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Quantity discount pricing for container transportation services by shipping lines

Ming Yin [a,b], Kap Hwan Kim [a,*]

[a] Department of Industrial Engineering, Pusan National University, Changjeon-dong, Kumjeong-ku, Busan 609-735, Republic of Korea
[b] College of Transport and Communications, Shanghai Maritime University, 1550 Haigang Avenue, Pudong New Area, Shanghai 201306, PR China

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ABSTRACT

Because transportation services provided by container lines to forwarders cannot be stored, they can be considered to be newsvendor-type products. This paper discusses a method used to optimize container lines' freight tariffs in order to maximize their expected profit by considering changes in order quantities made by forwarders responding to the price schemes suggested by the container lines. The container line freight tariff can be characterized by price-break points, discounted freight rates, and penalties for unsold space. An analytic model has been designed that addresses all-unit quantity discount schemes with single or multiple price-break points. Some properties regarding the optimal solution are suggested and a procedure to find the optimal freight tariff is provided. Numerical examples are provided that illustrate the solution procedure and various numerical experiments have been done in order to analyze the effectiveness of the quantity discount scheme employing a penalty.

1. Introduction

Being a very significant component of the international supply chain, the container liner industry plays an important role in the movement of goods all over the world. This industry has many distinct features that sets it apart from others, in such that the services provided by the lines can be presold but cannot be stored and the services are usually sold to intermediaries instead of directly to the real shippers. The intermediaries, hereinafter called "forwarders", are also usually identified as non-vessel operating common carriers (NVOCCs) in certain countries, e.g. China and the US. This indirect sales mode is very prevalent because shipping lines face tremendous shippers that usually exceed their direct sales capability. Forwarders usually collect and arrange shipments from real shippers, and sometimes even consolidate LCL (less than container load) cargoes into FCL (full container load) cargoes for the real lines. Their profit comes from the price difference between the freight collected from shippers and that paid to the lines.

Although the lines can usually, to a certain extent, take advantage of their traditional preponderant position during their pricing decision, a liner operator cannot decide the freight rate by merely considering his own profit; for the sustainable development of his business in a competitive market he must consider his forwarders' profit at the same time so that a reasonable profit share to them can be ensured. Given that the service quality by different lines is more or less at the same level, the offered freight rates become one of the key factors forwarders need to consider when choosing a specific container line. Of course, all rational forwarders will prefer to choose the one giving them the most profit.

"Product" in the container liner industry is the transport services provided by container lines. Obviously, this kind of product cannot be stored, because, once a particular voyage is undertaken, all unutilized slots on board will be wasted. Forwarders buy slots from lines wholesale and then sell them to the real shippers, which makes forwarders act in a similar manner to "newsvendors"; the corresponding slots can be thought of as "newspapers". In other words, slots bought and sold by forwarders can be defined as typical newsvendor-type products. Unlike most of other similar services, inventory and setup costs, in their common usage, are usually not involved in this kind of product.

In short, if the business relationship between the lines and forwarders is thought of as a kind of game, the lines can take the position of the game rule makers, and correspondingly the forwarders serve as newsvendor-type followers. When a certain line designs a set of game rules, he needs to take into account the followers' profit along with his own, otherwise he might lose the followers, leading to a loss in the competition with other lines. A simple price-cutting policy is not a proper way to ensure both the line's and his forwarders' profit. Instead, many lines adopt a differential pricing policy, e.g. a quantity discount (QD), granting discounts to certain forwarders whose order quantity exceeds certain preset price-break points. In this paper, not only are price-break points and freight rates studied, another important decision factor, the penalty rate, is also considered and optimized.

Crowther (1964) first discussed the possibility of simultaneously improving a supplier's profit and reducing his buyer's cost through the use of a QD scheme. He also described numerically how to

* Corresponding author. Tel.: +82 51 510 2419; fax: +82 51 512 7603.
E-mail address: kapkim@pusan.ac.kr (K.H. Kim).

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determine the terms of a QD scheme and how to divide the profit, as a result of the changes in price and order size, between the supplier and the buyer. Monahan (1984) analyzed how a supplier could design an all-unit QD system for a single customer. He examined a supplier conducting lot-for-lot production with an infinite production rate and showed that the supplier could increase his profit by offering an all-unit QD with one price-break point to a major buyer in order to induce the buyer to increase the order quantity.

Lee and Rosenblatt (1986) generalized Monahan's model and through it simultaneously determined the desired supplier's lot size and the buyer's order quantity. Goyal (1987a), Goyal (1987b) provided further research based on Lee and Rosenblatt's (1986) work and developed a certain algorithm improvement. Kim and Hwang (1988) analyzed how a supplier could determine the terms of a QD pricing scheme and developed a model from which an algorithm was derived for an optimal discount schedule under the assumption of an incremental discount system with a single price-break point. Kim and Hwang (1989) then derived formulas regarding the price and the order size, maximizing the economic gain of the supplier as a result of revising the price and the order size, the gain of the buyer, and the sum of the gains of both parties. They also suggested how the supplier could induce the buyer to use a mutually beneficial predetermined price and order-size level through the utilization of an all-unit or an incremental QD system. All of the above studies assumed that the demand rate was constant and independent of the price.

Khouja (1995) formulated and solved the newsvendor problem by developing a multiple price-break points discount. This solution addressed the objectives of maximizing the expected profit and maximizing the probability of achieving a target profit. He showed that the multiple price-break points discount provided a higher expected profit when compared to a single price-break discount. Khouja (1999) built a taxonomy of the literature on the single-period problem (SPP) and delineated the contribution of different SPP extensions. Lau and Lau (1999) presented a model used to design the pricing and return-credit strategy for a monopolistic manufacturer of single-period commodities. Khouja (2000) extended the SPP to the case in which demand was price-dependent; the multiple price-break points discount with prices under the control of the newsvendor was used to sell excess inventory. Lau, Lau, and Wang (2007) proposed a practical approach for designing a QD scheme for a manufacturer who supplied a newsvendor-type product to a large number of heterogeneous retailers. They showed that the expected-profit function could be easily optimized to derive QD schemes; these schemes were shown to be quite robust against errors in parameter estimation. Qin, Wang, Vakharia, Chen, and Seref (2011) reviewed the contributions about the newsvendor problem.

Related to shipment planning considering transport costs, Ang, Cao, and Ye (2007) discussed the multi-period sea cargo mix problem for international ocean shipping industry. Tsao and Sheen (2012) considered a multi-item supply chain with a credit period and freight discounts related to the weight of the cargo, outlined the optimal properties, and developed algorithms for solving the problems. Li, Bookbinder, and Elhedhli (2012) addressed the shipment planning problem for an airfreight forwarder considering various consolidation effects including the quantity discount.

Some other representative literature focusing on quantity discount include: Chakravarty and Martin (1989), Weng (1995), Wang and Wu (2000), Corbett and de Groote, (2000), Munson and Rosenblatt (2001), Li and Liu (2006), etc.

Generally, most studies of QD schemes have not addressed newsvendor-type products. In addition, hardly any research of the QD problem has considered penalty rate optimization. As it turns out, the setting of a penalty rate has a great impact on the profit and the cost for forwarders and lines. A high penalty rate induces forwarders to make a conservative decision and a low one inspires forwarders to set their order quantities more aggressively. The profit of the line is directly affected by the forwarders' ordering quantity. Consequently, in addition to considering the price-break points and the discounted freight rates, a great deal of attention should be paid to optimizing the penalty rate when designing a QD scheme.

Section 2 analyzes a QD pricing model with a single price-break point. Section 3 proposes an optimizing method for a QD pricing model with multiple price-break points. Section 4 provides the numerical analysis results; Section 5 gives some concluding remarks.

2. The single price-break point quantity discount scheme

A line and a forwarder agree upon their sales conditions in a service contract covering a certain period of time, in which the line offers a specific QD to the forwarder based on the required number of slots (20-foot equivalent units: TEUs). Usually, the more slots the forwarder promises to book during the period, the more favorable the offered discount by the line. Correspondingly, if the forwarder fails to actually book the full number of promised slots, the line will be compensated, which could be seen as a penalty for the breach of the minimum quantity promise in the service contract.

The following assumptions are used in this paper:

1. The all-unit QD system is used, which is the most popular pricing schedule in use today.
2. The same freight tariff is given to all forwarders.
3. The order quantity and discounted freight rate are continuous.

The following notations are introduced:

Input data for forwarders

N	The set of forwarder indices, $\{1, 2, \ldots, n\}$, where n is the number of forwarders
R	The freight rate offered by forwarders to shippers
D_i	The demand faced by forwarder i
$f_i(\cdot)$	The probability density function of the demand faced by forwarder i
$F_i(\cdot)$	The cumulative distribution function of the demand faced by forwarder i
$F_i^{-1}(\cdot)$	The inverse cumulative distribution function of the demand faced by forwarder i

Input data for the line

C	The unit carriage cost of the line, including both the fixed and variable costs
W_0	The regular freight rate announced by the line to the forwarders, which is assumed to be decided by the competitive market and given as an input parameter
P_0	The original penalty rate announced by the line to the forwarders, which is assumed to be decided by the competitive market and given as an input parameter

Decision variables

Q_i	The order quantity agreed upon between the line and forwarder i in their service contract
$W(\cdot)$	The freight rate agreed upon privately in the service contract, which is a function of the order quantity; its range is assumed to be (C, W_0)
P	The penalty rate agreed upon privately in the service contract