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Pricing and balancing of the sea–cargo service chain with empty equipment repositioning

Lei Xu [a], Kannan Govindan [b], Xiangzhi Bu [c,*], Yilin Yin [a]

[a] School of Management, Tianjin University of Technology, Tianjin 300384, PR China
[b] Department of Business and Economics, University of Southern Denmark, DK-5230 Odense M, Denmark
[c] Business School, Shantou University, Shantou 515063, PR China

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ABSTRACT

To sustain a business, firms have to reposition empty containers from a surplus port to a port with a shortage and incur repositioning costs if the realized demands are unbalanced in the sea–cargo service chain. In this paper, we study a sea cargo service chain with one carrier and two forwarders providing transportation service between two ports, and there are potential demands for transportation services in both directions. We built a mathematical model to study how the carrier and forwarders determine pricing and empty equipment repositioning (hereafter EER) decisions. We find that whether or not the carrier and forwarders use pricing policies to balance the cargo demands depends on the potential demand imbalance volume between two ports. We also investigate the EER sharing strategy on whether to share the EER cost or undertake it solely. It is found that there exists a threshold, and when the EER cost is beyond the threshold value, the carrier assumes all of the repositioning costs; otherwise, the forwarder assumes all of the repositioning costs. Lastly, we study a subsidy contract between both forwarders and expand to study an EER sharing mode between the carrier and both forwarders.

1. Introduction

The global sea cargo business is one of the fastest-growing industries. Starting in the 1990s, the globalization of world economy has accelerated the containerization of sea trade [1,2]. Today, over 60% of the world's maritime cargo transported is in containers; moreover, some routes are containerized up to 100% [3]. However, international trade is typically unbalanced: certain areas are predominantly exporting areas, whereas others are mainly importing areas. This imbalance generates certain logistical challenges to the management of empty containers [4]. In practice, EER is part of the commodity package for recycling and redistribution of reverse logistics [5]. For this reason, it is considered an inefficient method of transportation. Nevertheless, due to the intrinsic imbalance, it is difficult to eliminate repositioning costs. Therefore, this issue has been becoming a curse for the transportation industry. In 2003, empty containers constituted approximately 20% of the total number of transported containers, increasing the repositioning costs up to $11 billion [6]. According to [7], in the ocean containerized transportation industry, 60% of the containers that crossed from Asia to North America and 41% of those from Asia to Europe, came back empty in 2005. Recently, a series of solutions to the EER have been proposed in the literature and in practice, such as information sharing, using foldable containers, sharing container fleets and equipment transportation optimization. However, solutions from the perspective of the whole service chain are yet to be seen.

In the sea–cargo service chain, there exist different members such as shippers, forwarders (or consolidators), carriers, integrators and consignees. Shippers can choose to send cargo either through an integrator, directly through the carrier, or through a forwarder. The forwarders usually have marketing expertise and long-term relationships with shippers, which attracts demand that is not directly accessible to carriers [8]. Carriers typically pre-allocate a large proportion of available capacity on specific ships to forwarders while the remaining capacity is sold to either direct shippers or forwarders on an ad-hoc basis. Forwarders may pay a fixed amount well in advance of a departure either as full payment for the capacity booked or as a capacity reservation fee, so the type and pricing of the contract are interesting problems worth study.

Pricing in the transportation industry – besides its usual usage for revenue management as in many other industries – is also a useful tool for cost management [9]. In sea–cargo service chain, by pricing, a forwarder can directly adjust its realized demands as well as EER costs while the carrier can adjust the capacity contract pricing to indirectly influence the cargo demand and EER cost. This

* Corresponding author. Tel.: +86 754 8650 3661; fax: +86 754 8290 3442.
E-mail addresses: xzpu@stu.edu.cn, steve.xbu@gmail.com (X. Bu).

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fact makes the pricing problem in the sea–cargo supply chain more interesting and yet more complex. However, little is known about how to set contract and retailing prices optimally in a sea–cargo service chain with EER. Furthermore, the outcome of the EER cost sharing policies between carrier and forwarders in such a sea cargo service chain largely remains unknown.

Our research aims to provide understanding of these issues by constructing and analyzing a mathematical model which explicitly considers EER costs and the sharing policy between carrier and forwarders. We focus our study on the sea–cargo service chain between bi-directional ports with price dependent demands. EER cost sharing can make the carriers and forwarders share the risk of cargo imbalance jointly. Such risk sharing behavior could influence the pricing policy of carriers and forwarders which will further affect the potential demand between the ports and the EER cost.

More specifically, we mainly address the following research topics identified from the cited gap:

1. As the leader of the service chain, how carrier determines the sharing policy of the EER cost. For example, the carrier completely undertakes the EER costs, the carrier and forwarders share the EER activity jointly, and the forwarder undertakes the EER activity solely.
2. Given the cost sharing policy, how the carrier manages the EER activity and capacity pricing policy (i.e., balancing the potential cargo demand of dual directions by pricing) or maximizing the profits by repositioning empty containers.
3. Given the cost of the sharing policy, how the forwarder should determine the pricing policy in the port with surplus containers and what the forwarder's response is to the port with the container shortage.
4. How the pricing and empty cost sharing policies affect the profit for the carrier and forwarder and how it affects the performance of the whole service chain.
5. How the forwarders set subsidy contracts to solve EER problems.

The rest of the paper is organized as follows: Section 2 briefly reviews the relevant literature; Section 3 gives a detailed description of the problem and constructs an elementary model; Section 4 details the optimal pricing strategy of the carrier and forwarders under EER; Section 5 investigates the influence of the sharing policy on the performance of the whole service chain as well as the subsidy contract between two forwarders; Section 6 details a numerical study on the pricing and sharing policy, and in Section 7 an extension is given; concluding remarks are presented in Section 8. To simplify our exposition, all proofs and mathematical derivations are provided in the appendix.

2. Literature review

There are mainly three streams of literature related to our work: EER, supply chain contracts, and pricing in transportation markets.

The earlier studies on EER mainly concentrate on technology aspects, for example, container refurbishment and storage and maintenance [10], [11] and [12]. Since the 1990s, considerable work has been done from the business perspective. The first work was proposed by Crainic et al. [13] to address the problem of inlands empty container transportation where a general model with stochastic cargo demand and supply was built. Later on, Cheung and Chen [1] put forward a two-stage stochastic network model and analyzed the strategy of redistribution and costs of renting empty shipping/containers.

The Markovian decision method is employed in Song [3], which studied the multi-period transportation problem. Li et al. [14] addressed the empty redistribution problem in single port and proposed the optimal rental policy then extending to a multi-port problem by analyzing the flexibility of the heuristic method. More recently, Song and Dong [15] studied a problem of joint cargo routing and EER at the operational level with multiple service routes in a shipping network. While the aforementioned studies mostly focus on finding an optimal EER policy, few studies refer to operation and coordination issues from the perspective of the sea–cargo service chain, as well as the pricing policy for transportation participants.

The second stream of research is about the supply chain contract and coordination issues with long term and spot markets. Wu et al. [16] developed bidding strategies in the presence of a long-term contract market and a short-term spot market, incorporating only market risk in the form of spot price uncertainty and assuming demand and cost as deterministic. Spinler [17] extended the model based on Wu et al. [16] to a general valuation framework by incorporating state-contingent demands and costs and a willingness-to-pay function depending on the state of the world. Recently, many studies on supply chain contract problems focus on the application of flexible contract in cargo business. Hellerman and Huchzermeier [18] took Lufthansa Cargo AG (LGA) as an example to discuss the policies of capacity allocation and pricing and emphasize the potential value of flexible contracts. Hellerman [19] studied the application of real options in the air cargo industry and finds that the real option contract was better than the price-only option. More flexible contracts were put forward in Gupta [20]. Amaruchkul et al. [21] extended the previous work by considering the information asymmetric problem. While the above works mainly focus on the application of supply contracts, little study involves the pricing policy and EER problems.

Another stream of literature related to our work is on pricing and revenue management in the transportation market. Hueley and Petersen [22] studied optimal freight pricing problems in a network system with multiple shippers and carriers. They showed a two-part tariff charged by the carrier (or coalition of carriers) can achieve maximum system profits. Wan and Levary [23] proposed a negotiation procedure for shippers contracting with ocean carriers, which came from a linear programming model with sensitivity analysis. Toptal and Bingöl [24] studied the transportation pricing problems of a truckload carrier in a setting that consists of a retailer, a truckload carrier, and a less than truckload carrier. They modeled the problem as an underlying inventory replenishment problem and considered the availability of two modes of transportation with different structures. Considering pricing and EER problems, Gorman [25] formulated a carrier's pricing problem as a mathematical programming model in a network and provided an efficient computational algorithm to solve the problem. Equipment repositioning is required if the demand flow in the network is unbalanced. Topaloglu and Powell [26] addressed the problem of how to coordinate the pricing and fleet management decisions of a carrier in a network where the cost of EER plays a significant role. The most related work to ours is Zhou and Lee [9] which studied a transportation market with two firms providing transportation service between two locations with EER. They found that in the duopoly market the optimal pricing strategy of a firm was either to achieve the balance of realized demands or treat these two directions as two separate markets. While in a duopoly market, they found that a higher EER unit cost may help firms to obtain higher profits. However, they just addressed a one-echelon problem. In contrast, we extend the previous work by developing the joint pricing policy of three echelon supply chain which consists of the carrier, forwarders, and the shippers. We also analyze the optimal joint pricing policy and the repositioning cost