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Improving the supply chain's performance through trade credit under inventory-dependent demand and limited storage capacity

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ABSTRACT

The present paper develops a performance-improving model through trade credit for a two-echelon supply chain, where a supplier sells a single product through a retailer who has limited storage space and faces an inventory-dependent end demand. We consider the non-integrated and integrated optimizing model. Under the non-integrated optimizing model, we present how the supplier determines the trade credit period to induce the retailer ordering more so as to reduce the supplier's operating cost and enhance sales volume of products as well. The proposed model shows that the presented trade credit policy can increase each member's profitability but also the profitability of the whole channel. Furthermore, we develop a theorem to efficiently determine the optimal inventory and trade credit policy for the integrated optimizing model.

1. Introduction

In the classical EOQ model, it is assumed that a retailer must pay for items once he/she received them from a supplier. However, many suppliers usually allow in practice their retailers a trade credit for settling the account without any interest charged. For example, Wal-Mart, the largest retailer in the world, has used trade credit as a larger source of capital than bank borrowings. Also, Aaronson et al. (2004) reported that "60.8 percent of firms had outstanding credit from suppliers". This type of trade credit is equivalent to offering the retailers short-term interest-free finance in stock. Hence, the trade credit should affect the retailer's conduct of order significantly. In this regard, a lot of research papers discussed the inventory problems with trade credit. For example, researchers like Haley and Higgins (1973), Goyal (1985) studied the effect of trade credit period on the optimal inventory policy. Zhou (1997) discussed the impact of different rules for delay in payment on the retailer's order policy. Recently, by using a DCF approach, Chung and Liao (2009) developed an inventory model where trade credit is dependent on the quantity ordered. However, these papers assumed that the demand was a known constant. They ignored the effects of price on the demand volume. In order to reflect it in inventory models with trade credit permitted, Teng et al. (2005), Sheen and Tsao (2007) have employed price-sensitive demand. Tsao and Sheen (2008) studied the problem of dynamic pricing, promotion and replenishment for a deteriorating item subject to the supplier's trade credit and the retailer's promotional effort. In their paper, they adopted a price- and time-dependent demand function to model the finite time horizon inventory for deteriorating items.

Besides price and promotion, many marketing researchers, such as Levin et al. (1972) and Silver and Peterson (1985), noted that holding higher inventory level in the retail industry would probably make retailers sell more items. It implies that the inventory level of items also affects their marketing demand. Since a delay of payments directly reduces inventory cost, trade credit policy actually encourages the retailer to order a larger lot size of items, and ultimately leads to a greater sales volume. Hence, from retailers' side, a key question is how to determine their order batch size for a given trade credit policy if demand is stock-dependent. Under ignoring capacity limitation of warehouses, Sana and Chaudhuri (2008) analyzed a kind of EOQ model with a current-stock-dependent demand rate where a supplier gives a retailer both a credit period and a price discount on the purchase of merchandise. Soni and Shah (2008) developed the optimal ordering policy for retailers who face a stock-dependent demand and two progressive credit periods offered by suppliers. Recently, Min et al. (2010) developed a lot-sizing model for deteriorating items with a current-stock-dependent demand and delay in payments. In reality, however, the available capacity of warehouse is always limited. In this paper, we will further consider under any given trade credit policy how retailers determine their order batch sizes when they face limited storage capacity and an inventory-level-dependent demand.

All the researches mentioned above are implemented from the perspective of the retailer. However, to the best of our knowledge, only limited researches have been done from the perspective of the supplier. Kim et al. (1995) formulated a model to determine the optimal credit period for the supplier and the optimal sales price and corresponding order quantity for the retailer. In their

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model, they restricted their analysis to non-cooperative leader–follower relationship and the supplier's order decision to the lot-for-lot (LFL) policy. Abad and Jaggi (2003) reconsidered Kim et al.'s problem, and developed a model for determining optimal supplier and retailer policies. Luo (2007) considered a two-echelon inventory-coordinated model where the supplier entices the retailer increasing order quantity through a permissible trade credit. Arkana and Hejazi (2011) designed a coordination mechanism based on a credit period in a two echelon supply chain. However, these models consider a constant demand or a price-sensitive demand only. Moreover, they assumed that retailers had unlimited storage space. Recently, Zhou et al. (2012) developed a two-echelon supply chain model with trade credit, in which the retailer faces limited display shelf space, but can stock the remaining to the backroom. Our paper also focuses on how the supplier designs the trade credit policy to maximize his/her own profits when the retailer faces the inventory-dependent demand and limited storage space, but cannot rent the warehouse to stock the remaining.

The above models consider the objective from either the retailer's or the supplier's perspective. However, in the global competitive marketplace, the retailer and the supplier should cooperate as a whole and establish a long-term cooperative relationship. Goyal (1976) first studied a seller–customer inventory model. After that, many researchers discussed ordering/pricing issues for an integrated supply chain, such as Banerjee (1986), Wee and Yang (2007). Abad and Jaggi (2003) further considered a supplier–buyer integrated model under trade credit policy. Recently, Ho et al. (2008) and Chen and Kang (2010) discussed the operational impact of a "two-part" trade credit policy in an integrated inventory model. To compare with the decentralized setting, we also develop in this paper an integrated supply chain model, in which the retailer faces the inventory-dependent demand and limited storage space.

The remainder of the paper is organized as below. Section 2 presents assumptions and notations used in the paper. In Section 3, we construct the retailer's and supplier's objective function in a decentralized setting. In Section 4, we specify the condition under which the supplier can get benefits from offering the retailer trade credit, and provide the method of how to set such a trade credit policy. While Section 5 gives the integrated optimizing model with trade credit, Section 6 shows numerical analysis of parameters of the proposed models. The paper ends with Section 7.

2. Assumptions and notations

The following notations and assumptions are made in formulating the model.

2.1. Notations

I is a subscript identifying a specific level in a supply chain ($i=r$, s; where s=supplier and r=retailer).$\boldsymbol{p}$ is the unit selling price; $\boldsymbol{A_i}$ is order cost of level i; $\boldsymbol{h_r}$ is inventory holding cost per unit item per year for the retailer, excluding the cost of capital; s_i is the opportunity cost per unit item per year at level i, excluding the holding cost, which may be measured in practice by $I_i c_i$, where c_i is the procurement unit cost for level i and I_i the interest charges per \$ investment in inventory per year at level i; $\boldsymbol{g_r}$ is the opportunity gain per unit item per year for the retailer, which may be estimated similarly by $I_e c_r$, where I_e is the interest earned per \$ per year for the retailer; H_r is the inventory cost per unit item per year for the retailer, $\boldsymbol{H_r}=(h_r+s_r)$; $\boldsymbol{W}$ is the retailer's storage capacity; $\boldsymbol{T}$ is the order cycle of the retailer; $\boldsymbol{M}$ is the permissible delay in payment in time units (decision variable); $\boldsymbol{Q}$ is the order quantity of the retailer (decision variable); $\boldsymbol{Q_M}$ is the retailer's order quantity when $T=M$.

2.2. Assumptions

(1) Time horizon is infinite. (2) Shortage is not allowed. (3) The item is not damaged either physically or technically. (4) Replenishment is instantaneous. (5) The trade credit period, the supplier offers begin at the time when the retailer receives the ordered items. (6) During the trade credit period, the retailer's sales revenue is deposited in an interest-bearing account. At the end of this period, the account is settled and the retailer starts paying for the interest charges on investment in inventory. (7) The supplier's warehouse capacity is sufficiently large. The retailer's warehouse capacity has limited capacity of W units, and he/she does not plan to rent warehouse (i.e. the rent cost is very large). Hence, the retailer's order quantity is not more than the capacity of his/her warehouse. (8) Like Kim et al. (1995) and Abad and Jaggi (2003), we also assume that I_r and I_e are equal to the annual cost of short-term capital. (9) The demand rate is deterministic and is a function of instantaneous stock level $I(t)$. Suppose the demand function is given by $D(t)=\alpha I(t)^{\beta}$, where $\alpha>0$ and $0<\beta<1$ are scale and shape parameters, respectively. This type of demand pattern has been employed by many researchers, such as Baker and Urban (1988), Zhou and Yang (2005).

Based on the assumptions and notations made above, the inventory level $I(t)$ can be described as (Zhou et al. 2012)

$$I(t)=[Q^{1-\beta}-\alpha(1-\beta)t]^{1/(1-\beta)}, \quad 0\le t\le T \tag{1}$$

Noting $I(T)=0$, one has

$$T=\frac{Q^{1-\beta}}{\alpha(1-\beta)} \tag{2}$$

If $T=M$, from (2) one has

$$Q\equiv Q_M=\left[\alpha M(1-\beta)\right]^{1/(1-\beta)} \tag{3}$$

3. The mathematical model

3.1. The retailer's mathematical model

For any credit period M given by the supplier, the retailer's problem is to determine the order lot size Q that maximizes his/her annual profit, which consists of the following elements:

(1) Ordering cost per cycle$=A_r$; (2) sales revenue per cycle$=pQ$; (3) purchase cost per cycle$=c_rQ$; and (4) inventory holding cost is $h_rQ^{2-\beta}/[\alpha(2-\beta)]$;

When the supplier offers a trade credit period of M unit time, the retailer has two choices about his/her order decision as given below.

Choice 1: $T\le M$ $(Q\le Q_M)$

In this choice, the retailer's replenishment cycle is less than the trade credit period given by the supplier. Based on the assumption (6), the retailer does not need paying for interest charges on investment in inventory. Referring to Zhou et al. (2012)'s analysis, the retailer's payable interest is zero and the interest earned per cycle $=g_rQM-g_r\frac{Q^{2-\beta}}{\alpha(2-\beta)}$

Choice 2: $T>M$ $(Q>Q_M)$

Similar to Choice 1, in this choice, the retailer's replenishment cycle is greater than the trade credit period provided by the supplier. Hence, the retailer needs paying for interest charges on investment in inventory. We can get the interest payable per cycle$=\frac{s_r\left[Q^{1-\beta}-\alpha(1-\beta)M\right]^{\frac{(2-\beta)}{(1-\beta)}}}{\alpha(2-\beta)}$.

And the interest earned per cycle

$$=g_rQM-g_r\frac{Q^{2-\beta}-[Q^{1-\beta}-\alpha(1-\beta)M]^{\frac{(2-\beta)}{(1-\beta)}}}{\alpha(2-\beta)}.$$