VERIFYING LINER SHIPPING ALLIANCE'S STABILITY BY APPLYING CORE THEORY

Dong Yang MFI, University of Southern Denmark Email: yang@sam.sdu.dk

Miaojia Liu MEL, Erasmus University Rotterdam Email: mliu@ese.eur.nl

Xiaoning Shi IWI, University of Hamburg Email: shi@econ.uni-hamburg.de

ABSTRACT

The core is a vital concept in cooperative game theory and has been widely used in the analysis of the alliances' stability. Generally speaking, when cost functions are continuous functions of the output, the severity of empty core decreases as the size of the market increases. However the liner shipping industry is an exceptional case due to its characteristic of 'lumpy transport'. The core is periodically empty as transport demand increases, and this feature is affected by the discontinuities of the marginal cost of the liner carriers. This paper focuses on economic performance and stability of the liner shipping alliances, where business cooperation is realized by pooling mega vessels. Deploying mega-ships has certain influence on the shipping alliance and can change the conditions of non-empty core of shipping market. The core's condition lies on the fact that a stable alliance depends, not only on its potential profitability, but also on none of the members can be at an advantage better off by forming any sub-coalition. To demonstrate the core situation in liner shipping alliance, a cost function is firstly identified on the basis of two assumptions regarding cooperation: 1) pooling vessels and 2) deploying mega-ships, if needed. Taking demand curves and cost functions as basis, the conditions of shipping market core are then observed. The difference between pre-alliance conditions and post-alliance conditions is emphatically discussed. As another important part of this study, a case study with three liner carriers is conducted in order to show the possible operating slot intervals of member carriers in forming the alliance to avoid the empty core from carriers´ perspective. Conclusions are drawn based on results of the case study.

Keywords: Liner shipping alliance, Cost function, Core, Mega-ship, Stability

1. INTRODUCTION

One of the most significant developments in the liner shipping industry over the past decades is the formation of strategic alliances. Since mid-1870s, the liner conference system had already been developed in an attempt to deal with excessive capacity and cut-throat price competition. Over the following century, numbers of agreements on freight rates, numbers of services, ports served, goods carried and acceptable mechanism of revenue sharing (pool agreement) have been constantly developed. With the trend of containerization, standardization and global competition, the liner conference system was almost exempted from anti-trust legislation by the late 1980s (Stopford 2009). In an altered strategy of cooperation, a variety of forms of alliance appeared that aimed to lower unit costs. Since 2008, the financial crisis put enormous strains on the once booming global industry. The shipping industry benefits from globalization more than almost any other sector, but this has also made it more vulnerable to the economic slowdown. Freight rates and charter rates have plunged with vessels being laid off, and order books being cancelled.

Despite the recession, the recent decade has witnessed a steady increase in the size of containerships deployed along the world´s busiest maritime routes, seeking for the benefit of economies of scale (Imai et al., 2006). However, these ships do not fully enjoy economies of scale in the current market as there is a clear surplus of fleet capacity and loading factors are low. They start their voyages with half-empty slots - if they start at all. As a result, mega-ships may present sunk cost for ship-owners. Consequently, there is surely an extensive formation and recombination of new liner shipping alliances resulted.

A new framework of the shipping industry might emerge very soon. Recently, there have been some convincing cases. For instance, Maersk Line and CMA CGM—two of the top three companies—are ahead of the curve when it comes to consolidating resources with at least nine joint vessel sharing and multi-lateral slot sharing agreements to cover the main East/West route. More changes related to other liner shipping companies are still expected to take place.

Concerning the economic stability of competitive markets developed in the last century, game theory has been regarded as one of the most effective tools for analyzing market behavior. In particular, the theory of "core" in games implies that competition is frequently unstable and inefficient under some fairly common cost and demand conditions. "When costs are characterized by indivisibilities (for example, avoidable costs) and demand is finely divisible, the core of market may be 'empty'. In other words, a competitive equilibrium frequently fails to exist. As a consequence, competitive interactions between firms can not generate an efficient allocation of resources." (Pirrong, 1992, p.89)

This paper focuses on liner shipping alliance, which operates on a certain route. On basis of Sjostrom and Pirrong´s work, this paper expands the application of theoretical framework of the core to stability of an alliance formed by pooling increasing size of mega-ships. We try to explicitly demonstrate economic performance and stability of such an alliance. The remaining part of the paper is organized as follows: in Section 2, a literature review of liner shipping alliances, deployment of megaships, game theory as well as the application of core into the liner shipping industry is put forward; Section 3 discusses alliance formation and cost function regarding the deployment of mega-ships within the liner shipping alliance; After giving a brief introduction of core theory in Section 4; Section 5 discusses the stability of the alliance from the perspective of profitability (total cost saving) and market demand; Section 6 analyzes the stability from another core´s condition, where no members of the alliance can be better off by forming any other sub-coalition; Section 7 summarizes the work.

2. LITERATURE REVIEW

Shipping conference as well as its successor - strategic alliance has a long history among liner companies because of fierce competition. Poulsen (2007) addresses liner shipping strategic alliance from a historical aspect. He points out that historians and shipping analysts have argued that it is a technological innovation – the container, which drove shipping companies toward cooperation because an investment in such new technology required access to a very large group of customers and large quantities of cargo. In terms of cooperating, liner companies are able to handle a critical mass of cargo and capital for such a major investment. Haralambides et al. (2002) denotes more details on cooperative motivations, which include wider geographical coverage, operational efficiency, risk and investment sharing, economies of scale and so on. Brooks (2000) identifies the types of technical cooperation agreements such as slot-chartering agreements, coordinated services, equipment sharing agreements and vessel-pooling consortium or joint venture. Cariou (2002) provides an "empirical estimation of horizontal effect" in alliance operational synergies and its result shows that collective action works better in achieving economies of scale.

As for deployment of mega-ship, Cariou (2002) explains that economies of scale does not restrict to the vessels only, but requires an upgrade of the whole string with large vessels. Imai et al. (2006) analyzes viability of mega containership considering competitive circumstances by using game theory. His paper concludes that mega-ships are competitive in all scenarios for Asia–Europe route, while viable for the Asia–North America route only when the freight rates and costs of feeder services are low. Furthermore, he also addresses that as world trade increases, the ship size increases in a corresponding manner in order to enhance the economies of scale. Veldman (2009) is concerned that the assessment of shipping costs versus ship size elasticity for Post-Panamax ships ranging from about 5,000 TEU to 14,000 TEU and the timing of the introduction of bigger ships of up to 20,000 TEU.

Game theory has been broadly applied in transport related research. It has already been regarded as an effective methodology to explain the emergence of cooperation and competition in the transportation market. In particular, the Shapley value is used to analyze varieties of allocation problems, including cooperative profit assignment, marginal cost in entering coalitions, minimizing maximum unhappiness and separable and non-separable costs. On one hand, Yang and Odani (2005) as well as Krajewska and Kopfer (2006) work on similar topics, optimizing the inland cooperative transportation system to pursue maximal common profit and calculate reasonable side payments for each member in the system. On the other hand, Shi and Voß (2008) study iterated cooperation and possible deviations among the liner carriers in terms of constructing non-cooperative games. Comparatively, core is an even more prominent and widely accepted notion of fair allocation of costs and stability in cooperative game theory.

Some research regarding destructive competition arguments based on the idea of an empty core appeared in the late 1980s and early 1990s. Sjostrom (1989, 1993) recognizes that one of the reasons that would result in an empty core is inefficient entry; while this article emphasizes that marginal cost pricing can disrupt competitive equilibrium when costs are indivisible, even if further entry is precluded or if the threat of entry does not constrain prices. Pirrong (1992, p.90) also emphasizes that the possibility of discontinuities in marginal cost at capacity makes tests of the relation between status of the core and size of the market problematic. He explicitly tests the existence of such discontinuities in cost data. Song and Panayides (2002) apply core theory to the liner shipping strategic alliances. In that paper, they analyze not only the cost allocation but also fair profit allocation among members within liner shipping alliances, which could be viewed as one of the conditions that keep consortia or alliances stable. A similar idea can also be seen in Ryoo and Thanopoulou (1999). Agarwal and Ergun (2009) study the liner alliance by core theory from companies´ perspective, they design a mechanism to guide companies in an alliance to follow optimal collaborative strategies, among which one possible mechanism could be to provide side payments to the companies, as an additional incentive, to motivate them to act in the best interest of the alliance while maximizing their own profit simultaneously.

Applications of core theory can also be found in other transport fields. Button (2003) explores both the application of core theory in the air transportation industry and the desirability of government actions to alleviate associated players' performance. Yang and Odani (2007) study the fair allocation and subsidization under the circumstance of a possible unprofitable inland transportation alliance with core and ε-core.

3. COST FUNCTION OF LINER COMPANIES

The liner industry kept flourishing for several years before 2008. Demand kept increasing and sometimes it exceeded existing capacities. Meanwhile, liner companies were aware that increasing supply would, to some extent, increase total revenue. Consequently, they booked new vessels in the hope of gaining more market share and obtaining more profits. The current order book shows that many liners are gradually preparing their capacities by amplifying their fleets with new vessels of up to 10,000-13,000 class (Containerization, March 2009).

Facing the unexpected devastating global economic crisis, the market becomes greatly unfavorable to liners with the delivery of these new vessels. To cope with such situation, many carriers chose to enter or leave previous alliances and adjust cooperation with their competitors. Alliances are meant to reduce capital costs, financial risks, and can gather significant amount of cargoes. Therefore, it is applicable to deploy larger and more efficient containerships on deep sea routes. Considering the upcoming delivery, pooling mega-ships is obviously a suitable form of cooperation and it has recently been widely adopted in the industry. On one hand, it can save investment, reduce unit cost, extract bargaining power and achieve economies of scale. On the other hand, carriers can still fully control their own sales and marketing activities.

There are two hypotheses for the strategy of pooling vessel, which is to be analyzed in this section: 1) different liner carriers can ship their cargoes collectively in one vessel under a certain service frequency (we assume weekly service in this paper), and 2) they can deploy even larger vessels. It is obvious that the alliance is better off by exchanging and operating existing fleet through which a higher loading factor and a lower unit cost can be achieved.

According to the hypotheses, two segments of cost function are identified, i.e., $f(q)$ and $g(q)$. $f(q)$ denotes the different unit costs per TEU relating to different ship size with fully loading. $g(q)$ denotes unit costs relating to certain size ship with variable loading factor.

$$f(q_i) = \begin{cases} c(s_1) & q_i \le s_1 \\ \dots & \\ c(s_n) & s_{n-1} \le q_i \le s_n \end{cases} \qquad n = 1,2,3\ \dots$$

$$g(q_i) = c(s_i) \cdot s_i / q_i \qquad q_i \le s_1$$

Where q_i denotes the cargo volume that carrier i needs to transport; $c(s_i)$ is the lowest unit cost (fully loaded) of ship with s_i as size.

Based on available literature, Figure 1 can be drawn to illustrate minimum costs for the Europe - Far East trade route. Figure 2 shows the change of the unit cost with increasing loading factors based on data from Figure 1. Especially, the container handing cost at the port is not included in the original source, and the unit cost is only related to ship cost. So it is feasible to calculate $g(q)$ by diverse loading factors.

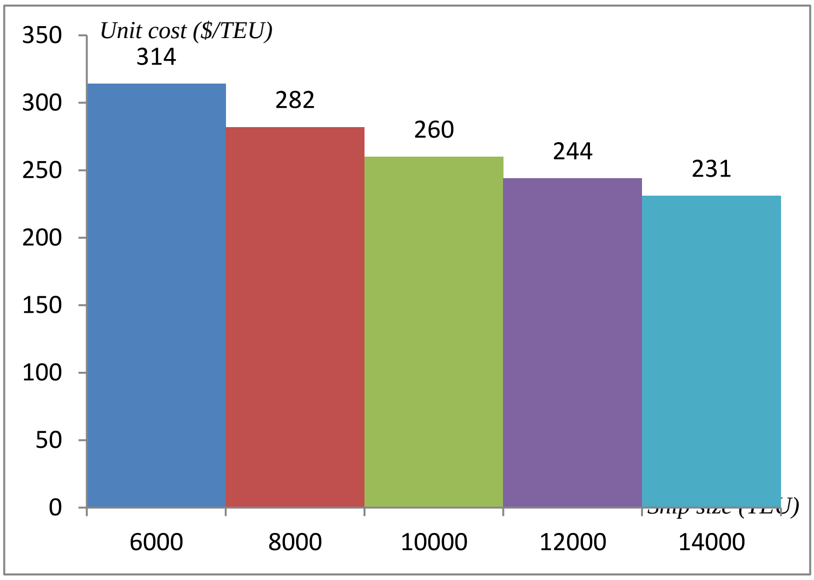

Figure 1 Minimal unit cost of different size of container ships
Source: Author´s elaboration with data from Veldman 2009

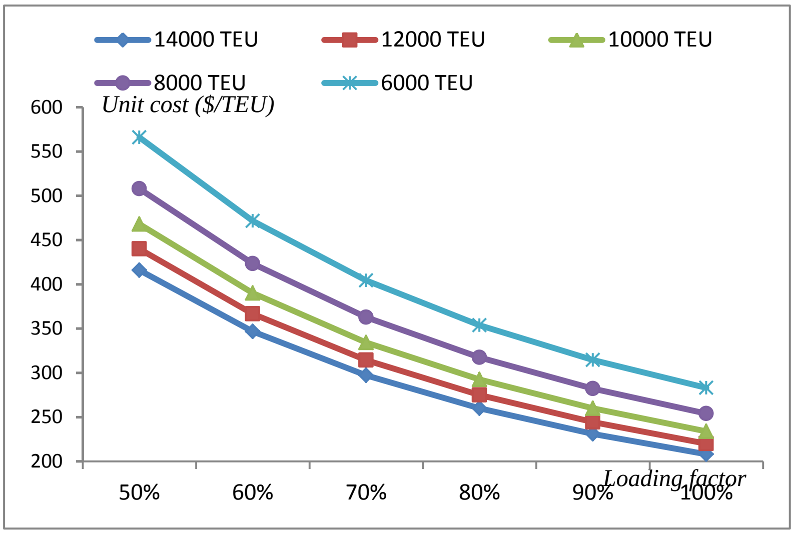

Figure 2 Unit cost with changes of loading factor
Source: Authors' own composition

In the above mentioned Figure 1 and Figure 2, the y-axis denotes unit cost ($/TEU) while the x-axis denotes ship size in Figure 1 and loading factor in Figure 2, respectively. Figure 1 shows that $f(q)$ is a segment function composed by a series of sub-functions, which covers a broad area of q. In contrast, $g(q)$ is a continuous concave function with a finite area relating to a certain ship size s_i. However, both $f(q)$ and $g(q)$ have the characteristic of sub-additivity as shown below:

$$f(q_i + q_j) \leq f(q_i) + f(q_j)$$

$$g(q_i + q_j) \leq g(q_i) + g(q_j) \quad s_i \leq q_i, q_j \leq s_{i+1}; \quad s_i \leq q_i + q_j \leq s_{i+1}$$

Sub-additivity is an important concept in game theory. Normally, a cost saving strategy must be supported by some stable solutions if its characteristic function is sub-additive. However, the cost function of pooling vessel strategy, which is expressed by $h(q)$, is neither $f(q)$ nor $g(q)$ but $f(q)\cdot g(q)$. It means that when q is smaller than the ship size s_i, the unit cost diminishes with the increase of q. However, if carriers pool vessels, the weekly demand q has a high possibility to exceed supply, i.e. s_i, then pooling a larger ship of s_{i+1} is obviously more realistic, with an assumption in this paper that each increment of ship size is 2,000 TEUs. The unit cost probably jumps to a higher level with a lower loading factor though the fully-loading unit cost gets decreased like $c(s_{i+1}) \leq c(s_i)$. The above mentioned cost function of pooling vessel can be seen in Figure 3.

In Figure 3, the optimal unit cost ($h(q)$) by pooling larger vessel is marked with shadows. Different curves present unit costs of given ship sizes. Especially, in case there are two carriers i, j who are operating individually, even if $s_i \leq q_i + q_j \leq s_{i+n}$, they will deploy two s_i sized ship ($q_i \leq s_i$ and $q_j \leq s_i$) separately. Then the cost function is shown as the upper curve of 6,000 TEU (there are two curves of 6,000 TEU ship in this figure) in Figure 3.

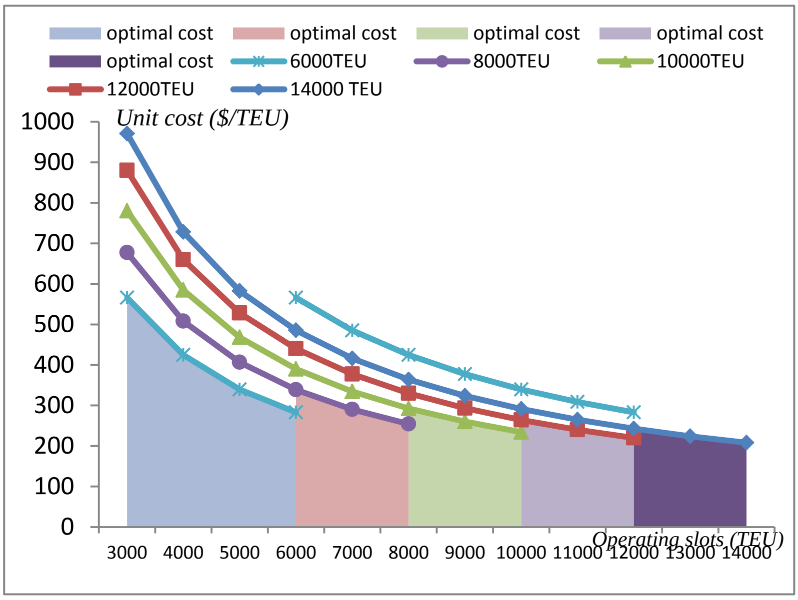

Figure 3 Optimal unit cost with vessel pooling
Source: Authors' own composition

Based on the above discussion, the unit cost of individual player in an alliance is

$$h(q_i) = \begin{cases} c(s_1)s_1/q_i & q_i \le s_1 \\ \quad \ldots & \\ c(s_i)m(s_i)s_i/\sum q_i & q_i \le s_i,\ s_{n-1} \le \sum q_i \le s_n \end{cases} \qquad n = 1,2,3 \ldots$$

Collective unit cost of the grand alliance

$$h(Q) = \begin{cases} c(s_1)s_i/Q & Q \le s_1 \\ \quad \ldots & \\ c(s_n)s_n/Q & s_{n-1} \le Q \le s_n \end{cases} \qquad Q = \sum q_i,\ \ n = 1,2,3 \ldots$$

Since this form of cooperation is only valid over a specific period of time, we suppose that this cost function is mainly for consideration of short-term market and will rarely bring impact to long-term market.

4. Core in cooperative game theory

Compare to non-cooperative game, a cooperation game aims to solve problem when a group of decision-makers decide to take on a project together with tight binding agreements for achieving their joint objectives such as increasing total revenues (profit maximization) or decreasing total costs" (Song and Panayides, 2002). Generally speaking, cooperative game theory includes five pivotal features (Zagare, 1984)., which are listed as follows: 1) A player can be either an individual or a group of individuals, playing a role as a decision-making unit; 2) All the decisions given by the players produce an outcome; 3) The options available to players to bring about particular outcomes are called strategies; 4) Strategies are linked to outcomes by a mathematical function of a characteristic function; 5) Information types of involved players and their options under coordination strategies. A shipping alliance which applys vessel pooling strategy also comprises various players, different combinations of coalitions, particular players' strategies and outcomes. Table 1 shows segments of a cooperative game in a liner shipping alliance of this paper.

Table 1 Segments of a cooperative game in a liner shipping alliance

Cooperative game	Liner shipping alliance
Player	Liner shipping carriers
Coalition	Every possible combination of involved players, where carriers are bound by contracts
Strategy	Pooling mega-ships on a certain route to provide weekly service for all the alliance members instead of operating individually.
Outcome	Mainly reduce cost in this paper, but it is also helpful to afford investment, reduce exposure to risk, extract bargaining power, realize economies of scale but keep independence
Characteristic function	Carrier's cost function before cooperation, coalition's cost function after cooperation, or the difference of outcomes between individual service and collective service

Source: Adapted from Song and Panayides (2002)

The mechanisms of a cooperative game can be simply expressed that the players are assumed to choose which coalitions to form based on their estimations of the way the payment will be divided among coalition members. Figure 4 shows the relationship among the components in a cooperative game corresponding to table 1.

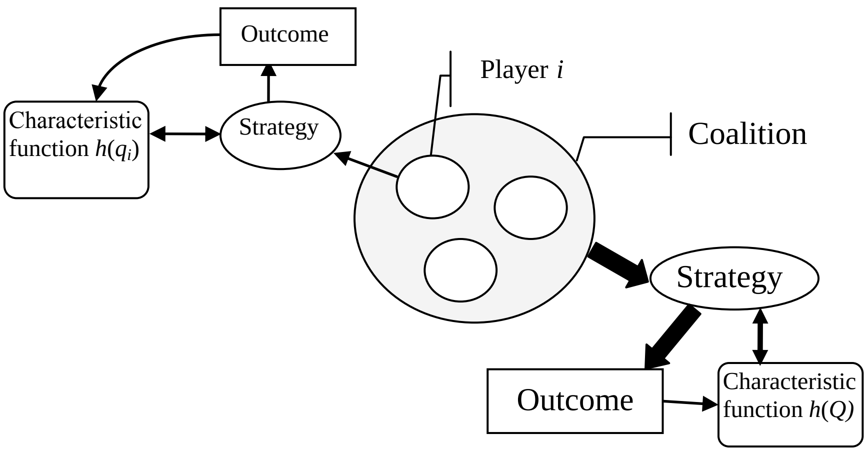

Figure 4 A brief relationship in a cooperative game
Source: Authors' own composition

In cooperative game theory, core is normally used to evaluate the alliance´s stability with a set of imputations, which is an n-dimensional vector of payments to the participants of a *n*-player game. An imputation is said to be in the core when there is no group within the economy who could be better off by trading amongst itself (Button, 2003, p.7). In other words, the method for estimating cooperative costs is based on two preconditions: the wellknown profitability condition which means cooperation should bring profit, and a new precondition, which postulates that the split of a cooperative profit is in its core, i.e., the core of cooperation is non-empty. In that sense, "the non-empty core preconditions not only helps to estimate cooperative costs and to explain why profitable cooperation might not be formed, but also provides an understanding of possible future breakups of completed cooperation. Besides, it sheds light on both understanding the stylized fact that cooperation is likely to occur in markets plagued by excess capacities and explaining the finding that industries for lumpy goods will have an empty core when demand is low." (Zhao, 2009, p.9)

The following section discusses empty core in liner shipping alliance based on the above mentioned first precondition-profitability.

5. Empty core in the liner shipping market

As for inland haulage and air transportation, the unit capacities of a truck and an airplane are insignificant with comparison to the entire market demand. But this is not true for liner shipping service as the capacity of a single container ship is too large to be ignored. Hence, the marginal cost can be regarded as continuous in land and air transport but a serious sub-function in shipping market with increase of operating slots. In addition, the fixed costs for vessels are normally very high and it is cost consuming to leave the ship idle. As a result, the carrier's supply curve is discontinued at the price where it equals to a minimum average cost. On the other hand, liner industry is characterized by 'lumpy transportation', identical commodities and wide variability in demand. Variability in demand always induces to the imbalance and instability of demand and supply.

In this case, we assume that there exists three identical companies, and each of them has one 6,000 TEU vessel. Figure 5 shows two demand curves and three cost functions corresponding to different numbers (1, 2, 3) of ships, which are operated by three carriers (A, B, C) in the market, respectively.

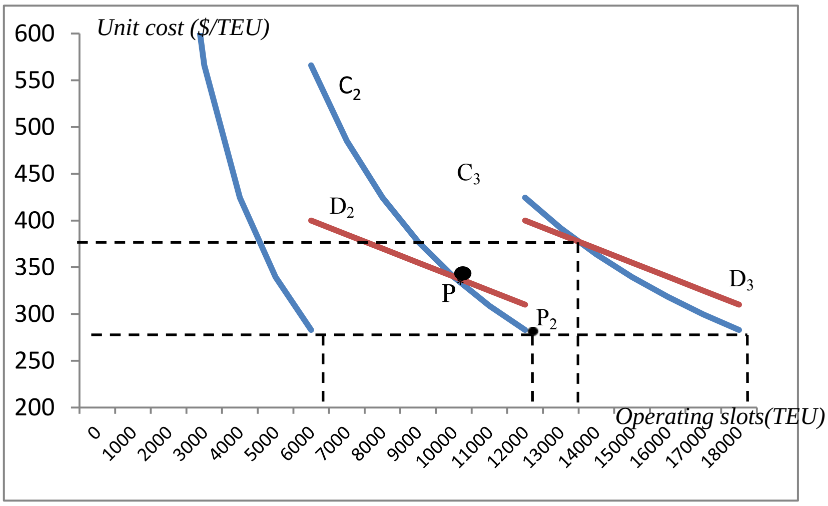

Figure 5 Core's condition of shipping liner market
Source: Adapted from Sjostrom (1989)

Point P* is the intersection of assumed demand curve D_2 and cost function C_2 which presents the unit cost in the case that two 6000 TEU ships deployed in the market by two companies simultaneously. The area to the left of this point indicates that the marginal cost fails to cover operating unit costs when carrier operates below capacity. The area to the right of this point however means it becomes profitable. If the market demand is a little more than 12000 TEU, but two carriers in the market offering 12,000 TEUs (two ships) at price P_2 which means fully loading, other firms would drop their offers because they could not cover costs with the remaining demand. However, supposing the market is free to enter and perfect competition, there probably will be a third carrier who is coming back to the market to fill up the exceeded demand, then competition drives the unit cost jump to be higher than the market price.

If the market has undifferentiated product (like container transport) and free entry like liner shipping market, there will be excess capacity than the demand, then at least one carrier must ship less containers than its capacity. To satisfy the shippers' demands, carriers would have to accept losses by running at lower loading factors or even keeping the ship idle to save the avoidable costs. The core is therefore empty because there is no profit in the market according to core´s condition 1 -- profitability. Even if the demand has some wide deviation from D_3 to D_2 or to a larger "D_4" (Demand increases, but keep price and demand elasticity same), there is no difference with empty core dilemma.

Result of Pirrong (1992, p.98) shows that "the divergence between minimum acceptable and maximum feasible surplus does not systematically decline even in large markets with lumpy commodity." When there are discontinuities in marginal costs, one cannot expect the market size to mitigate the severity of empty core problems. Excess capacity occurs periodically due to variations in demand and the core is periodically empty.

Consequently, the following issues are derived from the above mentioned discussion: 1) ways to relax conditions of empty core and 2) effects of using relevant ways to relax conditions.

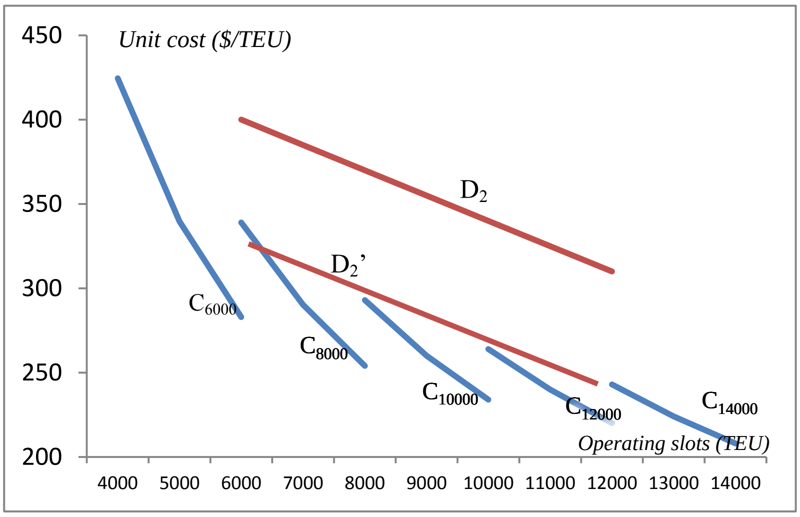

Figure 6 Average cost function of cooperative liner alliance
Source: Authors' own composition

Figure 6 shows the cost function with regards to different size vessels (6,000 TEU, 8,000 TEU, 10,000 TEU, 12,000 TEU, 14,000 TEU) of pooling ships, which are operated by liner carriers collectively. Then, still referring to the same demand curve of D_2 in Figure 5, it is obvious that the alliance can earn positive profits from new cost functions and avoid the periodically empty-core in such condition of demand. However, it does not mean that the empty core will be avoided at all. If the demand curve shifts down from D_2 to D_2', the empty-core will appear again in the market. Therefore, the strategy of cooperation only can relax empty-core condition instead of completely avoiding it.

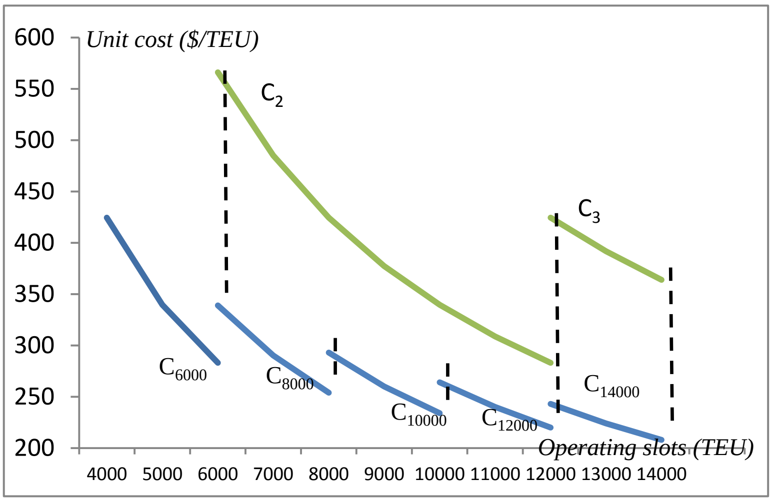

Figure 7 Average cost function of competitive and cooperative market
Source: Authors' own composition

Figure 7 shows the contrast of two cost functions. Some interesting result can be observed. Firstly, the periods that have discontinued are shortened with the cooperative cost function, which means, it is flexible to respond to market changes by strategy of pooling vessel. Secondly, the difference for periods changing is also lessened, which means, it is less risky for increasing shipping capacities than deploying one more new ship. This is due to the fact that liner carriers share fix costs and variable costs by sharing their vessels.

The intervals of different profits are now to be observed from another point of view. For a competitive situation and if the market is symmetrical, the cost saving is equal to market price minus total operating unit costs of all carriers involved. For individual carriers, related market profit in competition can be calculated as

$$P - x_c(\sum s_i)/\mathrm{Q}$$

For an alliance, collective market profit from cooperation is

$$P - x_c(\mathrm{S})/\mathrm{Q}$$

The assumed demand curve D_2 provides the *P*, and Figure 8 shows two different curves between expected price and two cost functions.

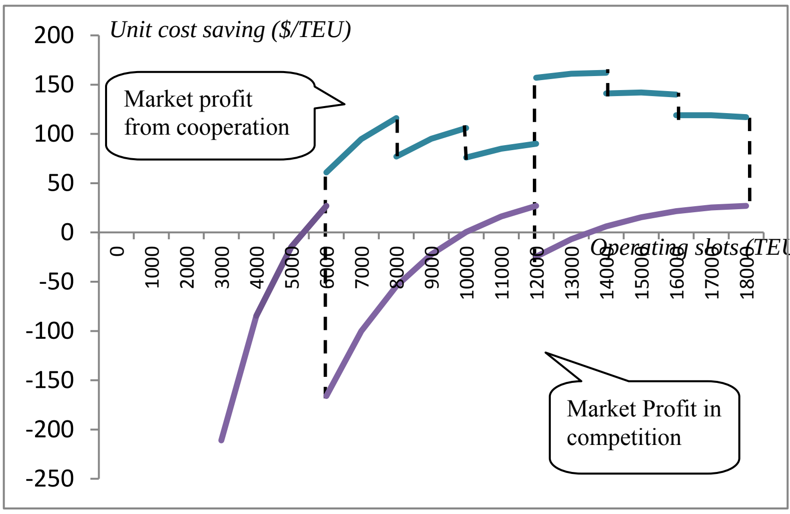

Figure 8 Change of unit profit of competition and cooperation
Source: Authors' own composition

As for the case of competition, when the ship size is fixed, more demand mean more carriers, and more possibility of profitability even if the market profit is sometimes minus, that is, periodically empty core. With more carriers entering the market, the increasing trend of marginal profit slows down. That is because new members share the market risk but at the same time they share the market profit as well.

As for the case of cooperation, the intervals as well as the jumping profit difference is shorter, and the increase of marginal cost remains more gently than the competition case. It shows that the alliance is more profitable, more flexible to cope with empty core and it is less sensitive to the changing demand.

However, the profitability brought by cooperation is not enough for its stability. As we mentioned before, a stable alliance not only relies on profitability, but also relies on the fact that alliance member can get a better payoff in a rational distribution designed by the core. The following section discusses empty core in liner shipping alliance based on the above mentioned second precondition - effects of carriers in the liner shipping alliance.

6. Empty core in the liner alliance

In order to investigate the logic of the non-empty core precondition, it is supposed that the core of a cooperative coalition (which coincides with the core of the market) is empty. For each proposed allocation plan of cooperative profits (i.e., a cooperative proposal), empty core implies the existence of a potential coalition whose members could guarantee more profits than those provided by the proposal. Based on profit-seeking behavior, it would be unreasonable for the members of this potential coalition to accept the proposal, because they would receive less than their worst profits if they did (Zhao, 2009, pp.374-375). Song and Panayides (2002) developed an example of two scenarios to illustrate the situation. There are several coalitions comprising all of or any of three liner carriers, i.e., L1, L2, L3, taking into account the following two scenarios:

> **Scenario 1** If L1 will obtain more revenue by adopting the "Go alone" policy instead of staying in the alliance, this carrier will surely leave the alliance.
>
> **Scenario 2** If L1 and L2 can obtain no less than those revenues obtained in a sub-coalition comprising of L1 and L2, L3 will be discarded from the three-person coalition and L1 and L2 will surely reconstruct a new coalition.

Based on that, even the deficit could be avoided by forming alliance among liner carriers. The alliance might be still in an unstable situation. Suppose a perfect competitive niche-market composed by three liner carriers. Each carrier operates one vessel and has a market share of q_i, the ship sizes are all s_i and $s_i \geq q_i$, and each increment of ship size is Δs.

Here, if there are still three carriers L1, L2, L3, $s_1 = s_2 = s_3$ = 4,000 TEU, $q_1 = q_2$ = 3,100 TEUs, q_3 = 2,600 TEUs. Δs=2,000 TEUs (ship size can be upgraded to with 4,000+2,000n TEUs). Then, even the grand coalition (8,800 TEUs by deploying 10,000 TEU ship) is more profitable than operating individually, and it probably is not stable since a sub-coalition {L1, L3} seems to have a lower unit cost (5,700 TEUs by deploying 6,000 TEU) based on the cost function developed in Section 3.

To show the stable imputations in core, we need to explain the core´s second pre-conditions mathematically before. Suppose that the market price is stable at p and the alliance is profitable, $p \geq h(Q)$. $h(Q)$ is the unit cost of alliance. It should be noted that in this case, the sub-additivity ($h(S \cup T) \leq h(S) + h(T)$, if S, T are sub-coalition and $S \cap T = \emptyset$) of the whole cost function cannot be pre-judged because of the discontinued of it. Here, supposing R is a set of coalition structures β_i which are defined for a coalition S={1,2,…, n } as,

$$R=\{\beta_1, \beta_2, \ldots \beta_m\},$$

$$\beta_i=\{B_{i1}, B_{i2}, \ldots. B_{im}\} \quad B_{i1} \cup B_{i2} \cup \ldots \cup B_{im} = S$$

Where, B_{ip} is a sub-coalition which could be an individual or a combination of individuals, p = 1,2,…, m. If $p \neq q$, $B_{ip} \cap B_{iq} = \emptyset$.

Heuristically, a coalition structure represents the 'breaking up' of set N into mutually disjoint sub-coalitions. Suppose such a structure is reached. It is assumed that each of the coalitions B_{ip} cost $h(B_{ip})$.

Each coalition structures β_i presents an imputation, which is stable in the sense that no coalition has both the power and inclination to change it. However, the grand coalition is encouraged in this case, suppose its unit cost configuration is $X=(x_1, x_2, \ldots x_n,)$. To reach this goal, an obvious requirement will be that of individual rationality

$$x_i \leq h(i) \qquad for\ all\ x_i \in X$$

A further possible requirement may be that no coalition structure β will form instead of the grand coalition if one of its sub-coalitions can cost less than the cost vector x_i gives it. Thus

$$\sum_{i \epsilon s} x_i \leq min_{\beta_i \in R} \left\{ \sum_{\beta_{ip} \in S} h(\beta_{ip}) \right\} \quad x_i \in X$$

For example, on the assumption that a three person game of N= {1, 2, 3}, the individual and collective rationality of this game should satisfy:

$$x_1 + x_2 + x_3 \leq c(1234)$$
$$x_1 \leq c(1), x_2 \leq c(2), x_3 \leq c(3)$$
$$x_1 + x_2 \leq min\{c(12), c(1) + c(2)\}$$
$$x_1 + x_3 \leq min\{c(13), c(1) + c(3)\}$$
$$x_2 + x_3 \leq min\{c(23), c(2) + c(3)\}$$

The explanation of the allocation's profitability in liner shipping alliance is briefly demonstrated below. As aforementioned, liner carriers are not willing to lose control over their individual sales and marketing activities by pooling vessels. In general, before entering into an alliance, a contract will be enacted by potential alliance members, prescribing the pooling transport capacities for every member carrier. Conventionally, this is decided by their current market share, which means their variable cost after cooperation relating to their previous transport capability in the market. In another word, it is basically equal to their variable cost between pre-cooperation and post-cooperation. On the other hand, it is also pointed out that many large ships have already on their order book. Therefore, we assume that the fixed costs of vessels do not change according to their usage, which means that those fixed costs are not related to the coming cooperative strategies. As a result, fixed costs can be viewed as sunk costs in this case. In this paper, we consequently consider the difference between carrier's unit cost pre-alliance and post-alliance.

Then, we presume that there is a three-person liner alliance game of *N*= {*i*, *j*, *k*}, the core's condition of this game is:

$$x_i = x_j = x_k = h(q_i + q_j + q_k)$$
$$x_i \leq min(\forall h(q_i), \forall h(q_i + q_j))$$

If we suppose that $c(s_i)$ is the minimum cost per individual unit. $c(s_{ij})$ is a unit cost of the sub-coalition composed by carriers *i* and *j*. $c(s_{ijk})$ is a unit cost of the grand alliance of carriers *i*, *j* and *k*. Based on our cost functions shown in Section 3, this gives

$$c(s_i) \cdot s_i/(q_i + q_j + q_k) \leq c(s_j)s_j/q_i$$

And $$c(s_{ijk}) \cdot s_{ijk}/(q_i + q_j + q_k) \leq c(s_{ij})s_{ij}/(q_i + q_j)$$

The equation means that when the marginal revenue of operating slots for the alliance is bigger than the marginal cost for updating ship size, the core's condition is to be kept.

From the perspective of sequential games, we construct formation process of a three–carrier-shipping alliance as follows: two carriers *i* and *j* first initiate an alliance, later on, the third carrier *k* enters and thus they together forms a three-carrier-alliance. If we also assume that a six degree size of ship (with an increment of 2,000 TEUs) was available for the alliance, A flow chart of three carriers´ alliance formation in case that the operating slots of carrier *i* are less than 8,000 TEUs can be calculated and drawn as Figure 9.

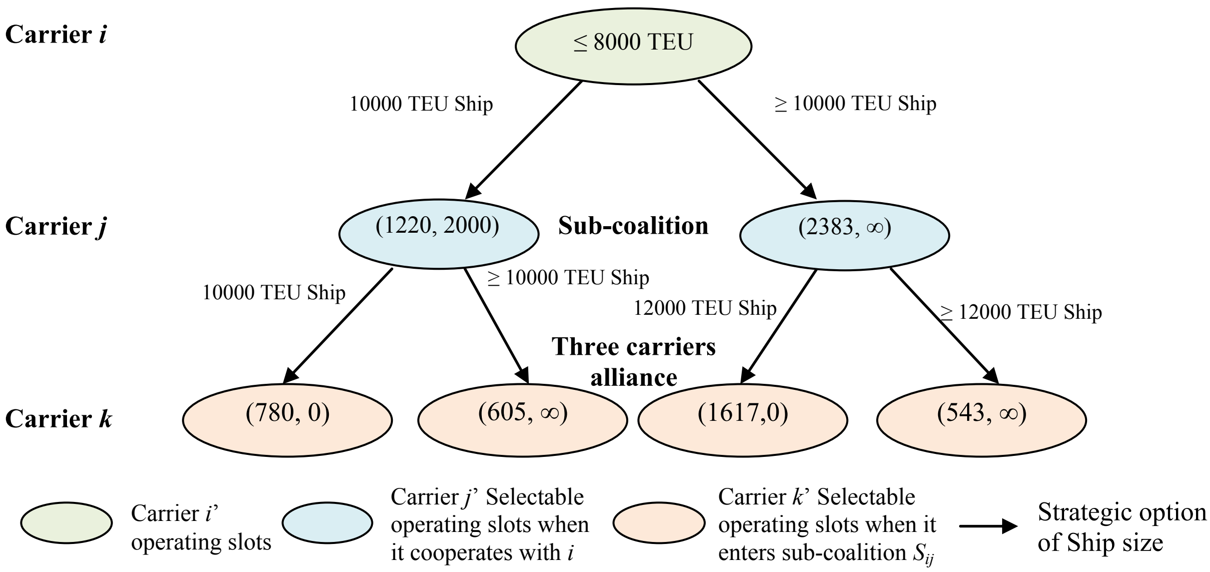

Figure 9 Stable intervals of a three-carrier-alliance
Source: Authors' own composition

If we regard the safe strategic operating slots interval of member companies as stable imputations, in this figure, the core is stable when operating slots of carrier *j*, which cooperate with *i* in succession, is from 1,220 TEUs to 2,000 TEUs or more than 2,383 TEUs. The two operating slot intervals correspond to strategies of deploying 10,000 TEU ship or even larger ship – with more than 10,000 TEU respectively. With the third carrier, carrier *k*´s enrollment, there are four possible safe strategic operating slot intervals – (780, 0), (∞, 605), (1,617, 0) and (∞, 543) for *k* relating to either changing ship size or not changing in accordance to two deploying ship size of sub–coalition s_{ij}.

The followings also deserve discussion regarding Figure 9.

Firstly, although it shows carrier *k* has more options than carrier *j*, there is no actual advantage relating to the order of alignment. Because the safe intervals of carrier *i* and carrier *j* are incomparable, carrier *k*´s operating slot intervals are decided by *j*´s operating slots. The stability of grand alliance is independent of the order of alignment and only depends on the cost function.

Secondly, assuming the minimal increment of changing ship is only 2,000 TEUs, then the most reasonable choice of the three carriers´ alliance is to deploy a ship more than 12,000 TEUs. Then both carrier *i* and carrier *j* have the broadest options for their operating slots. Considering the narrow operating slot intervals of other options, it is advisable to adopt a strategy of slots chartering or slots exchanging agreement than forming alliance, that is, if no mega-ship available.

Thirdly, there are some overlaps among (780, 0) and (605, ∞), (1617,0) and (543, ∞), where the core is non-empty which means that the alliance maintains stable either by keeping the previous ship size or by deploying a larger ship. However, since it is general practice of liner carriers to always save some slots in order to meet sudden demand fluctuations, it is advisable to deploy ship with larger size when facing these overlaps.

The stability of different ship sizes of three person games can be seen as in the following Table 2

Table 2 Safe operating slot interval of three liners´ alliance

Q (TEU)	≤ 6000	≤ 8000	≤ 10000	≤ 12000	≤ 14000	≤ 16000
q_j/Interval1	(1185, 2000)	(1220, 2000)	(1262, 2000)	(1236, 2000)	(1385, 2000)	(1370, 2000)
q_k/ zone 1	(815,0)	(780,0)	(738,0)	(764,0)	(615,0)	(630,0)
q_k/ zonel 2	(608, ∞)	(605, ∞)	(634, ∞)	(537, ∞)	(575, ∞)	(587, ∞)
Overlap1	207	176	105	209	49	62
q_j/Interval2	(2280, ∞)	(2383, ∞)	(2438, ∞)	(2557, ∞)	(2675, ∞)	(2649, ∞)
q_k/ zone 3	(1720, 0)	(1617, 0)	(1562, 0)	(1443, 0)	(1325, 0)	(1351, 0)
q_k/ zone 4	---------	(543, , ∞)	(583, ∞)	(504, ∞)	(544, ∞)	(564, ∞)
Overlap2	---------	1074	997	938	780	787

Source: Authors' own composition

In this case, *Q* denotes carrier *i*'s operating slots. Interval 1 and interval 2 are corresponding safe containers intervals of carrier *j* to keep sub-coalition s_{ij} absolutely stable. The q_k/zone1,2,3,4 shows carrier *k*'s consequent container intervals to keep the possible non-empty core of different cases for the three carriers' alliance following the carrier *j* allying with carrier *i*.

In addition, we show the trend of the assumed third carrier *k*'s cargo intervals by Figure 10, whereby it is possible to keep core non-empty in a three-player alliance game when ship size get gradually increased as shown in Table 2.

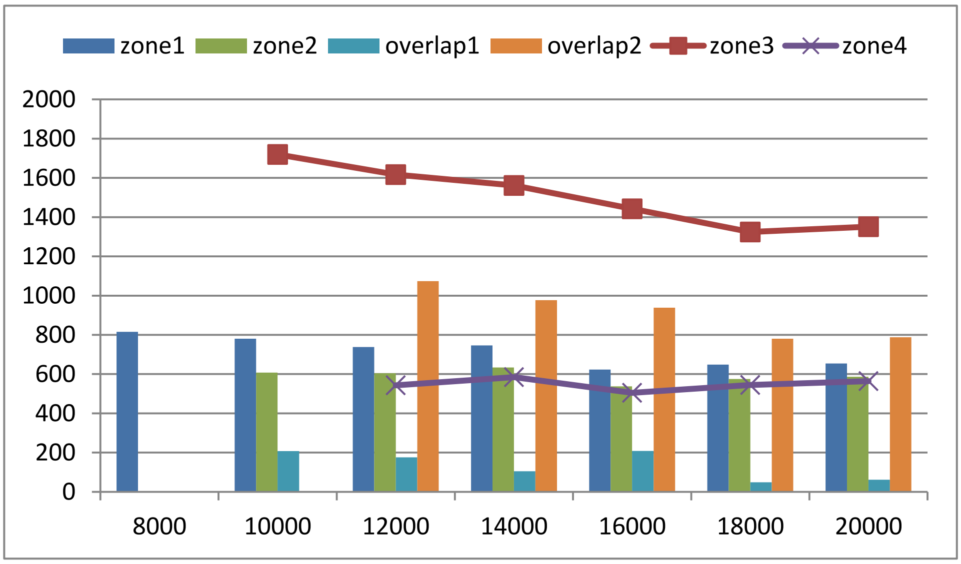

Figure 10 Stable interval and overlap of the third carrier k
Source: Authors' own composition

In Figure 10, all zones decline with the increase of ship size but there are different indications. It appears to be increase of safe operating slot intervals with a decline of zone 2 and 4 than a decrease of safe operating slot interval with a decline of zone 1 and 3 when larger ships are deployed. In short, the overall trend of change of zones is a little increasing but negligible when the magnitude of the ship size and increment of 2,000 TEUs are taken into consideration. This means the advantage of employing larger vessels to overcome empty core becomes more significant with increasing ship sizes. This is not, however, conclusive. In contrast, the trend towards overlapping intervals is decreasing significantly. This demonstrates that the possible safe 'buffer' for changing larger size ships becomes narrow. In other words, price of sharing fixed cost becomes larger as ship size increases.

7. Conclusions and further research

International shipping market can be recognized as an unstable market to which more and more carriers adopted shipping alliance as their strategies to ensure their operations and protect themselves from over competition. This is particularly true with the increasing ship size where alliances have the advantage to guarantee the loading factors and reduce shipping cost. However joining alliances or employing bigger ships can only, to some degree, help to avoid the uncertainties but is not always the perfect solution to the ever-changing market.

Core theory is widely considered as a useful tool of game theory and it is also suitable to investigate the stability of shipping alliance. To the authors' best knowledge, this paper is the first attempt to take the mega ships into consideration and apply core theory to investigate the influence of mega ships to the stability of shipping alliances.

Based on the core theory, two standards were mentioned and applied in the analysis, which are profitability and reasonable allocation. The former is proved by introducing a cost function for liner shipping alliances, which adopts the strategy of pooling mega ships. Then the periodically empty core of the shipping market caused by unprofitability and the influence on it of this strategy of alliance was explained. As a matter of fact, this strategy is adopted by an alliance in the hope of reducing unit costs of its member liner carriers. However, although such a strategy can improve the stability of the alliance to some degree, it will not change the empty core situation that appears periodically.

To further explicitly describe the influence of this strategy on the stability of alliance, the profit allocation principles are discussed by an illustrative case study. Some conclusions are drawn based on the above mentioned discussion. For example, order of alignment will not affect alliance. In addition, it may also be appropriate to pool mega ship, or to use slots chartering, or to apply slots exchanging strategy when mega ship is not available. However, taking advantage of deploying larger vessels to overcome empty core becomes more popular in practice.

Hopefully, this study will enhance understanding of the turbulence of shipping markets and decision-making behavior in the liner shipping sector.

Future research may include: 1) more factors regarding to strategy of deploying mega-ship like change of sea lane, reduction of frequency and so on. 2) other forms of cooperation in the liner shipping industry together with certain conditions of stability; 3) expansion of the research to cover studies of alliances involving more than the three players examined here. 4) a practical case study.

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