clusters, and the international shipping lines calling at these ports. According to their location, Chinese coastal ports can be grouped into five port clusters, namely Bohai Rim, Yangtze River Delta (YRD), Southeast, Pearl River Delta (PRD), and Southwest port clusters (Figure 1).[4] Global liners serve the Chinese international trade by calling at a total of 31 ports in these five clusters. The throughputs of these ports in 2014, and the liner services to and from each port in 2011 and 2015, are shown in Figure 2. The data on container throughput are from the Statistics Yearbook of China (www.stats.gov.cn), and the liner service information in 2011 and 2015 are from the Alphaliner online database (www.alphaliner.com). Since liner shipping services may change at any time in a year, the data for each year represent the available services at the time of download. In addition, due to the very high subscription cost of the Alphaliner database, we are only able to obtain two years' data. Nevertheless, it is sufficient to observe the general trend for the change of liner services calling at Chinese ports.

[4]Note that here 'China' refers to mainland China, Hong Kong, and Taiwan.

Figure 2
Container Throughput and Change of Liner Services at Chinese Ports



From Figure 2, we can see that container trade activities are very active in Chinese coastal ports. There are nine ports with container throughput higher than 10 million TEUs in 2014. The distributions on the number of liner services are largely consistent with the port throughput. Their distributions are largely stable over the five years between 2011 and 2015, except for Hong Kong, and to a lesser extent, Xiamen, which saw an obvious drop in the number of services. The drop in Hong Kong is mainly due to competition from the other ports in PRD. Xiamen is a port specialised for cross-strait trade, and the drop is mainly due to its capacity limits.

3.1 Overview of liner shipping services calling at Chinese ports in 2011 and 2015

Due to the high volume of international trade, many Chinese ports are among the busiest container ports in the world. In 2015, seven out of the top 10 busiest container ports in the world were from (mainland) China;[5] among the top 20, 10 are from China. This large trade volume requires a large number of liner services, and Table 1 summarises basic information

Table 1
Summary of Statistics on Liners Serving Chinese Coast, 2011 and 2015

	Services	*Weekly capacity (million TEUs)*	*Number of ships*	*Average size*	*Median size*
2011	539	1.87	2,841	3,499	2,576
2015	531	2.19	3,229	4,117	2,702

[5]Source: www.chinaports.org/info/201511/190122.htm.

Table 2
Service Attributes for the Liners Serving China, 2011 and 2015

	Rank	*Service number*		*Average ship size*		*Total weekly capacity*	
	2015	*2011*	*2015*	*2011*	*2015*	*2011*	*2015*
Maersk Line	1	59	39	5,969	5,114	351,292	199,007
MSC	2	23	14	8,708	6,447	190,569	90,264
CMA CGM	3	53	57	6,763	8,054	356,676	458,164
Evergreen Line	4	44	62	3,948	5,786	174,728	360,513
Hapag-Lloyd	5	12	20	3,992	5,869	47,901	117,384
COSCO	6	27	31	2,820	4,465	74,948	139,906
CSCL	7	55	66	5,181	7,109	283,987	469,200
Hamburg Süd	8	12	19	3,905	7,929	46,862	150,650
Hanjin	9	28	28	4,216	5,113	118,056	143,175
MOL	10	20	18	5,556	4,556	110,903	82,715
OOCL	11	20	27	3,421	3,972	68,429	107,252
Yang Ming	12	19	25	2,970	3,868	56,425	96,697
APL	13	24	13	5,264	4,471	126,333	58,123
NYK	14	19	18	3,125	3,339	58,590	60,108
UASC	15	19	34	7,055	9,323	134,048	316,987
HMM	16	15	11	4,240	4,092	63,605	45,010
K Line	17	72	58	4,996	4,118	358,824	238,422
Zim	18	9	9	4,478	5,378	40,300	48,398
PIL	19	25	26	3,422	3,980	81,595	103,480
Wan Hai	20	29	31	2,796	2,775	81,088	87,640
Chinese liners		257	290	2,734	3,707	704,113	1,084,475
Other Asian liners		246	246	3,860	4,015	941,756	986,105
Non-Asian liners		139	124	6,045	5,631	826,992	698,062
Alliance		39	94	6,529	9,160	254,620	861,066

Source: www.alphaliner.com.

about the liner shipping services calling at Chinese ports. Since, in liner shipping, there is no fixed slot allocation to each port in a service, the total weekly capacity in the table is the sum of the weekly capacities for all the liner services calling at Chinese ports. Although the number of services serving the Chinese coast dropped slightly from 539 to 531, the total weekly capacity has increased significantly from 1.87 million to 2.19 million TEUs. During these five years, the number of ships increased by 13.66 per cent, while the average ship size grew by 17.67 per cent. In addition, the number of ships below 8,000 TEUs decreased by 4.39 per cent, while those above 8,000 TEUs increased by 79.80 per cent.

All major carriers have services to and from China. Table 2 compares the major attributes of their services between 2011 and 2015. During these five years, most liners have increased ship size and weekly capacity, except for those who have recently formed new alliances. For example, Maersk and MSC have reduced their service number, ship size and weekly capacity during these five years. This has increased the influence of alliances: average ship size has increased from 6,529 to 9,160 TEUs, and weekly capacity has grown by 3.38 times, from 254,620 TEUs in 2011 to 861,066 in 2015.

Among liners serving the Chinese coast, Chinese liners (including those from Mainland China, Hong Kong and Taiwan) had the most significant growth, in both ship size and capacity. The average ship size increased by 35.59 per cent, and total weekly capacity grew by 54.02 per cent. For other Asian liners, the ship size and capacity increased by 4.02 per cent and 4.74 per cent, respectively. The capacity of non-Asian liners dropped, due to an increase in the number of alliances.

3.2 Capacity deployment by port clusters and shipping routes

Figure 3 shows the aggregated weekly capacity, throughput, and trade value in each of the five clusters. For the same reason as stated in Section 3.1, the weekly capacity of a cluster is the total capacity of all the services visiting the cluster. PRD and YRD are the two clusters with the highest weekly capacity and throughput. Southwest ports are much smaller than the other four clusters. For the Bohai Rim cluster, the capacity is less than the throughput because domestic liners are not included in capacity calculation, but it nevertheless contributes to the total throughput in the region.

Figure 3 shows a good match between capacity distribution and trade value, except in the Southeast cluster. This is because of the nature of data used in the capacity calculation — we use service capacity rather than actual slot allocation to each port. As long as a service visits a port in that cluster, its capacity will be counted.

Liners deploy more capacity onto the routes with high demand. According to the Alphaliner Database, there are three main trade routes (namely, Trans-Pacific, FE–Europe, and Intra-Asia) and 10 sub-routes serving Chinese trade. Figure 4 summarises the weekly capacity and average ship size of all the routes in 2011 and 2015.

The lines in Figure 4 indicate the weekly capacity allocated onto each route (left axis), while the bars represent their average ship sizes (right axis). FE–Europe trade uses the largest ships on average, followed by FE–Middle East route. The FE–Europe (FE–Med and FE–NEurope) had a significant drop in weekly capacity while the Intra-Asia route had the largest growth in capacity in 2015. In fact, top liners such as Maersk, MSC and

Figure 3

Trade Value, Weekly Capacity, and Throughput of Clusters

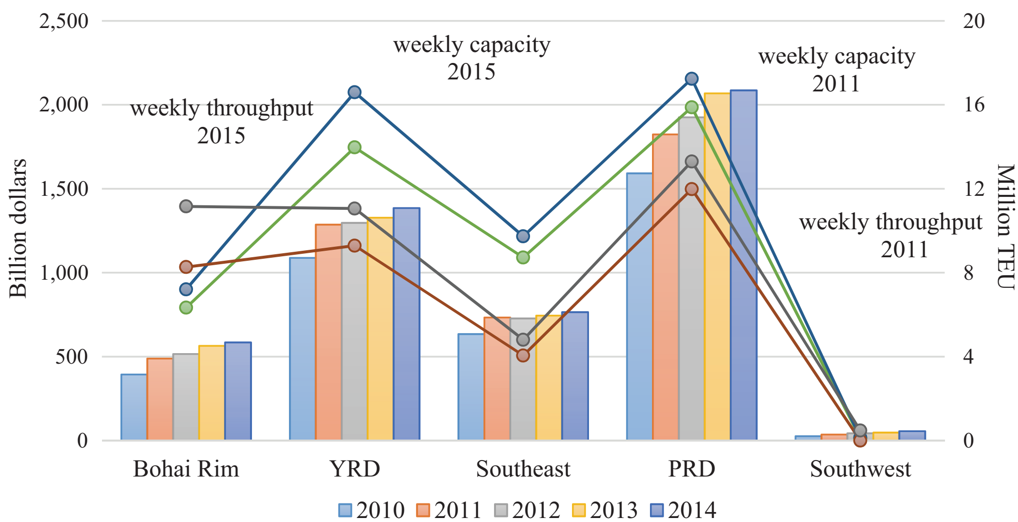
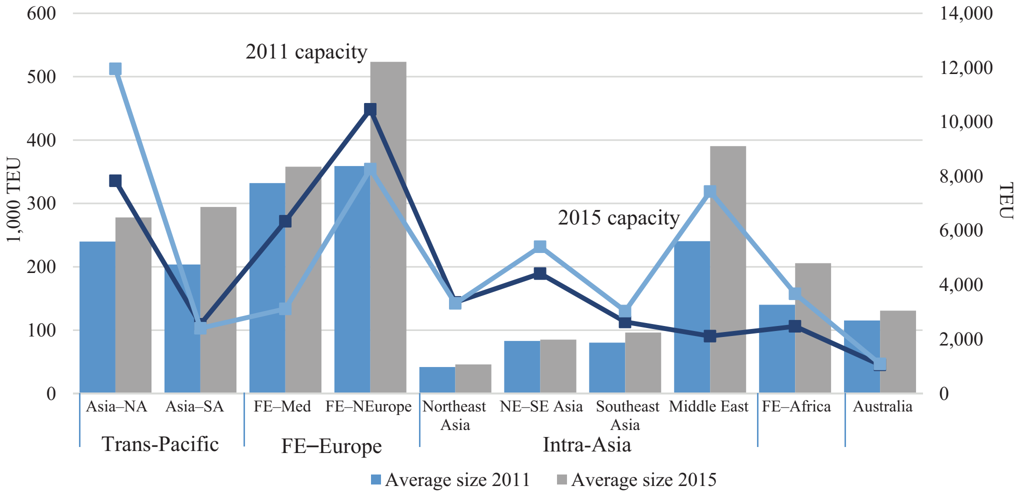


Figure 4
Weekly Capacity and Average Ship Size on the Shipping Routes Serving China



CMA CGM which used to focus on FE–Europe or Trans-Pacific, have deployed more and bigger ships in Inner Asia routes.

As shown in the figure, long-distance routes generally deploy bigger ships. For example, the average ship size on FE–NEurope route is 10 times larger than that in Intra-Asia's Northeast Asia route. Also, the average ship sizes on each route increased from 2011 to 2015. The most significant increase happened in the China–Middle East route (62.35 per cent) while the increase on the NE–SE Asia route is only 2 per cent.

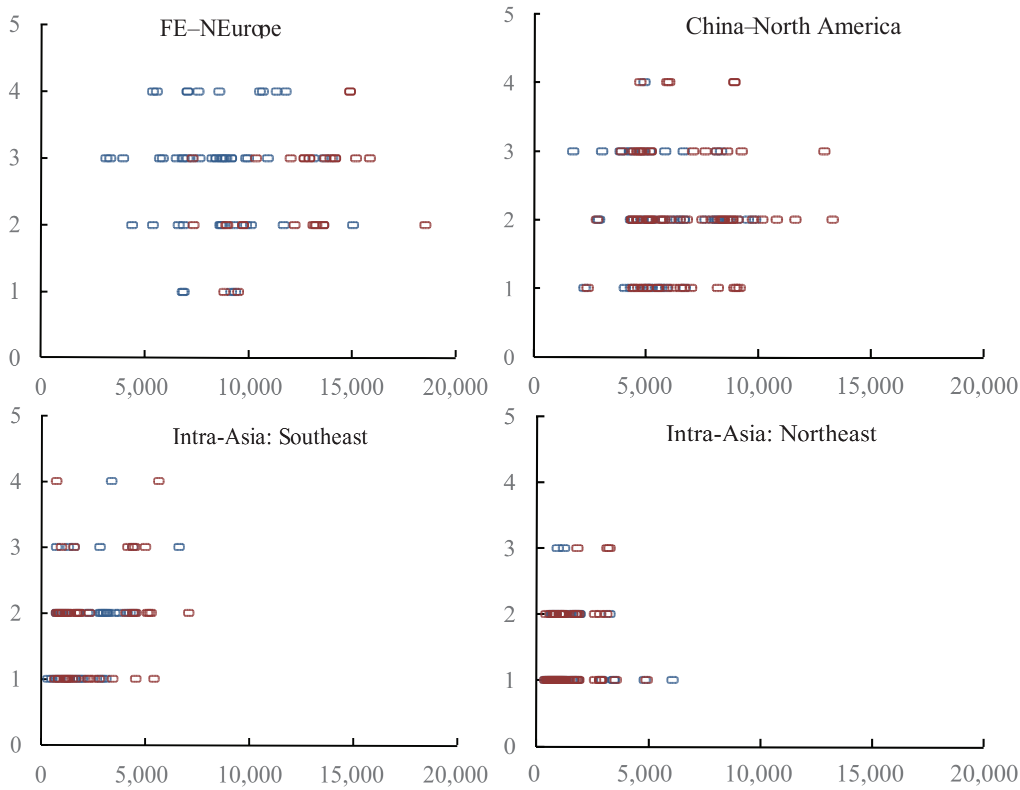
3.3 Relationship between ship size and cluster/port visits by trade routes

From Figures 3 and 4, we can see the capacity deployed to different clusters, and the relationship between ship size and trade route. Next we present the relationship between cluster/port visits and ship size for selected routes. Figure 5 presents the distribution of number of cluster visits by ship size in four selected trade routes. The top two figures are for long-distance routes, which use significantly larger ships than the short distance trades in the lower two figures. In the top panel, the FE–NEurope route generally uses larger ships than the China–North America trade routes. In the lower panel, the Northeast Intra-Asia trade routes use the smallest vessels, and visit a smaller number of clusters.

Figure 6 shows the distribution in the number of port visits by ship size in the same four shipping routes. The distributions in ship size follow a similar pattern to those in Figure 5. It is clear that the long-distance routes, such as FE–Europe and Trans-Pacific, deploy larger ships and visit more clusters/ports. The 18,000 TEU vessels only appear in the FE–NEurope routes.

This section has provided a general description of the Chinese container ports, the port clusters, and global liners serving China's international trade. Next, we describe the important factors that might affect liners' decisions on the number of clusters to visit, and the number of port calls; this is then followed by a statistical modelling.

Figure 5
Cluster Visits and Ship Size in Selected Trade Routes

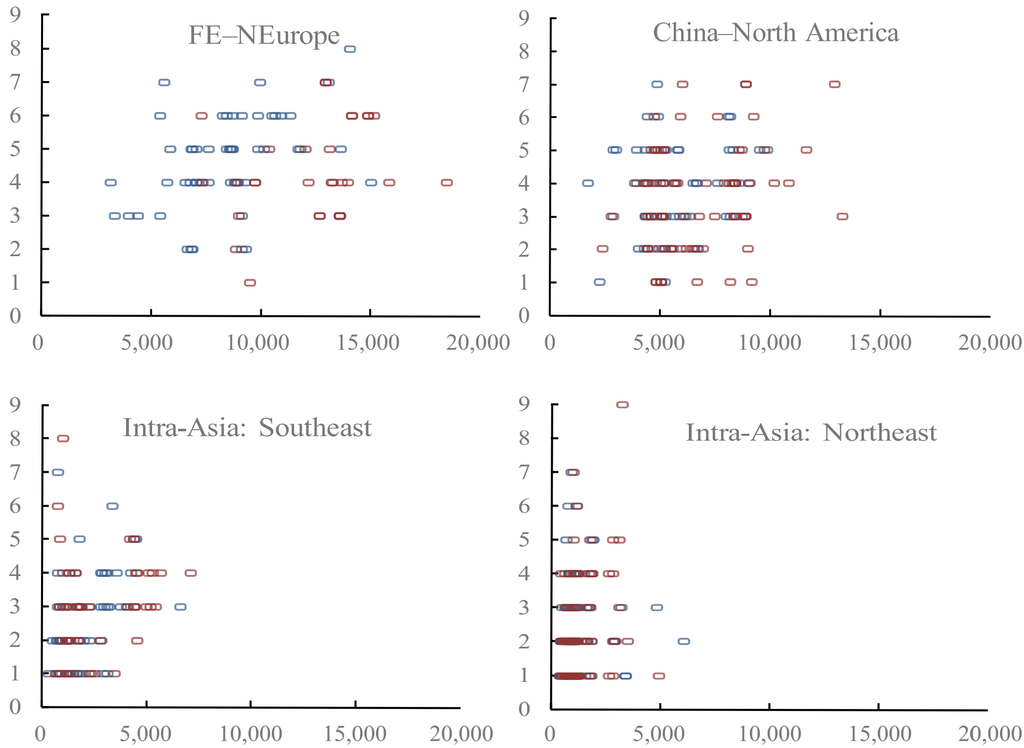


4.0 Important Factors for Liner Service on Cluster Visits and Port Calling

Liners' decisions on the strings of ports to serve naturally depend on both internal and external factors. Many external factors, such as international trade volume on each route and of each coastal province, the throughput of each port, and the physical or operational conditions of a port and so on, are all very important factors in such decisions. However, these variables are not service specific. For example, all services on the same route are facing the same demand. Therefore, the international trade on each route cannot be used to explain the behaviour in cluster visits or the number of port calls for different services on the same route. The focus of this study is to analyse the impacts of internal attributes on the number of cluster/port visits.

The internal factors include the size of the ships (*Size*), the number of days in a round-trip (*Time*), the number of days per visit (*Frequency*), and a set of dummy variables indicating the nationality of the operator (*China*, *OtherAsia*, *NonAsia*), whether the service is provided by an alliance (*Alliance*), the trade routes of the service (Asia–North America, Asia–South America, FE–Med, FE–NEurope, NE–SE Asia, Southeast Asia, Middle East, FE–Africa, Australia).

Figure 6
Port Visits and Ship Size in Selected Trade Routes



Size, *Time* and *Frequency* are the three most important attributes of a liner service. The summary statistics of these variables are shown in Table 3. As noted in the previous section, there is a general trend that larger ships may visit more clusters/ports. However, as mentioned earlier, many researchers predicted that larger ships may adopt the H&S system. For the international liners serving the Chinese coast, it is not clear whether the H&S system has already been adopted, and whether the result is a reduction in the number of clusters visited or just a reduction in the number of ports visited. Therefore, in this study, we used size, and the square of size (*Size_2*), to test the relationship between ship size and the number of clusters/ports visited.

Table 3
Descriptive Statistics of Ship Size, Time, and Frequency

Variable	*Mean*	*Std*	*Min*	*Max*
Size	3805.505	3447.835	175	18,340
Time	40.01589	30.29516	7	147
Frequency	7.085008	1.350475	0.875	27

Source: www.alphaliner.com.

Table 4
Correlation between Port/Cluster Calls and Round-trip Time in Three Main Routes

	2011		*2015*	
Route	*Port call number*	*Cluster call number*	*Port call number*	*Cluster call number*
Transpacific	−0.08802	−0.05266	0.380562	0.312973
FE–Europe	0.026963	0.102344	0.434431	0.156206
Inner Asia	−0.00515	0.030441	0.235231	0.299633

Most liner services try to maintain weekly services. As shown in Table 3, the distribution of the liner frequencies is centred around seven days with very small standard error. Therefore, although frequency is an important factor, it may not be significant in the statistical test, as the variance is not large enough.

In addition to ship size, the number of days for the round trip (*Time*) is also an important factor in a liner's decision on the number of clusters/ports to visit along Chinese coast. For a longer shipping route, the larger fixed and voyage costs require the service to visit more ports/clusters so as to earn more by carrying more cargoes. Therefore, it is postulated that the round-trip time will have a positive impact on the number of clusters/ports visited. Table 4 presents the correlations between port/cluster calls along the Chinese coast and the round-trip time on three main routes. It has to be noted that endogeneity should not be a concern in our study, as the main factor influencing the round-trip time is the trade route. The impact of visiting Chinese ports/clusters on the round-trip time is not certain. As shown in Table 4, the correlations between the two are small and on some routes, even negative.

Ship size and round trip time may work together to affect the decision on cluster/port visits. For smaller ships, an increase in round-trip time may have different impacts on port/cluster visits as compared with larger ships. Similarly, for shorter round-trips, the increase in ship size may also have different impacts compared with the longer trips. Therefore, we also designed an interactive term, *Size_time*, to test the joint impact of time/size on the cluster/port visits.

Different trade routes have different properties, in addition to the size of the ships and the round-trip time. These attributes may also play a role in the decision of cluster/port visits. From the statistics in Figure 5, it is clear that FE–NEurope and China–North America services visit more clusters. To test this route specific nature, 10 dummy variables were designed to distinguish our 11 trade routes. The number of services on each route and their percentage in a total of 1,070 services are shown in Table 5. Since our study area is the liner services for Chinese ports, the four Inner Asia routes account for about 60 per cent of the total sample.

The behaviour of cluster/port visits may also be affected by the different nationality of the liner operator. To test this effect, a set of dummy variables are designed, including Chinese liner, Other Asian Liner, and Non-Asian Liner. Since many services are provided by alliances, and the members in an alliance may come from different countries, a fourth category — Alliance — is created to indicate whether the service is provided by an alliance. The distribution of this set of dummy variables is shown in Table 6.

Finally, a dummy variable 'Year 2015' is created to distinguish services in 2015 from those in 2011.

Table 5
Description of Dummy Variables for Different Shipping Routes

Variable	*Obs*	*Share (%)*
Asia–North America	139	13.00
Asia–South America	38	3.55
FE–Med	52	4.86
FE–NEurope	83	7.76
Inner Asia–Northeast Asia	261	24.39
Inner Asia–NE–SE Asia	217	20.30
Inner Asia–Southeast Asia	115	10.76
Inner Asia–Middle East	51	4.77
FE–Africa	68	6.36
Australia	34	3.18
Sum	1,059	98.94

Table 6
Distribution of Liners' Nationality and Alliance Membership

Variable	*Obs*	*Share (%)*
Chinese liner	547	51.12
Other Asian liner	492	45.98
Non-Asian liner	263	24.58
Alliance	133	12.43

5.0 Empirical Analysis of Cluster/Port Call Decisions in Liner Shipping Services

This section presents the econometric models for analysing the impact of the potential factors on the decision of cluster/port visits. For cluster visits, since only 6.35 per cent of the services call on four or five clusters, we grouped these two categories into the category 'visit three or more clusters'. For ports, the maximum port call numbers are 10, so Ordinary Least Square (OLS) regression models can be used here.

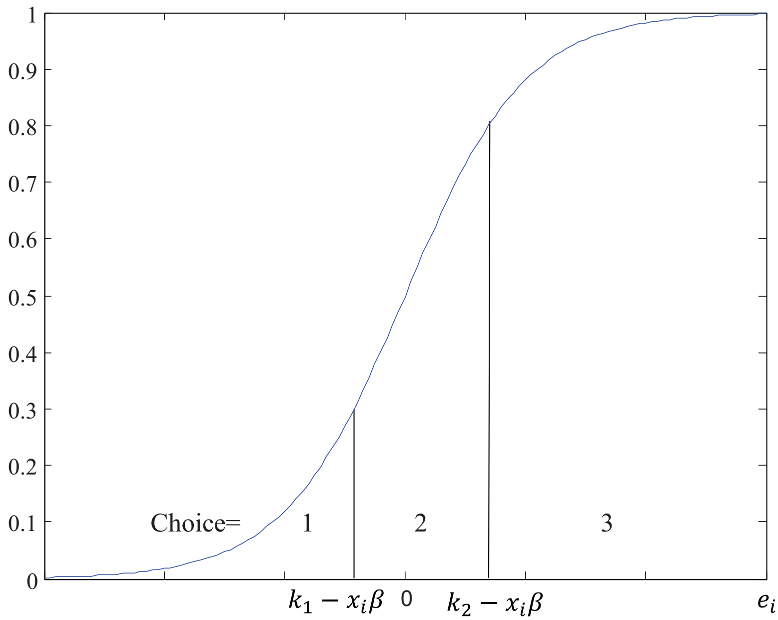
5.1 Statistical models for the number of clusters/ports to visit

Two statistical models were adopted to analyse liners' decisions on the number of clusters/ports to visit. For cluster visits, Ordered Logit models are applied; while for port calls, the OLS method is used. The Ordered Logit model is widely used in modelling discrete choice behaviours where choice alternatives are ordered categories. In our model, there are only three categories: the liners that visit one cluster, two clusters, or three or more clusters. Assuming that visiting more clusters can bring more benefits to the liners, it is natural to adopt Ordered Logit models. Next we explain the model formulation.

Denote x_i as a set of attributes for liner service i, such as those explained in Section 4, then the total utility obtainable from this service, U_i, can be written as:

$$U_i = x_i\beta + e_i, \tag{1}$$

Figure 7
Cumulative Distribution of the Error Term



where β is a vector of coefficients to be estimated, and e_i is the error term following logistic distribution. The cumulative distribution function of the error term can be written as $\Phi(e_i) = \exp(e_i)/1 + \exp(e_i)$, which can be illustrated by Figure 7. Since utility is not observable, and what we can observe is the number of clusters visited, it is necessary to assume that a carrier may obtain a higher utility by visiting more clusters. This is reasonable, as the purpose of visiting more clusters is to serve more hinterlands.

Assume that there are some thresholds, or cut-off points. If U_i exceeds a certain cut-off point k_1, the liner shipping service would call at two or more clusters; if U_i exceeds cut-off point k_2 ($k_2 > k_1$), then the liner shipping service would call at three or more clusters. From the cumulative distribution function, the probability of three different cluster choices can be written as:

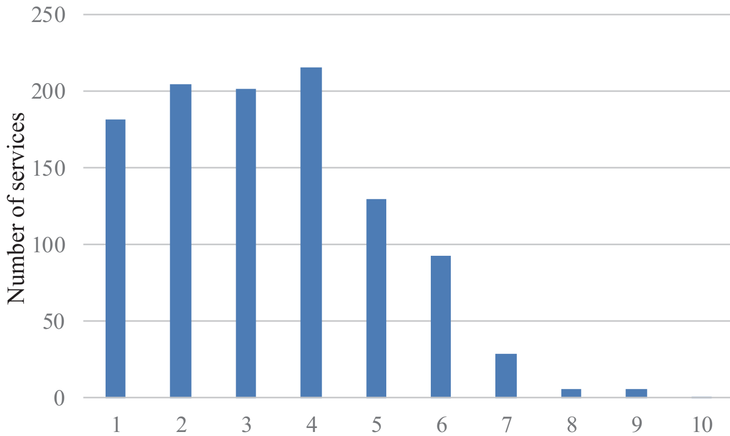
$$\begin{aligned} &P(Choice = 1) = P(U_i < k_1) = P(e_i < k_1 - x_i\beta) = \Phi(k_1 - x_i\beta) \\ &P(Choice = 2) = P(k_1 \leq U_i < k_2) = \Phi(k_2 - x_i\beta) - \Phi(k_1 - x_i\beta) \\ &P(Choice = 3) = P(U_i > k_2) = 1 - \Phi(k_2 - x_i\beta). \end{aligned} \quad (2)$$

From these equations, the log-likelihood function can be specified, and the Maximum Likelihood method can be applied to estimate the parameters.

To apply the ordered-logit model we have an assumption that an ordered-logit alternative should be independent and irrelevant with higher categories. We will use the Brant test to testify whether our model violates the assumption in the empirical study.

Unlike the number of cluster visits, the number of port calls is more spread out. As shown in Figure 8, only three categories (call at two, three, or four ports in a service)

Figure 8
Distribution of Liner Services According to Number of Ports Visited



have more than 190 observations. However, to apply the ordered-logit model, as a rule of thumb, the number of observations for each category should be larger than 10 times the number of variables (Agresti, 1996, 2003). Since we have 19 variables, most of the categories cannot meet with the requirement. Therefore, it is not appropriate to apply an Ordered Logit Model. An OLS method is thus applied to analyse the number of ports visited, using the same set of variables described in Section 4.

5.2 Empirical results

To estimate the possible effect of turning point on size and the combined effect of size and time, we designed two sets of explanatory variables, one with *Size_2*, and the other with *Size_time*. For each set, we apply the Ordered Logit model and OLS model separately to estimate the impacts of the variables on cluster/port visits. Therefore, a total of four different models are estimated. The estimated coefficients are listed in Table 7.

The first two columns (Cluster1 and Port1) are estimated using the interact variable '*Size_time*', and the next two columns (Cluster2 and Port2) are obtained using the square of size (*Size_2*). Both cluster models have passed the Brant test, and their Pseudo R^2 are around 0.26. The two OLS models have Pseudo R^2 of around 0.40, showing all four models to have a reasonable fit level (McFadden, 1977). Also, most of the estimated coefficients are significant.

The general results can be summarised as follows:

- Compared with the year 2011, the liner services in 2015 had a lower number of cluster/port visits, while ships became bigger.
- Chinese liners tended to visit more clusters, while others visited fewer clusters. Non-Asian liners visited fewer ports, but not fewer clusters. Other Asian liners visited both fewer clusters and fewer ports. Chinese liners include operators from Taiwan and Hong Kong. Their main business focus is in the intra-Asia trade, and therefore may need to cover a larger geographical region. Non-Asian liners, such as Maersk, MSC, and CMA CGM, are mainly for east–west trade routes. They visit fewer ports,

Table 7
Estimated Results of the Cluster and Port Models

	Cluster1	*Port1*	*Cluster2*	*Port2*
Year 2015	−0.215	−0.179**	−0.239*	−0.188**
Chinese liner	0.398***	0.153*	0.407***	0.160*
Other Asia liner	−0.328**	−0.391***	−0.298**	−0.381***
Non-Asia liner	−0.273	−0.270**	−0.260	−0.265**
Frequency	0.072	0.045	0.092	0.054*
Alliance	−1.393***	−1.061***	−1.460***	−1.091***
Time	0.061***	0.040***	0.038***	0.030***
Size	0.371E-03***	0.253E-03***	0.276E-03***	0.214E-03***
Size_time	−0.414E-05***	−0.181E-05***		
Size_2			−0.106E-08**	−0.469E-08
FE–Med	1.324***	0.685***	1.221***	0.647**
FE–NEurope	1.086***	0.214	0.949***	1.614
Northeast Asia	−0.214	0.528**	−0.786**	0.251
NE–SE Asia	1.509***	1.000***	1.174***	0.845***
Southeast Asia	1.027***	0.666***	0.606*	0.466**
Middle East	1.167***	0.585***	1.083***	0.552**
FE–Africa	0.375	0.444**	0.514	0.508**
Australia	1.730***	1.364***	1.510***	1.260***
Other routes	−0.738	−0.356	−0.951	−0.454
_Cons		0.724		1.078***
/cut1	2.715		1.943	
/cut2	5.269		4.463	
Pseudo R^2	0.268	0.415	0.263	0.400
Turning points of size	14,855	22,099	12,745	

but not necessarily fewer clusters. In other words, they still need to visit an area with higher demand so as to collect more cargo.

- The services provided by alliances visited fewer clusters/ports. The ships used by Alliance, although bigger, are shared by many Alliance members. Ship space can be filled more easily than those operated by just one, independent operator. Therefore, they did not need to visit as many clusters/ports as others did to ensure a high loading factor. Table 6 shows that the absolute values of the coefficients for Alliance are larger than any nationality categories in all the four models.
- For the impact of different trade routes, most of them are largely positive and statistically significant, except for the two Trans-Pacific routes and North Asia Trade routes. For the FE–NEurope route, the coefficients for cluster visits are significant for both models, but not for port visits. Compared with Trans-Pacific routes, the services in the FE–Europe route usually need to visit more clusters, not necessarily more ports, to fill up the ship. Generally, the ships in FE–NEurope are bigger. Therefore, this implies that they may only call at the large hub ports in each cluster. For Intra-Asia routes, the coefficients of NE–SE are larger than any other sub-routes of Intra-Asia. This may be because it has to travel to almost all the coastal regions in China.
- The coefficient for Frequency is not significant, which is expected, as most liner services try to maintain a weekly call.

The coefficients on time and size are all positive significant in four models. However, the interacting term *Size_time* is negative and significant, but the coefficient for *Size_2* is negative and significant for the cluster model, but not for the port model. To show the marginal impact of round-trip time and ship size, it is necessary to derive the estimated statistical equation with respect to time and size, which are shown below.

Assuming the estimated coefficients for *Size*, *Time*, *Size_time*, and *Size_2* as β_s, β_t, β_{st}, and β_{s2}, respectively, the marginal probability for selecting more clusters in Cluster1 model are:

$$\begin{aligned} \frac{\partial \mathrm{P}(Choice \geq 1)_{\mathrm{Cluster1}}}{\partial size} &= \Phi(k_1 - x_i\beta)(\beta_s + \beta_{st}\mathrm{Time}) \\ \frac{\partial \mathrm{P}(Choice \geq 1)_{\mathrm{Cluster1}}}{\partial time} &= \Phi(k_1 - x_i\beta)(\beta_t + \beta_{st}\mathrm{Size}) \end{aligned} \tag{3}$$

and that for Cluster2 model is:

$$\frac{\partial \mathrm{P}(Choice \geq 1)_{\mathrm{Cluster2}}}{\partial size} = \Phi(k_1 - x_i\beta)(\beta_s + 2 \ast \beta_{s2}\mathrm{Size}). \tag{4}$$

The plots for the changes of these marginal probabilities with the change of round trip time and ship size are shown in Figure 9.

Figure 9(a) shows that the marginal effect is positive when the round-trip time is less than 90 days, but is negative when it is more than 90 days. This implies that larger ships will visit more clusters if the round-trip time is not too long. If the round-trip time is long, larger ships may not like to visit more clusters, as the cost of maintaining such a service is high.

Figure 9(b) indicates that the marginal impact of time is positive if the ship size is smaller than around 14,855 TEUs. In other words, for normal size ships there is a positive relationship between cluster visits and round-trip time.

Figure 9(c) is the change on marginal impact of ship size. If the ship is smaller than 12,745 TEUs, larger ships will visit more clusters. If it is larger than that, increasing the ship size will reduce the cluster visit.

The above results are obtained from the cluster models. For the port models, since they are obtained using OLS regression, calculating marginal impact is rather straightforward. For the Port1 model, the result is similar to the cluster model, except that the turning point of ship size/round-trip time is much larger. The turning point for marginal impact of time is 22,099 TEUs. As container ships of this size are only on the order books, we can conclude now that an increase in round-trip time will result in more port visits. The turning point for the marginal impact of size is 140 days. Since there are not many liner services that have such a long round-trip time, we can conclude that larger ships usually visit more ports.

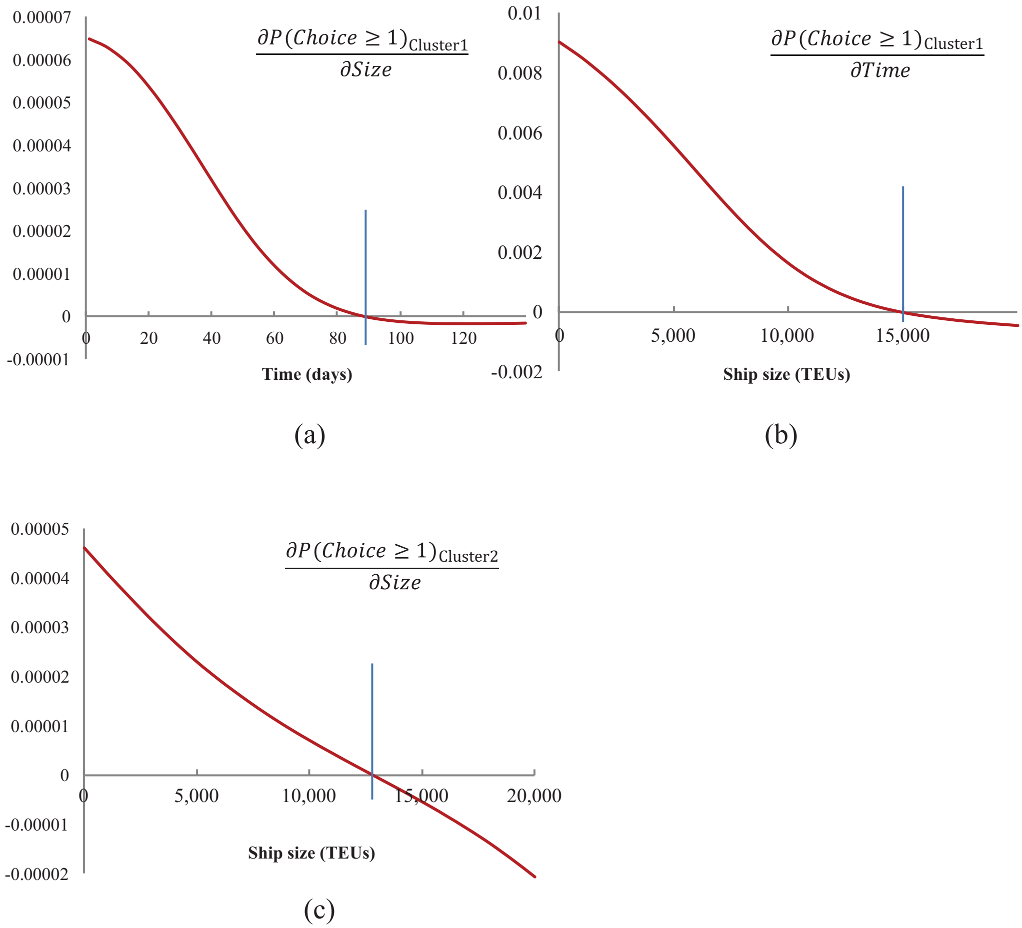
For the Port2 model, the coefficient of *Size* is positive and significant, while the coefficient of *Size_2* is not significant. This indicates that larger ships still call at more ports for the liners serving Chinese trade.

Combining the results from the cluster and port models, we can summarise as follows:

1. Generally, long round-trip time or larger ships tend to visit more clusters and ports.
2. If the round-trip time is too long, increasing ship size may reduce cluster/port visits. If the vessel is big enough, increased round-trip time can also reduce cluster/port visits.
3. Ships above 14,855 TEUs visit fewer clusters, but not necessarily fewer ports.

Figure 9

Marginal Probability for Cluster Visits with Time and Size in Two Cluster Models



These results revealed the impact of larger ships on the liner shipping networks. Unlike the H&S network theory, larger ships will only visit clusters with a high demand, but will not reduce the number of port calls. For example, Maersk and MSC launched AE-10/silk services from North Europe to the Far East using 11 18,340 TEU vessels in January 2015. It only serves two clusters (YRD and PRD) on the Chinese coast. However, it calls at both Hong Kong and Shenzhen in PRD, and Shanghai and Ningbo in YRD. Actually, from the statistics, many liner services always call at both these large ports when they visit these two clusters, even though the ports are very close. As shown in Table 8, among the liners that called at the YRD cluster in 2011, 92 per cent called at Shanghai, 68 per cent called at Ningbo, and 61 per cent called at both Shanghai and Ningbo ports. This number increased to 67 per cent in 2015. For those that called at the PRD cluster, 56 per cent and 54 per cent called at both Hong Kong and Shenzhen ports in 2011 and 2015, respectively.

Table 8
Number and Percentage of Services that Call at Both Larger Ports in One Cluster

	2011		*2015*	
	Number of services	*Percentage*	*Number of services*	*Percentage*
YRD	325	100	329	100
Shanghai	299	92	311	94.53
Ningbo	221	68	235	71.43
Both	199	61.23	222	67.48
PRD	366	100	340	100
Hong Kong	295	80.6	251	73.82
Shenzhen	270	73.77	261	76.76
Both	205	56.01	184	54.12

6.0 Summary, Conclusion, and Recommendations

The research analyses how the internal factors, such as trade routes, round-trip time, and nationality of the carrier or membership of liner alliances, affect liners' behaviour in determining the service regions (number of port clusters) and the number of ports to call at when serving the Chinese international trade. An Ordered Logit model was applied in analysing the number of clusters to visit, and an Ordinary Least Square model in analysing the number of ports, based on the information about all the liner services calling at Chinese ports in 2011 and 2015. Generally, the empirical results show that in 2015 the number of cluster/port visits by liners appeared to decrease. Chinese liners (including those in Hong Kong and Taiwan) visited more clusters/ports, but in contrast, non-Asian liners visited fewer ports, though not necessarily fewer clusters. Services provided by alliances visited fewer clusters and ports. For the trade routes, compared with Trans-Pacific routes, FE–NEurope tended to visit more clusters, but not ports.

More importantly, we found the turning points where the liner services may change from visiting more clusters/ports when the ship size or round-trip time increases. Normally, if the round-trip time is not too long, an increase in ship size will require visiting more clusters/ports. If the round-trip takes too long, services using large ships may have to reduce the number of clusters/ports by focusing on clusters/ports with a higher demand, because the cost of using more ships to maintain a weekly service is too high. Similarly, larger ships will normally visit more clusters/ports so as to increase the loading factor. However, if the ship size in a service is over a certain limit, the service may only visit those clusters with a high demand. However, in each cluster, if two ports are equally important, they will visit both.

This reveals the fundamental difference between the H&S structure in liner shipping and that in aviation. In aviation, liners in one service will only call at one hub in one region. However, in shipping there can be two hubs in close proximity, and they can both be on the same main line services, provided they both possess high cargo demands and have similar capacities that can accommodate the larger vessels.

The findings in this research have implications for both academic research and practice. As shown in the literature review, most of the studies on evaluating the economies of scale of large ships or optimisation of liner schedules often specify one hub in one region. However, in practice this assumption may not be true. Future studies on the H&S structure in liner shipping should examine the possibility of multi-hub ports in the same region. On the practical side, the possible H&S structure in liner shipping is a major factor in port expansion decisions. This study reveals that there could be multiple hub ports in close proximity. As long as there is sufficient demand and port facilities are efficient, the liner service will not skip these ports. Therefore, strategic capacity competition is not necessary, as this would only lead to overcapacity in port supply.

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