https://doi.org/10.1016/j.tre.2021.102287

Dr. Tsz Leung YIP

Department of Logistics and Maritime Studies,

The Hong Kong Polytechnic University

Hung Hom, Kowloon, Hong Kong

11th January 2021

Transportation Research Part E: Logistics and Transportation Review

Carrier-shipper risk management and coordination in the presence of spot freight market

Kelly Yujie WANG (ORCID ID: orcid.org/0000-0001-5707-8501)

Affiliation: 1. Business School, Guangxi University; 2. Guangxi Development Strategy Research Institute

Postal Address: Room 332, Building of Business School, Guangxi University, Nanning 530004, Guangxi, P.R. China.

Telephone: +86 15978192856 *Email*: wyj.kelly@connect.polyu.hk

Yuan WEN

Affiliation: China Development Bank

Postal Address: No. 87 of Luban Road, Nanning, Guangxi, P. R. China

Telephone: +86 13978896281 *Email:* kenny.wen@qq.com

Tsz Leung YIP (ORCID ID:**orcid.org/0000-0002-7277-7666) (*Corresponding author)**

Affiliation: Department of Logistics and Maritime Studies, The Hong Kong Polytechnic University

Postal Address: CD401A, CMA Building, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Telephone: +852 2766 4631 *Email:* t.l.yip@polyu.edu.hk

Zuojun FAN

Affiliation: International College, Guangxi University

Postal Address: International College, Guangxi University, Nanning 530004, Guangxi, P.R. China.

Telephone: +86 18878701208 *Email:* 18878701208@139.com

Declarations of interest: none

Carrier-shipper risk management and coordination in the presence of spot freight market

ABSTRACT

The spot freight market in the liner shipping industry has developed significantly in recent years and interplays with the long-term contract between carriers and shippers. Under this background, this paper presents a Stackelberg games model by taking into account both the carrier's long-term decision (on freight rate) as well as the shipper's long-term decision (on shipment capacity procurement amount) and spot market supplementary procurement decision. The shipper is risk-averse facing market uncertainty. Three basic shipping structures are considered: procuring only from carrier with long-term contract, only from spot market, and from both of these channels. We show that dual channels play different roles for the shipper. Although the spot market is not favourable for the carrier, it increases both the shipper's utility and the carrier-shipper's overall performance. Risk-aversion reduces the shipment capacity procurement amount, which protects the shipper but jeopardizes the carrier's and the carrier-shipper's overall performance. Fluctuation of market demand and spot freight rate have different (sometimes even opposite) impacts on the carrier and the shipper. Correlation of market demand and spot freight rate brings more uncertainty for the shipper but grants more leverage for the carrier. Coordination initiated by the carrier improves the carrier-shipper's overall performance substantially, but full coordination is not feasible owing to the shipper's aversion to risk. Quantity-discount rather than two-part tariff contract works.

Key words: liner shipping; freight rate; spot market; risk-aversion; Stackelberg games; coordination

1. Introduction

Under the Belt and Road Initiative (BRI), ocean shipping continues to play the most significant role in international transportation (Yang et al., 2018). Although maritime transportation has been well studied in terms of capacity management, pricing, and shipping supply chain coordination, how to balance performance efficiency with risk management is still not fully understood (Fransoo and Lee, 2013). The major market players in ocean shipping are carriers and shippers. Carriers, such as Maersk, Shell and OOCL, own the vessels with shipping capacity and provide logistics services through containers or bulk ships. Shippers, such as Wal-mart, Cargill, BHP and KOCH, transport products for manufacturers, suppliers, and exporters with services from carriers. As most of the countries along the BRI are developing or newly industrialized countries where market demand is more volatile and freight rate shows higher fluctuation, shippers and carriers are presented with greater challenges in maritime operation and risk management. The outbreak of COVID-19 pandemic brings about more turbulence on the global maritime market, and the importance of carrier-shipper risk management and collaboration is further highlighted (Michail and Melas, 2020).

In ocean shipping practice, there are two types of source for shippers to procure freight capacity. The first type is to sign a long-term contract with a carrier at a fixed price at a time when market demand and the freight rate in the spot market are still uncertain. The second type is to procure the shipment capacity in the spot freight market when the freight rate is realized. With the participation of freight forwarders and the development of the spot freight market, dual-channel sourcing of shipment capacity has become increasingly popular in maritime shipping. Therefore, there is a need to study the roles of the two channels and the way to coordinate them.

With the continuing development of the freight shipping industry, as well as the higher requirements demanded by the global supply chain, risk management has become an increasingly important issue for the shipping industry. Carriers are normally multinational corporations, meaning that they have various measures to counter risk, whereas shippers are focused on one specific industry and are less able to diversify risk. Therefore, in this paper, we take the risk-aversion of the shipper into account.

A typical case is as follows. Suppose that a tyre factory (shipper) plans to deliver tyres to the overseas market. Although the market demand and the shipping spot freight rate are both random, the tyre factory has the opportunity to enter into a long-term contract with a carrier. The carrier offers the unit freight rate for shipping the tyres, and the tyre factory decides the shipment capacity procurement amount accordingly. Three months later, if the market demand is realized as higher than the capacity, the factory will replenish shipment capacity from the spot market with the realized spot freight rate. If the market demand is realized as lower than the capacity, the carrier will charge cancelation penalty from the shipper, with the carrier reselling the excess capacity in the spot market. On the basis of this typical case, we attempt to address the following research questions: (i) What is the shipment capacity procurement strategy for the tyre factory (shipper) faced with dual channels, namely, long-term contract and spot market? (ii) How should the carrier conduct its pricing strategy, especially when facing potential competition from spot market? (iii) How does risk-aversion of the shipper affect the shipper's decision and the carrier's reaction? (iv) How to coordinate the carrier and the shipper facing risks from market demand and spot freight rate, so as to improve their overall performance? (v) How does the correlation between market demand and spot freight rate affect decision-making for the carrier and the shipper?

To better address the research questions, three cases of the shipping structures are summarized (as shown in Table 1) and studied.

Table 1
Cases of shipping structures.

Case	Description
LC	The shipper only procures freight capacity with long-term contract from the carrier.
SF	The shipper only procures freight capacity in the spot freight market.
DC	The shipper procures freight capacity from both the carrier with long-term contract and from spot freight market, namely dual-channel procurement.

The basic model is formulated whereby the shipper only procures freight capacity with long-term contract from the carrier (LC case). Two sub-cases are investigated: (i) the carrier offers freight rate contract without coordination; (ii) the carrier offers a designed quantity-discount contract to the shipper so that both parties can be better off. When it comes to the SF case, there is no sub-case because only the shipper makes decision of shipment capacity procurement amount. Similar to the LC case, two sub-cases, namely uncoordinated and coordinated, are considered in the DC case.

By analytical investigation and numerical study, this paper obtains the following major insights: (i) the dual channels play different roles for the shipper; the presence of spot market brings about competition for the carrier, which is not favourable for the carrier but is good for the carrier-shipper's overall performance; (ii) risk-aversion reduces the shipment capacity procurement amount of the shipper, which protects the shipper but jeopardizes the carrier's and the carrier-shipper's overall performances; (iii) the fluctuation of market demand and spot freight rate have different (sometimes even opposite) impacts on the carrier and the shipper; (iv) the correlation between market demand and spot freight rate brings greater fluctuations and uncertainties for the shipper but grants more leverage for the carrier; and (v) *coordination* can be achieved by a designed contract offered by the carrier, whereas *full coordination* cannot be achieved owing to the risk-aversion of the shipper; quantity-discount rather than two-part tariff contract works.

To the best of our knowledge, this paper is the first attempt to investigate carrier-shipper coordination and risk management issues arising from the ocean freight industry with demand and freight rate uncertainties. The main theoretical contributions are three-fold. First, we set up an analytical framework for risk management of carrier and shipper facing market demand and spot freight rate uncertainties. The model is readily extended to consider additional factors such as incomplete information, carriers' / shippers' competition and multi-period games. However, as they are not the scope of this study, we leave them for further research. Second, the framework of coordination (including definition, coordination contract design and optimization) in the presence of downside risk-aversion is developed, which can be applied to other transportation, logistics or supply chain scenarios. Last, this paper contributes to the research of double marginalization by showing effective mitigation under downside risk-aversion. Besides, there are two main empirical applications. First, the analysis and comparison of different shipping structures illustrate how to mitigate double marginalization under uncertainties, and improve carrier-shipper's overall performance in steps. Second, the different (sometimes even opposite) impacts of fluctuation and correlation of demand and spot freight rate on carrier and shipper imply different strategies of managing risk among the maritime parties.

The rest of the paper is organized as follows. The relevant literature is reviewed in section 2. Section 3 formulates the stylized model setting. Sections 4 to 6 study the optimal decisions of the different shipping structures. Section 7 provides a numerical study and parametric analysis, and section 8 concludes the paper.

2. Literature review

This paper primarily relates to research of liner shipping in global supply chains and BRI (Lee and Song, 2017; Yang et al., 2018). There were studies on carrier's revenue management through freight rate optimization (Wang et al., 2015), or shipper's outsourcing strategies for selecting carrier with lower freight rate (Joo et al., 2017). Two typical game theory models (Nash noncooperative and Stackelberg games) were discussed in transportation systems modelling by Fisk (1984). Many research studies based on game theory models were developed thereafter. To name a few, Wang et al. (2014) presented three game-theoretical models to analyze shipping competition between two carriers; Yang et al. (2019) considered the Stackelberg games that the shipper has private information regarding low-season demand and the carrier designs two-part tariff contracts that can improve carrier-shipper's overall performance. The model in this paper is based on Stackelberg games, which formulate leader-follower asynchronous games between carrier and shipper.

The vertical relation between upstream carrier and downstream shipper is also related to industrial economics, especially double marginalization as externality of such vertical relation (Spengler, 1950; Tirole, 1988). There were studies of double marginalization in the field of transportation and logistics, especially air transport (Zhang and Zhang, 2006; Zou et al., 2011; Zhang and Czerny, 2012; Gayle, 2013). Mitigation solutions to double marginalization normally includes vertical integration, franchise fee (two-part tariff), resale-price maintenance (RPM), horizontal competition, etc. As for liner shipping, some research investigated the vertical integration of carrier and terminal operator (2013), or the vertical integration of ocean and inland shipping lines (2018). The investigation of Fugate et al.(2009) indicated closer operational collaboration between carrier and shipper. Nevertheless, vertical integration between carrier and shipper is not common practice. Yang et al. (2019) designed a two-part tariff contract that carrier and shipper can be better off. This paper shows that two-part tariff contract, which is effective in risk-neutral scenarios, does not work if the shipper is risk-averse. A quantity-discount freight contract instead is designed to mitigate double marginalization in this situation.

Apart from carrier-shipper's vertical relation, spot freight market is another key concern of this paper. The current research in spot market and shipping finance focuses on factors impacting spot freight rate volatility (Kavussanos et al., 2004; Xu et al., 2011), methodologies of formulating or forecasting spot freight rate (Budak et al., 2017; Chen et al., 2017; Prochazka et al., 2019), and freight rate risk management (Alexandridis et al., 2018). Compared with the current research of this stream, we focus on analyzing the impact of spot market on the decisions and performances of carrier and shipper.

Long-term contract with the carrier and short-term replenishment from the spot market is an issue of dual-channel sourcing strategy. One kind of dual-channel sourcing is among competing carriers without considering spot market, which was investigated by Liu and Wang (2019) and Wang et al. (2020). The other kind of dual-channel sourcing considers spot market. For instance, Lee et al. (2015) examined the fractional price matching contract offered by the carrier to the shipper in the ocean freight service industry. The authors showed that by sharing some risk with the shipper, the carrier could receive higher demand from the shipper. In the presence of the spot market, Yang et al. (2017) designed a floating price contract for the carrier to offer to the shipper to address the issue of the shipper in the low season. Compared with Lee et al. (2015) and Yang et al. (2017), this paper provides comprehensive study of different shipping structures and considers downside risk management.

Maritime risk management has drawn much attention in recent research, including review and summarization of risk management framework (Chang et al., 2015; Choi et al., 2016; Choi, 2021), modelling of the pricing strategies of risk-averse competing ocean carriers (Zheng et al., 2017), and application of blockchain technology countering supply chain operations risk (Choi et al., 2019). Compared with this stream of research, this paper defines *coordination* and *full coordination* with a downside risk measure, develops feasible coordinating contract and shows reason why some other type of contracts is not workable.

Despite current research into the liner shipping collaboration and risk management, little has been done on the coordination and risk management in the presence of spot market and a comparison of different shipping structures, which is the theoretical contribution this paper is going to make.

3. Model formulation

We set up a stylized Stackelberg games model incorporating carrier's and shipper's decisions. The sequence of events is as follows (Fig. 1).

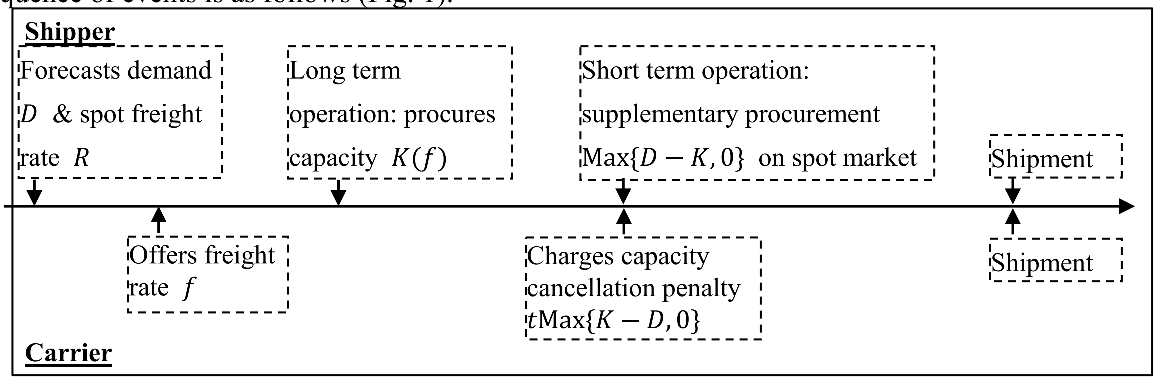

Fig. 1. Sequence of events.

The carrier, who has long-term relation with the shipper, offers a long-term contract with unit freight rate f to the shipper. For simplicity but without loss of generality, the unit shipping cost for the carrier is assumed to be a constant and exogenous value c. The shipper gains unit revenue p when it satisfies the market demand after completing the shipment.

Facing random demand D and spot freight rate R, the shipper places a shipment capacity procurement amount K to the carrier. Demand D has a cumulative distribution function (CDF) $H(\cdot)$ and a probability distribution function (PDF) $h(\cdot)$. We denote $\bar{H}(\cdot)=1-H(\cdot)$ as the tail distribution.

A few days before the shipping date, the market demand D is realized, and the shipper has a chance to make a supplementary shipment capacity procurement Max$\{D-K,0\}$ from the spot market with freight rate R. Suppose that $R=\alpha+\beta D+\gamma$ is positively correlated with market demand, where γ is the fluctuation of the spot freight rate independent of demand, with CDF $G(\cdot)$ and PDF $g(\cdot)$. $\gamma\in[\underline{\gamma},\infty)$, where $\underline{\gamma}$ is the lower bound of γ such that $R\geq 0$. α is the basic rate, and β is the coefficient of correlation between demand and spot freight rate. β should be positive because higher market demand should result in a higher spot freight rate.

When the spot freight market is available, the carrier allows capacity cancellation from the shipper subject to a unit penalty t. The penalty should cover the carrier's cost, so that $t\geq c$. The carrier sells out the excess capacity Max$\{K-D,0\}$ in the spot market with price σR, where $\sigma\in(0,1)$ represents the discount that captures commissions, transaction costs, and other handling fees. We assume that $\sigma E(R)\leq c$, which means that the expected revenue from reselling should be less than the unit cost of the carrier.

The carrier is assumed to be risk-neutral because it is usually larger, operates globally, and can diversify among different shippers. The shipper is assumed to be risk-averse because it is facing random market demand and spot freight rate. We consider a piecewise-linear utility function u_s as follows to describe the loss-aversion of the shipper, which has been widely used in Prospect Theory

(Kahneman and Tversky, 1979):

$$u_s = \begin{cases} \pi_s - \pi_0 \ , if\ \pi_s \geq \pi_0 \\ \theta(\pi_s - \pi_0), if\ \pi_s < \pi_0 \end{cases} \quad (1)$$

where π_s is the shipper's profit, π_0 is the reference profit level, and $\theta \geq 1$ is the coefficient of loss-aversion. Higher values of θ imply higher levels of loss-aversion. $\theta = 1$ means risk-neutral. Without loss of generality, the reference profit level is normalized to zero, that is, $\pi_0 = 0$.

The notations used in this paper are summarized in Table 2.

Table 2
Summary of notations.

Notation	Meaning
D	Random demand with CDF $H(x)$ and PDF $h(x)$.
R	Random spot freight rate. $R = \alpha + \beta D + \gamma$, where α is the basic rate, and β is the coefficient of correlation between demand and spot freight rate.
γ	Fluctuation of the spot freight rate independent of demand, with CDF $G(\cdot)$ and PDF $g(\cdot)$. $\gamma \in [\underline{\gamma}, \infty)$, where $\underline{\gamma}$ is the lower bound of γ such that $R \geq 0$.
c	Unit shipping cost for the carrier.
p	Unit revenue for the shipper.
t	Unit penalty charged by the carrier upon the cancellation of shipment by the shipper.
σ	Discount for the carrier to resell excess capacity in the spot market.
θ	Coefficient of loss-aversion of the shipper.
$\widetilde{(\cdot)}_c$	Denotes values of the carrier for LC Uncoordinated sub-case: $\widetilde{\Pi}_c$ is expected profit.
$\widetilde{(\cdot)}_s$	Denotes values of the shipper for LC Uncoordinated sub-case: $\widetilde{U}_s$ is expected utility; $\widetilde{\Pi}_s$ is expected profit; $\widetilde{L}_s$ is expected loss; $\tilde{\pi}_s$ is profit; $\tilde{u}_s$ is utility.
$\widetilde{(\cdot)}$	Denotes other values for LC Uncoordinated sub-case: $\widetilde{\omega}$ is threshold of demand making profit positive for the shipper; $\widetilde{K}^*$ is optimal shipment capacity procurement amount of the shipper; $\tilde{f}^*$ is optimal freight rate of the carrier; $\widetilde{K}_n$ is the shipper's optimal shipment capacity procurement amount if it is risk-neutral.
$\widetilde{(\cdot)}_o$	Denotes values for LC Coordinated sub-case: $\tilde{f}_o$ is optimal freight rate of the carrier; $\widetilde{K}_o$ is optimal shipment capacity procurement amount of the shipper.
$\widehat{(\cdot)}$	Denotes values for SF case: $\widehat{\Pi}_s$ is expected profit of the shipper; $\widehat{K}$ is shipment capacity procurement amount of the shipper.
$(\cdot)_c$	Denotes values of the carrier for DC Uncoordinated sub-case: Π_c is expected profit.
$(\cdot)_s$	Denotes values of the shipper for DC Uncoordinated sub-case: U_s is expected utility; Π_s is expected profit; L_s is expected loss; π_s is profit; u_s is utility.
$(\cdot)$	Denotes other values for DC Uncoordinated sub-case: ω is threshold of demand making profit positive for the shipper; K^* is optimal shipment capacity procurement amount of the shipper; f^* is optimal freight rate of the carrier; K_n is the shipper's optimal shipment capacity procurement amount if it is risk-neutral.
$(\cdot)_o$	Denotes values for DC Coordinated sub-case: f_o is optimal freight rate of the carrier; K_o is optimal shipment capacity procurement amount of the shipper.

4. The case considering only the long-term contract (LC case)

To explore the effect of the spot freight market on the decisions of carrier and shipper, we first analyze the case considering only the long-term contract between them. Owing to the lack of spot market, we assume that the carrier charges full cancellation penalty from the shipper.

4.1. Contracting without coordination

We first study the sub-case in which the carrier offers freight rate contract without considering coordination. The carrier's objective function is to maximize its expected profit by deciding the optimal freight rate f, that is, $\underset{f\geq c}{\text{Max}}\, \widetilde{\Pi}_c(f) = (f-c)K$. The carrier faces no market demand uncertainty, and gains higher profit with higher freight rate it charges or higher shipment capacity procurement amount the shipper places. The expected profit of the shipper is $\widetilde{\Pi}_s = pE\text{Min}\{K, D\} - fK$. The first term is expected revenue depending on the smaller value of expected demand or shipment capacity procurement amount, and the second term is cost of using the carrier's shipping service. The expected loss function and the utility function of the shipper are denoted as $\widetilde{L}_s$ and $\widetilde{U}_s$ respectively. Lemma 1 reveals the relations among $\widetilde{U}_s$, $\widetilde{\Pi}_s$ and $\widetilde{L}_s$.

Lemma 1: *In the LC case, the shipper's objective function is:*

$$\underset{K\geq 0}{\text{Max}}\, \widetilde{U}_s(K) = \widetilde{\Pi}_s + (\theta - 1)\widetilde{L}_s \tag{2}$$

where $\widetilde{L}_s = \int_0^{\widetilde{\omega}} (py - fK)h(y)dy$. $\widetilde{\omega} = \frac{f}{p}K$ *is the threshold of demand making profit positive for the shipper.*

We direct readers to the Appendix, in which all proofs are contained. The shipper's expected loss function is the integral calculus of its profit function where it is negative due to insufficient demand. The integral calculus is over the interval of demand less than the threshold $\widetilde{\omega}$. A higher freight rate f or shipment capacity procurement amount K indicates higher threshold of demand making profit positive for the shipper. The shipper's expected utility is the expected profit plus expected loss weighted by the loss coefficient $\theta - 1$.

In the carrier-shipper games, the carrier offers the freight rate first, and then the shipper decides shipment capacity procurement amount. By backward induction, we first analyze the shipper's optimal shipment capacity procurement decision $\widetilde{K}^*$ given the carrier's freight rate f, which is shown in Proposition 1.

Proposition 1: *In the LC case: (i) conditional upon the freight rate f given by the carrier, the optimal shipment capacity procurement amount $\widetilde{K}^*$ for the shipper exists and is unique, which can be obtained from:*

$$p\overline{H}(K) - f = (\theta - 1)fH(\widetilde{\omega}) \tag{3}$$

(ii) $\widetilde{K}^* \leq \widetilde{K}_n \leq \widetilde{K}_i^*$, where $\widetilde{K}_n = \overline{H}^{-1}(f/p)$ and $\widetilde{K}_i^* = \overline{H}^{-1}(c/p)$ are the shipper's shipment capacity procurement amounts if it is risk-neutral, or it is integrated with the carrier.

We observe that the left-hand side of Equation (3) is the marginal profit of the shipper, while the right-hand side is the marginal risk of loss, which is the multiplication of the loss probability $H(\widetilde{\omega})$, freight rate f and loss coefficient $\theta - 1$. The shipper's optimal shipment capacity procurement amount is obtained when these two margins equal.

By comparing the first-order conditions, we observe that the optimal shipment capacity procurement amount $\widetilde{K}^*$ is smaller than the amount $\widetilde{K}_n$ if it is risk-neutral, and the amount $\widetilde{K}_i^*$ if it is integrated with the carrier. Note that the integrated scenario, though seldom observed in practice, serves as an ideal upper bound of carrier-shipper performance because it fully mitigates double marginalization. Proposition 1 (ii) implies that both the decentralized decision of carrier-shipper and the shipper's risk-aversion are factors resulting in lower shipment capacity procurement amount. We go on to solve the optimal freight rate decision of the carrier, and eventually obtain the unique equilibrium of the carrier-shipper games, as given in Proposition 2.

Proposition 2: *In the LC case, (i) the equilibrium for the games between the carrier and the shipper $(\widetilde{f}^*, \widetilde{K}^*)$ exists and is unique, and can be obtained through Equation (3) and the following equation:*

$$\widetilde{K}^* + f\frac{d\widetilde{K}^*}{df} = c\frac{d\widetilde{K}^*}{df} \tag{4}$$

where

$$\frac{d\widetilde{K}^*}{df} = -\frac{1 + (\theta - 1)[H(\widetilde{\omega}) + \widetilde{\omega}h(\widetilde{\omega})]}{ph(K) + \frac{(\theta - 1)f^2h(\widetilde{\omega})}{p}} \leq 0 \tag{5}$$

(ii) $\widetilde{K}^*$ *and* $\tilde{f}^*$ *are decreasing in* θ.

Equation (4) shows the carrier's trade-off between marginal revenue and marginal cost on left- and right-hand sides. Equation (5) shows that $\widetilde{K}^*$ is sub-modular in f, which means that in equilibrium the shipper's optimal shipment capacity procurement amount is decreasing in the carrier's freight rate. That is because a higher freight rate charged by the carrier will discourage the shipper's willingness to procure shipment capacity. Both the shipper's optimal shipment capacity procurement amount and the carrier's optimal freight rate are decreasing in the coefficient of loss-aversion. This implies that the more risk-averse is the shipper, the less capacity the shipper procures, and the carrier will also lower the freight rate to stimulate the shipment capacity procurement amount.

4.2. Contracting with coordination

In this sub-section we study how the carrier and the shipper can work cooperatively even though they make decisions separately, so that both parties can be better off. Because risk-aversion is considered for the shipper, the definition of what is the Pareto improvement needs to be clarified. Gan *et al.* (2005) provided a definition of coordination between supplier and retailer with the downside risk measure of Value at Risk (VaR). Similar to Gan *et al.* (2005), we define *coordination* and *full coordination* between the carrier and the shipper with the downside risk measure of loss-aversion, as follows.

(i) The *coordination* of carrier and shipper is realized if the sum of the expected profit of the carrier and the expected utility of the shipper $\widetilde{\Pi}_c + \widetilde{U}_s$ is maximized subject to (1) both the carrier and the shipper have Pareto improvement; and (2) the carrier and the shipper share the Pareto improvement equally.

(ii) With *coordination*, the *Full coordination* is further defined as that the capacity can be increased to the amount $\widetilde{K}_i^*$.

Given the definitions of *coordination* and *full coordination*, Proposition 3 summarizes a feasible non-linear freight rate contract offered by the carrier that coordinates the carrier and the shipper to achieve better overall performance.

Proposition 3: *In the LC case: (i) the carrier and the shipper can be coordinated under any circumstance, and the coordinated contract offered by the carrier is* $\tilde{f}_o(\widetilde{K}_o)$ *for the shipper that procures capacity* $\widetilde{K}_o$. *The coordinated solution* $\{\tilde{f}_o(\widetilde{K}_o), \widetilde{K}_o\}$ *can be uniquely solved from:*

$$p\overline{H}(K) - c = (\theta - 1)cH(\widetilde{\omega}) \tag{6}$$

$$\frac{df}{dK} = -\frac{f - c}{K} \tag{7}$$

(ii) $\widetilde{K}^* \leq \widetilde{K}_o \leq \widetilde{K}_i^*$. *The non-linear contract* $f(K)$ *is decreasing convex in* K.

(iii) Full coordination cannot be achieved under any circumstance.

In order to coordinate the shipper, the carrier has to offer a long term freight rate contract that induces the shipper to procure more shipment capacity by sharing its risk. As such, the freight rate depends on the shipment capacity procurement amount and it is a non-linear contract. Furthermore, it is proved that the non-linear freight rate $f(K)$ is decreasing convex in capacity K, which means that the marginal effect of reducing freight rate to induce higher capacity is increasing. The contract $f(K)$ is in the nature a quantity-discount contract. It is observed that the commonly used two-part tariff contract to mitigate double marginalization is not applicable in the risk-aversion scenario, because an ex-post transfer payment cannot relieve the downside risk that the shipper encounters. In contrast, the non-linear contract designed in Proposition 3 share the shipper's risk before demand and freight rate uncertainties resolve. That is the reason why it works for risk-averse scenario.

Proposition 3 reveals that the coordination contract always exists and is unique. In Equation (6), the left-hand side $p\overline{H}(K) - c$ shows the marginal profit when the carrier and the shipper act as integrated, while the right-hand side $(\theta - 1)cH(\widetilde{\omega})$ shows the overall marginal loss for the carrier and the shipper. The optimal shipment capacity procurement amount is obtained when these two margins equal. By comparing Equations (3) and (6), we can observe that the coordination contract increases marginal profit and reduces marginal risk, which explains why the contract can induce the shipper to procure more capacity. Nevertheless, the capacity with *coordination* cannot reach the ideal upper bound $\widetilde{K}_i^*$, owing to the risk-aversion of the shipper. It implies that to better coordinate the shipper, the carrier not only has to induce the shipper to place higher shipment capacity procurement amount, but also has to consider how to relieve the risk-aversion of the shipper.

5. The case considering only the spot freight market (SF case)

In this section, we study the case that considers only the spot freight market. Hence, there is only the shipper's shipment capacity procurement decision K. As the spot freight rate R is realized almost together with the market demand D, the shipper picks a capacity equal to demand, that is, $\widehat{K} = D$ if $p > R$. Then, the shipper's profit function is $\widehat{\pi}_s = (p - R)D | p > R$. Because there will be no chance of losses, the shipper's expected utility equals to its expected profit, which is:

$$\widehat{\Pi}_s = \int_0^{\infty} \int_{\underline{Y}}^{\lambda(y)} [p - (\alpha + \beta y + x)] y g(x) h(y) dx dy$$

where $\lambda(y) = p - \alpha - \beta y$. If there is only the spot freight market, the shipper does not have to make a decision but can just wait until the spot freight rate is realized together with the market demand. On the one hand, the shipper will not suffer losses; but on the other hand, it cannot maximize its utility by optimizing the capacity decision.

6. The case considering both the long-term contract and the spot freight market (DC case)

In this section, we analyze the case considering both the long-term contract and the spot freight market, that is, the DC case. The trade-off for the shipper in the long-term contract with the carrier is that on the one hand it provides more guarantees for the shipment capacity procurement for the shipper, but on the other hand it requires the shipper to make a decision facing both demand and spot market uncertainties. The trade-off for the shipper on the spot freight market is that although it provides an opportunity for the shipper to replenish capacity if there is a shortage of capacity, or cancel at the expense of penalty if there is excess capacity, the spot market imposes freight rate uncertainty upon the shipper. As for the carrier, the presence of the spot freight market is also a double-edged sword. On the one hand, the spot market is a source of competition for the carrier, but on the other hand the carrier can also benefit from the spot market for reselling excess shipment capacity. Note that if the spot market freight rate $R < p$, then the shipper will replenish from the spot market; if $R \geq p$, then the shipper will not replenish from the spot market.

6.1. Contracting without coordination

As in the LC case, we first study the sub-case in which the carrier offers freight rate contract without considering coordination. The carrier's objective function is:

$$\underset{f \geq c}{\text{Max}} \Pi_c(f) = fEMin\{K, D\} - cK + E[(t + \sigma R)\text{Max}\{K - D, 0\}] \tag{8}$$

with the three terms meaning expected revenue from shipper, shipping cost, and expected penalty plus reselling income on the spot market, respectively. The shipper's objective function is to maximize its expected utility:

$$\max_{K\geq 0} U_s(K) = \Pi_s(K) + (\theta - 1)L_s(K)$$

where the expected profit is:

$$\Pi_s(K) = pE\text{Min}\{K, D\} - fK + E[(p - R)\text{Max}\{D - K, 0\}|p > R] - tE[\text{Max}\{K - D, 0\}]$$

The first two terms are expected revenue and cost of long-term contract for shipment capacity procurement. The third term is expected profit of spot market replenishment, and the last term is expected penalty due to excess shipment capacity procurement of long-term contract. It can be simplified as:

$$\Pi_s(K) = pE(D) - fE\text{Min}\{K, D\} - E[\text{Min}\{p, R\}\text{Max}\{D - K, 0\}] - tE\text{Max}\{K - D, 0\} \quad (9)$$

with the four terms meaning total expected revenue meeting entire demand, cost of long-term contract for shipment capacity procurement, expected cost of spot market replenishment (and opportunity loss if spot freight rate is higher than unit revenue), and expected penalty due to excess shipment capacity procurement of long-term contract.

The shipper's expected loss is:

$$L_s(K) = \int_0^{\omega} [(p - f + t)y - tK]h(y)dy \quad (10)$$

where $\omega = \frac{t}{p-f+t}K$. We can observe that the shipper's profit $\pi_s < 0$ if $D < \omega$ and $\pi_s \geq 0$ if $D \geq \omega$. As such, ω is the threshold of demand making the profit positive for the shipper.

In the carrier-shipper games, the carrier offers its freight rate first, and then the shipper decides capacity. Using backward induction, we first analyze the shipper's optimal capacity decision given the freight rate f. The strict uniqueness of equilibrium in the DC Uncoordinated sub-case, as shown in Propositions 4 and 5, can be secured by a mild assumption that $t + \alpha + E(\gamma) \geq f$. Note that $\alpha + E(\gamma)$ is the minimum expected spot freight rate even if demand falls to zero. As such, the assumption means that the unit penalty of shipment cancellation plus minimum expected spot freight rate is greater than the carrier's freight rate. Proposition 4 gives the optimal capacity decision for the shipper given the carrier's freight rate offer:

Proposition 4: *In the DC case: (i) conditional upon the freight rate* f *given by the carrier, the optimal capacity* K^* *for the shipper exists and is unique, which can be obtained from:*

$$\int_K^{\infty}\int_{\underline{\gamma}}^{\lambda(y)} (\alpha + \beta y + x)g(x)h(y)dxdy + \int_K^{\infty}\int_{\lambda(y)}^{\infty} pg(x)h(y)dxdy - f\int_K^{\infty} h(y)dy$$

$$- t\int_0^K h(y)dy = (\theta - 1)tH(\omega) \quad (11)$$

(ii) $K^* \leq K_n \leq K_i^*$, *where* K_n *and* K_i^* *are the shipper's optimal capacity if it is risk-neutral, or it is integrated with the carrier.*

Similar to the LC case, we observe that the left-hand side of Equation (11) is the marginal profit of the shipper consisting of marginal opportunity gains of not replenishing at spot market minus marginal procurement cost, while the right-hand side is the marginal risk of loss. The shipper's optimal shipment procurement capacity amount is obtained when the left-hand side equals to the right-hand side. Compared with the fluctuation of demand, the fluctuation of the spot freight rate does not cause a loss for the shipper. This is because the replenishment is done at the time that both the random market demand and freight rate are realized, meaning that shipper does not suffer uncertainty from the spot market. By comparing the first-order conditions, we observe that the optimal shipment capacity procurement amount K^* is smaller than the amount K_n if it is risk-neutral, and the amount K_i^* if it is integrated with the carrier. It implies that both the decentralized decision of carrier-shipper and the shipper's risk-aversion are factors resulting in lower shipment procurement capacity amount. We continue to solve the optimal freight rate decision of the carrier, and eventually obtain the unique equilibrium of the carrier-shipper games, as given in Proposition 5.

Proposition 5: *In the DC case, (i) the equilibrium for the games between the carrier and the* *shipper* (f^*, K^*) *exists and is unique, and can be obtained together through Equation (11) and the following equation:*

$$H(K) + \left(K + f\frac{dK^*}{df}\right)[1 - H(K)] + \int_0^K \int_{\underline{\gamma}}^{\infty} [\sigma(\alpha + \beta y + x) + t]\frac{dK^*}{df} g(x)h(y)dxdy = c\frac{dK^*}{df} \quad (12)$$

where

$$\frac{dK^*}{df} = -\frac{1 - H(K) + (\theta - 1)\dfrac{t^2 h(\omega)K}{(p - f + t)^2}}{h(K)[\text{Min}\{\alpha + \beta K + E(\gamma), p\} - f + t] + (\theta - 1)\dfrac{t^2 h(\omega)}{p - f + t}} \leq 0 \quad (13)$$

(ii) K^* *and* f^* *are decreasing in* θ, *and increasing in* β.

Equation (12) shows the carrier's trade-off between marginal revenue and marginal cost on left- and right-hand sides. From Equation (13) we observe that K^* is sub-modular in f, which means that in equilibrium the shipper's optimal shipment capacity procurement amount is decreasing in the carrier's freight rate. This is because a higher freight rate charged by the carrier will discourage the shipper's willingness to procure the shipment capacity. Both the shipper's optimal shipment capacity procurement amount and the carrier's optimal freight rate are decreasing in the coefficient of loss-aversion for a similar reason to that in the LC case. In addition, these two optimal decisions are increasing in the coefficient of correlation between demand and spot freight rate. This is because if demand makes a greater impact on the spot freight rate, the shipper will procure more capacity in advance with the carrier to avoid spot freight rate fluctuation, and the carrier will also increase the freight rate to gain higher profit.

6.2. Contracting with coordination

Similar to the LC case, the *coordination* of carrier and shipper in the DC case can be defined as: the sum of the expected profit of the carrier and the expected utility of the shipper $\Pi_c + U_s$ is maximized subject to (i) both the carrier and the shipper have Pareto improvement; and (ii) both the carrier and the shipper share the Pareto improvement equally. And the *full coordination* in the DC case can be further defined as: with *coordination*, the capacity K can be increased to the amount K_i^*. Given the definition of *coordination* and *full coordination*, Proposition 6 summarizes a feasible non-linear freight rate contract offered by the carrier that coordinates the shipper to achieve better overall performance.

Proposition 6: *In the DC case, (i) the carrier and the shipper can be coordinated under any circumstance, and the coordinated contract offered by the carrier is* $f_o(K_o)$ *for the shipper that procures capacity* K_o. *The coordinated solution* $\{f_o(K_o), K_o\}$ *can be uniquely solved from:*

$$\int_K^{\infty} \int_{\underline{\gamma}}^{\lambda(y)} (\alpha + \beta y + x)g(x)h(y)dxdy + \int_K^{\infty} \int_{\lambda(y)}^{\infty} pg(x)h(y)dxdy$$

$$+ \sigma \int_0^K \int_{\underline{\gamma}}^{\infty} (\alpha + \beta y + x)g(x)h(y)dxdy - c = (\theta - 1)\int_0^{\omega} \left(\frac{df}{dK}y + t\right)h(y)dy \quad (14)$$

$$\frac{df}{dK} = -\frac{\int_K^{\infty} fh(y)dy + \int_0^K [t + \alpha + \beta y + E(\gamma)]h(y)dy - c}{\int_0^K yh(y)dy + \int_K^{\infty} Kh(y)dy} \leq 0 \quad (15)$$

(ii) $K^* \leq K_o \leq K_i^*$. *The non-linear contract* $f(K)$ *is decreasing convex in* K.

(iii) Full coordination cannot be achieved under any circumstance.

It is proved that the non-linear freight rate $f(K)$ is decreasing convex in capacity K, which means that the marginal effect of reducing freight rate to induce higher capacity is increasing. Proposition 6 shows that the coordination contract always exists and is unique. In Equation (14), the left-hand side shows the marginal profit when the carrier and the shipper act as integrated, and the right-hand side shows the overall marginal loss for the carrier and the shipper. The optimal shipment procurement capacity amount is obtained when these two margins equal. By comparing Equations (14) and (11), we can observe that the coordination contract increases the marginal profit and reduces the marginal risk, which explains why the contract can induce the shipper to procure more capacity. Nevertheless, the capacity with *coordination* cannot reach the ideal upper bound K_i^*, owing to the risk-aversion of the shipper. The implication is that after taking risk-aversion into consideration, though coordination and collaboration may improve the carrier-shipper's overall performance substantially, they cannot achieve the full effect of integration. The carrier has to care about not only the shipper's operational decision, but also its risk attitude and risk management strategy.

7. Parametric analysis and numerical study

7.1. Numerical study

Based on the general results derived from the modelling study, in this section we use the following data set for a typical numerical case to obtain more intuitive remarks and insights. Suppose that the random market demand D has a normal distribution with expected value $\mu(D)=100$ and standard deviation $\delta(D)=25$. Since the tail distribution beyond 3δ is extremely small, we can ignore the probability that $D<0$. Following the usual practice, the random fluctuation of the spot freight rate γ is supposed to be logarithmic normal distributed with expected value $\mu(\gamma)=2$ and standard deviation $\delta(\gamma)=1$. The coefficient of loss-aversion $\theta=2$, the basic price $\alpha=0$, the coefficient of correlation between demand and spot freight rate $\beta=0.01$, the unit shipping cost for the carrier $c=1.5$, the unit revenue for the shipper $p=3$, the unit cancellation penalty $t=1.8$, and the discount $\sigma=0.2$.

Table 3 summarizes and compares equilibrium decisions and performances among different cases, with the same data set. Note that performance means the sum of carrier's expected profit and the shipper's expected utility compared with that of DC case supposing carrier and shipper are integrated, setting the ideal upper bound.

Table 3
Equilibrium decisions and the expected profit / utility for different shipping structures.

Case	Sub-case	f^*	K^*	Π_c^*	U_s^*	$\Pi_c^*+U_s^*$	Performance
LC	Risk-neutral	2.5329	74.6893	77.1466	28.7857	105.9323	82.81%
LC	Uncoordinated	2.5452	69.2731	72.4042	25.9983	98.4025	76.93%
LC	Coordinated	2.3403	95.2156	80.0097	33.6192	113.6288	88.83%
SF	—	—	—	—	34.9698	34.9698	27.34%
DC	Uncoordinated	2.4297	65.7245	60.9641	44.9967	105.9608	82.84%
DC	Coordinated	2.1797	100.7434	70.1109	54.1435	124.2544	97.14%
DC	Ideal upper bound	—	104.5020	—	—	127.9176	100.00%

First of all, the gap between 82.81% and 100.00% performances can be interpreted as double marginalization purely due to decentralized decision of carrier and shipper, when the shipper is supposed to be risk-neutral. Then if risk-aversion is considered, the performance drops to 76.93%, owing to reduction in shipment capacity procurement amount. The carrier-shipper's overall performance is improved by changes in shipping structure or coordinating efforts of the carrier and the shipper. Introduction of spot market is beneficial for the shipper's and the carrier-shipper's overall performance, though the carrier suffers. The overall performance increases from 76.93% to 82.84%. Introduction of coordination contract creates win-win situation for both the carrier and the shipper, with the overall performance increases from 76.93% to 88.83%. If both the spot market replenishment and contract coordination are jointly applied, the overall performance then increases to 97.14%, showing that it is almost as good as the ideal upper bound performance even if the carrier and the shipper cannot virtually integrate. The gap between 97.14% and 100% is caused by risk-aversion of the shipper. It is notable that even though the expected spot freight rate R equals to the shipper's unit revenue p, the shipper still gain an expected utility of 34.9698 in the SF case because it is profitable for the shipper whenever R realizes to be smaller than p.

We also observe that the freight rate is smaller in DC case because the carrier faces competition from spot market; it is also smaller in coordinated sub-case because the carrier lowers the freight rate to induce a higher shipment procurement capacity amount of the shipper. Normally higher shipment procurement capacity amount indicates higher performance. But the DC Uncoordinated sub-case is an exception. Compared with LC Uncoordinated sub-case, the shipper procures less from the carrier, but the performance is higher, owing to that the presence of spot freight market dilutes the shipper's capacity procurement from the carrier.

7.2. Parametric analysis

To have a better understanding of how some key parameters impact the equilibrium solution and the corresponding performance, this sub-section conducts parametric analysis by changing only one parameter and keeping others the same as data set used in sub-section 7.1. The DC Uncoordinated sub-case will be taken as example as it is the typical case in practice, and the parametric analysis for other cases can be conducted similarly.

Table 4 presents the impact of demand fluctuation on the decisions and performance of the carrier and the shipper. The information in the table shows that the fluctuation of demand discourages the shipper's shipment capacity procurement, even though the carrier tries to lower freight rate to induce it. The performance of the carrier is sensitive to the demand fluctuation, while that of the shipper is not so sensitive, because the shipper can shift its shipment procurement capacity from the carrier to the spot freight market, but the carrier will suffer from the higher uncertainty of demand.

Table 4

Impact of the standard deviation $\delta(D)$ of the demand.

$\boldsymbol{\delta(D)}$	$\boldsymbol{f^*}$	$\boldsymbol{K^*}$	$\boldsymbol{\Pi_c^*}$	$\boldsymbol{U_s^*}$	$\boldsymbol{\Pi_c^* + U_s^*}$
15	2.5301	75.3741	77.5792	42.8385	120.4177
20	2.4822	70.2484	68.8937	44.2084	113.1020
25	2.4297	65.7245	60.9641	44.9967	105.9608
30	2.3772	61.5948	53.8270	44.9855	98.8126
35	2.3214	58.3575	47.5374	44.6220	92.1594

Table 5 presents the impact of the random fluctuation of the spot freight rate on the decisions and performance of the carrier and the shipper. The information in the table shows that, similar to the impact of demand fluctuation, the fluctuation of spot freight rate causes the carrier to reduce the freight rate and the shipper to reduce shipment capacity procurement amount. Quite counter-intuitively, however, the utility of the shipper increases as the fluctuation of spot freight rate increases, because the probability distribution of the spot freight rate moves left when the fluctuation of the spot freight rate increases, thereby reduces the overall cost of shipment capacity procurement for the shipper in the spot market. It shows that the fluctuation of the spot freight rate is not necessarily bad news for the shipper's and the carrier-shipper's overall performance.

Table 5

Impact of the standard deviation $\delta(\gamma)$ of the random fluctuation of the spot freight rate.

$\boldsymbol{\delta(\gamma)}$	$\boldsymbol{f^*}$	$\boldsymbol{K^*}$	$\boldsymbol{\Pi_c^*}$	$\boldsymbol{U_s^*}$	$\boldsymbol{\Pi_c^* + U_s^*}$
0.5	2.5616	66.9281	70.7550	30.7814	101.5363
0.75	2.4949	66.3470	65.7949	37.9795	103.7744
1	2.4297	65.7245	60.9641	44.9967	105.9608
1.25	2.3644	65.3717	56.4328	51.8377	108.2704
1.5	2.3101	64.5416	52.2623	57.7466	110.0088

Table 6 presents the impact of the correlation coefficient between demand and spot freight rate on the decisions and performance of the carrier and the shipper. From the figures we observe that the increase of correlation coefficient β enhances the bargaining power of the carrier, so the expected profit of the carrier increases substantially, whereas the utility of the shipper decreases greatly. And the carrier-shipper's overall performance is also jeopardized. In sum, correlation between demand and spot freight rate is not favourable for the carrier-shipper's overall performance because the carrier and the shipper have to serve the excess demand with higher spot freight rate and the profit is thereby squeezed.

Table 6

Impact of the correlation coefficient β.

$\boldsymbol{\beta}$	$\boldsymbol{f^*}$	$\boldsymbol{K^*}$	$\boldsymbol{\Pi_c^*}$	$\boldsymbol{U_s^*}$	$\boldsymbol{\Pi_c^* + U_s^*}$
0.005	2.1501	62.2382	40.5230	76.1546	116.6776
0.0075	2.3029	64.1681	51.4851	59.1273	110.6124
0.01	2.4297	65.7245	60.9641	44.9967	105.9608
0.0125	2.5322	66.5753	68.4865	33.8755	102.3620
0.015	2.6041	67.1979	73.8955	26.2321	100.1276

Table 7 shows the impact of the degree of risk-aversion θ on the decisions and performance of the carrier and the shipper. From the figures we observe that the increase of shipper's risk-aversion discourage the shipper's shipment capacity procurement from the carrier to avoid potential losses. The carrier in turn has to reduce freight rate to induce shipper's procurement. It can be seen that the carrier's expected profit and the shipper's expected utility decrease owing to the higher risk-aversion of the shipper.

Table 7

Impact of the degree of risk-aversion θ.

$\boldsymbol{\theta}$	$\boldsymbol{f^*}$	$\boldsymbol{K^*}$	$\boldsymbol{\Pi_c^*}$	$\boldsymbol{U_s^*}$	$\boldsymbol{\Pi_c^* + U_s^*}$
1.2	2.4397	67.6129	63.3636	45.5369	108.9005
1.6	2.4332	66.6998	62.0902	45.2121	107.3023
2.0	2.4297	65.7245	60.9641	44.9967	105.9608
2.4	2.4232	65.0812	59.9555	44.7331	104.6886
2.8	2.4207	64.2511	59.0383	44.3892	103.4275

7.3. Comparison of cases

Fig. 2 summarizes optimal shipment procurement capacity amount and carrier-shipper's overall expected utility in difference cases.

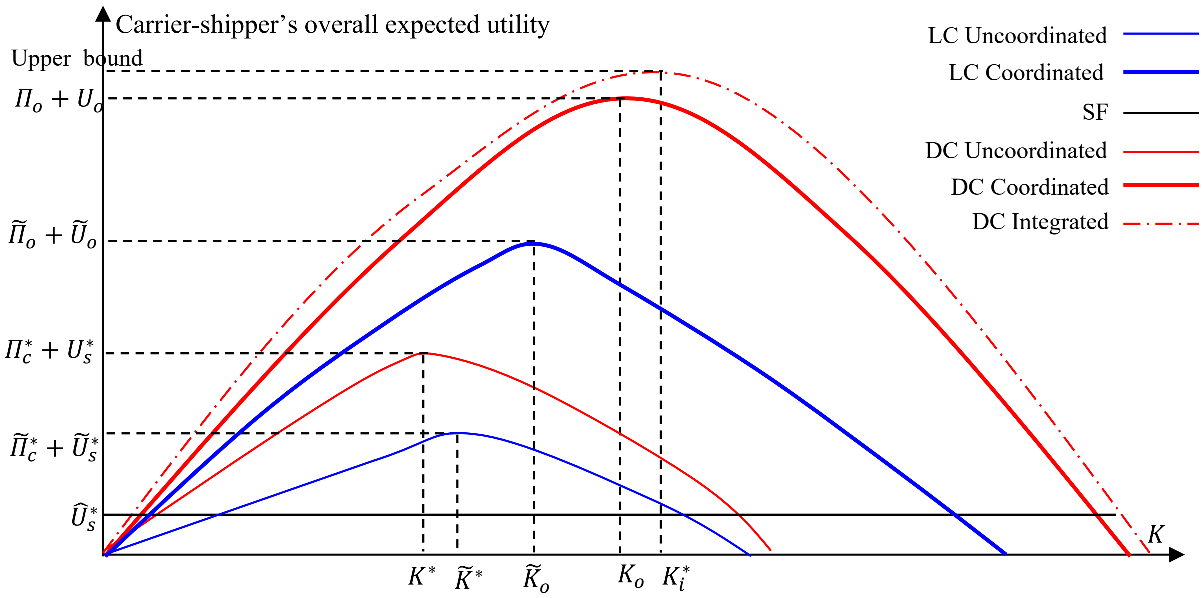

Fig. 2. Comparison of carrier-shipper's overall expected utility and capacity among cases (colour online).

Note: The horizon axis is the optimal shipment capacity procurement amount in each case; the vertical axis is the carrier-shipper's overall expected utility, that is, the sum of carrier's expected profit and the shipper's expected utility.

The ideal upper bound, supposing carrier and shipper are integrated in DC case, is marked as dash line. The LC Uncoordinated sub-case has the second-worst performance due to the decentralization of carrier and shipper, the lack of access to spot market and risk-aversion of the shipper. Through applying coordination contract, the carrier-shipper's overall performance can be improved substantially but cannot achieve the ideal upper bound due to risk-aversion of the shipper. The expected utility of the shipper in the SF case is irrelevant to freight rate or shipment capacity procurement decisions. It can be taken as the pure benefit of the spot market for the shipper, regardless of its managerial efforts.

Table 8 summarizes and compares sub-cases of the shipping structures studied, and thereby shows means to improve the carrier-shipper's overall performance.

Table 8

Summary and comparison of the shipping structures.

Case	Carrier	Shipper	Carrier-shipper's overall performance
SF	No involvement	No leverage on long-term contract form the carrier	$\widehat{U}_s^*$: worst performance
LC Uncoordinated	Offers long-term contract $\tilde{f}^*$; no competition from spot market	No leverage on the spot market, only procures $\widetilde{K}^*$ from the carrier	$\widetilde{\Pi}_c^* + \widetilde{U}_s^*$: better than SF case
DC Uncoordinated	Faces competition from spot market; offers long-term contract f^*	Enjoys benefit from dual-channel procurement; procures K^* from the carrier	$\Pi_c^* + U_s^*$: better than LC Uncoordinated sub-case
LC Coordinated	Improves its own and the carrier-shipper's overall performance by offering non-linear freight rate coordinating contract $\tilde{f}_o(\widetilde{K}_o)$	Induced by non-linear freight rate contract to procure $\widetilde{K}_o$ and benefits from coordination	$\widetilde{\Pi}_o + \widetilde{U}_o$: better than DC Uncoordinated sub-case
DC Coordinated	Improves its own and the carrier-shipper's overall performance by offering non-linear freight rate coordinating contract $f_o(K_o)$	Induced by non-linear freight rate contract to procure K_o and benefits from coordination	$\Pi_o + U_o$: better than DC Uncoordinated sub-case
Ideal upper bound	Supposing carrier and shipper are integrated, their overall performance reaches the ideal upper bound		

The SF case shows that the shipper gains the least because it abandons the profit if spot freight rate realizes to be higher than revenue, which highlights the importance of cooperation with carrier that offers long-term contract. The LC Uncoordinated sub-case, in return, highlights the essential role of spot freight market. When the dual channels are combined in DC Uncoordinated sub-case, performance is further improved and it shows that the spot market offers opportunities of replenishment for the shipper and reselling for the carrier. A well-designed non-linear freight rate contract offered by the carrier can improve the carrier-shipper's overall performance substantially. However, by no means the *coordination* can achieve the ideal upper bound performance.

8. Conclusions and future research

In this paper, we present a systematic study of different shipping structures in the presence of uncertainties of both market demand and spot freight market. Three cases are investigated: considering only the long-term contract with the carrier, only the spot freight market, and a combination of the two. In each case, we analyze the scenarios without or with coordination. Stackelberg games model is set up to formulate interaction of the carrier and the shipper. The optimality and equilibrium of different shipping structures are analytically derived, and the existence and uniqueness of the games are proved. In addition, the coordination solution for the carrier and the shipper is designed.

To the best of our knowledge, this paper offers the first investigation into shipping structure and risk management issues of the ocean freight industry with demand and freight rate uncertainties. On the basis of the modelling analysis and numerical experiments, we are able to draw the following major conclusions and insights:

First, we show that long-term contract with carrier combining short-term replenishment from spot freight market is favourable for the shipper's and the carrier-shipper's overall performance. These two channels play different roles for the shipper: the carrier's long-term contract reduces the risk of high spot freight rate, and the spot freight market reduces risk of mismatch between demand and shipment procurement capacity amount. The presence of the spot market dilutes the shipment capacity procurement from the carrier, which is not favourable for the carrier, but enhances the shipper's and the carrier-shipper's overall performance.

Second, we illustrate the impact of risks and the strategies of managing risks. Risk-aversion reduces the shipment capacity procurement of the shipper, which protects the shipper but jeopardizes the carrier's and the carrier-shipper's performance. Owing to their different positions in ocean supply chains, the fluctuation of market demand and spot freight rate have different (sometimes even opposite) impacts on the carrier and the shipper. For example, the fluctuation of spot market freight rate benefits the shipper but disfavours the carrier. The correlation of the spot market and demand gives more bargaining power to the carrier on the freight rate, which is beneficial for the carrier, but will decrease both the shipper's utility and the carrier-shipper's overall performance.

Last, the framework of coordination (including definition, coordination contract design and optimization) in the presence of downside risk-aversion is developed. We show that the carrier-shipper's overall performance can be improved substantially through a non-linear freight rate contract. However, *full coordination,* namely double marginalization is fully eliminated and integrated performance is achieved, is not feasible due to the risk-aversion of the shipper. It is also notable that the contract that coordinates the carrier and the shipper has a nature of quantity-discount rather than two-part tariff, because an ex-post transfer payment cannot relieve the downside risk that the shipper encounters.

The results of this paper provide insights into how the carrier and the shipper can better coordinate with each other, how the carrier-shipper's overall performance can be improved, and how the shipper can better manage shipment capacity procurement strategy taking risk management into account. Based on the model specified in this paper, various lines of future research could be considered, such as incomplete information, carriers' / shippers' competition, multi-period games, more complicated contracts like option contract offered by the carrier, etc. Besides, it is worthy to compare the modelling results with empirical data or cases to obtain further economic motivations and insights. Currently the study focuses on the coordination between carrier and shipper. Future research may concern the extended coordination between carrier and terminal operators, freight forwarders / NVOCC (non-vessel ocean common carrier), and in-land transportation services providers. It remains a challenge to examine and simplify this extended coordination whose functions may not be obtained in a closed form and to analyze how the joint performance would change.

Acknowledgements

We are grateful to the editors and reviewers for their insightful and constructive comments. This research was supported by China-ASEAN Collaborative Innovation Center for Regional Development Co-constructed by the Province and Ministry and Program for Changjiang Scholars and Innovative Research Team of "China-ASEAN Regional Development Team" (IRT_17R27).

Appendix

A.1. Proof of Lemma 1

Denote $\tilde{u}_s$ and $\tilde{\pi}_s$ as the utility and profit of the shipper respectively. From Expression (1) the definition of the utility function of the shipper, we have the expected utility as:

$$\tilde{U}_s(K) = E[\tilde{u}_s(K)] = E(\tilde{\pi}_s|\tilde{\pi}_s \geq 0) + \theta E(\tilde{\pi}_s|\tilde{\pi}_s < 0)$$

$$= E(\tilde{\pi}_s) - E(\tilde{\pi}_s|\tilde{\pi}_s < 0) + \theta E(\tilde{\pi}_s|\tilde{\pi}_s < 0) = E(\tilde{\pi}_s) + (\theta - 1)E(\tilde{\pi}_s|\tilde{\pi}_s < 0)$$

Note that $\tilde{\pi}_s > 0$ if $\tilde{\omega} > \frac{f}{p}K$ and vice versa. Hence the expected loss function is $\tilde{L}_s = \int_0^{\tilde{\omega}}(py - fK)h(y)dy$. Therefore we obtain Expression (2). □

A.2. Proof of Proposition 1

(i) The expected profit $\tilde{\Pi}_s$ taking derivatives against K yields $\frac{d\tilde{\Pi}_s}{dK} = p\overline{H}(K) - f$. $\tilde{\Pi}_s$ further taking second derivatives against K yields $\frac{d^2\tilde{\Pi}_s}{dK^2} = -ph(K) \leq 0$. Hence $\tilde{\Pi}_s$ is concave in K. In addition, the expected loss function $\tilde{L}_s$ taking first and second derivatives against K yields $\frac{d\tilde{L}_s}{dK} = -fH(\tilde{\omega}) \leq 0$, $\frac{d^2\tilde{L}_s}{dK^2} = -\frac{f^2}{p}h(\tilde{\omega}) \leq 0$. Hence $\tilde{L}_s$ is also concave in K. Hence the shipper's expected utility function $\tilde{U}_s$ is concave in K because $\theta - 1 \geq 0$. Then the unique optimal solution can be obtained from the first-order condition (3).

(ii) The first-order conditions for the LC case without coordination, supposing the shipper is risk-neutral and supposing the shipper integrates with the carrier are $\overline{H}(\tilde{K}^*)$, $\overline{H}(\tilde{K}_n) = f/p$ and $\overline{H}(\tilde{K}_i) = c/p$ respectively. Since $\frac{f}{p} + (\theta - 1)\frac{f}{p}H\left(\frac{f}{p}\tilde{K}^*\right) \geq \frac{f}{p} \geq \frac{c}{p}$ and $\overline{H}(\cdot)$ is a decreasing function, then we have $\tilde{K}^* \leq \tilde{K}_n \leq \tilde{K}_i^*$. □

A.3. Proof of Proposition 2

(i) The carrier's expected profit $\tilde{\Pi}_c$ taking derivatives against f yields:

$$\frac{d\tilde{\Pi}_c}{df} = \tilde{K}^* + (f - c)\frac{d\tilde{K}^*}{df}$$

Taking derivatives against f from the shipper's first-order condition (3) yields:

$$-ph(K)\frac{dK}{df} - 1 - (\theta - 1)\left[H\left(\frac{f}{p}K\right) + fh\left(\frac{f}{p}K\right)\left(\frac{K}{p} + \frac{f}{p}\frac{dK}{df}\right)\right] = 0$$

Note that $\tilde{\omega} = \frac{f}{p}K$. Then we have Equation (5), the right-hand side of which is observed to be negative, meaning that the equilibrium is unique.

(ii) Taking derivatives against θ in the first-order condition (3) yields:

$$-ph(K)\frac{dK}{d\theta} = fH(\tilde{\omega}) + (\theta - 1)\frac{f^2}{p}h(\tilde{\omega})\frac{dK}{d\theta}$$

Then we have:

$$\frac{d\tilde{K}^*}{d\theta} = -\frac{fH(\tilde{\omega})}{ph(K) + \frac{f^2}{p}h(\tilde{\omega})} \le 0$$

which means that $\tilde{K}^*$ is decreasing in θ. Furthermore, $\frac{d\tilde{K}^*}{df} \le 0$ shows that $\tilde{K}^*$ and $\tilde{f}^*$ are submodular. Therefore, as θ increases, the carrier will reduce the freight rate f anticipating that the shipper will reduce shipment procurement capacity amount K. Hence, $\tilde{f}^*$ is also decreasing in θ. □

A.4. Proof of Proposition 3

(i) In coordinating the shipper, we continue to assume that the carrier's freight rate $f \ge c$. It is reasonable because the carrier cannot afford a heavy subsidy to the shipper such that the freight rate charged is lower than its shipping cost. According to the definition of *coordination*, the objective function of the carrier and the shipper is:

$$\underset{f(K)\ge c, K\ge 0}{\text{Max}} \ \tilde{\Pi}_c + \tilde{U}_s \ [f(K), K]$$

$$s.t. \begin{cases} \tilde{\Pi}_c \ge \tilde{\Pi}_c^* \\ \tilde{U}_s \ge \tilde{U}_s^* \\ \tilde{\Pi}_c \ge \tilde{\Pi}_c^* + \frac{1}{2}\left[\tilde{\Pi}_c + \tilde{U}_s - \left(\tilde{\Pi}_c^* + \tilde{U}_s^*\right)\right] \\ \tilde{U}_s \ge \tilde{U}_s^* + \frac{1}{2}\left[\tilde{\Pi}_c + \tilde{U}_s - \left(\tilde{\Pi}_c^* + \tilde{U}_s^*\right)\right] \end{cases}$$

The meaning of the constraint conditions are that: the carrier's expected profit and the shipper's expected utility shall have improvement; both the carrier and the shipper shall be allocated at least half of the increment. The conditions can be simplified as $s.t. \tilde{\Pi}_c - \tilde{U}_s = \tilde{\Pi}_c^* - \tilde{U}_s^*$. The first-order condition of the objective function is:

$$\frac{d\left(\tilde{\Pi}_c + \tilde{U}_s\right)}{dK} = p\bar{H}(K) - c - (\theta - 1)\int_0^{\tilde{\omega}} \left(f + K\frac{df}{dK}\right) h(y)dy = 0$$

The equation $\tilde{\Pi}_c - \tilde{U}_s = \tilde{\Pi}_c^* - \tilde{U}_s^*$ taking derivatives on K yields:

$$2f - c + 2K\frac{df}{dK} - p\bar{H}(K) + (\theta - 1)\int_0^{\tilde{\omega}} \left(f + K\frac{df}{dK}\right) h(y)dy = 0$$

Compared the above two equations and we can have $\frac{df}{dK} = -\frac{f-c}{K}$, which is negative. And $\frac{d^2f}{dK^2} = \frac{2(f-c)}{K^2} \ge 0$, meaning that f is decreasing convex in K. Then the first-order condition can be simplified as Equation (6).

The value of the second derivative in the neighbourhood of $\tilde{K}_o$ is:

$$\left.\frac{d^2\left(\tilde{\Pi}_c + \tilde{U}_s\right)}{dK^2}\right|_{K=\tilde{K}_o} = -ph(K) - c - (\theta - 1)\frac{c^2}{p}h(\tilde{\omega}) \le 0$$

Hence, $\tilde{\Pi}_c + \tilde{U}_s$ is concave in the neighborhood of any stationary point $\tilde{K}_o$. Thus, the uniqueness of equilibrium $\left\{\tilde{f}_o\left(\tilde{K}_o\right), \tilde{K}_o\right\}$ is proved.

(ii) By comparing Equation (6) with Equation (3) and the first-order condition of $\tilde{K}_i^*$, we can observe that $\tilde{K}^* \le \tilde{K}_o \le \tilde{K}_i^*$, which means that with coordination, the shipment procurement capacity amount is larger, but it is still smaller than the value supposing carrier and shipper are integrated.

(iii) It can be obtained from (ii). □

5. Proof of Proposition 4

(i) If $D \geq K$, the profit function of the shipper is:

$$\pi_s = pD - fK - \text{Min}\{p, R\}(D-K) \geq pD - fK - p(D-K)$$

$$= (p-f)K \geq 0$$

which is positive. If $D < K$, then the profit function is $\pi_s = pD - fD - t(K-D)$. Then we have $\omega = \frac{t}{p-f+t}K$ as the threshold of demand. The profit is negative for $D < \omega$.

Denote $\lambda(y) = p - \alpha - \beta y$. Then Expression (9) expected profit function of the shipper can be written as:

$$\Pi_s = pE(D) - \int_0^K fyh(y)dy - \int_K^{\infty} fKh(y)dy - t\int_0^K (K-y)h(y)dy$$

$$-\int_K^{\infty}\int_{\underline{\gamma}}^{\lambda(y)} (\alpha+\beta y+x)(y-K)g(x)h(y)dxdy - \int_K^{\infty}\int_{\lambda(y)}^{\infty} p(y-K)g(x)h(y)dxdy$$

Π_s taking derivatives against K yields:

$$\frac{d\Pi_s}{dK} = -f\int_K^{\infty} h(y)dy - t\int_0^K h(y)dy$$

$$+\int_K^{\infty}\int_{\underline{\gamma}}^{\lambda(y)} (\alpha+\beta y+x)g(x)h(y)dxdy + \int_K^{\infty}\int_{\lambda(y)}^{\infty} pg(x)h(y)dxdy$$

Π_s further taking second derivatives against K yields:

$$\frac{d^2\Pi_s}{dK^2} = (f-t)h(K) - h(K)\int_{\underline{\gamma}}^{\lambda(K)} (\alpha+\beta K+x)g(x)dx - h(K)\int_{\lambda(K)}^{\infty} pg(x)dx$$

$$= h(K)[-\text{Min}\{\alpha+\beta K+E(\gamma), p\} + f - t] \leq 0$$

as per the assumption that $t + \alpha + E(\gamma) \geq f$. As such, Π_s is shown to be concave in K.

Expression (10) the shipper's expected loss function taking derivatives against K yields:

$$\frac{dL_s}{dK} = -t\int_0^{\omega} h(y)dy$$

L_s further taking second derivatives against K yields:

$$\frac{d^2L_s}{dK^2} = -\frac{t^2}{p-f+t}h(\omega) \leq 0$$

Therefore L_s is also concave in K. Then U_s is concave in K because $\theta - 1 \geq 0$. Then the unique optimal solution can be obtained from Equation (11).

(ii) Denote $\lambda(y) = p - \alpha - \beta y$. The expected profit supposing carrier integrated with shipper is:

$$\Pi_i = pE(D) - cK - \int_K^{\infty}\int_{\underline{\gamma}}^{\lambda(y)} (\alpha+\beta y+x)(y-K)g(x)h(y)dxdy$$

$$-\int_K^{\infty}\int_{\lambda(y)}^{\infty} p(y-K)g(x)h(y)dxdy + \sigma\int_0^K\int_{\underline{\gamma}}^{\infty} (\alpha+\beta y+x)(K-y)g(x)h(y)dxdy$$

Π_i taking derivatives against K yields:

$$\frac{d\Pi_i}{dK} = -c + \int_K^{\infty}\int_{\underline{Y}}^{\lambda(y)} (\alpha + \beta y + x)g(x)h(y)dxdy$$

$$+ \int_K^{\infty}\int_{\lambda(y)}^{\infty} pg(x)h(y)dxdy + \sigma\int_0^K\int_{\underline{Y}}^{\infty}(\alpha + \beta y + x)g(x)h(y)dxdy$$

Π_i further taking second derivatives against K yields:

$$\frac{d^2\Pi_i}{dK^2} = h(K)\left\{-\int_{\underline{Y}}^{\lambda(K)} (\alpha + \beta K + x)g(x)dx - \int_{\lambda(K)}^{\infty} pg(x)dx + \sigma\int_{\underline{Y}}^{\infty} (\alpha + \beta K + x)g(x)dx\right\}$$

$$= h(K)\{-E\text{Min}\{\alpha + \beta K + \gamma, p\} + \sigma E(\alpha + \beta K + \gamma)\} \leq 0$$

Note that $E\text{Min}\{R, p\} \geq \sigma E(R)$. Hence Π_i is concave in K and the unique optimal solution can be obtained from the first-order condition.

By rearranging the first-order conditions for DC case without coordination, supposing the shipper is risk-neutral and supposing the shipper integrates with the carrier, it can be observed that the right-hand sides of them have the following inequalities:

$$f\int_K^{\infty} h(y)dy + t\int_0^K h(y)dy + (\theta - 1)t\int_0^{\omega} h(y)dy \geq f\int_K^{\infty} h(y)dy + t\int_0^K h(y)dy$$

$$\geq c - \sigma\int_0^K\int_{\underline{Y}}^{\infty} (\alpha + \beta y + x)g(x)h(y)dxdy$$

because $f \geq c$ and $t \geq c$. The second derivatives of the left-hand sides are decreasing in K. Hence $K^* \leq K_n \leq K_i^*$. □

A.6. Proof of Proposition 5

(i) Expression (8) the expected profit of the carrier can be rewritten as:

$$\Pi_c = \int_0^K fyh(y)dy + \int_K^{\infty} fKh(y)dy - cK$$

$$+ \int_0^K\int_{\underline{Y}}^{\infty} [\sigma(\alpha + \beta y + x) + t](K - y)g(x)h(y)dxdy$$

Π_c taking derivatives against f yields the first-order condition Equation (12). Taking derivatives against f from the shipper's first-order condition (11) yields:

$$-\left[\int_{\underline{Y}}^{\lambda(K)} (\alpha + \beta K + x)g(x)dx + p\int_{\lambda(K)}^{\infty} g(x)dx\right]h(K)\frac{dK}{df}$$

$$= 1 - H(K) - (f - t)h(K)\frac{dK}{df} + (\theta - 1)\frac{t^2}{(p - f + t)^2}h(\omega)\left[(p - f + t)\frac{dK}{df} + K\right]$$

Then we have Expression (13) for $\frac{dK^*}{df}$. Since $t + \alpha + E(\gamma) \geq f$, it can be observed that the $\frac{dK^*}{df} \leq 0$, which means that the equilibrium is unique.

(ii) Taking derivatives against θ in the first-order condition (11) yields:

$$\left[-\int_{\underline{Y}}^{\lambda(K)} (\alpha + \beta K + x)g(x)dx - p\int_{\lambda(K)}^{\infty} g(x)dx + f - t\right]h(K)\frac{dK}{d\theta}$$

$$= tH(\omega) + (\theta - 1)\frac{t^2h(\omega)}{p - f + t}\frac{dK}{d\theta}$$

Then we have:

$$\frac{dK}{d\theta}=-\frac{tH(\omega)}{h(K)[\text{Min}\{\alpha+\beta K+E(\gamma),p\}-f+t]+(\theta-1)\dfrac{t^2h(\omega)}{p-f+t}}\leq 0$$

which means that K^* is decreasing in θ. Furthermore, $\frac{dK^*}{df}\leq 0$ shows that K^* and f^* are submodular. Therefore, as θ increases, the carrier will reduce the freight rate f anticipating that the shipper will reduce capacity K. Hence, f^* is also decreasing in θ.

Taking derivatives against β in the first-order condition (11) yields:

$$-h(K)\frac{dK}{d\beta}\int_{\underline{Y}}^{\lambda(K)}(\alpha+\beta K+x)g(x)dx+\int_K^{\infty}pg[\lambda(y)]h(y)dy+\int_K^{\infty}\int_{\underline{Y}}^{\lambda(y)}yg(x)h(y)dxdy$$

$$-ph(K)\frac{dK}{d\beta}\int_{\lambda(K)}^{\infty}g(x)dx+\int_K^{\infty}pg[\lambda(y)]h(y)dy-(f-t)h(K)\frac{dK}{d\beta}=(\theta-1)\frac{t^2h(\omega)}{p-f+t}\frac{dK}{d\beta}$$

Then we have:

$$\frac{dK}{d\beta}=\frac{2\int_K^{\infty}pg[\lambda(y)]h(y)dy+\int_K^{\infty}\int_{\underline{Y}}^{\lambda(y)}yg(x)h(y)dxdy}{h(K)[\text{Min}\{\alpha+\beta K+E(\gamma),p\}-f+t]+(\theta-1)\dfrac{t^2h(\omega)}{p-f+t}}\geq 0$$

which means that K^* is increasing in β. Furthermore, $\frac{dK^*}{df}\leq 0$ shows that K^* and f^* are submodular. Therefore, as β increases, the carrier will increase the freight rate f anticipating that the shipper will increase capacity K. Hence, f^* is also increasing in β. □

A.7. Proof of Proposition 6

(i) According to the definition of *coordination*, the objective function of the carrier and the shipper is

$$\underset{f(K)\geq c,K\geq 0}{\text{Max}}\ \Pi_c+U_s\ [f(K),K]$$

$$s.t.\begin{cases}\Pi_c\geq\Pi_c^*\\ U_s\geq U_s^*\\ \Pi_c\geq\Pi_c^*+\dfrac{1}{2}[\Pi_c+U_s-(\Pi_c^*+U_s^*)]\\ U_s\geq U_s^*+\dfrac{1}{2}[\Pi_c+U_s-(\Pi_c^*+U_s^*)]\end{cases}$$

The meaning of the constraint conditions are that: the carrier's expected profit and the shipper's expected utility shall have improvement; both the carrier and the shipper shall share be allocated at least half of the increment. The conditions can be simplified as $s.t.\Pi_c-U_s=\Pi_c^*-U_s^*$. The first-order condition of the objective function is $\frac{d(\Pi_c+U_s)}{dK}=0$, which is Equation (14). The equation $\Pi_c-U_s=\Pi_c^*-U_s^*$ taking derivatives on K yields:

$$2\frac{df}{dK}\int_0^K yh(y)dy+2\left(\frac{df}{dK}K+f\right)\int_K^{\infty}h(y)dy-c-\int_K^{\infty}\int_{\underline{Y}}^{\lambda(y)}(\alpha+\beta y+x)g(x)h(y)dxdy$$

$$-\int_K^{\infty}\int_{\lambda(y)}^{\infty}pg(x)h(y)dxdy+\sigma\int_0^K\int_{\underline{Y}}^{\infty}(\alpha+\beta y+x)g(x)h(y)dxdy+2t\int_0^K h(y)dy$$

$$+(\theta-1)\int_0^{\frac{t}{p-f+t}K}\left(\frac{df}{dK}y+t\right)h(y)dy=0$$

Compared the above equation with Equation (14) and then we can have Equation (15) which is negative. And

$$\frac{d^2 f}{dK^2} = \frac{2\left[\int_K^\infty f h(y)dy + \int_0^K [t+\alpha+\beta y+E(\gamma)]h(y)dy - c\right] + (f-t)h(K)\left[\int_0^K yh(y)dy + \int_K^\infty Kh(y)dy\right]}{\left[\int_0^K yh(y)dy + \int_K^\infty Kh(y)dy\right]^2}$$

$$\geq 0$$

meaning that f is decreasing convex in K. The value of the second derivative in the neighbourhood of K_o is

$$\left.\frac{d^2(\Pi_c + U_s)}{dK^2}\right|_{K=K_o}$$

$$= -h(K)\left\{\int_{\underline{Y}}^{\lambda(K)} (1-\sigma)(\alpha+\beta K+x)g(x)dx + \int_{\lambda(K)}^{\infty} [p-\sigma(\alpha+\beta K+x)]g(x)dx\, h(K)\right\}$$

$$-(\theta-1)\left\{\frac{\left[(p-f+t)t + tK\frac{df}{dK}\right]^2}{(p-f+t)^3} h\left(\frac{t}{p-f+t}K\right)\right\} \leq 0$$

Hence, $\Pi_c + U_s$ is concave in the neighborhood of any stationary point K_o. Thus, the uniqueness of equilibrium $\{f_0(K_o), K_o\}$ is proved.

(ii) By comparing Equation (14) with Equations (11) and the first-order condition of K_i^*, we can observe that $K^* \leq K_o \leq K_i^*$, which means that with coordination, the shipment procurement capacity amount is larger, but it is still smaller than the value supposing carrier and shipper are integrated.

(iii) It can be obtained from (ii). □

References

Alexandridis, G., Sahoo, S., Song, D., Visvikis, I., 2018. Shipping risk management practice revisited: A new portfolio approach. Transport. Res. Part A: Policy Pract. 110, 274-290.

Budak, A., Ustundag, A., Guloglu, B., 2017. A forecasting approach for truckload spot market pricing. Transport. Res. Part A: Policy Pract. 97, 55-68.

Chang, C., Xu, J., Song, D., 2015. Risk analysis for container shipping: from a logistics perspective. Int. J. of Logist. Manage. 26 (1), 147-171.

Chen, G., Rytter, N. G., Jiang, L., Nielsen, P., Jensen, L., 2017. Pre-announcements of price increase intentions in liner shipping spot markets. Transport. Res. Part A: Policy Pract. 95, 109-125.

Choi, T., 2021. Risk Analysis in Logistics Systems: A Research Agenda During and After the COVID-19 Pandemic. Transport. Res. Part E: Logist. Transport. Rev. 145, 1-8.

Choi, T., Chiu, C., Chan, H., 2016. Risk management of logistics systems. Transport. Res. Part E: Logist. Transport. Rev. 90, 1-6.

Choi, T., Wen, X., Sun, X., Chung, S., 2019. The mean-variance approach for global supply chain risk analysis with air logistics in the blockchain technology era. Transport. Res. Part E: Logist. Transport. Rev. 127, 178-

191.
Fisk, C. S., 1984. Game theory and transportation systems modelling. Transport. Res. Part B: Methodol. 18 (4), 301-313.
Fransoo, J. C., Lee, C. Y., 2013. The critical role of ocean container transport in global supply chain performance. Prod. Oper. Manage. 22 (2), 253-268.
Fugate, B. S., Davis Sramek, B., Goldsby, T. J., 2009. Operational collaboration between shippers and carriers in the transportation industry. Int. J. Logist. Manage 20 (3), 425-447.
Gan, X., Sethi, S. P., Yan, H., 2005. Channel coordination with a risk-neutral supplier and a downside-risk-averse retailer. Prod. Oper. Manage. 14 (1), 80-89.
Gayle, P. G., 2013. On the efficiency of codeshare contracts between airlines: is double marginalization eliminated? Amer. Econ. J.: Microecon. 5 (4), 244-73.
Joo, S., Min, H., Smith, C., 2017. Benchmarking freight rates and procuring cost-attractive transportation services. Int. J. Logist. Manage. 28 (1), 194-205.
Kahneman, D., Tversky, A., 1979. Prospect theory: An analysis of decision under risk. Econometr. : J. Econ. Soc. 47 (1), 263-291.
Kavussanos, M. G., Visvikis, I. D., Batchelor, R. A., 2004. Over-the-counter forward contracts and spot price volatility in shipping. Transport. Res. Part E: Logist. Transport. Rev. 40, 273-296.
Lee, C. Y., Tang, C. S., Yin, R., An, J., 2015. Fractional price matching policies arising from the ocean freight service industry. Prod. Oper. Manage. 24 (7), 1118-1134.
Lee, C., Song, D., 2017. Ocean container transport in global supply chains: Overview and research opportunities. Transport. Res. Part B: Methodol. 95, 442-474.
Liu, J., Wang, J., 2019. Carrier alliance incentive analysis and coordination in a maritime transport chain based on service competition. Transport. Res. Part E: Logist. Transport. Rev. 128, 333-355.
Michail, N. A., Melas, K. D., 2020. Shipping markets in turmoil: An analysis of the Covid-19 outbreak and its implications. Transport. Res. Interdisci. Persp. 7, 1-9.
Oscar, A., Pedro, C., Moner-Colonques, R., Jose, J. S., 2013. Vertical integration and exclusivities in maritime freight transport. Transport. Res. Part E: Logist. Transport. Rev. 51, 50-61.
Prochazka, V., Adland, R., Wallace, S. W., 2019. The value of foresight in the drybulk freight market. Transport. Res. Part A: Policy Pract. 129, 232-245.
Spengler, J. J., 1950. Vertical integration and antitrust policy. J. Polit. Econ. 58 (4), 347-352.
Tan, Z., Meng, Q., Wang, F., Kuang, H., 2018. Strategic integration of the inland port and shipping service for the ocean carrier. Transport. Res. Part E: Logist. Transport. Rev. 110, 90-109.
Tirole, J. (1988). The Theory of Industrial Organization, the MIT Press.
Wang, H., Meng, Q., Zhang, X., 2014. Game-theoretical models for competition analysis in a new emerging liner container shipping market. Transport. Res. Part B: Methodol. 70, 201-227.
Wang, J., Liu, J., Zhang, X., 2020. Service purchasing and market-entry problems in a shipping supply chain. Transport. Res. Part E: Logist. Transport. Rev. 136, 1-24.
Wang, S., Wang, H., Meng, Q., 2015. Itinerary provision and pricing in container liner shipping revenue management. Transport. Res. Part E: Logist. Transport. Rev. 77, 135-146.
Xu, J. J., Yip, T. L., Marlow, P. B., 2011. The dynamics between freight volatility and fleet size growth in dry bulk shipping markets. Transport. Res. Part E: Logist. Transport. Rev. 47, 983-991.
Yang, D., Jiang, L., Ng, A. K., 2018. One Belt one Road, but several routes: A case study of new emerging trade corridors connecting the Far East to Europe. Transport. Res. Part A: Policy Pract. 117, 190-204.

Yang, D., Pan, K., Wang, S., 2018. On service network improvement for shipping lines under the one belt one road initiative of China. Transport. Res. Part E: Logist. Transport. Rev. 117, 82-95.

Yang, R., Gao, X., Lee, C., 2017. A novel floating price contract for the ocean freight industry. IISE Trans. 49 (2), 194-208.

Yang, R., Lee, C., Liu, Q., Zheng, S., 2019. A carrier-shipper contract under asymmetric information in the ocean transport industry. Annal. Oper. Res. 273 (1), 377-408.

Zhang, A., Czerny, A. I., 2012. Airports and airlines economics and policy: An interpretive review of recent research. Econ. of Transp. 1 (1-2), 15-34.

Zhang, A., Zhang, Y., 2006. Rivalry between strategic alliances. Int. J. Indus. Organ. 24 (2), 287-301.

Zheng, W., Li, B., Song, D., 2017. Effects of risk-aversion on competing shipping lines' pricing strategies with uncertain demands. Transport. Res. Part B: Methodol. 104, 337-356.

Zou, L., Oum, T. H., Yu, C., 2011. Assessing the price effects of airline alliances on complementary routes. Transport. Res. Part E: Logist. Transport. Rev. 47 (3), 315-332.