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Supply chain coordination with stock-dependent demand rate and credit incentives



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ABSTRACT

In this paper, we consider a supply chain which consists of a single manufacturer and a single retailer with a single product type. Demand is assumed to be dependent on the retailer's stock level. Without coordination, the retailer determines its order quantity to maximize its own profit, which is usually smaller than the manufacturer's economic production quantity. Three coordination policies are presented to coordinate the manufacturer's and the retailer's decisions. First, the credit period policy and the quantity discount policy are developed and the total profits under the two policies are compared. Then we develop a centralized supply chain policy and show that there is a unique optimal order quantity to achieve a perfect coordination. The centralized supply chain can get higher or equal channel profit while the credit period policy and the quantity discount policy are easier to achieve. Numerical examples are provided to illustrate the proposed policies.

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1. Introduction

In many real-life situations, the demand rate may be affected by the stock level, especially some perishable goods, such as vegetables, fruits, bread, etc. For a high level of inventory attracts more visibility and also may imply that the goods are popular and fresh. Since the perishable goods should be sold out in a short time and produced in small quantity, the manufacturer should often strike the balance between the production efficiency and market demand rate duo to the stock-dependent demand. In the literature, researchers usually used quantity discount policy to persuade retailers to order the quantity more than EOQ. In reality, offering a credit period (delay in payment) to retailers could be more effective for perishable goods. For, in credit period, retailers can earn revenue and save interests, which may alleviate pressure of the fund. There are several advantages of credit period mentioned by Shinn and Hwang (2003) and Sarmah et al. (2007). (i) Credit period can be seen as a means of competition to win over more orders. (ii) It can help to build a good long-term relationship with partners. (iii) Through credit, the manufacturer also shows a commitment of good quality to its customers. (iv) Credit period can also be seen as an important form of financing, especially in developing countries, where the financial service is not quite

convenient. Therefore, the credit period policy may perform better than quantity discount policy sometimes. Although credit period is already used by many suppliers or manufacturers to promote market competition, it is still less talked about in the literature. This paper deals with the trade credit mechanism of supply chain with stock-dependent demand. In the following, we briefly review the relevant literature.

Many researchers have considered coordination issues such as replenishment policies and quantity discount schedule between manufacturers and retailers in supply chain management. First, Goyal (1977) considered an integrated inventory model with a single supplier and a single retailer. Rosenblatt and Lee (1985) determined the retailer's order quantity and the supplier's lot size when the supplier offers a linear quantity discount schedule. The above models assumed constant demand rate, which is not influenced by the selling price. In reality, the pricing strategy is also quite important in supply chain management. Weng (1995) considered the quantity discount policy to reduce the supplier's cost and increase the retailer's demand when the demand rate at the retailer's end is price-sensitive. Viswanathan and Wang (2003) considered quantity discounts and volume discounts as coordination mechanisms in distribution channels with a price-sensitive deterministic demand. Later on, many researchers have enriched literature on the problem of coordination issues of replenishment policies and pricing strategies, such as Munson and Rosenblatt (2001), Khouja (2003), Chen and Simchi-Levi (2006), Ouyang et al. (2009), etc.

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All the above works on supply chain coordination concerned the assumption that the demand rate is constant or price-sensitive. As mentioned earlier, the demand rate may also be influenced by the stock level. [Whitin \(1957\)](#) found that the sales and inventory are not independent from each other and high-level inventory may bring about more sales. [Levin et al. \(1972\)](#) and [Silver and Peterson \(1985\)](#) considered that the consumption rate is proportional to the inventory displayed. [Baker and Urban \(1988\)](#) developed a deterministic inventory model in which the demand rate is a polynomial function of instantaneous stock level. Later on, researchers considered more practical issues in the inventory model with stock-dependent demand, such as fixed life time, shortages and deterioration, etc. [Mandal and Phaujdar \(1989\)](#) presented an inventory model for deteriorating items, assuming the demand rate is a linear function of current stock level. [Sarker et al. \(1997\)](#) determined the optimal production cycle when the demand rate is stock-dependent and shortages are backordered. [Zhou and Yang \(2003\)](#) determined the optimal lot-size for the items with a stock-dependent demand rate and a fixed lifetime. Recently, [Dye and Ouyang \(2005\)](#), [Wu et al. \(2006\)](#), [Yang et al. \(2010\)](#) and [Sajadieh et al. \(2010\)](#) enriched literature of inventory model with stock-dependent demand. [Zhou et al. \(2008\)](#) considered quantity discount as the coordination mechanism with stock-dependent demand and showed that the quantity discount policy may also achieve full channel coordination. However, no papers considered trade credit as the coordination mechanism for perishable goods.

In this paper, a single-manufacturer and single-retailer supply chain is considered and the demand rate at the retailer's end is dependent on the instantaneous stock level. The credit period and quantity discount are used as incentives to coordinate the manufacturer's and the retailer's activities. The comparison of credit period and quantity discount policies is made for the manufacturer to choose. The division of surplus profit between the manufacturer and the retailer is also discussed. We also show that the centralized supply chain can always achieve equal or higher channel profit than both credit period and quantity discount policies. Nevertheless, the credit period and quantity discount policies are easier to achieve. The results are illustrated with some numerical data.

2. Model formulation for the supply chain coordination

The following assumptions and notations are used through the whole paper. Additional assumptions and notations are listed when needed.

Assumptions.

- (1) The demand rate $D(t)$ at the retailer's end is dependent on the instantaneous stock level $q(t)$, $D(t) = aq(t)^b$, $a > 0$, $1 > b > 0$. a is the market scale parameter and b is the elasticity of the demand with respect to the stock level. There are several advantages of this demand pattern mentioned in [Baker and Urban's \(1988\)](#) paper: (i) the marginal increase in demand rate goes down for higher inventory levels, which has already been observed in reality. (ii) The elasticity parameter b can represent the ratio of the change in demand to the change in inventory. And we can expect this function to provide a good approximation with varying values of a and b . (iii) This function is simple and easy to use and the parameters can be easily estimated by regression.
- (2) Shortages are not allowed.
- (3) The lead time is zero.
- (4) The manufacturer follows the lot-for-lot policy.

- (5) The retailer replenishes the inventory when all the items are sold out.
- (6) The manufacturer bears the transportation cost, which is $e + fQ$. e is the fixed cost per shipment and f is the unit transportation cost.

Notations

p	selling price per unit
w	wholesale price per unit
Q	order quantity (decision variable)
c	manufacturer's production cost per unit
$q(t)$	retailer's stock level at time t
R	manufacturer's production rate
μ	discount rate on the wholesale price
M	credit period that the supplier offers to the retailer
h_r	holding cost per unit per unit time for the retailer
h_m	holding cost per unit per unit time for the manufacturer
T	replenishment cycle length
T_m	manufacturer's production length per cycle
I_r	interest which can be earned per \$ per year by the retailer
I_m	interest which can be earned per \$ per year by the manufacturer
A_r	retailer's ordering cost
A_m	manufacturer's setup cost
π_r	retailer's average profit
π_m	manufacturer's average profit
π_c	channel's average profit

Consider a supply chain which consists of a single manufacturer and a single retailer. Within each replenishment cycle, the manufacturer produces items at a constant production rate R for T_m , $T_m \leq T$, and dispatches them to the retailer at the end of each cycle. The retailer's inventory is depleting at a decreasing rate due to the stock-dependent demand until the inventory becomes zero (see [Fig. 1](#)).

Since the demand rate is equal to the decrease in the inventory level, we can describe the retailer's stock level $q(t)$ by the following differential equation:

$$\frac{dq(t)}{dt} = -aq(t)^b, \quad 0 \leq t \leq T. \quad (1)$$

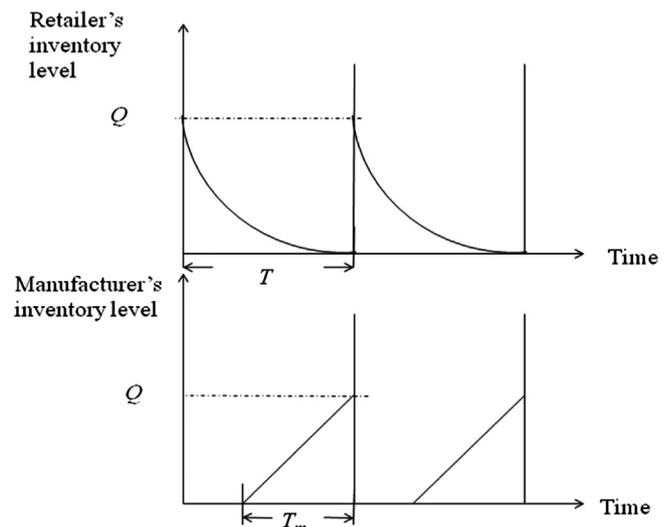


Fig. 1. Retailer's and manufacturer's stock levels.

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