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Coordinated replenishment and marketing policies for non-instantaneous stock deterioration problem ☆

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ABSTRACT

This paper provides an integrated model for dynamic pricing and inventory control of non-instantaneous deteriorating items. To tackle dynamic nature of the problem, not only the price is modeled as a time-dependent function of the initial selling price and the discount rate but also the impact of changes in price is incorporated into the demand model. The product is sold at the initial price value in the time period with no deterioration; subsequently it is exponentially discounted to boost customer's demand. Inspired by the influential impact of promotion on stimulating sales, the demand rate is linked to the frequency of advertisement in each replenishment cycle as well. Useful theoretical results are derived demonstrating existence and uniqueness of the optimal solution based upon which an iterative solution algorithm is developed. The solution procedure is illustrated through numerical examples that are accompanied by sensitivity analyses of the key parameters of the model.

1. Introduction

In classical inventory problems, it is assumed that products have an infinite shelf life, while the majority of items lose their initial values over time and for some of them this occurs faster than usual which is called deterioration. Most of the deteriorating items maintain their original quality for some extent of time and then start to lose their freshness as time passes. These items are known as non-instantaneous deteriorating items (Soni & Patel, 2013).

Retailers tend to increase inventory depletion rate to minimize the negative impact of deterioration and enhance profit of the system. Increasing inventory depletion rate falls into marketing policies and there is a direct link between demand rate and customer level of satisfaction. These days, price is considered not only as a way to earn revenue but also as an influential factor in customer satisfaction. In other words, pricing is an essential strategy for a retailer to achieve its maximum profit (Dye, Ouyang, & Hsieh, 2007). Therefore, trade-off between pricing and replenishment policies in inventory management problems is undeniable and firms can enhance their profit by integrating these two policies.

It is well established that there is a negative relationship between demand and the price of a product (Avinadav, Herbon, & Spiegel, 2013) and this relationship can be modeled in a diverse variety of ways. Despite the mentioned diversity, these demand models fall into two main categories named additive and multiplicative demand models. Kocabiyikoglu and Popescu (2011) have provided some examples of common demand models in this area.

Inspired by the importance of pricing and inventory management of deteriorating items, an integrated model for dynamic pricing and inventory control of deteriorating items is developed in this paper. To reflect dynamic nature of the problem, selling price is modeled as a time-dependent function of the initial price and discount rate and the effect of changes on price is incorporated into the demand model. The demand rate is dependent on frequency of advertisement in each replenishment cycle as well. In order to obtain the optimal solution, useful theoretical results are established based upon which an iterative solution algorithm is developed.

The remainder of the paper is structured as follows. In Section 2, literature body of the problem is reviewed. Section 3 represents the formulated mathematical model. Section 4 provides the theoretical results and solution algorithm. Numerical results and sensitivity analyses of the obtained optimal solutions are represented in Section 5. Finally Section 6 finishes the paper with conclusion and recommended future research directions.

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2. Literature review

The rich literature body of the problem can be classified with respect to different factors such as demand, deterioration and other related inventory assumptions. In this paper, the related literature is classified with respect to demand factor including price-dependent demand models, price and time-dependent demand models and price and stock-level-dependent demand models.

2.1. Price-dependent demand models

Wu, Ouyang, and Yang (2006) was the first research to assume non-instantaneous deterioration which was appropriate for deterioration pattern of many products. Soni and Patel (2012) investigated optimal pricing and inventory policies for non-instantaneous deteriorating items as well. This model was extended by Soni and Patel (2013) by considering imprecise deterioration free time and credibility constraint.

Shah, Soni, and Patel (2013) provided one of the few studies which investigated the impact of advertisement on demand. They considered an inventory system with non-instantaneous deteriorating items in which demand rate was a function of selling price and the frequency of advertisement in each replenishment cycle. Begum, Sahoo, and Sahu (2012) applied three-parameter Weibull distribution to present time-dependency of inventory deterioration rate. Soni and Joshi (2013) proposed a generalized economic order quantity-based model for deteriorating items under bi-level trade credit financing.

Cai, Feng, Li, and Shi (2013) proposed one of the rare studies on dynamic pricing which modeled price as a function of time. Optimal policy was obtained by considering feedback of price on demand per time unit. Wang, Zhang, and Tang (2013) also considered price as a function of time and modeled a non-instantaneous deterioration pattern.

2.2. Price and time-dependent demand models

In addition to Shah et al. (2013), Tsao and Sheen (2008)discussed the dependency of demand on advertisement. Demand was modeled as a linear function of price, exponential function of time and quadratic function of advertisement cost.

Herbon, Levner, and Cheng (2014) discussed using Radio Frequency Identification (RFID) system to control the quality of perishable items. As a noble feature of their model, price was considered to decreases exponentially over time. In Panda, Saha, and Basu (2013) the pricing and inventory control policies were investigated for non-instantaneous deteriorating items. This was one of the very rare studies in which the selling price in each cycle could be obtained by defining price as a function of initial price and discount parameter. In addition to this research, Valliathal and Uthayakumar (2011), Maihami and Abadi (2012) and Ghoreishi, Mirzazadeh, and Weber (2013) incorporated non-instantaneous deterioration into their model.

2.3. Price and stock-level-dependent demand models

Teng and Chang (2005) provided the first model which considered price and stock-level-dependent demand for deteriorating items in an economic production quantity model. In Chen and Chien (2009), pricing and inventory management policies were investigated for the base-stock inventory model with FIFO policy. Giri and Bardhan (2012) studied a single-period inventory model with price and stock-level-dependent demand rate in a bi-level supply chain.

In spite of the rich and wide-spread literature of the problem, there exist some research gaps. In practice, advertisement plays a key role in stimulating demand, however there are very few studies linking demand to advertisement. We have incorporated this factor into our demand function. In reality, the inventory holding cost of deteriorating items increases over time; this consideration has not been investigated sufficiently. In this paper, the holding cost is modeled as a general time-dependent function. In context of dynamic pricing, there are few studies modeling price as a time-dependent function by defining discount variable, whereas the price is formulated as a time-dependent function of initial selling price and discount rate in this paper. Finally, to the best of our knowledge none of the presented papers incorporated the effect of changes on price into the demand function. This consideration enhances dynamic feature of the problem and is embedded into our proposed demand function.

3. Notations and Assumptions

The following parameters and variables are used throughout the text, in order to model our joint pricing and inventory control problem.

Parameters

c_p	The constant purchasing cost per unit
c_o	The ordering cost per order
c_d	The deterioration cost per unit
c_a	Cost of each advertisement
$h(t)$	The holding cost per unit per time unit
t_d	The length of deterioration free time

Variables

A	The frequency of advertisement in each cycle (decision variable)
$p(t)$	The dynamic price of product per unit at any time t (decision variable)
T	The replenishment cycle of the product (decision variable)
$I_1(t)$	The inventory level at time $t(0 \leqslant t \leqslant t_d)$
$I_2(t)$	The inventory level at time $t(t_d \leqslant t \leqslant T)$
I_0	The maximum inventory level
Q	The order quantity
$p'(t)$	Changes in price per time unit
OC	The total ordering cost
HC	The total inventory holding cost
PC	The total purchasing cost
AC	The total advertisement cost
DC	The total disposing cost
$TP(p(t), A, T)$	The total profit per time unit of the inventory system

The following assumptions structure our proposed model:

1. The planning horizon is infinite.
2. The replenishment rate is infinite and the lead time is zero.
3. The inventory system involves single non-instantaneous deteriorating item.
4. As the non-instantaneous deterioration starts, the selling price tends to decrease to increase the inventory depletion rate. Due to computational tractability and as in Herbon et al. (2014), the dynamic price of the product decreases exponentially over time and it is formulated as: $p(t) = \begin{cases} p_0 & 0 \leqslant t \leqslant t_d \\ p_0 \exp(-\sigma(t - t_d)) & t_d < t \leqslant T \end{cases}$ where p_0 is the initial price and $\sigma \in \pi$ is of discount variable for each time unit passing after the start of deterioration. In this paper $\pi = \{0.1, 0.2, \ldots, 0.8, 0.9\}$.