# ANALYZING LINER SHIPPING OPERATIONS WITH BIGGER SHIPS AND LARGER ALLIANCES: THEORY AND PRACTICE

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**A thesis submitted in partial fulfilment of the requirements**

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# CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text

______________________________ (Signed)

__________ Wu Xiaofan ________ (Name of student)

# ABSTRACT

The liner shipping industry is under a series of continuous changes: ships are getting bigger, the market is more volatile and more carriers are joining larger alliances. Theory predicted that larger ships would adopt 'hub-and-spoke' structure in liner shipping networks and call fewer ports in their services. That may intensify the competition among regional container ports for the hub position. However, the empirical study of liner shipping services calling Chinese ports in 2011 to 2015 shows that carriers are not calling fewer ports as ship size increases. The apparent contradiction between the theory and the observed facts motivated this study to answer following questions: What is the current relationship between port call decisions and ship size? How do liner shipping operators decide port calls with large containerships in a competitive market? How do large containerships and alliances affect the financial performance of liner shipping companies?

Firstly, the thesis collects information of liner shipping services calling Chinese ports in 2011 and 2015 from Alphaliner database and identifies the effects of service attributes on hinterland/port choice by ordered logit regressions and OLS regressions. This study finds that increasing ship size within a certain range leads to more clusters/ports visit. Beyond that, larger ships visit fewer clusters, not necessary fewer ports. Therefore, for a hinterland with a high demand for shipping, there can be more than one hub in the same region.

Secondly, this thesis establishes an analytical model of port selection behavior in liner shipping services. The decision on the number of port calls is analyzed in both transshipment and no-transshipment case. Specifically, the study introduces the model in a duopoly market where two operators compete using price discount. It

identifies the optimal condition on the number of port calls in a single-operator market and that in competitive market. The simulated results of liner shipping services between China and North America in 2011 and 2015 show that there may be turning points. Before these points, larger ships require calling more ports to fill up the capacity; after these points, larger ships will call fewer ports, as it requires a higher demand at the port to cover the fixed port access cost.

Finally, the thesis investigates the moderating effects of large containerships and alliances on how the external/internal factors affect the financial performance of operators. This empirical study involves 20 liner shipping companies during 2001 to 2015. By a fixed-effect panel data model with Log-Log regression, this study shows that the revenue of the company dominated with large containerships (CDWLS) is more sensitivity to prices, average ship size and capacity change; joining alliances can alleviate these effects. The operating cost of CDWLS is less sensitive to the change in bunker price and their operating cost can even decrease as the average ship size increases. Joining alliances can bring companies economies of scope, and reduce the impact of inflation. However, joining alliances can increase the impact of bunker prices on operating cost. It can also reduce the benefits of economies of scale for CDWLS to increase their average ship size due to the lack of flexibility.

The main contributions of this research are two folds. In theory, it supplements the 'Hub-and-Spoke' network structure in maritime transportation networks by adding some critical condition for its validity. The port call decision model in competitive market also supports the hypothesis of 'contestable market' in previous research. The third study tests the moderating effects of large ships and alliance in financial performance. In practice, this research helps both port and liner shipping operators

in policy making and investment decisions. For ports, it is the demand of the region that determinates whether to expand the port and invest in facilities. For liner shipping operators, they should consider both external and internal factors in large ship investment and cooperation strategy decisions.

**Key words**: liner shipping operation; large containership; port call; alliance; financial performance

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# TABLE OF CONTENT

# TABLE OF FIGURES

# TABLE OF TABLES

# Chapter 1 : INTRODUCTION

This chapter provides the background, aims and research questions of this thesis on liner shipping operation focusing on the effects of ship size growth and shipping alliance. The current trends of liner shipping market and the industry are presented first, followed by a series of research questions and the structure of this research.

## 1.1 Research background and recent trend in liner shipping operation

A liner shipping service refers to a fleet of container vessels of similar capacity, operated by one or more liner shipping companies, carrying containerized cargoes through a predetermined sequence of ports in a fixed schedule. Since the emergence of containerization, liner shipping has fundamentally reshaped the world shipping by providing scheduled services with high reliability and low cost. This is partly due to the economies of scale brought up by increasing number of ever-larger ships in the world liner fleet. From Figure 1-1, we can find that in the past decades, the largest container ships in the water have increased from 1,530 to 21,413 TEUs.

Concurrent with this trend is the continuous re-structuring in liner shipping industry. As of July 20, 2017, the top 3 liner operators control about 42.6% of the world's capacity, the top 6 controlled 63.1%, and the top 20 had 87.0%. The three major alliances (2M+HMM, OCEAN Alliance and THE Alliance), with members from the top 20 liner operators, operated 85.7% of the world's capacity. In addition, the recent mergers between COSCO and CSCL,[1] and between CMA CGM and NOL,[2] have accelerated the concentration process.

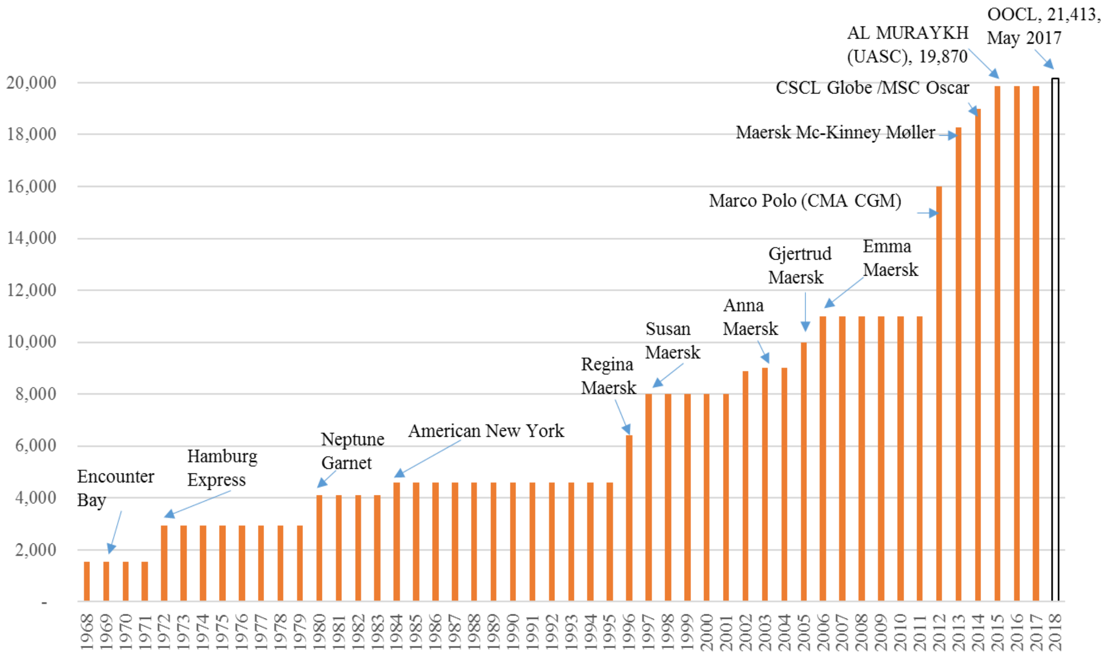


Figure 1-1: Largest container ships in the world, 1968-2018

Liner shipping industry is experiencing a more densely-connect global network as well as a more concentrated market. There are more than 3,500 services for 11 different shipping lanes calling ports more than 9000 times per week[3]. Starting from April 1 of 2017, the three major alliances account for 95% of the capacity on the Far East-North America route, and 99% on the Far East-Europe/Mediterranean route, according to Alphaliner weekly newsletter on March 29, 2017.

On the bright side, larger ships enable 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.

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

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

[3] http://www.worldshipping.org/ accessed Oct. 24, 2016

However, the trend of increasing ship size and market concentration has raised concerns for both container ports and liner shipping operators:

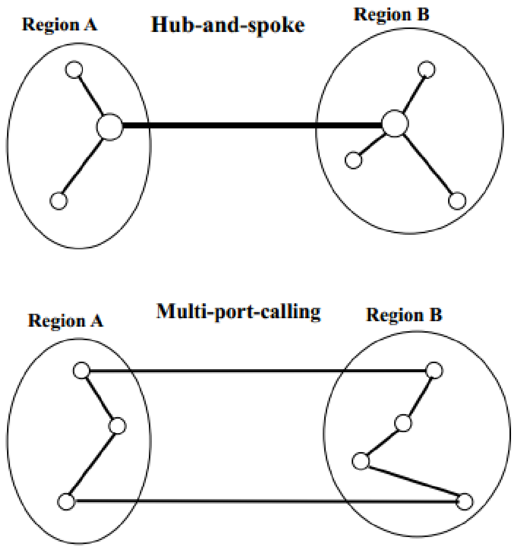



Figure 1-2: Structures of two networks[4]

(1) Major port operators are concerned about the impacts of the Hub-and-Spoke (H&S) structure network structure in an increasingly concentrated liner shipping market. The H&S structure, which is common in aviation, has appeared in literature to describe the possible liner shipping networks when ships are getting larger (Figure 1-2). For traditional multi-port networks, ships call every port in their itineraries. While in H&S structure, mega container ships only travel between hub ports in regions. The secondary shipping legs from hub to spokes are conducted by barges. Hayuth (1981) stated that with the increasing of ship size, container flow would concentrate in few load center. That would increase the competition among the regional ports. Therefore, major port operators feel an urge to invest aggressively to expand or upgrade their facilities to better attract larger ships, reduce

[4] source: Imai, Shintani, & Papadimitriou, 2009

congestion, improve efficiency, and compete for the hub position, which may result in overcapacity in port supply.

(2) Liner shipping companies are interested in the operations management strategies to improve their profitability in the changing market. Large containerships are preferred because of their advantages in unit cost. Such advantage can only be realized with high load factors and proper freight rate. From Figure 1-3, we can find how liner shipping market prices fluctuate during 2001 to 2015. Although liner shipping market's demand dropped in 2008's global financial crisis, the total supply and demand of container shipping still keep increasing. The figure shows that the overcapacity on major trading routes and volatility in freight rate will haunt liner shipping markets for a long time. Therefore, to guarantee a stable performance in the market, liner shipping operators have to make not only operational decisions on the optimal ship size, port calls and prices but also strategical decisions on cooperation or even joining alliances.

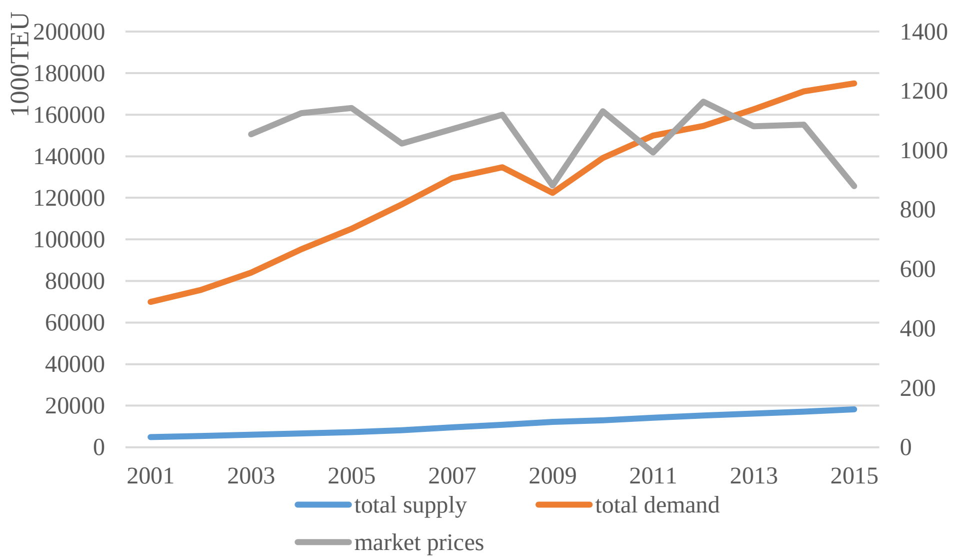



Figure 1-3: Changes in liner shipping market from 2001 to 2015

Therefore, it is essential for both port authorities and liner shipping operators to know whether large ships call fewer ports. Figure 1-4 shows the distribution of the number of Chinese ports called by ships with different size (in TEUs) in international liner shipping services in 2015. Each dot indicates the number of Chinese ports called by a liner service with ship size on the horizontal axis. From the figure, we can find that although the dotted trend line appears to be concave, there is not a very clear trend that larger ships call fewer ports.

What is the relationship between ship size and port call in liner shipping? Will the contestable liner shipping market affect such relationship? What should liner shipping companies do to improve their profitability in the contestable market? This thesis focuses on above questions in operations management of liner shipping and aims to give answers to above questions with both theoretical and empirical studies.

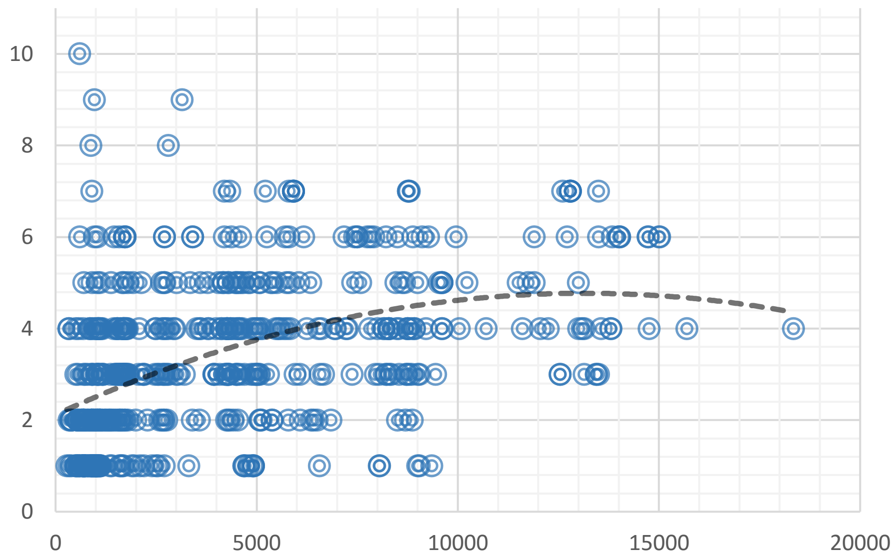



Figure 1-4: Distribution of liners' port call number in Chinese Coast by ship size in 2015

## 1.2 Research questions

**Question 1:** As a ship is getting bigger, it should visit more regions or call more ports in liner shipping service to load more cargo. However, many studies stated larger ships would decrease port calls due to the adoption of H&S network structure. Which one is true?

The first study of this thesis explores the statistical evidence on the relationship between the number of clusters (the set of ports that serve the same hinterland) or ports visited and ship size of liner shipping services. This empirical study is based on details of all liner shipping services calling Chinese ports in 2011 and 2015, which included the services on the busiest shipping routes of the world. It applied ordered-logit models to investigate how factors such as duration, frequency and ship size affect the decision on the number of port clusters to visit. This empirical study has provided a general description of the Chinese container ports, the port clusters, and global liners serving China's international trade. Moreover, the results of this study show the turning points where the liner shipping services may change from visiting more clusters/ports when the ship size or round-trip time increases. This finding will have implications for port investors and liner shipping companies in practice.

**Question 2**: The statistics show that over a certain limit, larger ships visit fewer port clusters, but not necessarily fewer ports in existing liner shipping services calling Chinese ports. However, most studies asserted that larger ships would call fewer ports. Why should larger ships call fewer ports? Set aside the physical condition of the ports, under what condition larger ships will call smaller number of ports? Are turning points affected by the competition in the market?

This study builds theoretical models to analyze the decision of how many ports to call in a liner service from the profit maximizing behavior of the operators. The liner shipping market in any trade route is assumed to be contestable. In the basic model where there is only one operator, whether to call a port depends on the relative magnitude of the incremental costs of calling the port versus the expected earnings. When they are two operators, both will offer discounts based on the contestable price when it is hard to fill up the ship, which will call more ports depends on not only ship size, but also on its market share. A numerical analysis is conducted to test the model results. The result in this study can help to understand whether larger ships make fewer number of port calls, which could provide practical guidance on both ports and shipping companies. This study can also give guidelines on the liner shipping network studies on how many ports to include in their optimization model and the optimal ship size decisions.

**Question 3**: The above two research questions focus on how ship size and other factors affect liner shipping operators' behavior in the contestable market. In the volatile liner shipping market, it is urgent for carriers to improve their profitability to survive. How do external and internal factors affect the operating revenue and costs of liner shipping company? Will large container ships and alliance membership moderate the relationship between those factors and financial performance? What strategy can improve the profitability of the liner shipping company?

The third study focuses on the financial performance of 20 major liner operators from 2001 to 2015. Fixed-effect panel data models are applied to investigate the moderating effects of large containership and alliance membership. The results of this study show that the revenue for companies dominated with large ships is more sensitive to the change in freight rate, average ship size and capacity. Joining alliances can reduce these impacts. Meanwhile, the operating cost for these companies is less sensitive to the bunker price. Because of economies of scales, the cost also decreases with the average ship size of those companies. However, if they join alliances, the benefits of economies of scale will be reduced. The bunker price has more impacts on the operating cost of alliance members. In addition, alliance members can have economies of scope and less sensitive to inflation. Moreover, this study provides the ship investment and cooperation strategies in different market conditions for different company attributes, which can help the operation decision of liner shipping companies in practice.

## 1.3 Structure of the thesis

This thesis is organized as follows:

Chapter 1 is the introduction part. In this chapter, we propose three major research questions after state current trend of growing ship size in the liner shipping industry.

Chapter 2 is the literature review part. This thesis has involved three topics in liner shipping: the growing ship size, port call decisions and companies' financial performance. Therefore, this chapter reviews studies from several aspects: the optimal ship size under economies of scales, liner shipping networks design with large ships, concentration in liner shipping market and factors contribute to liner shipping operators' profitability.

Chapter 3 is an empirical study on the relationship between ship size and cluster/port call numbers. Firstly, this part describes the background to Chinese ports and port clusters, and the liner services to and from China. Then, major factors affecting cluster/port visits and the methodologies are introduced. Finally, the empirical results analysis and summary are presented.

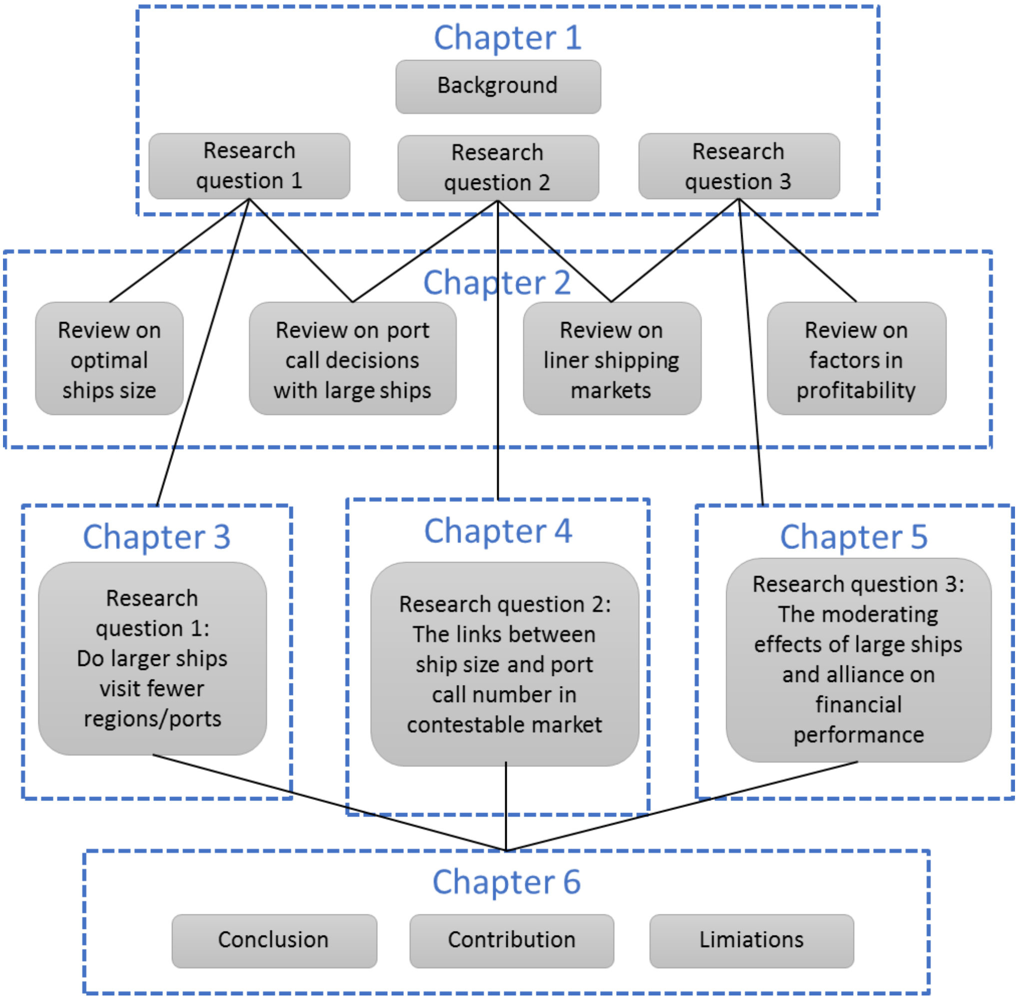



Figure 1-5: The structure of the thesis

Chapter 4 is a theoretical analysis based on findings in Chapter 3. It builds a decision model of single liner operator on the number of ports to call in a contestable market first. Both no-transshipment and transshipment cases are analyzed. Next section presents the port call decision in a duopoly model, each competing by offering discounts based on contestable market price. The last two section provides a numerical simulation and summarizes the major findings in this research.

Chapter 5 focuses on the moderating effect of large containerships and alliances on the financial performance of liner shipping companies. With financial and operational data of 20 liner shipping companies from 2001 to 2015, this study builds basic models to examine how internal and external factors affect the revenue and cost, and extended models to test the moderating effect of large containerships and alliances. The profitability analysis based on the result of the extended model can help the liner shipping companies to make decisions on new ship investment and cooperation strategies.

Chapter 6 summarizes the results and contributions of all three studies. It also includes the research limitations and future research directions.

# Chapter 2 : LITERATURE REVIEW

This thesis aims to study liner shipping operation strategies with large ships and alliances. Therefore, this chapter reviews studies in liner shipping operators' optimal ship size decisions, optimal network design, concentration and financial performance. This chapter will also identify the research gaps of previous studies.

## 2.1 Research on optimal ship size in liner shipping

From the very beginning of liner shipping, experts noticed the growth of ships brought economies of scale. Gilman and Williams (1976) decomposed the total travel cost into maritime and inland cost that related to ship size directly. They found the large ships have lower total investment, lower operating costs and travel faster than small ships.

Jansson & Shneerson (1982) analyzed optimal ship size from the perspective of minimizing 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 analyzed economies of scale from the perspectives of both the liner operators and the shippers, which enables the identification of economies of trade density (Jansson & 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.

Cullinane and Khanna (1999) calculated shipping cost per TEU in 1995. They confirmed the economies of scales in voyage and found that the improvement in port productivity indeed strengthened the advantages of large ships (above 1500 TEU). In the later research, Cullinane and Khanna (2000) argued that the optimal ship size would continue increase as long as large ship strategies worked in the competition.

However, competition is inevitable in the maritime network and overcapacity has haunted liners since the financial crisis in 2008. More constraints of ship size growth were mentioned in recent works. Generally, three factors impede the explosion of large ships:

The first constraint is the load factor. Only with enough container demand, the mega containerships were economical compared with normal ships (Perakis & Jaramillo, 1991). Lim (1994) evaluated the scale economies of container ship using an empirical study on container service earnings and costs performance. The results showed that the optimal ship size is affected by many factors including distance, load factor and routes. Later, Lim (1998) further pointed out that pursuing economies of scale cannot be a panacea to the profitability of carriers, and cooperation is a more desirable method for better returns.

The second constraint of ship size growing is the cost of in-transit inventory. As the Ronen (1983) pointed out in 1983, this constraint was the main problem for industrial operations, who own one or several containerships for their own product transport. Different from liner shipping services, the industrial operators do not need to offer a fixed-schedule service between ports, and they have to take the costs of in-transit inventory into consideration when purchasing ships. One typical optimal ship size study on that topic was from Hsu and Hsieh (2007) in 2007. This study calculated the optimal ship size and frequency for industrial operators by minimizing the cost of travelling with a hub-and-spoke structure network.

The third limitation for ship size growth is the capacity of canal or port, for example, the Suez Canal (Wan, et al., 2013).

In the studies of scale economies in liner shipping, researchers analyze cost structure and compare costs of different ship sizes. They also discuss the limitations for large containerships to achieve the economies of scales. As a conclusion, the optimal ship size decision problem was a compromise of ship price, operating cost, freight rate and demand.

## 2.2 Research on liner shipping network design with large ships

### 2.2.1 Factors of networks design in liner shipping

Liner shipping is a scheduled transport service which calls fixed ports in fixed frequency. Therefore, researchers try to figure out why lines called certain ports rather than others. Current literature of shipping has concluded factors for liner shipping operators calling container ports:

Malchow and Kanafani's work (2001) of early port selection model application in shipping viewed vessel sizes as a factor affects the choice of ports. The work of Nir and Lin, et al. (2003) analyzed three common models in port selection studies and asserted influence of liners' characteristics through the questionnaire. The indicators of liners characteristics chosen here were the routing and frequency. Tiwari, Itoh and Doi (2003) had the most attributes in estimating of port selection among several harbors in East Asian. They had listed 13 characteristics for ports, ship liners and shippers. Ship size, voyage distance and travelling time were taken into consideration in the model of Zondag and Bucci (2010). Tavassy, Minderhoud, et al. (2011) constructed the routine choice model with the same factors. The common factors of liners' feature in researches are:

(1) Ship size

(2) Ocean distance/Time

(3) Frequency

(4) Shipping companies/Shippers

(5) Shipping lanes

However, there are different results in the effect of some factors in port call decisions. For example, in Malchow and Kanafani's research (2004), port due turned out to be an insignificant factor in carriers port-selection process since it was too small compared with the total shipping charge. Port selection factors differed in accordance with who the decision maker is. Murphy and Daley (1994) offered a comparison of port choice criteria in their paper, demonstrating that shippers and carriers had different views in those factors. Also, research results of factors were often in conflict. Tiwari, Itoh and Doi's conclusion (2003) was that port location was the most significant factors in East Asian ports in 2003. Garcia-Alonso and Sanchez-Soriano (2009) measured the appeal of a port by volume, type, port efficiency and cost, concluded that it was the hinterland transportation that affected the port selection. Another example of collision opinions was the effect of ship size. Malchow and Kanafani (2001) found the ship size was significant in the port call decision in 2001. However, in their 2004's research, ship size appeared to be insignificant even with the same models in the same area (Malchow & Kanafani, 2004).

### 2.2.2 Liner shipping network design with large ships

As we mentioned in the introduction part, some academic studies consider H&S networks as the trend of liner shipping network structures with growing ship size.

However, 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 the H&S network using mega-containerships, versus 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.

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 decentralization from the data between 1995 and 2011, where secondary ports lowered the centrality of larger ones. As ship size is increasing over time, liner shipping services would call more secondary ports.

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. 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 could co-exist in very close proximity, such as Hong Kong and Shenzhen.

Considering the benefits of 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 minimizing 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 first study will identify 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 status of the application of H&S networks due to the increase in ship size, and how this affects choices of liner shipping operators as to the regions to serve, and the number of port calls. In addition, it points out that the formation of H&S networks in liner shipping may not necessarily follow the same pattern as those in aviation (Zhang, et al., 2011).

## 2.3 Research on concentration in liner shipping industry

Liner shipping industry is viewed as a typical contestable market that has no barrier for firms to entry or exit. Since there are no sunk costs, the firm already in the market cannot prevent the entrant, the firm in the market is a price-take rather than price maker even if there is only one player in the market. Early empirical study of Davies (1986) revealed that with low sunk costs and entry costs as well as instable alliances, North American line industry was in fact a contestable market in late 1970s.

In the early study of liner shipping industry organization, the theory of empty core is used to explain the competition in the contestable market. Sjostrom (1989) tested 24 routes in West Coast of US in 1982. His results supported the market was an empty core market rather than a cartel. He suggested that agreements between shipping companies could establish equilibrium in the market and avoid empty core. Pirrong (1992) complemented the study of Sjostrom (1989) by providing condition for empty core market: when operators could have the same costs and could contract with many shippers simultaneously. In that case, liner shipping companies may have price competition and incentive to form coalitions.

The contestable market of liner shipping are getting concentration. From early shipping conference agreements to now global alliances, carriers are motivated to cooperate by scale economies in large ships and financial risk control in investment. Zerby and Conlon (1978) were the first to look into liner shipping market cooperation. With trade volume and profit data in Europe-Australia lane from 1958 to 1968, they found that shipping industry naturally existed overcapacity because of demand fluctuation in short run. Shipping conference can relieve the effect of demand shift by rate setting. Ohta and Hidekazu (2000) provided analysis of operators' profitability in free competition, conference (fixed optimal market prices) and alliance (fixed service level but individual operator's optimal prices) by analytical models. They found when demand is inelastic, conferences and alliances would coordinate to get market equilibriums by pricing optimization. Combined network design and profit allocation, Agarwal and Ö Ergun (2010) applied the game theory together with optimization programming and gave a collaborative strategy for shipping alliance members. Fusillo (2013) has built a stability market indicator for top carriers in 14 U.S. ocean liner import markets from 1988 and 2010. The entry, exit and demand growth are identified as the important factors for the market stability. The work also showed that carriers tended to be more concentrated for scale economies, including H&S networks and mega ships.

The competition and cooperation in liner shipping market can affect companies' ship size, fleet capacity, price and port rotation decision. Wang and Meng (2014) studied three different competition patterns of a new liner shipping market based on two-stage game-theoretical models. They found that for ship capacity decisions, operators would always increase capacity as demand increase; for deterrence strategies, incumbents would offer low freight in different cases. Kou and Luo (2016) built a game theory model to study the capacity expansion decision in competitive shipping market where market demand is proportional to the capacity share. It reveals that the competition will naturally result in overcapacity and Prisoners' Dilemma. Angeloudis et al. (2016) developed a three-stage game to study and compare the service network design, container assignment and service provision of monopoly and competing liner shipping companies for given demand between port-pairs, with three decision variables at each stage: fleet capacity, port rotation and pricing.

## 2.4 Research on liner shipping operators' financial performance

For decades, researchers tried to find out the best operation strategy for liner shipping companies to achieve maximum profit. The research on companies' financial performance is comprehensive and rich. Generally, a company's financial performance is affected by both external and internal factors (Capon, et al., 1990).

### 2.4.1 General factors in liner shipping companies' financial performance

The external factors include the market prices and raw material prices. For line shipping industry, most common-used variables are the freight rates and oil prices (Tran & Hans-Dietrich, 2015). Notteboom and Bert (2009) analyzed the effect of bunker prices in liner shipping costs of North Europe–East Asia loop. They found even in large post- panama containerships, the bunker prices had significant impacts on the operating costs, although costs might react late than the bunker price fluctuation.

The internal factors include the scale of the company, assets and employee numbers etc. Almost all researchers adopted companies' fleet capacity and total assets as important factors in the profitability studies (Panayides & Neophytos, 2011; Lun & Marlow, 2011; Tran & Hans-Dietrich, 2015; Wang, et al., 2014). Some studies also investigated the effect of company organization in carriers' performance (Lambertides & Christodoulos, 2008; Syriopoulos & Tsatsaronis, 2011).

Panayides and Neophytos (2011) used SFA(Stochastic Frontier Analysis) and DEA(Data Envelopment Analysis) methods to study the efficiency of companies in shipping. The inputs are assets, investments and employees. The study found liner shipping companies had a higher operational efficiency (outputs are revenue and costs) than dry bulk and tanker companies due to scale economies and network optimization. But container shipping sector had lower market efficiency (outputs are profit and book value) than tanker sector. That implied the liner shipping market had increasing uncertainty and decreasing freight rate since 2008. Tran and Hans-Dietrich (2015) collected 20 companies' annual performance from 1997 to 2012 to investigate the effects of market prices, oil prices, carriers' capacity and average ship size. They used log-regressions and found that market price, raw material prices and companies' capacity affected revenue and costs growth.

The internal factors of financial performance also include firm management. There are empirical studies on effects of innovation (Zahra & Sidhartha, 1993), Merger and Acquisition (M&A) (Ramaswamy & Waegelein, 2003), vertical integration (Vickery, et al., 2003) and diversifications (Tallman & Li, 1996). However, not many studies in maritime field investigate how companies' strategies affects their financial performance.

Jenssen and Randøy (2006) conducted a survey for 46 Norwegian shipping companies and adopted structural equation models to investigate the impact of innovation on shipping firms' performance. They found the organization of shipping companies was a moderator that affected the innovation that contributes to its financial performance. By analyzing the M&As of NYK and Showa Line, OSK and Navix Line, Choi and Shigeru (2013) found M&A improved market power and turnover of bidders by an increase in fleets. The target bulk shipping companies also improved their financial safety with higher profitability and lower financial leverage ratio. Yang, Marlow and Lu (2009) used SEM (Structural

Equation Modeling) to test how supply chain management capability affect financial performance of line shipping services in Taiwan. The results of 123 questionnaire responses showed that higher logistics management capability led to better financial performance of firm performance in containership sector.

### 2.4.2 The impacts of large ships and alliance in profitability

For liner shipping companies, the average ship size is an important feature in performance due to the economies of scale (Jansson & Shneerson, 1982). Besides, companies with large containership may have different operating pattern compared with small ships. Notteboom and Bert (2009) calculated four different size ships' daily fuel consumption and found larger ships had lower bunker costs per slot and lower sensitivity to fuel prices changes. Fusillo (2013) studied market share of carriers in U.S. and found large containerships were deployed in the main route that has higher competition degree, such as FE-Europe or Transatlantic routes. Therefore, companies with larger ships may face fiercer competition and have lower load factors.

However, few empirical studies show the direct effects and moderator effects of ship size in liner shipping companies' financial performance. Bang et al. (2012) studied 14 liner shipping companies' efficiency from top 20 global carriers in 2008. Based on the DEA results, they adopted the Tobit model to further examine the impacts of firm's operational and strategic management on performance. They found ship size improved the financial efficiency (inputs are assets and capital expenditure; outputs are revenue and profit) although decreased the operational efficiency (inputs are ship numbers and capacity; outputs are cargoes carried). However, Tran and Hans-Dietrich (2015) found that the average ship size was an insignificant factor in liner shipping companies' financial performance change during 1997 to 2012.

Shipping alliance is a unique phenomenon in liner shipping industry. Joining alliance can help carriers against the pressure of competition in major shipping routes (Panayides & Wiedmer, 2011). Haralambides (2004) compared the Westbound Atlantic rates in different period and found the rates were stable when operators cooperated. When companies joint shipping alliance, they had to obey the alliance's fleet schedule. Therefore, they cannot adopt slow steaming to save costs when bunker prices are high (Notteboom & Bert, 2009). Besides, alliance member can reconstruct their networks with higher frequency and reduce unit costs in port calls (Heaver, et al., 2000). That means the alliance members may have different sensitivity in prices, bunker prices and capacity.

The study of Bang et al. (2012) suggested that alliance membership improved carriers' market financial efficiency, namely the profit and revenue. Their results show joining alliances had insignificant effects in operational efficiency. Because of lack of released data and instability of organization, few empirical studies analyze the effect of joining alliance in companies' financial performance.

The above reviews show how different factors affect liner shipping companies' profitability. Among all factors, large container ship and alliance membership can have moderating effects in financial performance. However, no empirical studies have examined those impacts yet. In addition, most previous studies are based on DEA methods and focus on inputs and outputs between companies in the certain year. Those studies cannot measure how companies' efficiency changes in different market conditions. Therefore, to investigate 'moderating effects' of large containerships and alliance membership, the third part of this thesis conducts a long-term accounting-based empirical study for liner shipping companies' financial performance.

# Chapter 3 : DO LARGER SHIPS VISIT FEWER REGIONS/PORTS? AN EMPIRICAL ANALYSIS ON GLOBAL LINERS SERVING CHINA

This chapter empirically study how global carriers determine the regions to serve and the number of ports to call in Chinese Coast based on their service schedules in 2011 and 2015. By ordered logit regressions and OLS regressions, we find that increasing ship size within a certain range leads to more clusters/ports visit. Beyond that, they visit fewer clusters, not fewer ports. Therefore, even two ports are very close, as long as they are efficient, they may both be called in a service. This signifies the difference of the Hub-and-Spoke structures in liner shipping with that in aviation whereas it is not necessary to have two hubs in the same place.

## 3.1 Introduction

Intuitively, larger vessels in an international shipping service should visit more regions or call 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?

As shown from Section 3.2 below, China is by far the largest country in containerized trade. 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 behavior of liner shipping networks serving the Chinese trade.

Based on the data of liner services to and from China, this paper analyzes 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 12000 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 behavior 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 chapter is organized as follows: Section 3.2 describes the background to Chinese ports and port clusters, and the liner services to and from China. Then, in Section 3.3, the major factors affecting cluster/port visits are introduced, together with the description of the data. Section 3.4 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 3.5 contains a summary of the results and discusses policy recommendations.

## 3.2 Liner shipping services calling at Chinese ports: 2011-2015

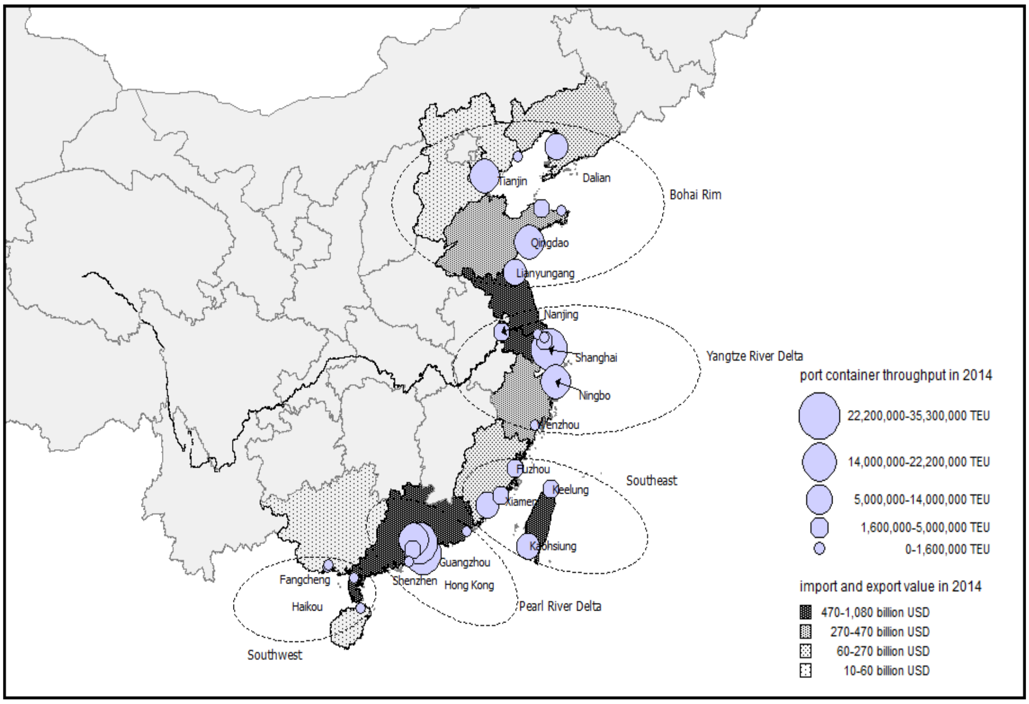



Figure 3-1: Distribution of five port clusters and container ports in China

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 3-1). 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 3-2. The data on container throughput are from the Statistics Yearbook of China[5], and the liner service information in 2011 and 2015 are from the Alphaliner online database[6]. Since liner shipping services may change at any time in a year, the data for each year represent the available

[5] www.stats.gov.cn

[6] www.alphaliner.com

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.

From Figure 3-2, we can see that container trade activities are very active in Chinese coastal ports. There are 9 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 specialized for cross-strait trade, and the drop is mainly due to its capacity limits.

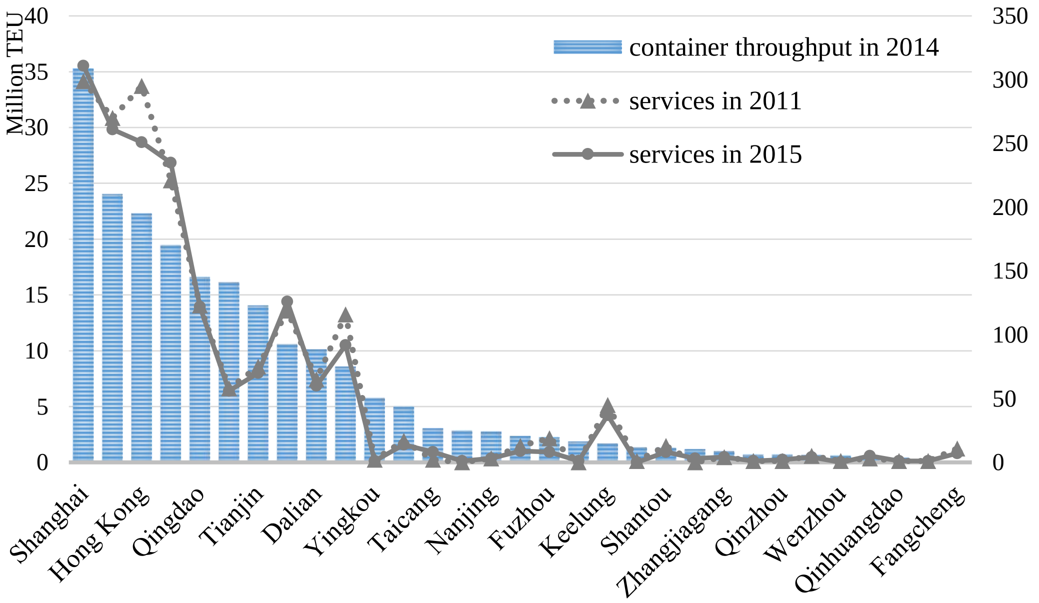



Figure 3-2: Container throughput and change of liner services at Chinese ports

### 3.2.1 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;7 among the top 20, 10 are from China. This large trade volume requires a large number of liner services. Table 3-1 summarizes basic information 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 to 2.19 million TEUs. During these five years, the number of ships increased by 13.66%, while the average ship size grew by 17.67%. In addition, the number of ships below 8,000 TEUs decreased by 4.39%, while those above 8,000 TEUs increased by 79.80%.

Table 3-1: 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 | 2841 | 3499 | 2576 |
| 2015 | 531 | 2.19 | 3229 | 4117 | 2702 |

All major carriers have services to and from China. Table 3-2 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

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

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.

Table 3-2: 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 | 2734 | 3707 | 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 |

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%, and total weekly capacity grew by 54.02%. For other Asian liners, the ship size and capacity increased by 4.02% and 4.74%, respectively. The capacity of non-Asian liners dropped, due to an increase in the number of alliances.

### 3.2.2 Capacity deployment by port clusters and shipping routes

Figure 3-3 shows the aggregated weekly capacity, throughput, and trade value in each of the five clusters. For the same reason as stated in section 3.2.1, 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.

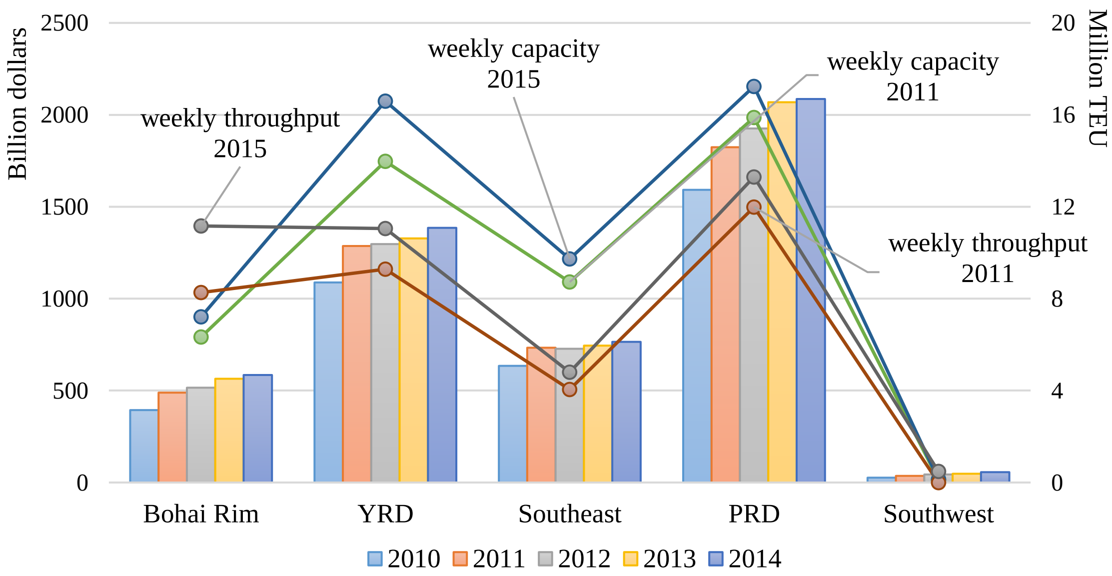



Figure 3-3: Trade value, weekly capacity and throughput of clusters

Figure 3-3 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 3-4 summarizes the weekly capacity and average ship size of all the routes in 2011 and 2015.

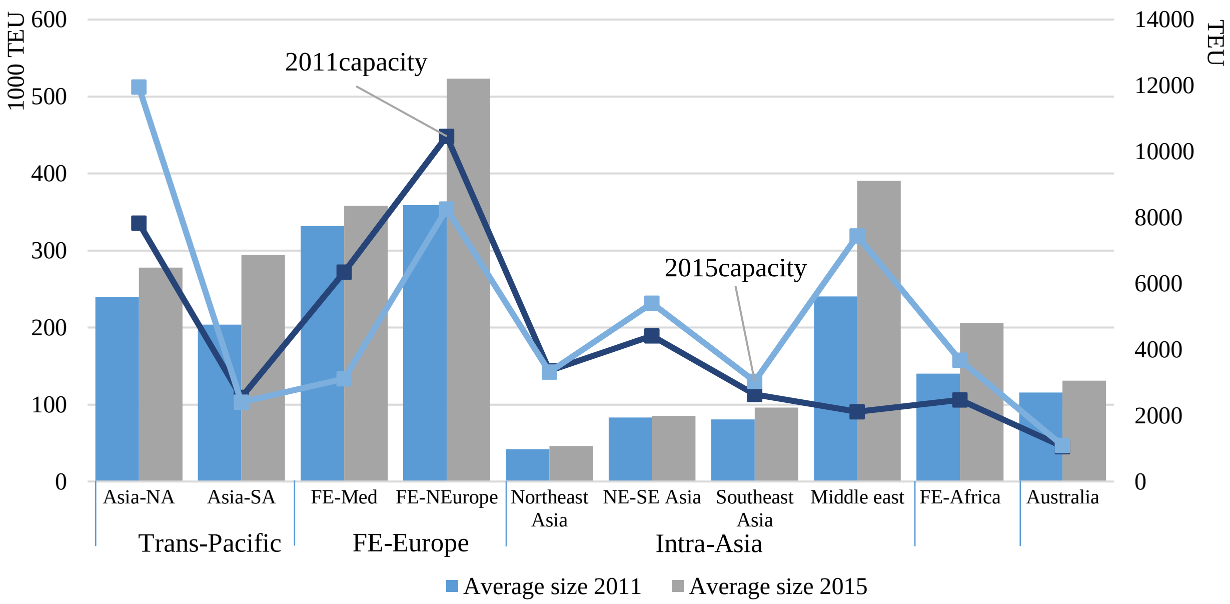



Figure 3-4: Weekly capacity and average ship size on the shipping routes serving

The lines in Figure 3-4 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 & FE-NEurope) had a significant drop in weekly capacity while

Intra-Asia route had the largest growth in capacity in 2015. In fact, top liners such as Maersk, MSC and CMA CGM that 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%) while the increase on the NE-SE Asia route is only 2%.

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

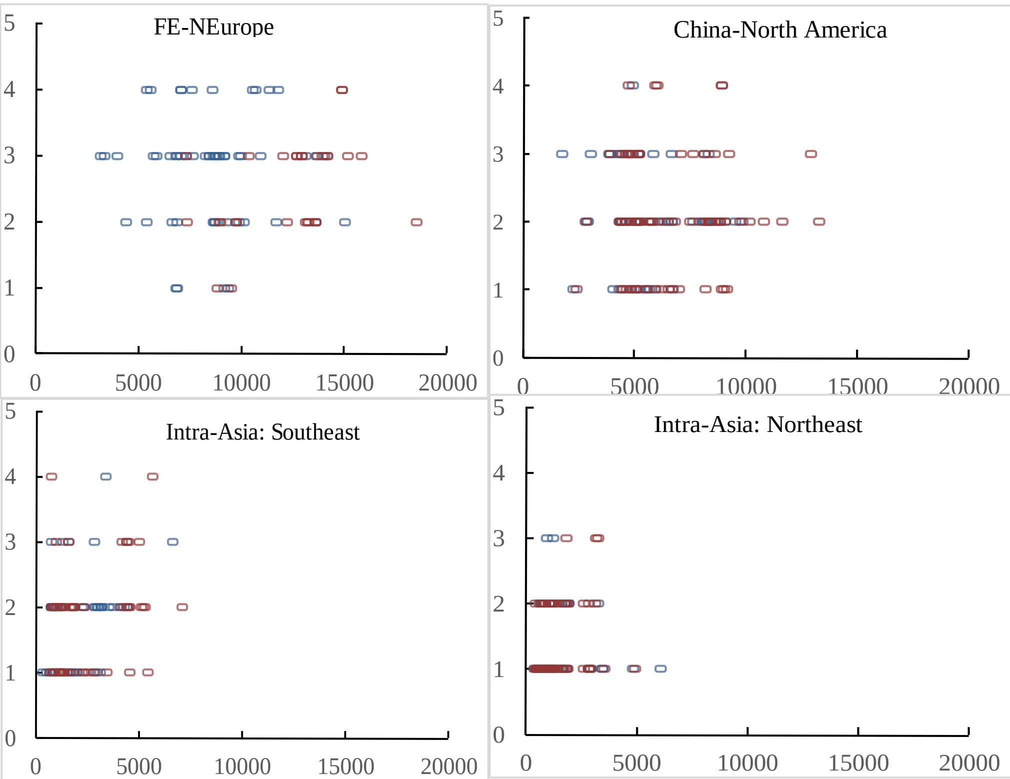



Figure 3-5: Cluster visits and ship size in selected trade routes

From Figure 3-3 and Figure 3-4, 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 3-5 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 3-6 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 3-5. 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.

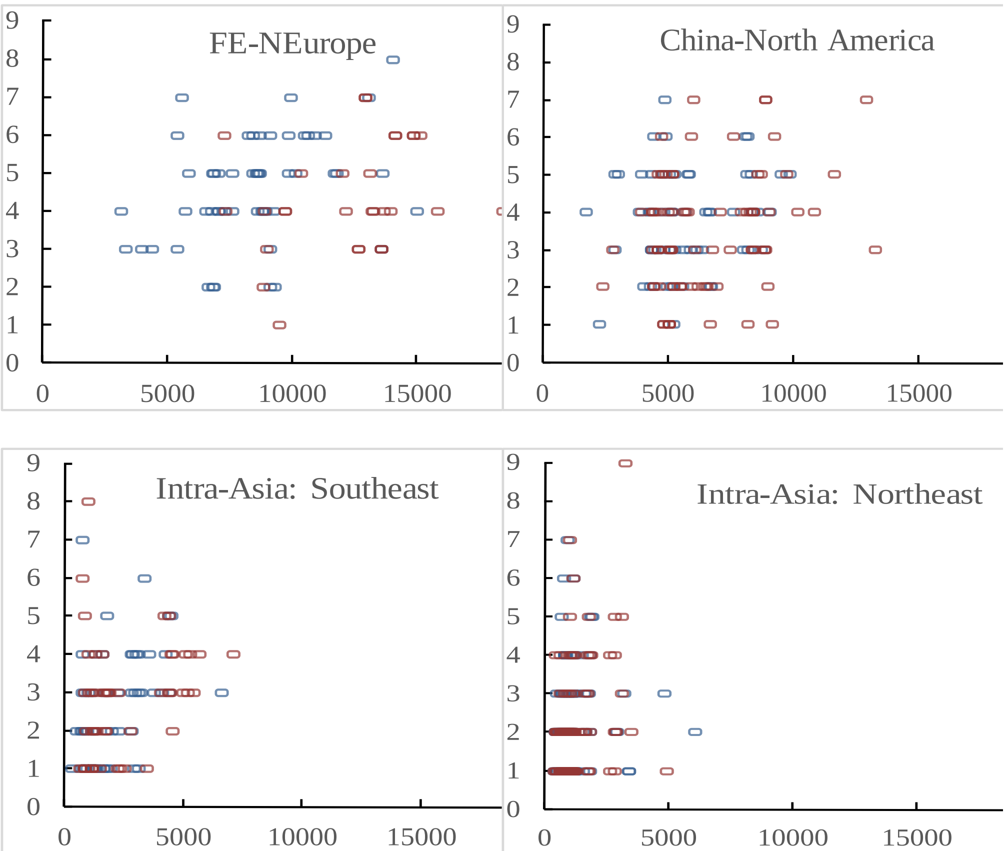



Figure 3-6: Port visits and ship size in selected trade routes

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 first describe the important factors that might affect liners' decisions on the number of clusters to visit, and the number of port calls, which is then followed by a statistical modeling.

## 3.3 Important factors for liner services 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 etc., 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 behavior in cluster visits or the number of port calls for different services on the same route. The focus of this study is to analyze 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*).

*Size, Time* and *Frequency* are the three most important attributes of a liner service. The summary statistics of these variables are shown in Table 3-3. As noted in 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 3-3: Descriptive statistics of ship size, time and frequency

| **Variable** | **Mean** | **Std** | **Min** | **Max** |
|---|---|---|---|---|
| Size | 3805.505 | 3447.835 | 175 | 18340 |
| Time | 40.01589 | 30.29516 | 7 | 147 |
| Frequency | 7.085008 | 1.350475 | 0.875 | 27 |

Most liner services try to maintain weekly services. As shown in Table 3-3, the distribution of the liner frequencies is centered around 7 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.

Table 3-4: Correlation between port/cluster calls and round-trip time in three main routes

| Route | **2011** | | **2015** | |
|---|---|---|---|---|
| | **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 |

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 3-4, 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 3-5, 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 1070 services are shown in Table 3-5. Since our study area is the liner services for Chinese ports, the four Inner Asia routes account for about 60% of the total sample.

Table 3-5: 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 | 1059 | 98.94% |

The behavior 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 3-6.

Table 3-6: 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% |

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

## 3.4 Empirical analysis of cluster/port call decisions in liner shipping services

This section presents the econometric models for analyzing the impact of the potential factors on the decision of cluster/port visits. For cluster visits, since only 6.35% of the services call on 4 or 5 clusters, we grouped these two categories into the category 'visit 3 or more clusters'. For ports, the maximum port call numbers are 10, so Ordinary Least Square (OLS) regression models can be used here.

### 3.4.1 Statistical models for the number of clusters/ports to visit

Two statistical models were adopted to analyze 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 modeling discrete choice behaviors 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 3.3, then the total utility obtainable from this service, $U_i$, can be written as:

$$U_i = x_i\beta + e_i \tag{3-1}$$

where $\beta$ 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 $\Phi(e_i) = \frac{exp(e_i)}{1+exp(e_i)}$, which can be illustrated by Figure 3-7. 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.

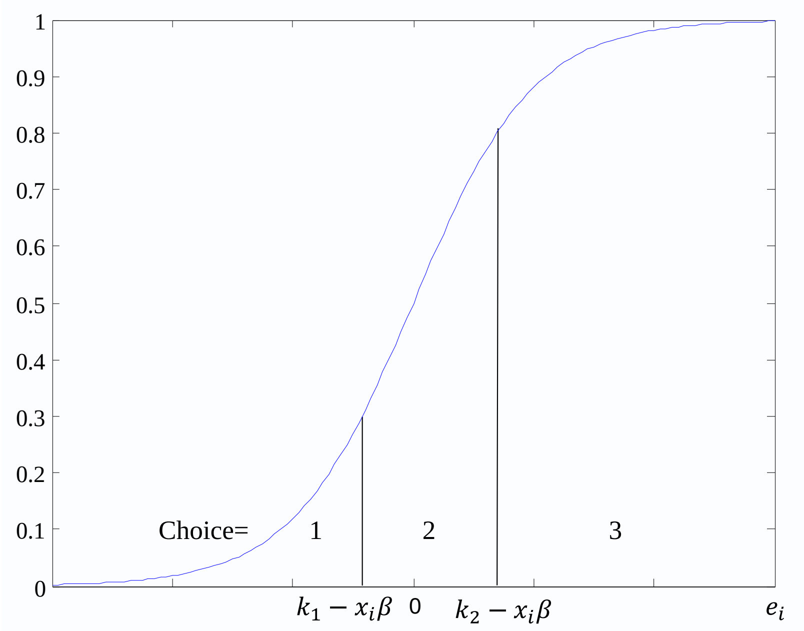



Figure 3-7: Cumulative distribution of the error term

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:

$$P(Choice = 1) = P(U_i < k_1) = P(e_i < k_1 - x_i\beta) = \Phi(k_1 - x_i\beta)$$

$$P(Choice = 2) = P(k_1 \leq U_i < k_2) = \Phi(k_2 - x_i\beta) - \Phi(k_1 - x_i\beta) \qquad (3\text{-}2)$$

$$P(Choice = 3) = P(U_i > k_2) = 1 - \Phi(k_2 - x_i\beta)$$

From these equations, the log-likelihood function can be specified, and 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.

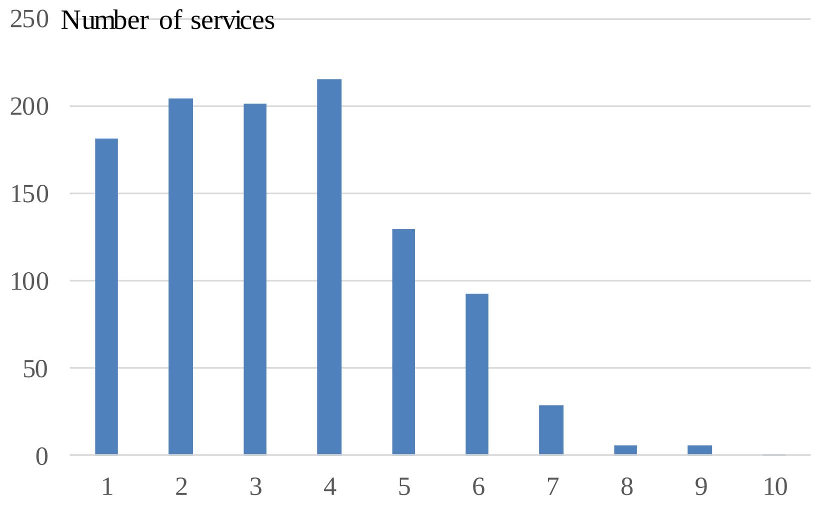



Figure 3-8: Distribution of liner services according to number of ports visited

Unlike the number of cluster visits, the number of port calls is more spread out. As shown in Figure 3-8, only three categories (call at 2, 3, or 4 ports in a service) 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 analyze the number of ports visited, using the same set of variables described in Section 3.3.

### 3.4.2 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 applied the Ordered Logit model and OLS model separately to estimate the impacts of the variables on cluster/port visits. Therefore, four different models are estimated. The estimated coefficients are listed in Table 3-7.

Table 3-7: 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 R2 | 0.268 | 0.415 | 0.263 | 0.400 |
| Turning points of size | 14855 | 22099 | 12745 | |

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 R2 are around 0.26. The two OLS models have Pseudo R2 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 summarized as follows:

(1) Compared with the year 2011, the liner services in 2015 had a lower number of cluster/port visits, while ships became bigger.

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

(3) The services provided by alliances visited fewer clusters/ports. The ships used by alliances, 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 load factor. Table 3-7 shows that the absolute values of the coefficients for Alliance are larger than any nationality categories in all the four models.

(4) 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 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 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.

(5) 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.

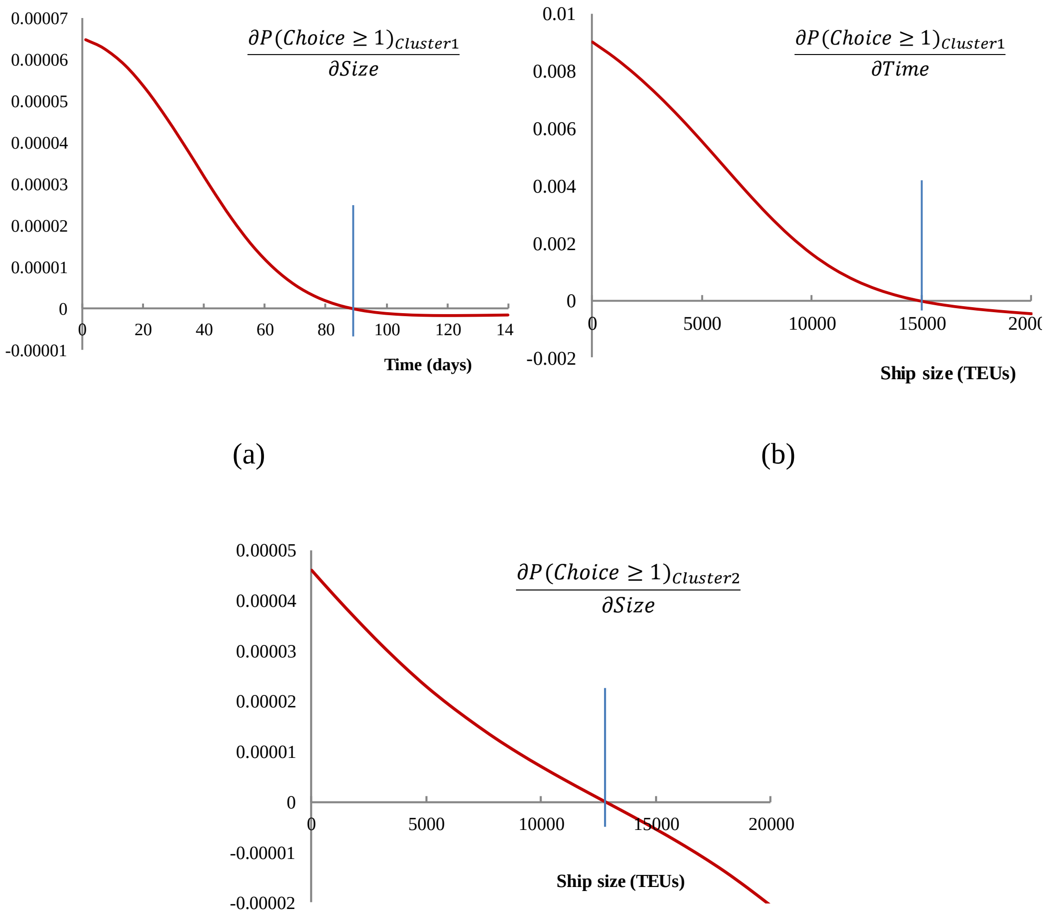
Assuming the estimated coefficients for *Size, Time, Size_time,* and *Size_2* as $\beta_s$, $\beta_t$, $\beta_{st}$, and $\beta_{s2}$, respectively, the marginal probability for selecting more clusters in Cluster1 model are:

$$\frac{\partial \mathrm{P}(Choice \geq 1)_{Cluster1}}{\partial size} = \Phi(k_1 - x_i\beta)(\beta_s + \beta_{st}Time)$$
$$\frac{\partial \mathrm{P}(Choice \geq 1)_{Cluster1}}{\partial time} = \Phi(k_1 - x_i\beta)(\beta_t + \beta_{st}size) \qquad (3\text{-}3)$$

And that for cluster2 model is:

$$\frac{\partial \mathrm{P}(Choice \geq 1)_{Cluster2}}{\partial size} = \Phi(k_1 - x_i\beta)(\beta_s + 2 * \beta_{s2}size) \qquad (3\text{-}4)$$

The plots for the changes of these marginal probabilities with the change of round trip time and ship size are shown in Figure 3-9.




(c)

Figure 3-9: Marginal probability for cluster visits with time and size in two cluster models

Figure 3-9 (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 3-9 (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 3-9 (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 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 summarize that:

(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.

Table 3-8: Number and percentage of services that call at both ports in one cluster

| | **2011** | | **2015** | |
|---|---|---|---|---|
| | **number of Services** | **%** | **number of Services** | **%** |
| 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 |

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 Far East using eleven 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 3-8, among the liners that called at the YRD cluster in 2011, 92% called at Shanghai, 68% called at Ningbo, and 61% called at both Shanghai and Ningbo ports. This number increased to 67% in 2015. For those that called at the PRD cluster, 56% and 54% called at both Hong Kong and Shenzhen ports in 2011 and 2015, respectively.

## 3.5 Chapter summary

The study analyzes how the internal factors, such as trade routes, round-trip time, and nationality of the carrier or membership of liner alliances, affect liners' behavior 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 analyzing the number of clusters to visit, and an Ordinary Least Square model in analyzing 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 load 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 optimization 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.

# Chapter 4 : THE LINKS BETWEEN SHIP SIZE AND PORT CALL NUMBER IN CONTESTABLE LINER SHIPPING MARKET

This chapter aims to understand the economic principles on liner shipping's port call decisions. Specifically, we intend to find the relationships between ship sizes and port call numbers through analytical modeling, comparative static analysis, and numerical simulation. We would also compare liners' port selection strategies with or without competition. Finally, the results from this study should help decision-makers in liner shipping industry in selecting the best size ships and port rotation, as well as the port operators on their port development strategies.

## 4.1 Introduction

One of the obvious trends in liner shipping industry in the past two decades is the increasing number of ever bigger containerships in the world fleet. Although the liner market still has not seen the sign of recovery, this trend is getting accelerated. According to Alphaliner monthly monitor at February 2017, there are 47 ships with capacity over 18,000 TEUs, which account for 4% of world containership fleet. However, a total of 58 such ships are on the orderbook, which represents a 127.6% increase over the existing capacity in this category. The biggest are six 21,100 TEU container vessels ordered by Orient Overseas Container Line in March 2015. Concurrent to this trend, liner shipping industry is experiencing a more densely-connect global network as well as a more concentrated market: there are more than 3,500 services for 11 different shipping lanes calling ports more than 9000 times per week[8]; starting from April 1st of 2017, the three major alliances (2M+HMM, OCEAN Alliance and THE Alliance) account for 95% of the capacity in the Far East-North America route, and 99% on the Far East-Europe/Mediterranean route, according to Alphaliner weekly newsletter on March 29, 2017.

Will the growing ship size lead to fewer ports call? Many academic studies asserted that as ship size grows, liner shipping operators would adopt Hub-and-Spoke (H&S) network and call only few hub ports to save cost (Hayuth, 1981; Notteboom, 1997; Imai, et al., 2009), similar to that in the aviation industry. Large ships will only visit the hub ports; hence the number of port calls will be reduced. The accelerated market concentration with mergers and alliances further increased the ability to use more large ships, which could enhance the trend of reducing port calls (Pierre & Ali, 2014; Wang & Cullinane, 2014).

However, statistics on the number of port calls for the international liner shipping services to and from China in 2011 and 2015 presents a different story (Wu et al., 2017). Figure 1-4 shows the distribution in the number of Chinese ports visited by ships with different capacity (in TEUs) in international liner shipping services. Each dot stands for the number of Chinese ports visited by a liner service with ship size in the horizontal axis. There is not a very clear trend that larger ships call fewer ports. Although the trend line appears to be concave, the hypothesis that increasing ship size can result in fewer number of port calls is not supported by statistical test (Wu et al., 2017). Then, a nature question to ask is whether the further increase of ship size will result in reduced port calls, if the current data does not support the hypothesis?

[8] http://www.worldshipping.org/ accessed Oct. 24, 2016

Examining the relationship between the number of port calls and the ship size can contribute to both liner shipping operators and port investors. Although there are plenty of research on liner shipping networks design, few studied the impact of increasing ship size on the number of port calls and explained such impacts from theoretical modeling.

This study tries to build a theoretical model to explain the number of port calls in international liner services from the fundamental economics in liner operation. Specifically, it addresses the decision on how many ports to call, rather than how to call these ports, for different ship size in a contestable single player market, or a duopoly market where each player competes using price discount based on the contestable market price. The result from this study can help to understand whether larger ships make fewer number of port calls. This can give guideline on the liner shipping network studies on how many ports to include in their optimization model. In practice, it can help decision makers in port investment facing increasing ship size, as it has always been a debate on whether a port should join the competition to become the regional hub port.

This chapter is arranged as follows. On the basis of theoretical assumptions, Section 4.2 discusses the decision of one liner operator on the number of ports to call in a contestable market. Section 4.3 presents the port call decision in a duopoly model, each competing by offering discounts based on contestable market price. Section 4.4 provides numerical simulation results for the analytical result in section 4.2 and 4.3. The last section summarized the major findings in this research.

## 4.2 Port call number decision of single liner operator

To analyze the number of ports to call, the assumptions on the structure of liner shipping market is essential. A full discussion on the market structure in liner shipping industry is beyond the scope of this paper. Interested readers please refer to Franck and Bunel (1991), Davies (1986) and Shashikuma (1995). We assume that the liner shipping market is contestable. There is a contestable market price (p) even when there is only one player in the service.

### 4.2.1 Model setup and justification

The purpose of this study is to analyze the port call decision in liner service. Several assumptions are required to simplify the analysis. First, the container line is assumed serving weekly between foreign countries in one continent and the destination in another continent. The ports at one side (for example, the foreign countries) are simplified as one port, to focus on the other (such as destination). There are several ports along the coastal area. At least one port will be selected to provide the service. The average access distance to a port is assumed to be constant $d$. The freight rates from each port to the foreign countries are assumed to be the same ($p$). To call a port, the ship needs to pay port due $C_p$, and additional ship operating cost due to the port access time $FC(k) * \frac{d}{v}$, where $FC(k)$ represents the fixed cost of the ship for ship size $k$ per time period, and $v$ the ship speed. Larger ships usually have higher fixed cost, i.e., $FC'(k) > 0$.

Generally, liners prefer to call ports with higher demand (Chang, et al., 2008). Therefore, it is reasonable to assume that liners will always call ports with higher demand first. This is equivalent to assuming that ports are sorted in descending order according to their demand. Then, the total number of containers that a ship can load from the ports called directly, $q_d(N)$, increases with the number of port calls N, i.e., $q_d'(N) = \frac{\partial q_d(N)}{\partial N} > 0$. In addition, this increment decreases with the port call numbers, i.e., $q_d''(N) < 0$. In addition to direct calls, a ship can also accept containers transshipped from other ports. The total demand of transshipped containers $q_i$ is assumed to be a function of both the number of selected ports $(N)$ and feeder ports $(T)$, i.e., $q_i = q_i(N, T)$. The transshipment cost is assumed to be $C_t$, and the container handling cost $(VC)$ is assumed to be constant for both transshipment and direct containers.

For weekly services, the total annual profit of the whole fleet in a year is $\frac{365}{7}$ times the profit of one round-trip. Therefore, without considering about the uncertainties and seasonal variations, it should be sufficient to consider the profit maximization problem of one round-trip for given constrains:

$$\max \pi = (p - VC)[q_d(N) + q_i(N,T)] - C_p N - C_t q_i(N,T) - FC(k)\frac{2L+N*d}{v} \tag{4-1}$$

s.t. $q_d(N) + q_i(N,T) \leq k$, $N \geq 1$, and $T \geq 0$

The decision variables are the number of ports $(N)$ in short run, and ship size $k$ in the long run. Market price is given, reflecting the nature of contestable market (Davies, 1986) in liner shipping industry. The case of no competition is presented first, followed by the analysis when there are competitors in the same route.

### 4.2.2 Optimal number of port calls in a contestable market for single operator

A liner operator can load both direct and transshipment containers. Since the focus is on the number of ports to call directly, it is assumed that transshipment demand is sufficient to fill up the ship. Then, whether to take transshipment cargo depends on the whether $p - VC > C_t$. If yes, it is better to fill up the rest of the capacity; otherwise, no transshipment will happen. Therefore, the problem in Eq.(4-1) converts to:

$$\max_N \pi = (p - VC)q_d(N) + max(p - VC - C_t, 0) * [k - q_d(N)]$$

$$- C_pN - FC(k)\frac{2L + N * d}{v} \quad (4\text{-}2)$$

s.t. $q_d(N) \leq k$, and $N \geq 1$.

The process of solving this profit maximization problem is straight forward using KKT condition. The result can be described below:

If capacity constraint is binding, i.e., $q_d(N) = k$, the optimal decision is to select the ports with highest demand, fill up the ship, and then sail across the ocean. Therefore, the optimal number of port calls $N^*$should satisfy:

$$q_d(N^*) = k \quad (4\text{-}3)$$

In this case, it is straight forward that increase ship size can increase number of port calls.

If capacity constraint is not binding, i.e., $q_d < k$, then the First Order Condition (FOC) is:

$$min(p - VC, C_t) * q'_d(N^*) = C_p + FC(k)\frac{d}{v} \quad (4\text{-}4)$$

and the Second Order Condition (SOC) is $min(p - VC, C_t)q''_d(N^*) \leq 0$, which is satisfied because the second term is negative.

The result can be illustrated in the following figure:

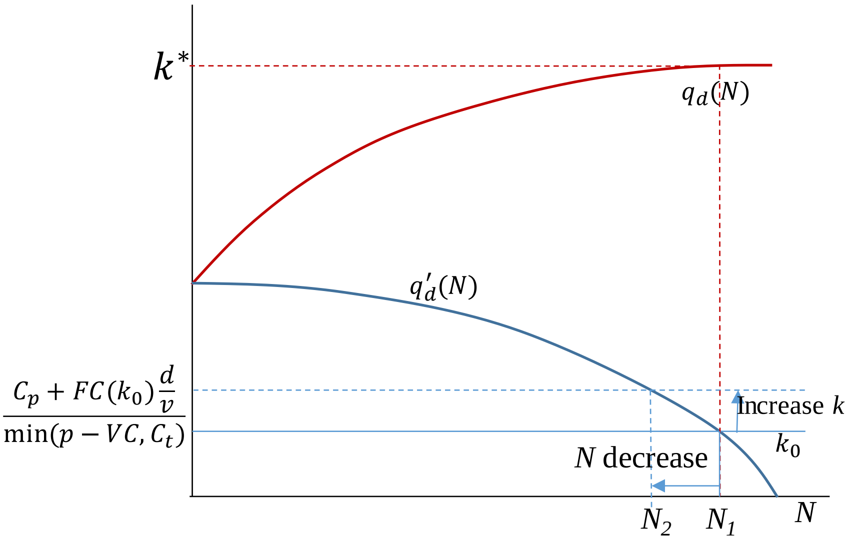



Figure 4-1: Illustration of the relationship between ship size and port call number

In Figure 4-1, the curve marked $q'_d(N)$ stands for the demand of port $N$. If transshipment is not economical, when earnings from calling port $N$, $(p - VC)q'_d(N)$, is larger than the cost to call the port, $c_p + FC(k)\frac{d}{v}$, it is better to call the port. Equivalently, whenever the curve is high than the solid horizontal line, the liner will call the port. Otherwise, the ship should leave. If the curve crosses the horizontal line at $N_1$, then all the cargoes from the port number less than $N_1$, $q_d(N_1)$, will be loaded to the ship.

The top curve represents the cumulative demand from all $N$ ports, which is also the total number of containers a ship can carry when the $q'_d(N)$ curve is above the horizontal line. Of course, this total number of containers a vessel can load is limited by its capacity. Therefore, if ships are small relative to the high demand, larger ships will call more ports. However, when the ship gets larger, the horizontal line will shift up, due to increase in fixed cost. This requires a higher demand for a port call. Therefore, over certain capacity level, continued increase of ship size will lead to calling fewer number of ports. For example, assume the optimal capacity that the

$q_d'(N)$ curve intersects with the horizontal line is $k^*$, and the ship is filled up. Then using a larger ship ($k_1 > k^*$) will shift the horizontal line up (the dotted line). Then the number of ports will be reduced to $N_2$, and the ship will leave with empty container slots.

When $p - VC > C_t$, the decision to call a port or to transship the cargo depends on which option incurs lower costs, as they have the same earnings. Therefore, if $C_t q_d'(N) > C_p + FC(k)\frac{d}{v}$, it is better to call the port; otherwise, transshipment. Using the same figure, for the same capacity, the horizontal line will be higher when transshipment is allowed. Then, the number of port calls will be smaller, and ships will fill up the rest of the capacity with transshipment containers.

Therefore, from above description, the increase of ship size may lead to increase or decrease the number of port calls. For smaller ships, the increase of ship size will increase the number of port calls. However, over certain limits, continuing to increase ship size will reduce the number of port calls, because the cost to call the port is too high compared with the potential earnings from the port.

In addition to the size factor, the number of port calls also depends on the demand function $q_d(N)$. If overall demand is high, the $q_d'(N)$ curve will shift up, which will increase the number of port calls for large ships. For the same overall demand, if it is more concentrated on few larger ports, the larger ship will also call fewer number of ports. Besides, the decrease in port cost and ship fixed cost can increase the optimal port calls numbers for single liner operator. Finally, if the distance between ports is large, the number of port calls will be low.

## 4.3 Port call decision model when there are competitions

The previous part reveals the basic economic principle in determining the number of ports to call in designing a liner service without considering the competition from other services. In reality, competition always exists. Liner operators usually compete for customers by offering price discount. Therefore, in the competition model, we analyze two liner shipping operators, each has different ship sizes, compete by charging different prices. The total demand at each port remains the same, while the demand for each operator will decrease with its own price, and increase with the price of the competitor. Denoting $q_{ni}$ as the demand for operator $i$ ($i \in [1, 2]$), when both operators call port n, their demand functions are:

$$q_{n1} = \alpha q_n - rp_1 + rp_2 \tag{4-5}$$

$$q_{n2} = (1-\alpha) q_n - rp_2 + rp_1 \tag{4-6}$$

where $\alpha$ is the base market share of operator 1 when they charge the same price $p$. $p_1$ and $p_2$ are the prices of operator 1 and 2. They both should be larger than the variable cost VC, and less than the market price $p$. $r$ is the price effect, the same for both operators. When there is only one operator, such as operator 2, calling the port, it would take all the containers, i.e., $q_{n2} = q_n$.

If two operators call $N_1$ and $N_2$ ports (assume $N_1 \leq N_2$) , then the total demand for the two operators are:

$$Q_{N_1} = \alpha q_d(N_1) - rN_1 p_1 + rN_1 p_2 \tag{4-7}$$

$$Q_{N_2} = (1-\alpha) q_d(N_1) - rN_1 p_2 + rN_1 p_1 + q_d(N_2) - q_d(N_1), \tag{4-8}$$

since $q_d(N) = \sum_{n=1}^{N} q_n$. In addition, we assume the ship size of the two operators are $k_1$ and $k_2$. If a port is only called by one operator, the freight rate at the port would be the market price $p$.

In this game, liners' decisions on the number of port calls and pricing are assumed to be public information. They both decide the number of port calls first, then price. To analyse the possible equilibrium results, the model first solve for the optimal equilibrium price of each operator given the number of port calls; then find the equilibrium port call numbers. The condition for operator 2 to call more ports than operator 1 will be discussed. Similarly, the analysis with transshipment is provided separately.

### 4.3.1 Case I: No transshipment

The objective of each operator is to maximize its profit using pricing. The profit functions and capacity constraints for two operators are:

$$\pi_1 = (p_1 - VC)Q_{N_1} - \left[C_p + FC(k_1)\frac{d}{v}\right]N_1 - FC(k_1)\frac{2L}{v} \quad \text{s.t. } Q_{N_1} \le k_1 \tag{4-9}$$

$$\pi_2 = (p_2 - VC)[q_d(N_1) - Q_{N_1}] + (p - VC)[q_d(N_2) - q_d(N_1)] - \left[C_p + FC(k_2)\frac{d}{v}\right]N_2 - FC(k_2)\frac{2L}{v} \tag{4-10}$$

$$\text{s.t. } q_d(N_2) - Q_{N_1} \le k_2$$

The Lagrangian functions are:

$$L_1 = (p_1 - VC)Q_{N_1} - \left[C_p + FC(k_1)\frac{d}{v}\right]N_1 - FC(k_1)\frac{2L}{v} + \mu_1[k_1 - Q_{N_1}] \tag{4-11}$$

$$L_2 = (p_2 - VC)\left[q_d(N_1) - Q_{N_1}\right] + (p - VC)[q_d(N_2) - q_d(N_1)] - \left[C_p + FC(k_2)\frac{d}{v}\right] N_2 - FC(k_2)\frac{2L}{v} + \mu_2\left[k_2 - q_d(N_2) + Q_{N_1}\right] \quad (4\text{-}12)$$

Since the price decisions are made after the number of port calls, we first find the optimal equilibrium price in the competition game, then the number of port calls. Differentiate the above two Lagrangian equations with respect to (w.r.t.) their own price, the best response function of the two operators can be obtained:

$$p_1 = \frac{\alpha q_d(N_1)}{2rN_1} + \frac{1}{2}p_2 + \frac{VC + \mu_1}{2} \quad (4\text{-}13)$$

$$p_2 = \frac{(1-\alpha)q_d(N_1)}{2rN_1} + \frac{1}{2}p_1 + \frac{VC + \mu_2}{2}. \quad (4\text{-}14)$$

The equilibrium prices for both operators can be solved from these best response functions:

$$p_1^* = \frac{(1+\alpha)q_d(N_1)}{3rN_1} + VC + \frac{\mu_2 + 2\mu_1}{3} \quad (4\text{-}15)$$

$$p_2^* = \frac{(2-\alpha)q_d(N_1)}{3rN_1} + VC + \frac{\mu_1 + 2\mu_2}{3}, \quad (4\text{-}16)$$

The equilibrium price increases with the original market share, the average demand of the called ports, and possible shadow prices, decreases with the price sensitivity of demand. If both have no capacity constraints, their prices will be determined by their market share. The difference of their prices can be written as:

$$p_1^* - p_2^* = \frac{2\alpha - 1}{3}\frac{q_d(N_1)}{rN_1} + \frac{\mu_1 - \mu_2}{3} \quad (4\text{-}17)$$

From this, it is clear that when there is no capacity constraint or their shadow prices are equal, their price difference is only determined by their market share. If their market shares are equal (α=0.5), their price will be equal. If player 1 has a higher market share (α>0.5), its price can be higher. If an operator has a large market share, it does not need to reduce the price as much as its competitor to attract customers. When the average demand is high, the prices can be high for both operators, although the price differences can also be high. If the price sensitivity (r) is high, the price should be lower to achieve the same demand increase. Shadow price is inversely related with ship capacity. For smaller ships, the equilibrium price can be high as there is no needs to reduce price to fill up the space.

At the equilibrium price, the cargo volume carried by each firm can be written as:

$$Q_{N_1}^{*} = \frac{\alpha + 1}{3} q_d(N_1) - \frac{\mu_1 - \mu_2}{3} r N_1 \tag{4-18}$$

$$Q_{N_2}^{*} = \frac{(2 - \alpha)}{3} q_d(N_1) + \frac{\mu_1 - \mu_2}{3} r N_1 + q_d(N_2) - q_d(N_1) \tag{4-19}$$

For the second firm, the last part, $q_d(N_2) - q_d(N_1)$, is the remaining cargo volume after firm 1 stops calling any port. Before that, the cargo volumes of both firms include two parts. The first part is the equilibrium quantity when there are no capacity constraints or when shadow prices of the two firms are equal. The second part is quantity shift caused by different shadow prices. The operator with higher shadow price will shift some cargo volume to the one with less shadow price.

We will discuss the optimal price and port call decisions, as well as the condition for which operator will call more ports in 3 different situations: (1) When the two operators are over-capacity, $\mu_1 = 0, \mu_2 = 0$; (2) When one operator is fully loaded but the other one is overcapacity, i.e., $\mu_1 > 0, \mu_2 = 0$; (3) When both operators are fully loaded, $\mu_1 > 0, \mu_2 > 0$. The other case, $\mu_2 > 0, \mu_1 = 0$, does not need to be considered, as it is the same as case (2) by symmetric condition.

(1) When the two operators are over-capacity, $\mu_1 = 0, \mu_2 = 0$;

When both operators have no capacity constraints, from Eq. (4-17), it is straight forward that their price difference is:

$$p_1^* - p_2^* = \frac{2\alpha - 1}{3} \frac{q_d(N_1)}{rN_1}, \tag{4-20}$$

which shows that their price difference is only determined by their market shares. If their market shares are equal (α=0.5), they will charge the same price. For two operators, the one who has a higher market share will charge a higher price. Since with a large market share, the operator does not need to reduce the price as much as its competitor to attract more customer. Also, when the price sensitivity (r) is high, both operators have to lower their prices to achieve the same demand increase. When the average demand ($\frac{q_d(N_1)}{rN_1}$) is high, the prices for both firms can be high, although the price differences can also be high.

Substitute the equilibrium quantity and price into the respective profit function of each firm, and differentiate that w.r.t. $N_1$ and $N_2$, the FOCs will provide the decision on the number of port calls:

$$\frac{(1+\alpha)q_d(N_1)}{3rN_1} \frac{(1+\alpha)(2q_d'(N_1)N_1 - q_d(N_1))}{3N_1} = \left[C_p + FC(k_1)\frac{d}{v}\right] \tag{4-21}$$

$$(p - VC)q_d'(N_2) = \left[C_p + FC(k_2)\frac{d}{v}\right] \tag{4-22}$$

The condition for operator 2 is exactly the same as Eq. (4-4) when there is no competition, while that for operator 1 is a bit complicated due to competition, but conceptually the same. The first item is the average earning per port when there is competition, and the second is the additional quantity obtainable by calling one more port.

At the time when the first operator is pondering about whether to call the next port, operator 2 is actually doing the same consideration. To analyze what makes operator 2 call more ports than the competitor, we provide the condition for operator 2 to call more ports similar to Eq.(4-21):

$$\frac{(2-\alpha)q_d(N)}{3rN}\frac{(2-\alpha)(2q_d'(N)N-q_d(N))}{3N} > \left[C_p + FC(k_2)\frac{d}{v}\right] \qquad \text{(4-23)}$$

We can use Figure 4-2 to explain why operator 2 would call more ports. Before $N_1$, the two operators are using a similar way to determine the optimal price to charge and whether to call the next port. Operator 1 is using the solid line ② and ④ to determine whether to call next port, while the operator 2 is using dotted line ① and ③. Operator 1 will stop calling the ports when ② and ④ intersect, which is marked $N_1$ in the graph. Operator 2 will take all the cargoes and charge market price after that. Therefore, after operator 1 left (i.e., after $N_1$), operator 2 will using line ⑤ and ⑥ to determine when to leave. If the capacity is not big enough, it may leave earlier than the crossing point $N_2$.

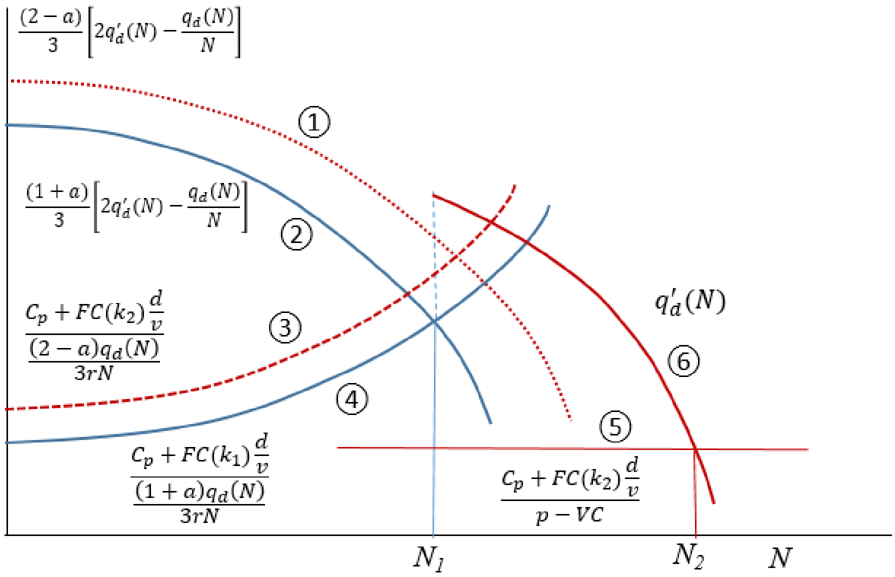



Figure 4-2: Illustration of number of ports to call in competition case

The conditions for determining which operator will stop calling more ports

Operator 1: $$\left(\frac{q_d(N)}{N}\right)\left(2q_d'(N)-\frac{q_d(N)}{N}\right)=\frac{\left[C_p+FC(k_1)\frac{d}{v}\right]}{(1+\alpha)^2/(9r)}, \quad (4\text{-}24)$$

Operator 2: $$\left(\frac{q_d(N)}{N}\right)\left(2q_d'(N)-\frac{q_d(N)}{N}\right)>\frac{\left[C_p+FC(k_2)\frac{d}{v}\right]}{(2-\alpha)^2/(9r)}, \quad (4\text{-}25)$$

Differentiating the LHS w.r.t $N$ gives $\left[\frac{q_d(N)}{V}\right]'\left[2q_d'(N)-\frac{q_d(N)}{N}\right]+\frac{q_d(N)}{N}\left\{2q_d''(N)-\left[\frac{q_d(N)}{N}\right]'\right\}$. Since $q_d''(N_1)<\left[\frac{q_d(N_1)}{N_1}\right]'<0$, as the average port demand is always decreasing at a slower speed than the port demand itself. Also, $2q_d'(N)-\frac{q_d(N)}{N}$ has to be positive from Eq.(4-24). Therefore, the LHS is a decreasing function of $N$. Then, the condition for operator 2 to call more ports is:

$$\frac{\left[C_p+FC(k_1)\frac{d}{v}\right]}{(1+\alpha)^2}>\frac{\left[C_p+FC(k_2)\frac{d}{v}\right]}{(2-\alpha)^2} \quad (4\text{-}26)$$

This shows that when there are no capacity constraints, for the same market share ($\alpha$=0.5), larger ships will call fewer ports. For the same ship size, the one has higher market share will call more ports. This indicates in the competitive environment, when both operators cannot fill up the ships, larger vessels do not necessarily have advantages over smaller ones, unless it has corresponding larger market share.

As both operators still have unfilled capacities, it is obvious that increase capacity will increase the port access cost, which will reduce the number of ports to call for both operators.

(2) When one operator is fully loaded but the other one is overcapacity, i.e., $\mu_1 > 0, \mu_2 = 0$;

If operator 1 has the capacity constraint ($\mu_1 > 0, \mu_2 = 0$), we can get the shadow prices of operator 1 through capacity constraint:

$$\frac{\alpha + 1}{3} q_d(N_1) - \frac{\mu_1}{3} rN_1 = k_1$$

$$\mu_1 = \frac{(\alpha + 1)q_d(N_1) - 3k_1}{rN_1} \quad (4\text{-}27)$$

Shadow price is inversely related with ship capacity. For smaller ships, the equilibrium price can be high as there is no needs to reduce price to fill up space. Take that shadow prices into Eqs.(4-15)(4-16), the prices of the two operators can be obtained:

$$p_1^* = \frac{(1 + \alpha)q_d(N_1) - 2k_1}{rN_1} + VC \quad (4\text{-}28)$$

$$p_2^* = \frac{q_d(N_1) - k_1}{rN_1} + VC \quad (4\text{-}29)$$

Both $p_1^*$ and $p_2^*$ should be smaller than or equal to $p$. Substitute the equilibrium prices into the profit function of operator 1, we can get the FOC of $N_1$:

$$\pi_1^*(N_1) = \left(\frac{(1+\alpha)q_d(N_1)}{3rN_1} + \frac{2}{3} * \frac{(\alpha+1)q_d(N_1) - 3k_1}{rN_1}\right) k_1 - \left[C_p + FC(k_1)\frac{d}{v}\right] N_1 - FC(k_1)\frac{2L}{v} \quad (4\text{-}30)$$

$$\frac{\partial \pi_1^*(N_1)}{\partial N_1} = \left(\frac{(1+\alpha)q_d(N_1) - 2k_1}{rN_1}\right)' k_1 - \left[C_p + FC(k_1)\frac{d}{v}\right] \quad (4\text{-}31)$$

In this case, since operator 1 has capacity constraint, increase ship capacity will increase port call numbers, i.e., $\frac{\partial N_1}{\partial k_1} > 0$. For operator 2, its profit function with optimal prices is:

$$\pi_2^*(N_2) = \left(\frac{q_d(N_1)}{rN_1} - \frac{k_1}{rN_1}\right)(q_d(N_1) - k_1) + (p - VC)[q_d(N_2) - q_d(N_1)] - \left[C_p + FC(k_2)\frac{d}{v}\right] N_2 - FC(k_2)\frac{2L}{v} \quad (4\text{-}32)$$

To understand why the operator 2 is still calling more ports when operator 1 stops, differentiate the above equation w.r.t. $N_1$ when $N_2 = N_1$.

$$\frac{\partial \pi_2^*(N_2)}{\partial N_1} = 2\frac{q_d(N_1) - k_1}{rN_1} q_d'(N_1) - \frac{(q_d(N_1) - k_1)^2}{rN_1^2} - \left[C_p + FC(k_2)\frac{d}{v}\right]$$
$$= \left[\frac{q_d(N_1) - k_1}{rN_1}\right]\left[2q_d'(N_1) - \frac{q_d(N_1) - k_1}{N_1}\right] - \left[C_p + FC(k_2)\frac{d}{v}\right] > 0 \quad (4\text{-}33)$$

Compared with the condition of operator 1 port call decision in Eq.(4-24)(4-25), we can get the condition for determining which operator will stop calling more ports:

Operator 1: $$\left((1+\alpha)\frac{q_d'(N)}{N}-(1+\alpha)\frac{q_d(N)}{N^2}+2\frac{k_1}{N^2}\right)\frac{k_1}{r}=\left[C_p+FC(k_1)\frac{d}{v}\right] \quad (4\text{-}34)$$

Operator 2: $$\left(2\frac{q_d'(N)}{N}-\frac{q_d(N)}{N^2}+\frac{k_1}{N^2}\right)\frac{(q_d(N)-k_1)}{r}>\left[C_p+FC(k_2)\frac{d}{v}\right] \quad (4\text{-}35)$$

When the ship of operator 1 just has enough capacity to carry the equilibrium number of TEUs, i.e., $k_1=\frac{\alpha+1}{3}q_d(N), \mu_1=0$. Substitute this special $k_1$ into the above two conditions, we can obtain the following condition:

Operator 1: $$\frac{(1+\alpha)^2}{9}\left(3q_d'(N)-\frac{q_d(N)}{N}\right)\frac{q_d(N)}{rN}=\left[C_p+FC(k_1)\frac{d}{v}\right] \quad (4\text{-}36)$$

Operator 2: $$\frac{2(2-\alpha)}{9r}\left(3q_d'(N)-\frac{q_d(N)}{N}\right)\frac{q_d(N)}{rN}>\left[C_p+FC(k_2)\frac{d}{v}\right] \quad (4\text{-}37)$$

In case (1), the LHS has been proved to be a decreasing function of $N$. Therefore, the condition for operator 2 to call more ports at this turning point ($k_1=\frac{\alpha+1}{3}q_d(N), \mu_1=0$) is:

$$\frac{\left[C_p+FC(k_1)\frac{d}{v}\right]}{(1+\alpha)^2}>\frac{\left[C_p+FC(k_2)\frac{d}{v}\right]}{2(2-\alpha)} \quad (4\text{-}38)$$

In the no constraint case Eq.(4-26), the denominator of operator 2 is $(2-\alpha)^2$. Since $2(2-\alpha)\geq(2-\alpha)^2$, the $k_2$ can be larger in this case compared with no constraint case. The differences between the two cases show how demand affect operators' decisions. When the demand is low (both operators have no capacity constraints), it is not advantageous to deploy a larger vessel because the condition to visit another port is harder to satisfy; when the demand is high and the other has capacity constraint, a larger ship might be profitable since it can carry all the cargo afterwards.

When $k_1 < \frac{\alpha+1}{3} q_d(N),\ \mu_1 > 0,$ operator 1's ship size is smaller than the turning point. Compare the LHS of Eq.(4-36) which is at the turning point, with that of Eq.(4-34) which is the constrained condition, the former should be larger than the latter since the RHS is an increasing function of $k_1$, i.e.:

Operator 1: $\frac{(1+\alpha)^2}{9}\left(3q_d'(N) - \frac{q_d(N)}{N}\right)\frac{q_d(N)}{rN} > \left((1+\alpha)\frac{q_d'(N)}{N} - (1+\alpha)\frac{q_d(N)}{N^2} + 2\frac{k_1}{N^2}\right)\frac{k_1}{r}$

For operator 2, similarly, we compare the LHS of Eq.(4-37) with that of Eq.(4-35). Since the LHS is decreasing function of $k_1$, the follow should be valid:

Operator 2: $\frac{2(2-\alpha)}{9r}\left(3q_d'(N) - \frac{q_d(N)}{N}\right)\frac{q_d(N)}{rN} < \left(2\frac{q_d'(N)}{N} - \frac{q_d(N)}{N^2} + \frac{k_1}{N^2}\right)\frac{(q_d(N)-k_1)}{r}$

Since in the constrained case, we are using a smaller LHS for operator 1 of Eq.(4-36) and using a larger LHS for operator 2 of Eq.(4-37), it can be seen that the $k_2$ can be even larger than that in the turning point cases. Therefore, when the demand is high, the company with larger ships will call more ports than the smaller one.

(3) When both operators are fully loaded, $\mu_1 > 0, \mu_2 > 0$

In this case, the capacities of both operators are fully utilized, either due to demand too high or ships too small. Combine capacity constraints of the two operators, we can get:

$$q_d(N_2) = k_1 + k_2 \tag{4-39}$$

Accordingly, optimal port calls $N_2$ is $q_d^{-1}(k_1 + k_2)$. It is straight forward to see that when ship size increase, the optimal port call number of operator 2 increases. Since $Q_{N_1} = k_1$, substitute these into the profit function of operator 2 (Eq. (4-10)), the profit function can be written as:

$$\pi_2 = (p_2 - p)(q_d(N_1) - k_1) + (p - VC)k_2 - \left[C_p + FC(k_2)\frac{d}{v}\right]q_d^{-1}(k_1 + k_2) - FC(k_2)\frac{2L}{v} \tag{4-40}$$

The optimal price now should be:

$$p_2^* = p, \tag{4-41}$$

as any price that is lower than the market price will make the first item negative. Then, the optimal strategy for operator 1 is also charging at the market price, as there is no reason to give discounts when there is no capacity left. The difference between this case and case (2) is that when both have capacity constraints, the number of port calls for operator 2 is fixed. Reduce the price is not an optimal solution for both operators. While in case (2), only one operator has capacity constraint. There is still needs for price competition.

The change of Best Response Function (BRF) of the two operators and their stable equilibrium can be illustrated using Figure 4-3. The solid line stands for the BRFs when there is no capacity constraint. The dotted horizontal and vertical lines stand for the maximum prices determined by the contestable market. Therefore, it is the bound for all the possible prices of two operators. When there are capacity constraints, the BRFs will shift out by half of their respective shadow prices. When only one operator has capacity constraints, the intersection of the BRFs will be the equilibrium prices. If both have capacity constraints, then there will be no competition. The equilibrium prices, even if it is lower than the maximum price, are not optimal, as both will be better off by charging the price determined by contestable market.

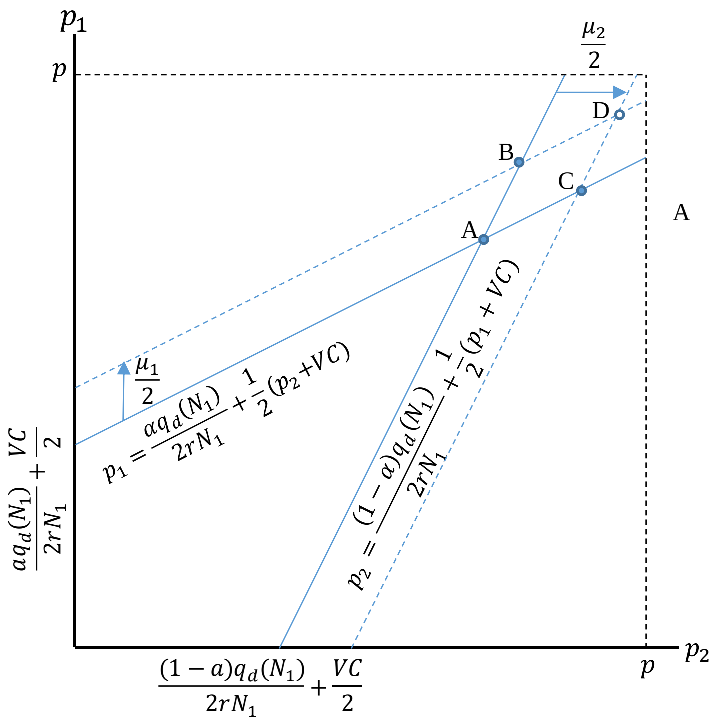



Figure 4-3: Change of BRF with different capacity constraints and equilibrium prices

The condition for operator 2 to call more ports can be written as:

Operator 1: $$\alpha q_d(N_1) = k_1 \qquad (4\text{-}42)$$

Operator 2: $$(1-\alpha)q_d(N_1) < k_2 \qquad (4\text{-}43)$$

As long as $\frac{k_2}{1-a} > \frac{k_1}{a}$, operator 2 will call more ports. The results show that when the demand is high and both operators have limited capacities, there will be no competition in the market and both players charge the contestable market price. Operators with larger ship and lower market share will call more ports.

### 4.3.2 Case II: With transshipment

In this case, operators will load containers, either by direct call or by transshipment, depends on the ship size. Following the same assumption as in the competition case, operator 1 will call few number of ports than operator 2, then quantity demanded for operator 1 for the direct call ports are the same as Eq. (4-7). However, even operator 1 stopped calling more ports after $N_1$, it still competes with operator 2 using $p_1$ through transshipment. Therefore, for operator 2, the demand function for direct call changes to:

$$Q_{N_2} = (1-\alpha)\sum_{n=1}^{N_2} q_n - rN_2 p_2 + rN_2 p_1.$$

Using $Q_{T_1}$ and $Q_{T_2}$ to denote the transshipment containers in all the ports, the transshipment quantity is determined by: the total demand from all the N ports, Q, at contestable market price $p$. Then total transshipment demand for both liners are:

$$Q_{T1} = \min(k_1 - Q_{N1}, Q - Q_{N2} - Q_{T2} - Q_{N1})$$

$$Q_{T2} = \min\left(k_2 - Q_{N2}, (1-\alpha)\sum_{n=N_2}^{N} q_n - r(N-N_2)p_2 + r(N-N_2)p_1\right).$$

Which essentially says that for each operator, the transshipment container will fill up the rest of the ship if there are capacity constraints (or demand is high), or load the rest of the containers. Then the problems for the two operators are:

$$\max \pi_1 = (p_1 - VC - C_t)(Q_{N_1} + Q_{T1}) + C_t Q_{N_1} - \left[C_p + FC(k_1)\frac{d}{v}\right]N_1 - FC(k_1) \quad (4\text{-}44)$$

s.t. $Q_{N_1} + Q_{T_1} \leq k_1$

$$\max \pi_2 = (p_2 - VC - C_t)(Q_{N_2} + Q_{T2}) + C_t Q_{N_2} - \left[C_p + FC(k_2)\frac{d}{v}\right] N_2 - FC(k_2)$$

$$\text{s.t. } Q_{N_2} + Q_{T_2} \le k_2 \tag{4-45}$$

(1) When one competitor has capacity constraint (assume it is operator 1)

In this case, $Q_{N_1} + Q_{T_1} = k_1$ and $Q_{N_2} + Q_{T2} = Q - k_1$, the Lagrangian function for above problem can be written as:

$$L_1 = (p_1 - VC - C_t)k_1 + C_t Q_{N_1} - \left[C_p + FC(k_1)\frac{d}{v}\right] N_1 - FC(k_1)\frac{2L}{v} + \lambda_1(p - p_1),$$

$$L_2 = (p_2 - VC - C_t)(Q - k_1) + C_t Q_{N_2} - \left[C_p + FC(k_2)\frac{d}{v}\right] N_2 - FC(k_2)\frac{2L}{v} + \lambda_2(p - p_2).$$

Then the FOCs for the profit maximization problem described in Eqs.(4-44) and (4-45) given price constraint ($p_1 \le p, p_2 \le p$) are:

$$k_1 - C_t r N_1 - \lambda_1 = 0, \lambda_1(p - p_1) = 0, p - p_1 \ge 0, \lambda_1 \ge 0 \tag{4-46}$$

$$Q - k_1 - rN_2 C_t - \lambda_2 = 0, \lambda_2(p - p_2) = 0, p - p_2 \ge 0, \lambda_2 \ge 0 \tag{4-47}$$

Where $\lambda_1$ and $\lambda_2$ are the Lagrangian multipliers. For a price increase in $p_1$, the revenue will increase by $k_1$, but direct cargo will reduce by $rN_1$. As the ship is filled up, the transshipment cargo will increase by same quantity, which will incur additional cost $rN_1C_t$. Therefore, if $k_1 - rN_1C_t > 0$, operator 1 will charge at the highest price $p$. For operator 2, although it still has capacity, the maximum cargo to carry is $Q - k_1$. For a price increase, the direct cargo will decrease by $rN_2$, which will also be filled up by the transshipment cargo and increase the transshipment cost $rN_2C_t$. Therefore, from Eq.(4-46), if $k_1 - rN_1C_t > 0$ and $Q - k_1 - rN_1C_t > 0$, the two operators would adopt the contestable market price, i.e., $p_1 = p_2 = p$. Even when they are equal to zero, pricing does not matter, as the gain (or loss) for a price change is always offset by the opposite change in the transhipment cost. If there is no competition, it is reasonable to assume that they will both charge at the contestable price $p$.

To analyze the optimal port calls for operator 1, substitute $\lambda_1 = k_1 - C_t r N_1$ and $\lambda_2 = Q - k_1 - rN_2 C_t$ into their respective Lagrangian function, and different w.r.t. their respective port call numbers, the FOCs are:

$$\alpha q_d'(N_1) = \frac{\left[C_p + FC(k_1)\frac{d}{v}\right]}{C_t} - r(p_2 - p)$$

$$(1 - a)q_d'(N_2) = \frac{\left[C_p + FC(k_2)\frac{d}{v}\right]}{C_t} - r(p_1 - p)$$

The last item always equals to zero as $p_1 = p_2 = p$. Since the $q_d''(N) < 0$, the condition for $N_2 > N_1$ is:

$$\frac{\left[C_p + FC(k_2)\frac{d}{v}\right]}{(1 - a)} < \frac{\left[C_p + FC(k_1)\frac{d}{v}\right]}{\alpha}$$

This result indicates that for larger ships to call more ports, it should have larger market share. If two operators serving the same region, if they have the same market share, the operator with high fixed cost will call fewer number of ports.

(2) When both have no capacity constrain:

In this case, the constraints in Eqs. (4-44) and (4-45) can be neglected, and the equilibrium price can be obtained by solving the FOCs in maximizing these two profit functions w.r.t. their respective prices:

$$p_1^* = \frac{(1+\alpha)q_d(N) - (N_2 + 2N_1)rC_t}{3rN} + VC + C_t \tag{4-48}$$

$$p_2^* = \frac{(2-\alpha)q_d(N) - (2N_2 + N_1)rC_t}{3rN} + VC + C_t \tag{4-49}$$

Substitute $(p_1^*, p_2^*)$ into profit function,The FOCs of both operators are:

$$\frac{\partial \pi_1}{\partial N_1} = \left[\frac{-rC_t}{3}(p_1^* - VC - C_t) - rC_t \frac{2C_t}{3N} N_1\right] + C_t \left\{\alpha q_d'(N_1) + \frac{rC_t}{3N} N_1 - r(p_1^* - p_2^*)\right\} - \left[C_p + FC(k_1)\frac{d}{v}\right] = 0 \tag{4-50}$$

$$\frac{\partial \pi_2}{\partial N_2} = \left[\frac{-rC_t}{3}(p_2^* - VC - C_t) - rC_t \frac{2C_t}{3N} N_2\right] + C_t \left\{(1-\alpha) q_d'(N_2) + \frac{rC_t}{3N} N_2 + r(p_1^* - p_2^*)\right\} - \left[C_p + FC(k_2)\frac{d}{v}\right] = 0 \tag{4-51}$$

SOCs of optimal port call numbers are

$$\frac{\partial^2 \pi_1}{\partial N_1^2} = \frac{2rC_t^2}{9N} + \alpha C_t q_d''(N_1)$$

$$\frac{\partial^2 \pi_2}{\partial N_2^2} = \frac{2rC_t^2}{9N} + (1-\alpha) C_t q_d''(N_2)$$

To ensure maximum profit, since $q_d''(N) < 0$, it is required that $|q_d''(N_1)| > \frac{2rC_t}{9\alpha N}$ and $|q_d''(N_2)| > \frac{2rC_t}{9(1-\alpha)N}$. Then the relationship between the optimal number of port calls and ship size can be obtained by differential Eqs.(4-50)(4-51) w.r.t. $k_1$ and $k_2$ respectively:

$$\alpha q_d''(N_1)\frac{\partial N_1}{\partial k_1} + \frac{2rC_t}{9N}\frac{\partial N_1}{\partial k_1} = \frac{FC'(k_1)\frac{d}{v}}{C_t} \tag{4-52}$$

$$(1-\alpha)q_d''(N_2)\frac{\partial N_2}{\partial k_2}+\frac{2rC_t}{9N}\frac{\partial N_2}{\partial k_2}=\frac{FC'(k_2)\frac{d}{v}}{C_t} \tag{4-53}$$

From the SOC condition, it is easy to see that $\frac{\partial N_1}{\partial k_1}<0$ and $\frac{\partial N_2}{\partial k_2}<0$. Therefore, larger ships will reduce the number of port calls in the competitive environment when transshipment is feasible and ship is too big or demand is too low.

From conditions of port call decision in Eqs.(4-50) and (4-51), we can get the condition for determining which operator will stop calling more ports:

Operator 1:
$$\alpha\left[q_d'(N_1)-\frac{q_d(N)}{N}\right]=\frac{C_p+FC(k_1)\frac{d}{v}}{C_t} \tag{4-54}$$

Operator 2:
$$(1-a)\left[q_d'(N_1)-\frac{q_d(N)}{N}\right]>\frac{C_p+FC(k_2)\frac{d}{v}}{C_t} \tag{4-55}$$

Since LHS is a decreasing function of $N_1$, the condition for operator 2 to call more ports can be written as:

$$\frac{\left[C_p+FC(k_2)\frac{d}{v}\right]}{(1-a)}<\frac{\left[C_p+FC(k_1)\frac{d}{v}\right]}{\alpha}$$

Which is similar with the condition in case (1) when one operator has capacity constraint.

## 4.4 Numerical studies

### 4.4.1 Preliminary settings

In this part, we use the liner shipping services between China and US West Coast as a background for numerical simulation for our analytical models. Suppose there are liner shipping services calling one port in U.S. and selecting ports to call at Chinese Coast. The sailing distance is about 6000 nm[9] and the round trip takes about 30 days[10] on the sea. Liner operators decide which ports to call among Shenzhen, Shanghai, Ningbo, Hong Kong, Qingdao and other 10 ports (max $N = 15$). The average time of additional port call $\frac{d}{v}$ is 2 days including handling time in ports.

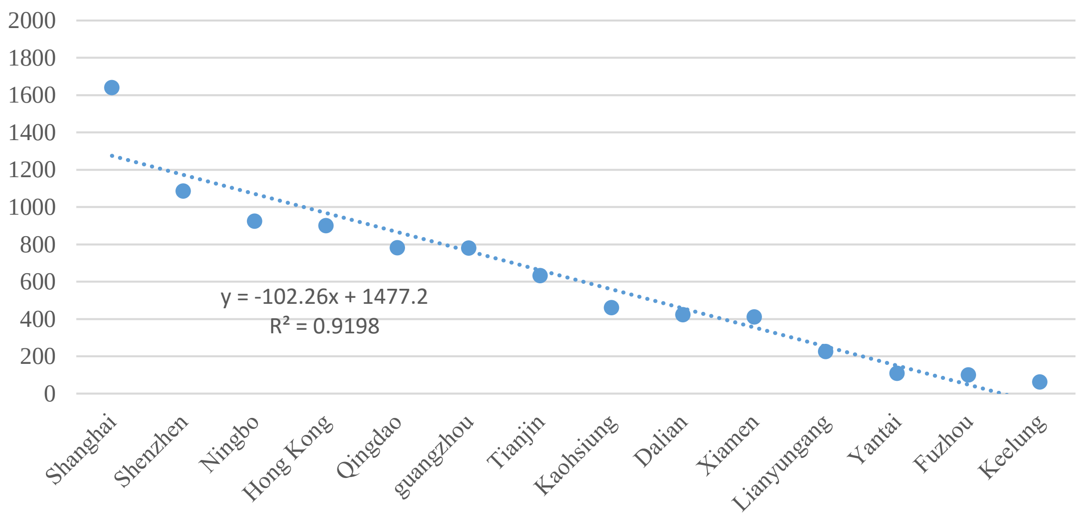



Figure 4-4: Relationship between port ranking and ports container demand

Since there is no exact data on the demand for container shipping in each port for a specific route, we estimate the weekly demand for Chinese export to US at each port based on their respective total container throughput in 2015, assuming the percentage of US trade are the same at each port. The trade value to US accounted for 22% of total export of Chinese ports (including exports from HK and Taiwan)

[9] Distance from Shanghai port to Port of Los Angeles.

[10] Average round trip time of liner shipping services information in 2011 and 2015 from Alphaliner Database.

in 2015[11]. We also assume that the weekly demand of China-US trade in 2015 is shared evenly among all the 94 liner shipping services in that route in 2015. In the following figure, we rank ports by the average weekly demand and find the linear relationship between port ranking and demand. Therefore, in this numerical study we assume a containership visiting N ports will obtain: $q_d(N) = 1500N - 50N^2$.

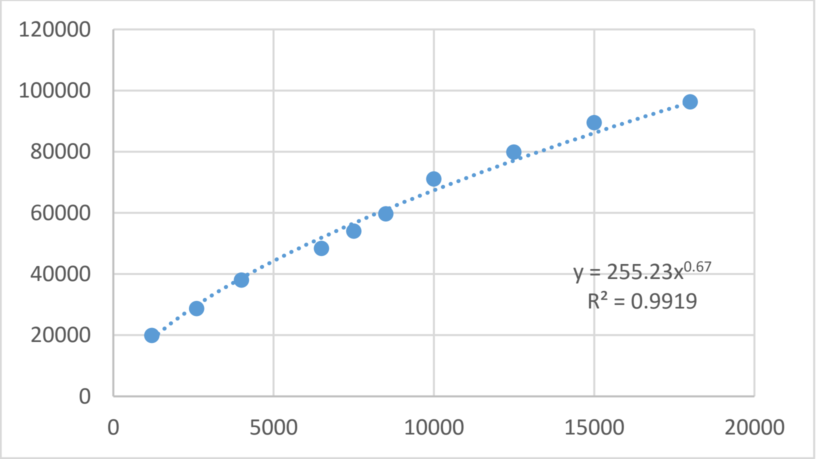



Figure 4-5: Relationship between ship size and daily operating cost (USD)

In our model, the daily fixed operating cost includes fuel, management and capital costs. It accounts for the majority of the shipping costs. According to Cullinane et al., (1999), the fixed operating cost is proportional to $(ship\ size)^{\frac{2}{3}}$. Wang et al. (2014) pointed out that the daily operating costs should be adjusted by oil price. Christa et al. (2008) estimated the relationship between daily costs (sum of capital costs, operating cost and bunker costs) and ship size, which are shown in Figure 4-5. Based on these previous studies and considering the shipping market data

[11] China Custom Data: Exports by Country (Region) of Origin/ Destination http://info.hktdc.com/hktdc_offices/mi/ccs/index_static_type/ExportsbyCountryofOriginFinalDestinationex.html

during 2011 and 2015, we assume that the relationship between daily costs and ship size $k$ is $300k^{\frac{2}{3}}$.

The freight rates are set at three different levels, 600USD, 800 USD and 1000USD per TEU, according to CCFI from 2011 to 2015. From the port fee analysis of a general container ship calling Shanghai port[12], we can estimate $C_p$ is 15000 USD per port call. The transshipment cost of each container is not available. It can only be estimated from the container handling cost in the origin/transship ports[10] and shipping cost between two ports[13]. These operational parameters are included in Table 4-1.

Table 4-1: Parameters used in numerical studies

| **Parameters** | | **Value** | **Unit** |
|---|---|---|---|
| Variable cost ($VC$) | | 100 | USD per TEU |
| Port fee ($C_p$) | | 15000 | USD per port call |
| | high | 1000 | USD per TEU |
| Freight rate ($p$) | median | 800 | USD per TEU |
| | low | 600 | USD per TEU |
| Operator 1's market share ($\alpha$) | | 0.25/0.5/0.75 | |
| Transshipment cost | | 600 | USD per TEU |

### 4.4.2 The port call number decision model of single operator

In the single operator model, optimal port call numbers (PCs), transshipment decisions and corresponding profit of one-round trip are depicted in Figure 4-6. The columns in the figure show the change of optimal port call number with the increase

[12] Data source: http://oil.chinaports.org/news.html?fid=1021

[13] Data source:张哲辉. "基于两阶段法的长江集装箱船舶运输系统优化." 水運管理 32.7 (2010): 34-38.

of ship size. The solid lines indicate the profit of the operator with the change of optimal port calls and ship size.

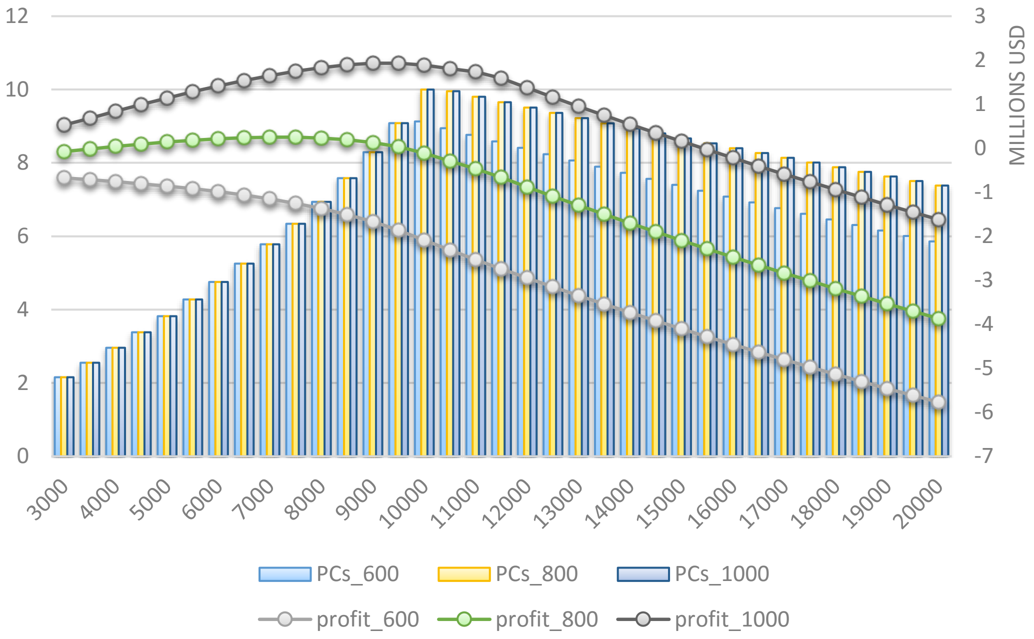



Figure 4-6: Numerical results of port call numbers and profit in single operator case

From Figure 4-6, we can find that with the increase of ship size, the number of port calls first increases, then decrease. The turning points of port calls decisions is between 9500-10000 TEU when price is low and are between 10000-15000 TEU when price is at 800 and 1200USD per TEU, which is similar to our result from empirical study that if the ship is larger than 10000-12000 TUES, increase ship size will result in fewer number of ports. This figure can also shed some lights on the optimal ship size in the long-run. When the freight rate is very low, liner operators always have negative profit. When freight rate is high, liner operator’s best choice is to call 9 ports with 9500 TEU ships. When freight rate is at 800 USD, the optimal ship size is 7000TEU and calls 5.7 ports average. During 2011 and 2015 when average market price is around 800USD/TEU, average ship size and port calls are

6500 TEU and 4.6 respectively. Considered the fluctuations in the market prices in 2011 and 2015, the real ship size and port call number is lower than simulation results.

### 4.4.3 The port call number decision model of two operators

In the competition model, we set the original market share of operator 1 at three levels $a = 0.25, 0.5, 0.75$ to test the operators' optimal choice in the competition model. The demand in $N$th port is set as $q_N = 2900 - 200N$ since there are two operators competing. The price effect is set to $\mathrm{r} = 2.5$. We will simulate the change of port call decisions with ship sizes in both no-transshipment ($p = 600$USD/TEU) and transshipment ($p = 1000$USD/TEU).

Case I: When there is no transshipment:

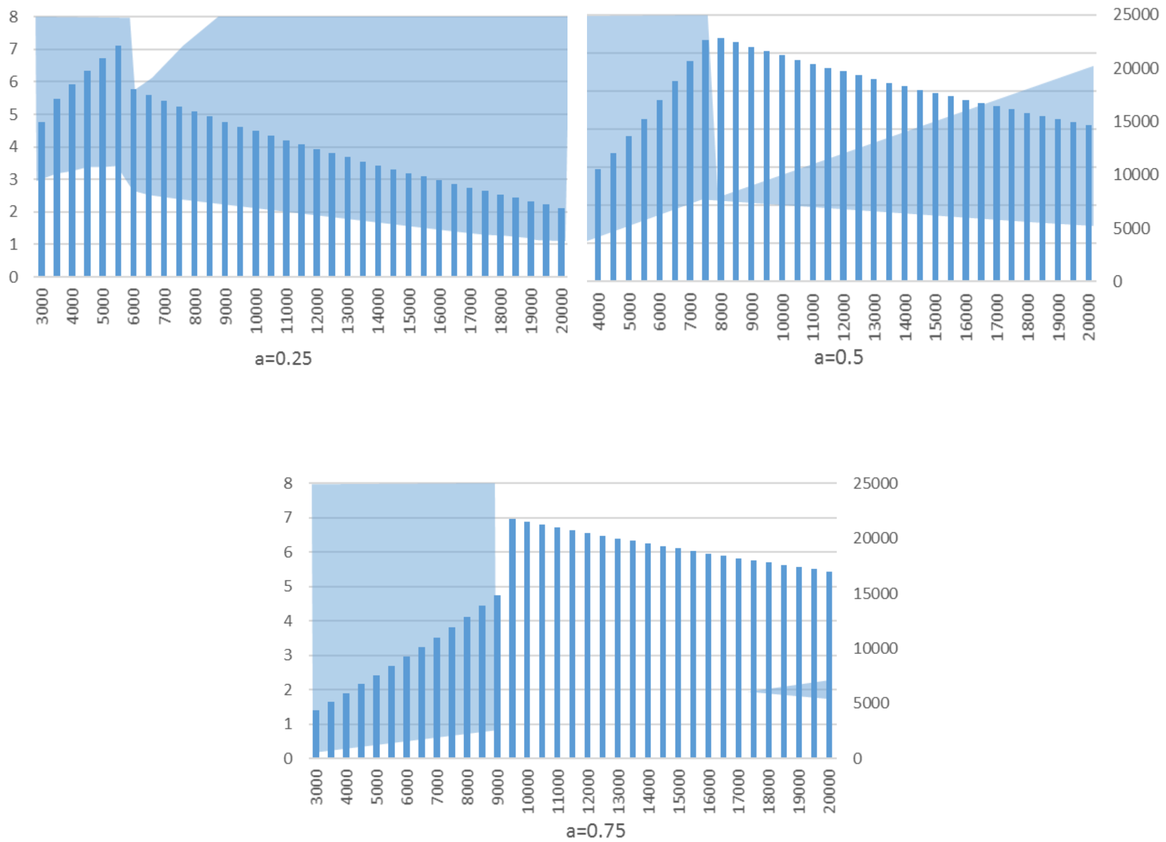



Figure 4-7: Simulation results for competitive case when there is no transshipment

The above figures show the optimal number of port calls for operator 1 (the column scaled by left vertical axis) with the change of ship size (horizontal axis) for different initial market share. They also include the required ship sizes (the shaded area measured by the right vertical axis) that make operator 2 calling more ports than operator 1.

For all three scenarios the optimal port call number of operator 1 first increases, then decreases. Its turning points are 5500TEU, 8000TEU and 9500TEU respectively for three initial market share. Its maximum profit happened at 3000 TEU (port call number 4.75), 7000TEU (port call number 5.7) and 9000TEU (port call number 4.7) respectively. These results show that operator 1 will use larger ships and gain more profit with higher market shares. For the same ship size, if it is less than the turning point, the port call number of operator 1 decreases as market share increases. However, if the ship is larger than the turning point, operator 1 will call more ports when its market share increase. That result explains why liner services provided by alliances generally calls fewer ports in 2011 and 2015 compared with those provided by individual companies. Because alliances have higher market share, and their ship size (average 5650 TEU in 2011; average 7070 TEU in 2015 ) is smaller than the turning points (in 2011 market share of alliance in Transpacific routes is 0.29 and turning point is 6000TEU, in 2015 $a = 0.5$ and turning point is 8000TEU).

The range of ship sizes required to make operator 2 call more ports than operator 1 depends on operator 1's ship size and market share. For all the 3 cases, the range will change at the turning point of operator 1, i.e., it depends on whether operator 1 is fully loaded. If it is fully loaded (left side of turning points), operator 2's minimum size is when it is also just fully loaded as specified in no transshipment model case (3), its maximum size is specified by no transshipment model case (2). When operator 1 is not fully loaded (right side of turning points), operator 2's ship size range is decided by the no transshipment model case (1). From all three graphs in Figure 4-7, it is clear that when operator 1 has a high market share, the possible range for operator 2 to call more ports than operator 1 will be smaller. When operator 1 has 75% market share, such a range will not be feasible when the ship size of operator 1 is between 9500-17500TEU. That means that operator with a higher market share will call more ports than its competitor.

Case II: When there is transshipment:

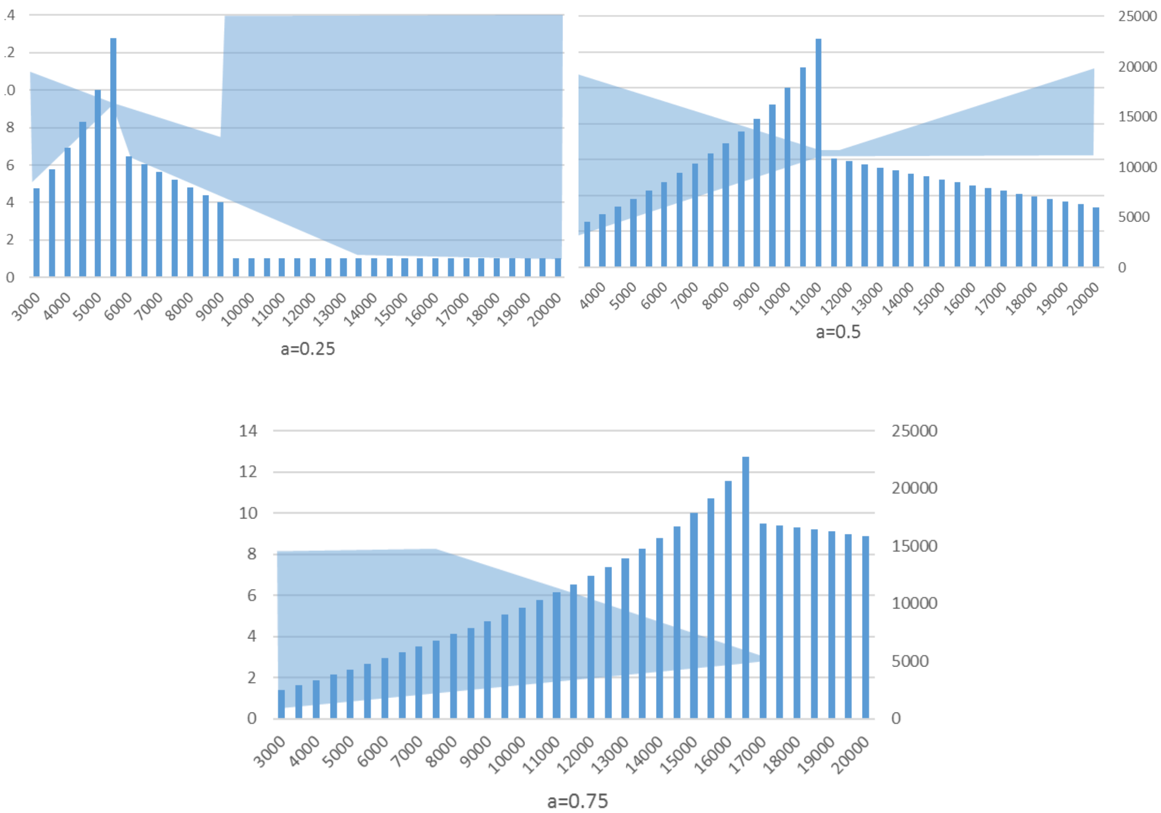



Figure 4-8: Simulation results for competitive case when there is transshipment

Similar with above case, we present the simulation results of port call decisions with transshipment in Figure 4-8: columns represent port call number of operator 1 when its ship size changes, shadow area shows how the change of the ship size range of operator 2 if it should call more ports than operator 1.

In the transshipment case, it is clear that the impact of ship size on port call number is also not monotonic. The turning points are 5500TEU, 11000TEU and 13500TEU respectively for α=0.25, 0.5, and 0.75. When $a = 0.25$, operator 1 will just call 1 port when its ship size exceeds 9000 TEU. The optimal direct port call number of operator 1 also increases as its market share increases. The maximized profit of operator 1 depends on operator 2's decision, generally around 9000-13000 TEU when $a = 0.25, 0.5, 0.75$. Compared with single operator cases, due to the competition from operator 2, operator 1 will call more ports before the turning points when $a < 0.5$. Even when $a = 0.5$, operator 1 would call more ports at size range between 9000-11000 TEU.

Similar with no-transshipment situation, the range of operator 2's ship size will also change with operator 1's market share. When operator 1 is fully loaded by direct port calls (left side of turning points), operator 2's minimum size to call more ports than operator 1 is determined by the transshipment model case (1), which should be less than overcapacity case. When operator 1 is not fully loaded (right side of turning points), operator 2's ship size range is decided by the transshipment model (2). That ship size range increases as operator 2's market share increases.

## 4.5 Chapter summary

In this chapter, we have constructed two models on the number of port calls based on assumptions that liner operators are profit maximizers in contestable market, they provide weekly service and select the ports with the highest demand. In the single operator model, the operator charge at contestable price. The optimal port call number exists a turning point with the ship size increases. Before that, larger ships require calling more ports to fill up the capacity; after that, larger ships will call fewer ports, as it requires a higher demand at the port to cover the fixed port access cost.

In the duopoly model, we assume that the two operators compete by offering discount based on the contestable market price. Theoretically, we established the relationship between the number of port calls with ship size and market share, and explained the condition for one operator to call more ports than the other, with or without the transshipment.

To put the theoretical model into a real environment, a numerical simulation is conducted based on the actual data of liner shipping services between China and North America in 2011 and 2015. The simulated result confirms the existence of turning point in all the possible cases. In addition, the simulation result from the single operator model is very close to the possible turning point in the data (Figure 1-4). This implies the liner shipping services are mainly operating in a contestable market. The price cutting behavior among the liner operators at the same route does not have significant impacts on the decision of number of port calls.

# Chapter 5 : THE MODERATING EFFECTS OF LARGE SHIPS AND ALLIANCES ON THE FINANCIAL PERFORMANCE OF LINER OPERATORS: AN EMPIRICAL ANALYSIS

This chapter investigates how having large ships and joining alliances moderate the impact of various internal and external factors of a liner shipping company on its financial performance-the operating revenue and cost. Based on the literature review and the practice of liner shipping industry, a conceptual model on revenue and cost is established and a series of hypotheses on the impacts of the two moderating factors is developed. A fixed-effect model was applied to the panel data of 20 selected liner shipping companies over 15 years' period. The moderators are found to have significant impacts on the revenue and cost. Also, only shipping companies with large ships can benefit from joining alliances. Even for them, joining alliances is not good when the market freight rate is increasing. This study can help the liner shipping companies to decide whether to increase its capacity by investing large ships, and decide whether to join alliances in different situations.

## 5.1 Introduction

Liner shipping has been providing global businesses with a high quality, safe and reliable transportation service with low cost, which enabled a fast development of international trade and globalization. Along with this process, the global shipping business becomes increasingly difficult. The liner shipping market slumped since financial crisis in 2008. The average daily earnings of a containership dropped from more than 20000 USD to less than 5000 USD[14] (Figure 5-1). Even so, the liner shipping companies continue investing in ever bigger ships to expand their capacities. From Figure 5-2, when the market price is in a downward trend during 2012 to 2015, there are increasing number of new orders and deliveries in new ships, especially the large containerships over 8000 TEU.

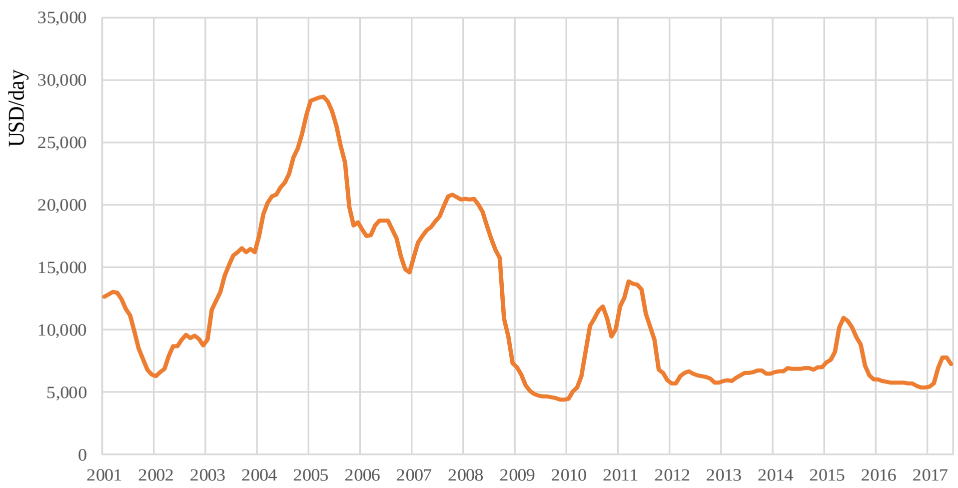



Figure 5-1: Clarksons' average containership earnings

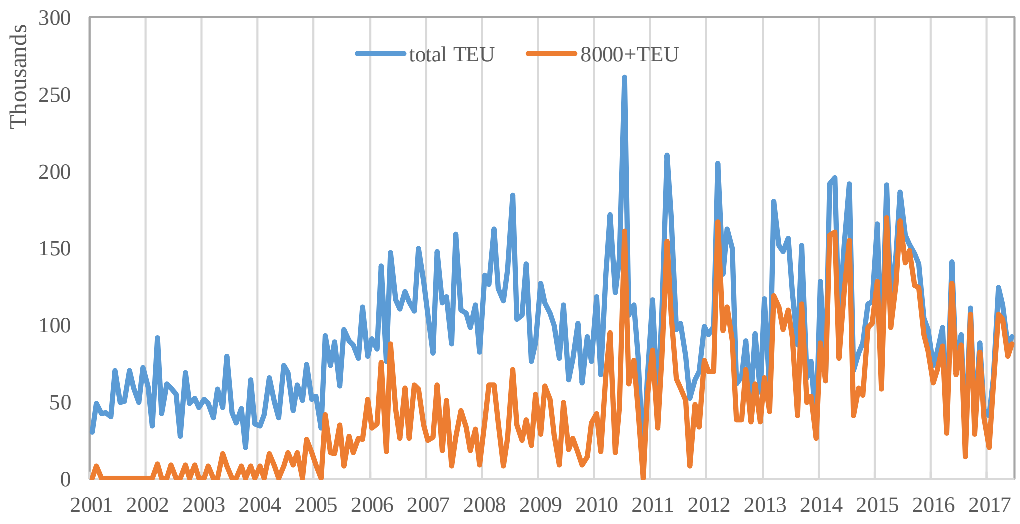



Figure 5-2: Total containership and 8000+ TEU containership deliveries

[14] Data source: http://www.clarksons.com/

Most of the large ships are deployed in the major East-West trade routes. The long-term overcapacity in these routes has intensified the competition between carriers and aggravated their already poor financial performance. The average gross profit margin was only 0.47 percent in the end of 2015[15] and in the first half year of 2016, just 6 of 17 major global carriers have managed to earn positive profit from line shipping business[16]. Most of the time, they are operating with negative operating margins during the period from 2009 to the first half of 2016, according to the data from Alphaliner. As depicted in Figure 5-3, within these seven and half years from the first quarter of 2009 to the second quarter of 2016, the average operating margin of 14 carriers is negative in 19 quarters, or 63 percent of the time.

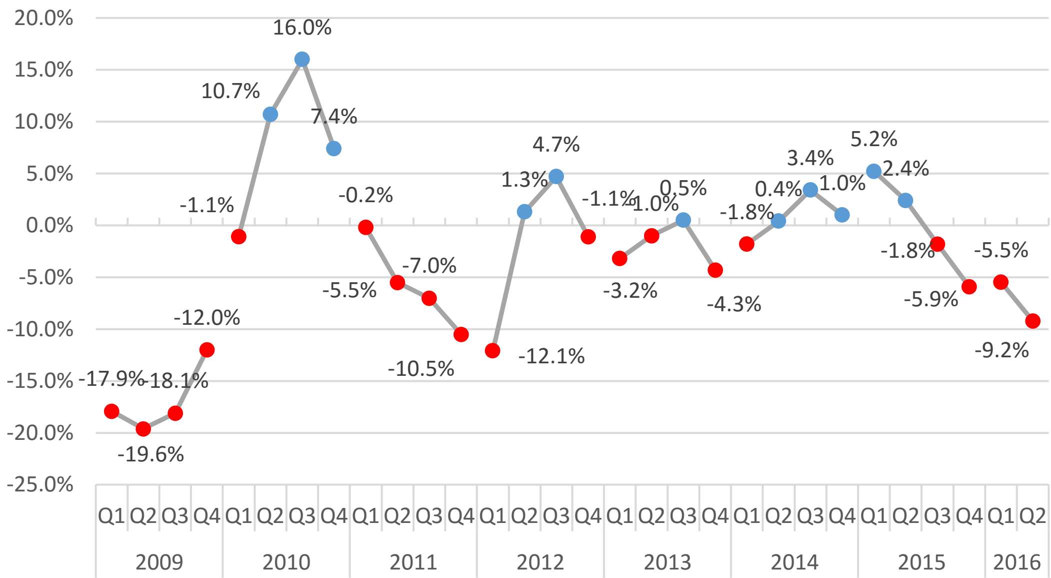



Figure 5-3: The average carrier operating margins from 2009Q1 to 2016Q2[17]

[15] Data source: gross profit margins = (revenue-cost)/cost, calculated by the author

[16] Alphaliner Weekly Newsletter, No. 27, 2016.

[17] Average of Maersk, CMA CGM(from 2010), APL, CSCL, Hanjin, Hapag-Lloyd, HMM, MOL, K Line, NYK, EMC, Yang Ming, Wanhai and Zim.

The continued loss in liner shipping has led to a series of structural changes in the industry. In the end of 2016, the shocking news on the bankruptcy of Hanjin, which used to be one of the top 10 carriers in the world, is an example. Besides, the Merge and Acquisition (M&A) between liner shipping giants are also partly caused by the glooming market condition. For instance, the M&A between COSCO (ranking 6$^{th}$) and CSCL (ranking 7$^{th}$) were merged into a new global carrier COSCO Shipping Co. Ltd ranking 4th in 2016. According to Alphaliner's analysis, among the top 20 global liner shipping companies in 2016, only 12 will remain in the market by 2018, based on confirmed news[18]. Therefore, it is now an essential and urgent task for liner shipping companies to adopt appropriate strategies to improve their revenue, cut down their costs and keep a stable financial performance to survive in the volatile market.

Having large containerships can benefit from economies of scale—when ship size increases, the cargo carrying capacity grows much faster than the cost (Jansson & Shneerson, 1982). Therefore, companies dominated with large ships (CDWLS) are able to offer a lower freight rate and attract more customers. In addition, the total capacity of a company indicates its market power (Luo, et al., 2014) and invest more capacity has become a strategy for shipping companies to compete in the market (Kou & Luo, 2016). Carriers believe that with more capacities, they can have higher market share and can gain extra profit. This made them to invest in more and bigger ships. As shown in Figure 5-2, the order of mega containership (8000+ TEU) dramatically increased just before the financial crisis at 2008. Those ships, delivered several years later, have increased the shipping capacity at the time

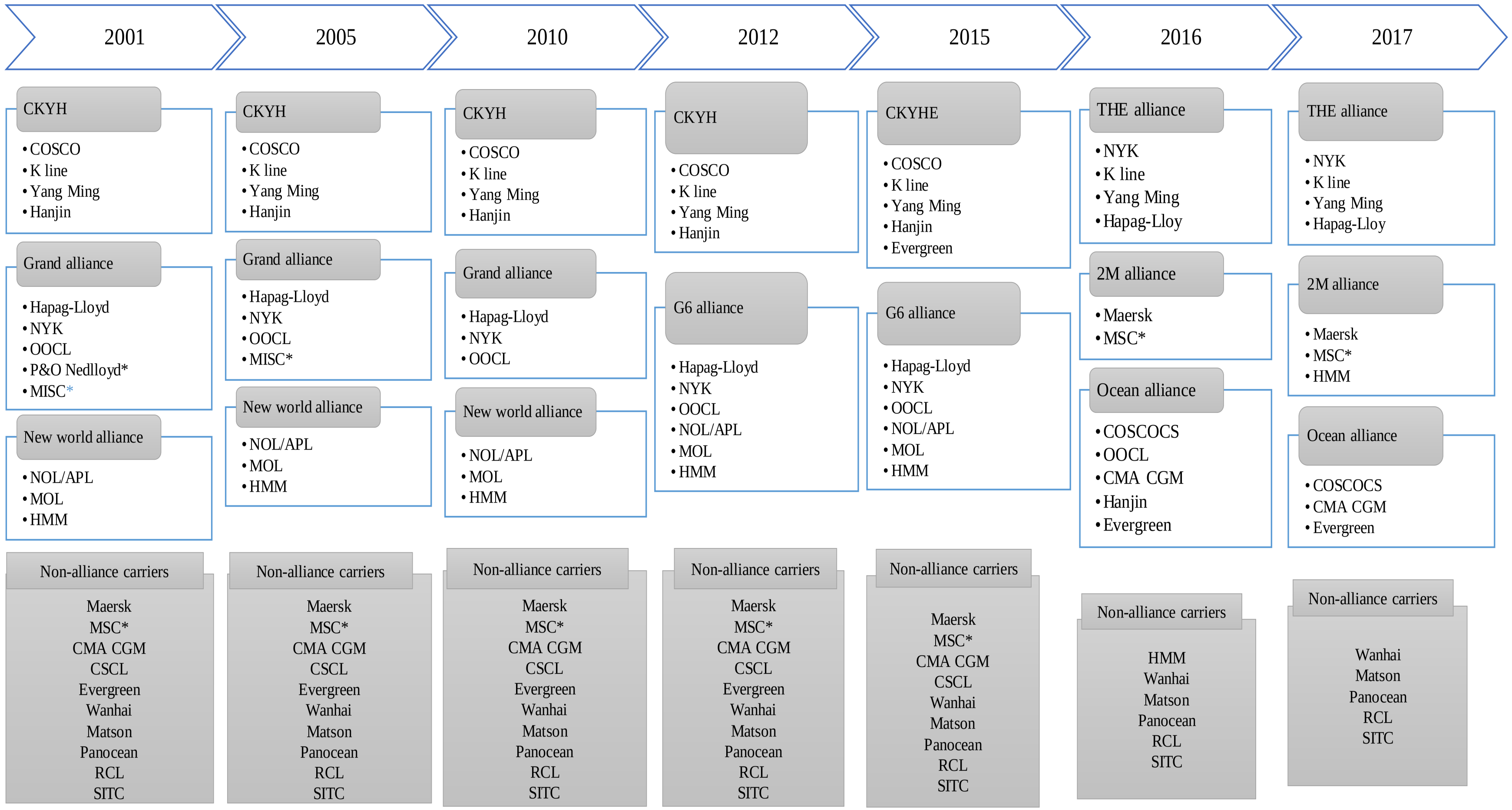
[18] Alphaliner Weekly Newsletter, No. 28, 2017.

when the market is already oversupplied. Then, is building larger ships still a good strategy for shipping company?

Joining alliances also becomes an attractive strategy for liner shipping companies. From 1998 to 2011, alliance members only control 20 to 30 percent of world fleet capacity. The top 3 liner shipping operators, Maersk, MSC and CMA CGM, which controlled about 37.7% of the liner fleet capacity, are still on their own. After that, due to the long sluggish market, the alliance structure has been undergone significant changes. Even the top 3 liner shipping companies are started to join alliances (Figure 5-4). As of July 1st, 2017, the three shipping alliances in the world, namely THE Alliance (NYK, MOL, K line, Hapag-Lloyd, Yang Ming), H2M (Maersk & MSC + HMM) and Ocean Alliance (CMA CGM, COSCO, OOCL, Evergreen), have controlled about 77.2% of world container carrying capacity and 96% of all East-West trades' capacity[19]. Traditionally, the reason to join alliances is to increase network coverage with the partners serving different areas. Now, the motivation has changed to make better use of the large ships and be more competitive than others in the same route. Under this situation, what kind of companies can really benefit from joining alliances, and is it always a good strategy for different market conditions?

These two questions motivated this research—to understand the moderating effect of having large ships and joining alliances on financial performance, i.e., the revenue and cost of a liner shipping company. Through a review of the literature and industry practices, a conceptual model on revenue and cost is established and a

[19] Data Source: http://www.porteconomics.eu/2017/04/20/the-puzzle-of-shipping-alliances-in-july-2016/




*Companies are not included in the study

Figure 5-4: Changes in alliance during 2001 to 2017 series of hypotheses on the impacts of the two moderating factors is developed. A panel data on the financial performance of 20 liner shipping companies from 2001 to 2015 are collected, together with the internal and external factors. The moderators are found to have strong impact on how these important factors affect the financial performance. Although the analysis is based on the past data, the can shade light on the future strategies of the liner shipping companies with regard to whether it is beneficial to invest in large ships, or join alliances in the changing market.

The next section develops the hypotheses on the impacts of the two moderators on the performance of liner shipping companies. Then, Section 5.3 designs both the basic and extended statistical models to test the hypotheses. Section 5.4 explains the empirical results and more in-depth analyses of the results are conducted in Section 5.5.

## 5.2 Research model and hypotheses development

### 5.2.1 Research model for liner shipping companies' financial performance

This study analyzes how having big ships and being alliance members moderate the impact of internal and external factors on the financial performance of shipping companies—the operating revenue and cost. The changes in ships' fair value due to market fluctuations only affect the book value of the ship and the accounting profits. The fixed cost of ship investment, such as the new ships, is not part of the operating cost. Therefore, these two are not included.

For the revenue, the most important external factor is the market freight rate. It is external because it is determined by the interaction between aggregated demand and supply of container freight market. It is outside of the control of any one company in the contestable market (Sjostrom, 1989; Shashikumar, 1995). Therefore, increase market freight rate will increase the revenue (Bang, Kang, Martin, & Woo, 2012; Tran & Hans-Dietrich, 2015).

For the cost, external factors include bunker price and consumer price index (CPI). The former is an important factor in the voyage cost. Although there are different opinions on the importance of bunker cost to the total operating cost (Davies, 1983; Notteboom & Bert, 2009), an increase in bunker price will naturally lead to the increase in operating cost, all else being equal. The CPI is used as the control variable, reflecting the general cost increase due to inflation. It is often said that the cost of shipping is not increasing, or even decreasing over time, due to the technology development in maritime transportation and economies of scale (Stopford, 2004).

The internal factors are the main attributes of a liner shipping company, including the total capacity, average ship size, and total assets. Usually, a large company is associated with high market share. It could have higher revenue (Alix, et al., 1999), but also incur higher costs (Tran & Hans-Dietrich, 2015). Average ship size represents the distribution of the ship size of that company. A company with many large ships will have a larger average ship size. It is commonly believed that large ships bring economies of scale. Therefore, the operating cost can be low (Lim S.-M. , 1994; Bang, Kang, Martin, & Woo, 2012). However, larger ships are often deployed in the major shipping routes where the level of competition is high. Therefore, the earning for the companies serving on these routes may not be necessary high (Davies, 1986; Cairns & Mahabir, 1988; Luo, et al., 2014).

Total asset of the company reflects the scale of the company, which includes the assets in both liner shipping and other activities. It is used as a control variable to separate the scale effect on the financial performance of liner shipping segment.

Another factor that may affect the financial performance is the depreciation (Gkonis & Psaraftis, 2010). Depreciation is closely related with ship size and operation time (Notteboom, 2006). Therefore, some may consider that liner shipping companies, especially those big liner shipping companies in the country with high tax rate, prefer invest in large containerships for higher depreciation and lower tax. However, since depreciation is already included in the operating costs in this study, the analysis in the moderating effects of having large ships and joining alliance will not be influenced.

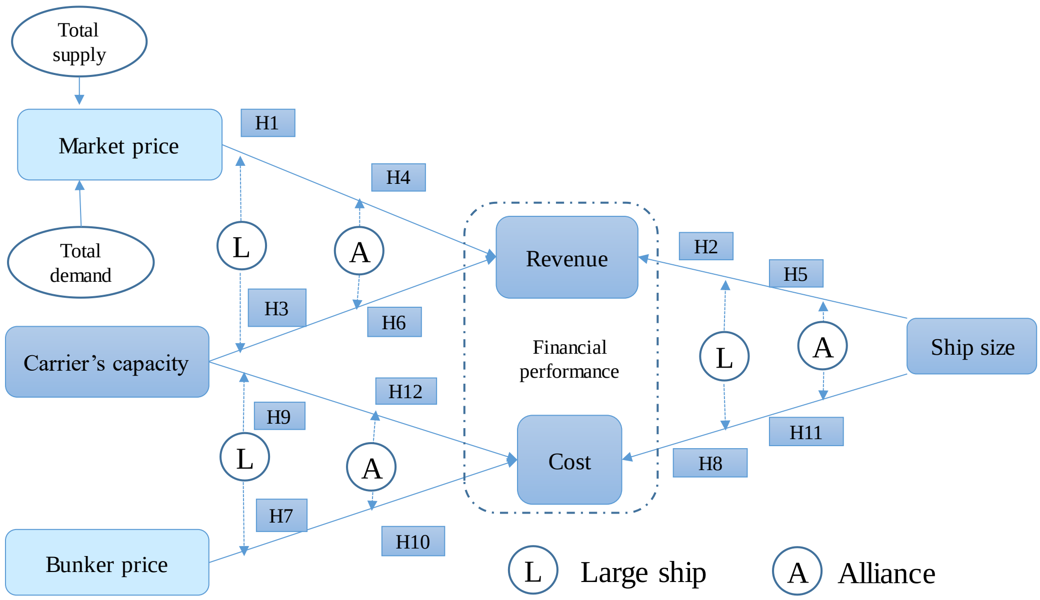



Figure 5-5: The relations of factors in carriers' financial performance

The relationship of these variables to the revenue and cost can be different for companies dominated with large ships (CDWLS) and if they are members of shipping alliances. These two moderators can affect the relationship between these internal, external factors and the financial performance of the shipping company.

These relationships are described in Figure 5-5. The hypotheses on the moderating effect are explained next.

### 5.2.2 Impacts of large ships on the revenue

From the statistics, all large liner-shipping companies have services in the main trade routes. They all deploy large ships to make full use of the economies of scale and to offer a lower price to attract customers (Christa, et al., 2008). That leads to a large concentration of excessive container capacity, especially large ships on these main trading routes (Fusillo, 2013). Fulliso (2003) pointed out that the excess capacity in the market could prevent potential entry, thus enabled the incumbents to keep a higher and stable market price. However, the empirical analysis of Lam et al. (2007) showed that the capacity concentration in main shipping routes such as Europe-Far East and Transpacific did not lead to high prices but more fluctuating freight rates. Therefore, the price changes are more significant in the main trade routes. Since CDWLS are more likely to operate on the main trade route, it is appropriate to postulate that:

**H1. CDWLS can earn more from the market price increase.**

The operators in the market are competing closely for higher load factor, especially on the main shipping routes. Graham (1994) commented that fierce competition is common on the routes of high trade volume, such as Transpacific, East Asia-Europe and Transatlantic, since these routes can provide the opportunity for liner operators to enjoy economies of scale. The statistics of turnover and profit margin of carriers on those routes in 1998-2002 also provided evidence of high competition (Lam, et al., 2007). For those larger shipping companies, further increase their average ship size can intensify the overcapacity, and may result in low load factor. All these can lead to lower revenue. Therefore, we postulate that:

**H2. For CDWLS, the growth of average ship size can have a negative impact on its revenue.**

In liner shipping industry, the total fleet capacity of a shipping company represents its market share (Kou & Luo, 2016). Liner shipping companies with high total capacity are also those with large ships. Large capacity enables the company to cover a larger geographical region with the higher frequency of services. A company having large ships is also a symbol of market power and market leader, which gives customer confidence for reliable and high-quality services. In addition, large shipping companies did not grow overnight. Based on the capacity growth of individual companies in 1998-2008, Luo et al. (2014) found that liner shipping companies with large ships expanded their capacity slower than smaller ones. It is the long experiences in the market that give them the advantage to outperform the others in the global competitive market. Therefore, it is postulated that:

**H3. For CDWLS, the growth of capacity can increase its earning.**

Companies with smaller ships usually have no market power, cannot compete with those with large ships. For them, increase total capacity may not lead to increase in operating revenue.

### 5.2.3 Impacts of alliance on the revenue

Liner cooperation has been existing in many different forms, from Consortium or conference in the early stage to the current form of global alliance. Originally, the purpose of cooperation is to stabilize freight rates, reduce competition or prevent potential entrants. For example, the purpose of the shipping conference is to fix price by agreement among the members (Kumar, 1999). Price collusion is not allowed in the current form of liner alliance. The original purpose of forming alliance is to extend the network coverage over new market areas, which is often called Global Strategic Alliance (Panayides & Wiedmer, 2011). Now alliance members can only cooperate in the form of Vessel Sharing Agreement, where each member contributes some ships, and agrees on responsibility to fill up certain container slots. They have to make prices individually and negotiate with their customers separately.

There are different views on the function of alliances on the market stability and company earning. Haralambides (2004) compared the Westbound Atlantic rates in different periods and found the rates were stable when operators cooperated. Agarwal and Ergun (2010) found that the profit allocation mechanisms of alliance guarantee member's revenue when demand fluctuates. Panayides and Wiedmer (2011) found that in the last ten years, the three alliances (Grand Alliance, New World Alliance and CKYH Alliance) had frequent increase or decrease of capacities or services, which reduced the pressure of competition when the demand was low, and stabilized the price when demand is high. Therefore, on the impact of being alliance members on the company revenue, the hypothesis is:

**H4. Being an alliance member reduces the sensitivity of revenue to the price change.**

The frequent capacity change in the alliances also enables a higher load factor for its members. Therefore, for the same container slots, it can generate more revenue than the non-alliance member. This is especially true when the market demand is low, as the members can work together to reduce the service capacity to keep high load factors. Thus, compared with the non-alliance companies, alliance members' capacity can have higher utilization rates. Therefore, alliance members gain more revenue than non-alliance members by increasing the ship size. Here comes the fifth hypothesis:

**H5. Being an alliance member increases the elasticity of revenue to the average ship size.**

Many shipping companies are serving the major East-West shipping routes where large shipping companies usually have market power. For them, being a member of any alliance may not be so attractive. For example, the largest two liner shipping companies (Maersk and MSC) were not members of any alliance for a long times until 2014, when they first proposed to form an alliance between them (called 2M). For smaller companies serving on the same route, being an alliance member seems to be more attractive to offset the market power of the big players. Slacks et al. (2002) claimed that one advantage for smaller players to join an alliance was to have higher market power. According to their statistics, alliances provide more frequent services compared with solo operators. The empirical study by Bang et al. (2012) showed that alliance membership was not a significant factor in capacity utilization. However, they did not compare the capacity utilization of the same companies with and without the alliance. Therefore, it cannot be concluded that forming alliance cannot increase utilization rate. In summary, large shipping companies (those with large capacity) have less incentive to join alliances, while smaller ones find it necessary to form alliance to resist the market power of the big players. All these implies the economic benefit of their decisions. Therefore, it is postulated that:

**H6. Being an alliance member can reduce the sensitivity of revenue to carrier's capacity.**

### 5.2.4 Impacts of large ships on the costs

For the companies with the same container carrying capacity, total fuel consumptions for CDWLS is lower than those with small ships (Cullinane & Khanna, 1999; Lim, 1998), due to economies of scale. Therefore, the total bunker cost for those with large containerships is less sensitive to the bunker price change.

In addition, large containerships have higher incentive to practice slow steaming when bunker price increases. This strategy would reduce the impact of bunker prices on operating costs (Ronen, 2011). Notteboom and Cariou (2013) found that slow steaming was common on the Europe-Far East trade where the ship size was usually above 8000 TEU. Therefore, it is postulated that:

**H7. Operating cost is less sensitive to the bunker price change for CDWLS.**

In addition to the benefits of bunker savings, larger ships can also save labor and administrative costs per container (Jansson & Shneerson, 1982). Many researchers pointed out that large containerships benefit from scale economies on the sea but suffer from scale diseconomies at the port (Jansson & Shneerson, 1985; Cullinane K, 2000). Large containerships are usually deployed on the longer routes with more time on the sea. Therefore, the scale economies are more significant for CDWLS than those with smaller ships. It is postulated that:

**H8. Operating cost decreases with average ship size for CDWLS.**

Large ships can have economies of scale because the cargo carrying capacity will increase much faster than the cost when increase ship size. However, just looking at the cost side, increasing capacity will always increase operating cost. For CDWLS, the impact of capacity increase on operating cost may be bigger. For companies with smaller ships, the deployment of these ships are more flexible (Mason & Rawindaran, 2013). Usually, they are working on regional trade (e.g. Wanhai) or in niche trade route (e.g., Matson). They either use dedicated terminal or have high bargaining power on the use of port facilities. Their increase in operating cost (such as port cost) for a capacity increase can be much smaller. Such effects have already be observed in aviation and rail transportation (Harris, 1977; Caves, et al., 1984). For CDWLS, they usually operate on the major route where number of players is large and competition is high. They usually cannot have bargaining power on use of port facilities. Therefore, their increase in operating cost due to capacity increase can be higher than that of the companies with smaller ships. This brings up the next hypothesis:

**H9. Operating cost is more sensitive to the total capacity change for CDWLS.**

### 5.2.5 Impacts of alliance on the costs

Alliance membership might bring extra expense in operation. The may be because the joint-decision process takes too long and insufficient communication among members (James, 1985). For liner shipping industry, Midoro and Pitto (2000) pointed out joint-service arrangement may prevent individual carriers allocating ships in efficient routes. The inefficient slot arrangement for alliance members may decrease the economies of scale in large ships and increase the sensitivity of operating cost to the bunker price changes.

Therefore, it is postulated that:

**H10. Operating cost is more sensitive to bunker price for shipping alliance members.**

Due to the same reason, the inflexibility in alliances may also lead to the different sensitivity of operating cost to the average ship size. Therefore, for the moderating effect of alliance on the sensitivity of operating cost to the change in average ship size, the hypothesis is:

**H11. Operating cost increases with the ship size for liner shipping companies in alliances.**

Follow the explanation above for H9, when companies join alliance, the increase in total operating cost due to capacity increase, including port cost and voyage cost, is shared among the alliance members (Heaver, et al., 2000). In addition, since alliance members have wider and denser liner shipping networks (Ferrari, et al., 2008), they will have more network externalities than those non-alliance operators. Therefore, we postulate that:

**H12. Operating cost is less sensitive to carrier's capacity for shipping companies in alliances.**

## 5.3 Data description and empirical model specified

### 5.3.1 Description of the data

The data on operating revenue ($Revenue$[20]) and cost ($Cost$) of liner shipping operators are collected from Thomson Reuters Eikon database[21]. The selected

[20] The variable names used in the statistical model are in the parenthesis.

[21] https://financial.thomsonreuters.com

period is 2001-2015 since it covered the expansion of liner shipping market before 2008 and the sluggish period after that crisis. The 2016 data is not included because many major structural changes, such as bankruptcy, merger and acquisition, happened in the industry, which makes it impossible to maintain data consistency.

A total of 20 liner shipping companies can be found in the database. Among them, 15 are among the top 20 largest liner shipping companies in 2015, including the top liner shipping companies such as Maersk (capacity ranking 1st in 2015), and the one ranked 35 on the list (Matson). Since liner shipping companies have many different businesses, the operating revenue and cost in the liner shipping segment are selected. The accounting earning or losses due to the changes in fair value are not included. Therefore, the operating costs can be looked upon as the total cost of bunker, port due, crew wage, and other possible ship operating costs. In addition, the total asset ($Asset$) of liner shipping company is used as an indicator for the scale of the company.

The internal attributes of the 20 liner shipping operators are collected from Alphaliner[22]. They include the total controlled capacity (in TEUs) ($Comteu$), the percentage point of chartered capacity ($Charter$), and number of ships. The average ship size ($Size$) of a company each year is computed from $Comteu$ and number of ships of that company. From Clarkson, the world average size of container ships can be calculated each year (Table 5-1). If a company has the average ship size larger than the world average, it is classified as CDWLS, A dummy variable ($Bigship$) is designed to represent the nature of such company.

[22] https://www.alphaliner.com

Another dummy variable $Alliance$ is used to study the moderate effect of joining alliances.

Table 5-1: The world average size of container ships from 2001 to 2015

| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|
| **Size** | 1782.49 | 1892.47 | 1994.22 | 2067.65 | 2152.32 | 2253.37 | 2392.53 | 2480.78 |
| | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **Unit** |
| **Size** | 2583.44 | 2700.83 | 2861.67 | 3019.46 | 3197.35 | 3374.38 | 3572.7 | TEU |

The freight rates of liner shipping market ($Price$) are from the China Containerized Freight Index (CCFI) during 2003 to 2015. Since this index is on daily basis, we use its annual average value. The annual total containership capacity and annual container transport volume from Clarksons Shipping Intelligence Network[23] are used to represents the total market supply ($Supply$) and demand ($Demand$) in the period. The bunker price at Singapore (380 cst, in $/tonne) is used to represent the bunker price ($BPrice$) during 2001-2015. Furthermore, the changes in other costs, such as port due, labor costs, maintenance cost, can also affect the shipping market. The global Consumer Price Index ($CPI$) is used as an indicator for the change of those costs.

The selected variables for the internal factors are company-specific time-series data. For the external factors, they are not company-specific. Table 5-2 presents a descriptive statistics for the internal factors of 20 companies, and external factors during the 2001-2015.

Table 5-2: A descriptive statistics of selected variables for liner shipping companies

| Variable | Unit | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| $Revenue$ | 1000USD | 5162664 | 4863492 | 95620.19 | 3.50E+07 |

[23] https://www.clarksons.net

| | | | | | | |
|---|---|---|---|---|---|---|
| $Cost$ | | 1000USD | 4945403 | 4520356 | 87892.73 | 3.21E+07 |
| Internal factors | $Asset$ | 1000USD | 9696689 | 1.36E+07 | 291737 | 7.45E+07 |
| | $Comteu$ | TEU | 391368.2 | 439636.7 | 6898 | 2894458 |
| | $Size$ | TEU | 3115.29 | 1267.643 | 558.8947 | 6816.571 |
| | $Charter$ | % | 47.63675 | 21.35013 | 0 | 99.3 |
| | $Bigship$ | - | 0.738832 | 0.439272 | 0 | 1 |
| | $Alliance$ | - | 0.503333 | 0.499989 | 0 | 1 |
| External factors | $Price$ | - | 1057.964 | 88.6843 | 879.3863 | 1163.909 |
| | $BPrice$ | USD/Ton | 380.1433 | 180.1041 | 133.11 | 664.06 |
| | $CPI$ | % | 96.1 | 9.247919 | 81.2 | 108.7 |
| Indirect factors | $Demand$ | 1000TEU | 125737.3 | 33023.8 | 69943.15 | 175069.4 |
| | $Supply$ | 1000TEU | 11033.64 | 4376.425 | 4916.108 | 18260.09 |

The variances of these variables are large, indicating there is a huge difference in the performance of these liner shipping companies.

### 5.3.2. Empirical model specification

There are three empirical models: the empirical model on the freight rate generation, the basic model on financial performance without the moderating effect, and the extended model considering the moderating effect. We apply log-log statistical model on all the statistical equations, to estimate the elasticity of each factor. In a log-log regression model, the relationship between dependent and independent variables can be written as:

$$ln(y) = a + b * ln(x) + \varepsilon$$

the coefficient $b$ is actually the elasticity of $y$ on $x$. Differentiate the equation with respect to $ln(x)$, it is easy to see that:

$$b = \frac{dln(y)}{dln(x)}$$

Which is exactly the definition of elasticity.

Freight rate is an external factor determined by the interaction between market demand and supply—the two factors not directly affect the revenue of the company. Therefore, a separated statistical model is used to estimate the indirect effect of market supply and demand on the revenue via market freight rate. The statistical model can be specified as:

$$lnPrice_t = \beta_0 + \beta_1 * lnDemand_t + \beta_2 * lnSupply_t + \beta_3 * Dummy08 + \varepsilon$$

Where $lnPrice_t$ represents the logarithm of $Price$ at year $t$, and $Dummy08$ is the dummy variable indicating the year after the financial crisis. It is used to estimate the change of the intercept after 2008. The basic statistical model for revenue and cost are:

$$lnRevenue_{it} = a_1 lnPrice_t + a_2 lnDemand_t + a_3 lnSupply_t + a_4 lnComteu_{it} + a_5 lnAsset_{it} + a_6 lnSize_{it} + a_7 Alliance_{it} + cons_{it} + \varepsilon_{it}$$

$$lnCost_{it} = \beta_1 lnBPrice_t + \beta_2 lnComteu_{it} + \beta_3 lnAsset_{it} + \beta_4 lnCharter_{it} + \beta_5 lnSize_{it} + \beta_7 Alliance_{it} + cons_{it} + \varepsilon_{it}$$

The extended model that considering the impact of moderate variables are:

$$\begin{aligned} lnRevenue_{it} = {} & a_1 lnPrice_t + a_2 lnComteu_{it} + a_3 lnAsset_{it} + a_4 lnSize_{it} \\ & + a_5 lnPrice_t * Bigship_{it} + a_6 lnComteu_{it} * Bigship_{it} \\ & + a_7 lnSize_{it} * Bigship_{it} + a_8 lnPrice_t * Alliance_{it} \\ & + a_9 lnComteu_{it} * Alliance_{it} + a_{10} lnSize_{it} * Alliance_{it} \\ & + \_cons_{it} + \varepsilon_{it} \end{aligned}$$

$$
\begin{aligned}
lnCost_{it} = {} & \beta_1 lnBPrice_t + \beta_2 lnComteu_{it} + \beta_3 lnAsset_{it} + \beta_4 lnCharter_{it} \\
& + \beta_5 lnCPI_t + \beta_6 lnSize_{it} + \beta_7 lnBPrince_t * Bigship_{it} \\
& + \beta_8 lnComteu_t * Bigship_{it} + \beta_9 lnSize_{it} * Bigship_{it} \\
& + \beta_{10} lnCPI_t * Bigship_{it} + \beta_{11} lnBPrice_t * Alliance_{it} \\
& + \beta_{12} lnComteu_t * Alliance_{it} + \beta_{13} lnSize_{it} * Alliance_{it} \\
& + \beta_{14} lnCPI_t * Alliance_{it} + \_cons_{it} + \varepsilon_{it}
\end{aligned}
$$

## 5.4 Empirical results

### 5.4.1 Regression result from the freight rate generation models

The regression results from the freight rate generation model are provided in Table 5-3.

Table 5-3: Statistical relation of market price with market demand and supply

| $lnPrice$ | Coef. | P>t | | | |
|---|---|---|---|---|---|
| $lnSupply$ | -0.76716 | 0 | F(3, 256) | = | 35.32 |
| $lnDemand$ | 0.903475 | 0 | Prob > F | = | 0 |
| $Dummy08$ | 0.142042 | 0 | R-squared | = | 0.2927 |
| $\_cons$ | 9.622749 | 0 | Adj R-squared | = | 0.2844 |

The total supply and demand of container shipping market are generally increasing during 2001 to 2015 (Figure 1-3). The demand had an obvious drop in 2008 due to the global financial crisis. The results in Table 5-3 show that for 1% increase in supply, the market freight rate will decrease by 0.77%; 1% increase in demand, it will increase by 0.90%. The significant coefficient of $Dummy08$ indicates that after the financial crisis, the market freight rates are more volatile.

### 5.4.2 Regression result from the basic models

The results from the basic models are presented to enable the comparison between the regression result with and without considering the moderating effect. The results without considering the moderating effect are shown in Table 5-4.

Table 5-4: Regression result from the base model

| | $lnRevenue$ | | | $lnCost$ | |
|---|---|---|---|---|---|
| | Coef. | P>z | | Coef. | P>z |
| $lnPrice$ | 0.87398 | 0.001 | $lnBPrice$ | -0.03025 | 0.729 |
| $lnComteu$ | 0.88398 | 0 | $lnComteu$ | 0.864362 | 0 |
| $lnAsset$ | 0.35966 | 0.001 | $lnAsset$ | 0.283047 | 0.003 |
| $lnSize$ | -1.2569 | 0 | $lnSize$ | -0.85356 | 0 |
| $Alliance$ | 0.1657 | 0.633 | $lnCharter$ | 0.201422 | 0.002 |
| $\_cons$ | 2.38105 | 0.278 | $lnCPI$ | 0.236133 | 0.005 |
| | | | $Alliance$ | 0.004917 | 0.988 |
| | | | $\_cons$ | 5.830235 | 0 |
| | | | | | |
| $sigma\_u$ | 0.5172 | | $sigma\_u$ | 0.4985 | |
| $sigma\_e$ | 0.3280 | | $sigma\_e$ | 0.3149 | |
| | | | | | |
| R-sq: | | | R-sq: | | |
| within = | 0.3182 | | within = | 0.4438 | |
| between = | 0.7725 | | between = | 0.7867 | |
| overall = | 0.7087 | | overall = | 0.7266 | |

The Hausman Test results is P=0.000<0.05, indicating that the panel data regression has fixed effects, which means each liner shipping operator has fixed intercept that does not vary with time. Therefore, we applied the panel data regression with fixed effect. In the regression, the independent variables explained 31.82% of total revenue, 44.38% of total operating costs for each company, showing an acceptable goodness of fit.

Without considering the moderation effect, the result shows that $Price, Comteu$ and $Asset$ have positive impacts on revenue of liner shipping company. Size has a negative impact on the revenue, and being a member of the alliance has no significant impact on the revenue by itself.

On the cost side, $BPrice$ is negative, but not significant. $Comteu$, $Asset$, $Charter$, and $CPI$ all have positive and significant impacts on the operating cost. $Size$ has a significant negative impact on the cost. Being an alliance member also have no significant impact. However, the coefficients of bunker price for costs are not significant, that may because bunker prices used in our regression is a yearly average variable that has limited fluctuations.

Table 5-5: Comparison on the capacity deployed in different routes

| Routes | Service number | | Ship number | | Total weekly capacity | | Average ship size | |
|---|---|---|---|---|---|---|---|---|
| | 2011 | 2015 | 2011 | 2015 | 2011 | 2015 | 2011 | 2015 |
| Transpacific | 83 | 94 | 700 | 974 | 4.45E+05 | 6.15E+05 | 5362.14 | 6546.53 |
| FE-Europe | 90 | 45 | 891 | 511 | 7.20E+05 | 4.88E+05 | 8126.19 | 10840.47 |
| Inner Asia | 310 | 334 | 827 | 1139 | 5.37E+05 | 8.23E+05 | 1700.71 | 2429.05 |

The average ship size ($Size$) has negative impact on the company revenue, may be due to the high competition in the major routes and low load factor. Our liner shipping services information in 2011 and 2015 shows that larger container ships are mainly deployed in major East-West Routes, such as FE-Europe and Transpacific routes (Table 5-5). The average ship size on FE-Europe and Transpacific routes is much larger than the world average (2861.67 TEU in 2011, 3572.7 TEU in 2015). The regional trade routes that are less competitive, such as Inner Asia routes, deploy smaller ships than the world average. If a company has high average size, its earnings can be lower than those with smaller average ship size. For the operating cost, for the companies of the same total capacity, high average ship size means fewer ships. Therefore, the company can enjoy economies of scale in ship management and overhead cost. In the regression result, the elasticity of operating cost with respect to average ship size is also negative.

### 5.4.3 Regression result from the extended models

Table 5-6: Regression result from the extended models

| | $lnRevenue$ | | | $lnCost$ | |
|---|---|---|---|---|---|
| | Coef. | P>z | | Coef. | P>z |
| $lnPrices$ | 0.60427 | 0.031 | $lnBPrice$ | 0.25889 | 0.04 |
| $lnComteu$ | 0.48473 | 0.021 | $lnComteu$ | 0.43583 | 0.045 |
| $lnAsset$ | 0.25751 | 0.01 | $lnAsset$ | 0.18597 | 0.041 |
| $lnSize$ | -0.2473 | 0.467 | $lnSize$ | -0.30204 | 0.395 |
| | | | $lnCharter$ | 0.03917 | 0.593 |
| | | | $lnCPI$ | 0.03242 | 0.76 |
| $lnSize\#Alliance$ | 2.50961 | 0 | $lnSize\#Alliance$ | 1.23307 | 0.005 |
| $lnComteu\ \#Alliance$ | -1.0725 | 0 | $lnComteu\ \#Alliance$ | -0.98680 | 0.001 |
| $lnPrices\ \#Alliance$ | -0.8733 | 0 | $lnCPI\#Alliance$ | -0.35339 | 0.008 |
| $lnSize\#Bigship$ | -3.3793 | 0 | $lnBPrice\#Alliance$ | 0.59941 | 0 |
| $lnComteu\ \#Bigship$ | 1.48812 | 0 | $lnSize\#Bigship$ | -1.76121 | 0 |
| $lnPrice\ \#Bigship$ | 1.1416 | 0 | $lnComteu\#Bigship$ | 1.41544 | 0 |
| | | | $lnCPI\#Bigship$ | 0.48349 | 0.001 |
| | | | $lnBPrice\#Bigship$ | -0.80135 | 0 |
| $\_cons$ | 2.73606 | 0.152 | $\_cons$ | 7.26227 | 0 |
| $sigma\_u$ | 0.68873 | | $sigma\_u$ | 0.70565 | |
| $sigma\_e$ | 0.2825 | | $sigma\_e$ | 0.27503 | |
| R-sq: | | | R-sq: | | |
| within = | 0.5067 | | within = | 0.5897 | |
| between = | 0.6581 | | between = | 0.5974 | |
| overall = | 0.6274 | | overall = | 0.5688 | |

The result from the extended model (Table 5-6) presents the moderating effect of $Bigship$ and $Alliance$. Similarly, the Fixed-Effect panel data models are applied to the revenue and cost equations. The goodness of fit has significant improvement. The within-group R-squares have increased to 50.67%, 58.97% respectively.

From this table, it is clear that the elasticity of firm performance depends on whether the firm is a member of alliances ($Alliance = 1\ or\ 0$) and whether it is dominated with large ships ($Bigship = 1\ or\ 0$).

The elasticity of revenue with respect to external factor ($Price$) and internal factor ($Size$ and $Comteu$) can be written as:

$$\frac{dlnRevenue}{dlnPrice} = 0.604 - 0.873 * Alliance + 1.142 * Bigship \quad (5\text{-}1)$$

$$\frac{dlnRevenue}{dlnSize} = 2.510 * Alliance - 3.379 * Bigship \quad (5\text{-}2)$$

$$\frac{dlnRevenue}{dlnComteu} = 0.485 - 1.073 * Alliance + 1.488 * Bigship \quad (5\text{-}3)$$

From above equations, it is clear that for CDWLS, the revenue will be more elastic to the change in market price, due to the high level of competitions in the deployed routes. The H1 is accepted. However, if they join alliances, the revenue will be more stable with the price change. Therefore, H4 is also accepted. For the internal factor, further increases in the average ship size can reduce revenue for CDWLS. Therefore, the H2 is accepted. For those companies, if they join alliance, the revenue reduction will be much smaller, due to the sharing on the revenue among the alliance members. Therefore, H5 is also accepted. Finally, for CDWLS, increase in total capacity can increase its revenue, but if it is an alliance member, the increase will be much smaller. Therefore, H3 and H6 are also accepted.

For the companies not dominated by big ships ($Bigship = 0$), nor a member of any alliance ($Alliance = 0$), the regression results are similar to the those from the basic model, except the estimated coefficient on $Size$. After considering the moderating effect, for those companies, increase average ship size does not have a significant impact on the revenue. This may reveal that for small shipping companies, the size of the ship does not matter.

For the internal control variable, increase the total asset of the company can increase revenue. This may reflect the impact of economies of scope in the operating of liner shipping companies.

On the cost side, the elasticities with respect to external and internal factors are:

$$\frac{dlnCost}{dlnBPrice} = 0.259 + 0.599 * Alliance - 0.801 * Bigship \quad (5\text{-}4)$$

$$\frac{dlnCost}{dlnSize} = 1.233 * Alliance - 1.761 * Bigship \quad (5\text{-}5)$$

$$\frac{dlnCost}{dlnComteu} = 0.435 - 0.987 * Alliance + 1.415 * Bigship \quad (5\text{-}6)$$

$$\frac{dlnCost}{dlnCPI} = -0.008 * Alliance + 0.483 * Bigship \quad (5\text{-}7)$$

From above, it can be seen that for the CDWLS, increase bunker price and ship size can reduce operating cost, as our H7 and H8 expected. For them, joining alliances reduces the flexibility of service route and ship deployment. Therefore, the cost saving of big ships are not very effective. This confirms H10 and H11. The estimated coefficient on $Comteu$ for CDWLS is positive significant. It confirms H9. CDWLS has the disadvantage compared with the companies with smaller ships, due to high competition on the major route and low flexibility to deploy their ship to the non-major route. However, the estimated coefficient on alliance is negative and significant. This indicates the dis-advantage of CDWLS can be alleviated by join alliances, which is consistent with H12. For the elasticity of CPI, the coefficient on $Bigship$ is positive and that on $Alliance$ is negative. For CDWLS, inflation will have a bigger impact on the operating cost, which also can be mitigated by joining alliance. Finally, for the internal control variable $Asset$, the estimated value is positive significant, indicating the existence of dis-economy of scope.

If the company is neither an alliance member, nor dominated with big ships, the estimated coefficient on $BPrice$ and $Comteu$ are all positive significant. Increase in bunker price and total fleet size will increase the operating cost. Fortunately, they are all inelastic, i.e., for 1% increase in bunker price and total capacity, the increase in the total operating cost is less than 1%. As a summary, the moderating impacts of large ships and alliance on the financial performance are present in Figure 5-6.

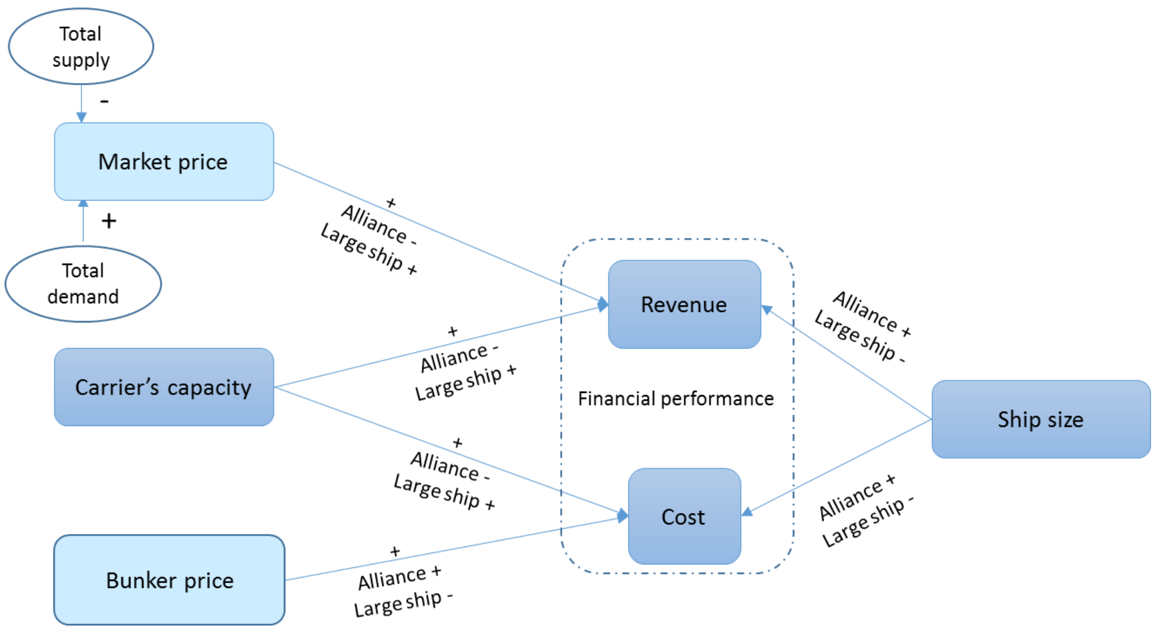



Figure 5-6: Impacts of large ships and alliance in financial performance

### 5.4.3 In-sample prediction errors

The sample time covers both the booming market before the 2008 financial crisis, and long sluggish period after that. The relationship between market supply and demand, as well as the behaviour of the shipping companies in these two periods are significantly different, which may affect the model performance.

Table 5-7: In-sample prediction on the mean revenue and cost of all the selected companies over time

| | Revenue | | | | Cost | | | |
|---|---|---|---|---|---|---|---|---|
| | Actual mean | Predicted mean | Error (%) | MAPE (%) | Actual average | Predict average | Error (%) | MAPE (%) |
| 2001 | | | | | 2312865 | 2331122 | 0.79 | 13.17 |
| 2002 | | | | | 2855763 | 2447696 | -14.29 | 14.44 |
| 2003 | 3759370 | 3344123 | -11.05 | 16.42 | 3363274 | 3042815 | -9.53 | 10.78 |
| 2004 | 4115204 | 3853648 | -6.36 | 18.47 | 3581848 | 3326241 | -7.14 | 22.00 |
| 2005 | 4867662 | 4587618 | -5.75 | 18.07 | 4167776 | 3810036 | -8.58 | 16.73 |
| 2006 | 5068529 | 4650683 | -8.24 | 12.94 | 4713937 | 4592246 | -2.58 | 14.63 |
| 2007 | 5558265 | 5033166 | -9.45 | 15.18 | 5022960 | 4869566 | -3.05 | 14.47 |
| 2008 | 6921830 | 5260995 | -23.99 | 18.53 | 6457458 | 5593320 | -13.38 | 19.06 |
| 2009 | 4600893 | 4776422 | 3.82 | 17.47 | 4831012 | 5309546 | 9.91 | 17.00 |
| 2010 | 6197860 | 5806311 | -6.32 | 13.55 | 5605496 | 5000187 | -10.80 | 13.90 |
| 2011 | 5289201 | 5685896 | 7.50 | 24.45 | 5388201 | 5993874 | 11.24 | 22.40 |
| 2012 | 5718269 | 6683573 | 16.88 | 21.70 | 5690193 | 5619130 | -1.25 | 18.00 |
| 2013 | 5272072 | 5710806 | 8.32 | 19.75 | 5168498 | 5012144 | -3.03 | 20.00 |
| 2014 | 6064766 | 5962588 | -1.68 | 11.06 | 5788013 | 5487634 | -5.19 | 12.00 |
| 2015 | 5462444 | 4831479 | -11.55 | 16.28 | 5231579 | 5386241 | 2.96 | 13.67 |

An in-sample prediction for the revenue and cost of each selected liner shipping company in each year was conducted using the result of the extended model. The actual and predicted mean, the prediction error and Mean Absolute Percentage Error (MAPE) for the revenue and cost are presented in Table 5-7. Since there are many companies, the MAPE in each year is calculated based on the percentage error of each company in that year.

On the revenue side, the prediction errors on the main value range from -23.99% to 16.88%. Under-estimation mostly happened before the financial crisis of 2008, and overestimation mostly happened after that. The actual earning is much lower than the predicted one after financial crisis. This may due to the impacts of overcapacity in the liner shipping sector, because it can increase competition and reduce the earning. Most of the MAPEs are larger than absolute value of the errors between predicted and actual means. This indicates that the predicted revenue of individual companies has a higher variance.

On the cost side, the estimation error is much smaller. This may due to the relatively stable costs in all the inputs, compared with the high volatility in the market price.

To illustrate the prediction accuracy, a comparison of the predicted and actual mean revenue and cost are shown in Figure 5-7. It is clear that the predicted can largely follow the trend of the actual value. Also, before 2008, the prediction underestimates the revenue and cost. After that, the many over estimates happened.

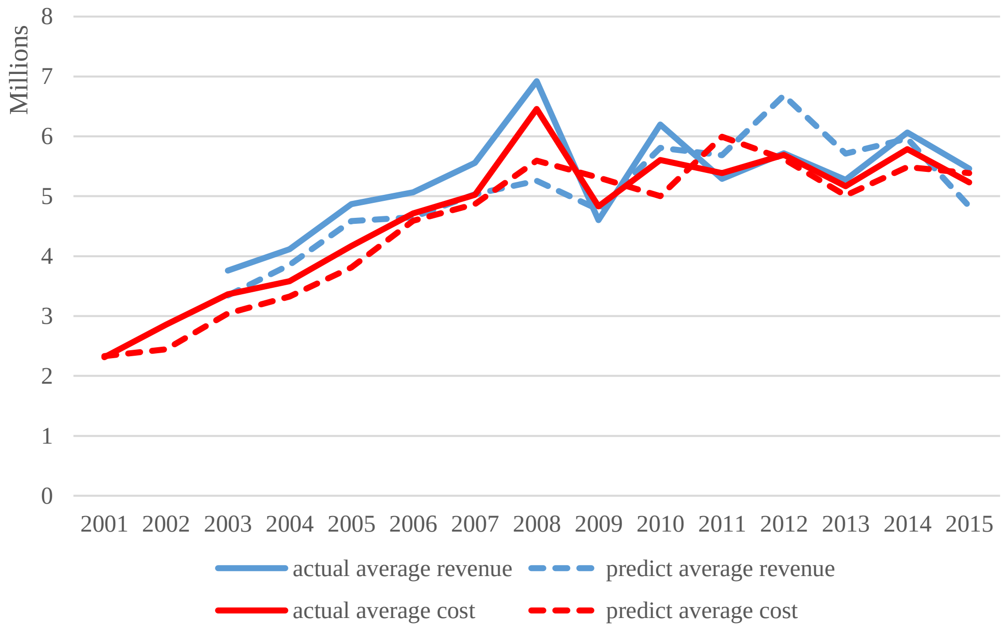



Figure 5-7: Predicted v.s. actual mean revenue and cost

Section 5.4 presents the results from the panel data analysis, and provides an explanation on the moderating effect of $Bigship$ and $Alliance$ on how the internal and external factors affects the revenue and cost. An assessment of prediction accuracy is also provided. This provides a basis for further analysis on what affects the profit ratio—an important measure for the performance of liner shipping company.

## 5.5 In-depth analysis of liner shipping companies' financial performance in 2001-2015

### 5.5.1 Analyzing the operating strategies of different liner shipping companies

Using $R_i$ and $C_i$ to represent the company-specific intercept in revenue and cost estimation, the revenue and cost equation can be written as:

$$Revenue = R_i * Asset^{0.26} * Price^{0.60-0.87Alliance+1.14Bigship} * Comteu^{0.48-1.07Alliance+1.49Bigship} * Size^{2.51Alliance-3.38Bigship}$$

$$Cost = C_i * Asset^{0.19} * BPrice^{0.26+0.60Alliance-0.80Bigship} * Comteu^{0.44-0.99Alliance+1.42Bigship} * Size^{1.23Alliance-1.76Bigship} * CPI^{0.48Bigship-0.01Alliance}$$

Then the profit ratio $\rho$ is:

$$\rho = \frac{R_i}{C_i} * Asset^{0.07} * Price^{0.60-0.87Alliance+1.14Bigship} * Comteu^{0.04-0.06Alliance+0.06Bigship} * Size^{1.28Alliance-1.62Bigship} * BPrice^{0.80Bigship-0.26-0.60Alliance} * CPI^{0.48Bigship-0.01Alliance}$$

From this, it is clear that the profitability of the company will depend on both the external and internal factors, as well as the moderating factors.

1. If the market is in the booming stage and market price is increasing, it is better not to join alliance, because it can reduce the profit ratio by 0.87 percent.

2. When the bunker price is rising, companies with relatively large ships can enjoy some advantage, as it can increase profit ratio. Also, it is not a good idea to join alliance, as it can increase the negative impact of bunker price on the profit ratio.

3. When there is inflation, CDWLS can suffer, while joining alliance can slightly alleviate such impacts.

4. For fleet capacity expansion, CDWLS has advantages. However, such benefits can be cancelled off by joining alliance.

5. For a CDWLS, further increase the average ship size can have a large negative impact on the profit ratio. However, joining alliance can reduce such impact, although cannot eliminate it.

6. For companies that are not in alliance, nor CDWLS, the increase in average ship size and inflation does not have obvious impacts. It will benefit from the increase of market freight rate, and suffer from bunker price increase. Fleet capacity can have positive, although small, impact on profit ratio.

7. Total assets, reflecting the overall scale of the company, have positive impact on the profit ratio.

### 5.5.2 Company-specific scaling factor

The company-specific intercept introduced in the previous section is the scaling factor of each company, represents the volatility of each company with respect to the changes in the internal and external factors. From the fixed-effect model, the intercepts can be obtained for each company, and the scaling factors are just the exponent of the intercept. These are provided in Table 5-8.

The scaling factor of each company are shown in Figure 5-8. Since CMA CGM is used as the bench mark, the intercept is 0 and the scaling factor as 1. For company $i$, the scaling factor $R_i$ and $C_i$ are calculated by $\exp(0 + intercept_i)$. The missing variables stands for the estimation that are not significantly different from the CMA CGM. Therefore, their scaling factors are equal to 1.

Figure 5-8 depicts the scaling factor for revenue and cost for different companies, according to their operating capacity. A large value indicates a higher volatility of that company in the revenue and cost compared with CMA CGM. The scaling factor in revenue is much larger than that in the cost side. The top liner shipping companies, such as Maersk and CMA CGM (1st and 3rd largest liner operators), have the lowest volatility. Maersk, the biggest liner shipping company in the world, is the most stable one in terms of both revenue and cost. Some small companies, such as SITC, RCL and Panocean, are also relatively stable. The most volatile one is HMM. Most of the others on the top 20 list are also not stable.

Table 5-8: Company-specific intercept and scaling factor

| | **Revenue** | | **Cost** | |
|---|---|---|---|---|
| | **Intercept** | $\boldsymbol{R_i}$ | **Intercept** | $\boldsymbol{C_i}$ |
| CMA CGM | base | 1 | base | 1 |
| COSCO | 1.52 | 4.57 | 1.18 | 3.25 |
| CSAV | 1.87 | 6.49 | 1.34 | 3.82 |
| CSCL | 1.21 | 3.35 | 0.85 | 2.34 |
| Evergreen | 1.19 | 3.29 | - | 1 |
| Hanjin | 1.43 | 4.17 | 1.01 | 2.75 |
| Hapag-lloyd | 1.41 | 4.09 | 0.88 | 2.41 |
| HMM | 1.99 | 7.31 | 1.51 | 4.53 |
| K line | 1.72 | 5.58 | 1.31 | 3.71 |
| Maersk | -0.61 | 0.54 | -0.83 | 0.44 |
| Matson | 1.11 | 3.03 | - | 1 |
| MOL | 1.15 | 3.16 | 0.88 | 2.41 |
| NOL(APL) | 1.43 | 4.18 | 1.02 | 2.77 |
| NYK | 1.09 | 2.97 | 0.89 | 2.44 |
| OOCL | 1.57 | 4.81 | 1.11 | 3.03 |
| Panocean | - | 1 | - | 1 |
| RCL | - | 1 | - | 1 |
| SITC | - | 1 | - | 1 |
| Wanhai | 0.91 | 2.48 | - | 1 |
| Yang Ming | 1.21 | 3.35 | 0.79 | 2.20 |

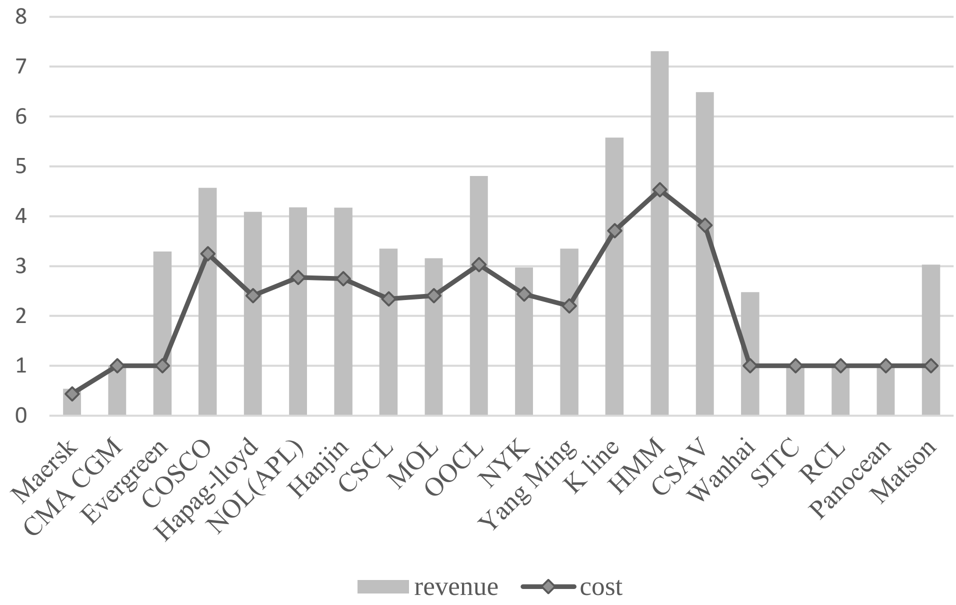



Figure 5-8: Scaling factors on revenue and cost for different shipping companies

## 5.6 Chapter summary and conclusion

Since the financial crisis in 2008, the liner shipping industry has become increasingly concentrated and overcapacity. To survive in the volatile and sluggish market, it is essential for liner shipping companies to decide their best operation strategies to improve financial performance. In this study, we studied the moderating effects of having large containerships and joining alliances on how the internal and external factors affect the financial performance, which can help the liner-shipping operators to survive in the troubled sea.

Through a review of existing literature on the financial performance and operation strategy of liner shipping companies, we developed a conceptual model on how having large container ships and joining alliances moderate the effect of internal and external factors. Based on the model, a series of hypotheses is developed on the moderating effects. Three empirical models are built to describe the market freight rate generation process, the basic relationship of revenue and cost with the internal and external factors, and the extended model that includes the moderating effects. A panel data that includes 20 liner shipping companies over 15 years are collected from various sources. A fixed-effect panel data model with Log-Log regression are conducted on the basic and extended models. An in-sample prediction is provided to show the model accuracy, and in-depth analyses on the profitability and scaling factor of individual company are provided.

Through the extended model, all the hypothesis are accepted, and the moderating effects are significant. Most of the companies dominated with large ships are operating in the routes with high competition. Therefore, their revenue is more sensitive to the changes in freight rate and total fleet capacity. For them, further increase the number of large ships will decrease revenue. Join alliances can reduce such effects. On the cost side, big ships have economies of scale, so it can reduce the impact of bunker price. For them, join alliance has many advantages, including economies of scope, and reduce the impact of inflation. However, being alliance members also has limitations, including lower flexibility. Therefore, it will increase the impact of bunker price and average ship size on the operating cost.

From the analysis of profitability, a set of strategies for liner shipping company to improve their performance are drawn. In a booming market, or when the bunker price is increasing, join alliances is not a good strategy. It is only beneficial for companies with large ships because they are operating in a market with very high competition. For those smaller ones operating in regional trade where the level of competition is low, join alliances is not a good strategy.

The scaling factors of each companies indicate that the major liner shipping companies operating in the major East-West trade routes have very volatile earnings, due to the high competition. The exception is Maersk, which has a stable earning compared with the rest of the companies in the sample. This indicates the effect of market power. On the other hand, the smaller companies, such as RCL, SITC and Panocean, are also very stable. This may reflect the low level of competition in their trade area.

# Chapter 6 : CONTRIBUTIONS AND LIMITATIONS

## 6.1 Conclusions

In this thesis, we analyzed liner shipping operations with ever increasing larger ships, trying to answer three questions: How ship size affects the decision of liner shipping services in number of ports to call and clusters to serve in the past? What is the theoretical relationship between the number of port calls and ship size? How large containerships and alliance affect the financial performance of liner shipping companies?

The first study of this thesis found that larger ships may not visit fewer ports, unlike in aviation. There are 'turning points'—liner services may change from visiting more clusters when ship size grows: larger ships will normally visit more clusters/ports to serve more cargo; if the ship size is over a certain limit, the service may decrease the number of cluster calls but not necessarily number of port calls.

The theoretical model of the second study reveals the mechanism in the decision on the number of port calls for liner shipping operators. The result shows whether larger ships calls more or fewer ports depends on the demand in the market. When the market is overcapacity or demand too low, operators have to call fewer ports and charge lower prices with larger ships; otherwise, they can call more ports and charge higher prices as long as the increment cost does not exceed the revenue that the operators can gain from additional port call.

Noticing the importance of large container ships and alliances in the industry, the third study analyzes their impacts on the financial performance of liner shipping companies. From the empirical results, we found that companies with more large container ships are facing high competition and could benefit more from economies of scale. Alliance members can enjoy high slots utilization and economies of scope, but lack of flexibility. Profitability analysis suggests that liner shipping companies should make the decisions on ship investment and joining alliances based on the market condition, to achieve a better and stable performance.

## 6.2 Contributions

This thesis has implications for both academic research and practice:

In theory:

The first study finds from the past statistics that the port call numbers in liner shipping services are not showing an obvious trend of decrease with the increase of ship size, revealing the fundamental difference between the H&S structure in liner shipping and that in aviation. In shipping, a service can call two hubs in a region; while in aviation, it only calls one hub. However, the two hubs in close proximity can only coexist with high demand in the hinterland and similar accessibility for large ships. As shown in Chapter 2, most studies of H&S network in liner shipping assume there is only one hub in one region. This result implies the two-hub situation should be taken into consideration.

The second study enhances the first study by theoretical models for both no-transshipment and transshipment cases. The study finds the conditions for one operators to call more ports than its competitors, which is a supplementary to the current literature in liner shipping networks design. Besides, the second study also reveals the pattern of price competition in liner shipping market: operators tend to charge a market price unless there are over-capacity in the market. The results support the hypothesis of ‘contestable market’ in previous research in Chapter 2.

The third part is an empirical study that connects the strategies of liner shipping companies with their financial performance. This is the first empirical study revealing that joining alliances is only beneficial for the liner operators when the market price is decreasing. This may indicate the instability of liner shipping alliance, which has just seen theoretical study in the literature. It also identifies the clear distinctions between CDWLS and companies with smaller ships in the major factors for financial performance and the benefits of joining alliances, points out the root cause for such differences: market competition. That provides the statistical support for the competition and cooperation analysis in liner shipping for companies with different properties.

In practice:

The study in liner shipping operations with increasing ship size can help both port authorities and liner shipping operators with their decision on the design of liner services and port expansion policy. The empirical results show that with enough demand, it is possible to have two, or even three hub ports, such as Shanghai and Zhoushan-Ningbo ports in the YRD, and Hong Kong, Shenzhen and Guangzhou ports in the PRD area. Therefore, it is reasonable for all the ports with suitable conditions to expand their facilities to accommodate large containerships. However, it may also cause overcapacity if the demand from the common hinterland is not sufficient. Therefore, the first requirement is to have a good understanding on the demand.

For liner shipping operators to design an optimal port rotation and service network, it is important to understand the possible impacts of increasing ship size and market concentration. The modelling results from port call decision under competition enable the liner operators to determine whether to call more ports than competitors in a service, and to decide a competitive price.

The last study can provide more detailed operation strategies for different companies facing their respective external conditions. For the companies dominated with large ships, the high competition on their service route forces them to join alliances when the market is sluggish. For those with smaller vessels, they often operate in a niche area where the level of competition is low. Therefore, it may not be beneficial to join alliances. For large shipping companies, continue to invest in large container ships may not be paid off: the lower demand and high competition prevent them enjoy the economies of scale, unless they join an alliance. However, if every member does the same, it will definitely result in over capacity.

## 6.3 Limitations and future studies

When the first study investigates the factors in the number of ports to call and the clusters to serve, the data are from liner shipping services calling Chinese ports in the year 2011 and 2015. The structure changes happened after 2015 have a very significant impact on the market competition and the behavior of players in the competitive market. Future research efforts in understanding the behavior of the few remaining large operators are definitely necessary, especially when all of them are operating in three large alliances.

The second study provides the theoretical model about the liner operators' decision on how many ports to call. The decision on how to call them is not included.

However, when applying the model in the design of liner shipping services, the problem of how to call them is necessary, and it has to involve many practical factors, such as the physical limitation on berth capacity and the distance between each ports. This then becomes a problem for operations research.

The third study analyzes the effect of large ships and joining alliances in financial performance. Such studies rely heavily on the available financial information of the company. Therefore, we can only include those publicized companies, as they are required to provide the financial data to the public. Also, we only included very few internal and external factors. If a longer time series data is obtainable, then it is possible to include more explanatory variables. For example, by including the information on the capacity allocation of each company to each route, it might be possible to identify the route-specific revenue and cost information, which can be used by the liner operators to optimize the capacity allocation in their liner shipping networks.

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