



The effect of preservation technology investment on a non-instantaneous deteriorating inventory model

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ABSTRACT

Considering an inventory system with a non-instantaneous deteriorating item, our objective is to study the effect of preservation technology investment on inventory decisions. The generalized productivity of invested capital, deterioration and time-depend partial backlogging rates are used to model the inventory system. The basic results of fractional programming are employed to prove the uniqueness of the global maximum for each case. We also establish several structural properties on finding the optimal replenishment and preservation technology strategies. Further, we use a couple of numerical examples to illustrate the results and conclude the paper with suggestions for possible future researches.

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1. Introduction

In the last two decades, the models for inventory replenishment policies involving deteriorating items have received the attention of several researchers. In real life, the deterioration phenomenon is observed on inventory items such as fruits, vegetables, pharmaceuticals, volatile liquids and others. The fundamental result in the development of economic order quantity model with deterioration is that of Ghare and Schrader [1] who established an exponentially decaying inventory for a constant demand. However, as evident by chemical and basic sciences, the rate of deterioration especially with regard to perishable food items is seldom constant. Consequently, Covert and Philip [2], Philip [3] and Tadikamalla [4] extended the model of Ghare and Schrader [1] for a variable rate of deterioration by assuming Weibull distribution and Gamma deterioration rates, respectively. Researchers including Datta and Pal [5], Abad [6,7], Wee [8], Benkherouf and Balkhi [9], Chakrabarty et al. [10], Papachristos and Skouri [11], Dye [12], Tsao and Sheen [13], Sarkar [14], Wang and Li [15] and Cai et al. [16] developed economic order quantity models that focused on time varying deterioration rate. For a detailed survey on the literature of deteriorating inventory model over the last two decades, we refer the readers to the review articles by Goyal and Giri [17] and Bakker et al. [18] and the references therein for more details on the subject.

However, the existing researches often assumed that the deterioration occurs as soon as the commodities arrive in inventory. In practice, most goods would have a span of maintaining

quality or original condition, i.e. no deterioration occurs during that period. It is commonly observed that food stuffs, firsthand vegetables and fruits have a short span of maintaining fresh quality, in which there is almost no spoilage. Wu et al. [19] and Ouyang et al. [20] first incorporated the phenomenon into the inventory model and termed it as “non-instantaneous deterioration”. They also found that if the retailer can effectively reduce the deteriorating rate of item by improving the storage facility, the total annual relevant inventory cost will be lowered. Chang et al. [21] then complemented the model of Wu et al. [19] for the situation that building up inventory is profitable. Meanwhile, Geetha and Uthayakumar [22] presented an extended model of Wu et al. [19] by considering reciprocal time-dependent partial backlogging rate. Maihami and Kamalabadi [23] and Maihami and Abadi [24] further extended the model of Ouyang et al. [20] by considering a price and time dependent demand. Recently, to characterize the more practical situation, Shah et al. [25] integrated time varying deterioration and holding cost rates in the inventory model where shortages were not prohibited. The main objective in their model is to find the retailer's replenishment, selling price and advertisement strategies which maximize the retailer's unit time profit.

In purchasing and material management, the deterioration of items is an important consideration in settling a replenishment schedule. The goal of inventory management is to improve return on investment by reducing non-essential inventory waste. However, the deterioration rate of goods in the above-mentioned papers is viewed as an exogenous variable, which is not subject to control. In the real market, the retailer can reduce the rate of deterioration of products by means of effective capital investment in warehouse equipments. For agreement with the practical inventory situation, Hsu et al. [26] proposed a deteriorating inventory model with

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constant demand rate and exponential decay which the retailer is allowed to invest the preservation technology to reduce the deterioration rate. However, the preservation technology cost is assumed to be a fixed cost per inventory cycle and this seems to be unrealistic. If new equipments, such as refrigeration units, are acquired, capital costs will occur. The cost of capital is often incorporated into models using an equivalent cost per period, or a leasing fee, which would probably be a cost per period, instead of a cost that is independent of the period length. Hence, a more realistic representation of is that it should be a cost per period, not a fixed cost per inventory cycle. Dye and Hsieh [27] then presented an extended model of Hsu et al. [26] by assuming the preservation technology cost is a function of the length of replenishment cycle. They further extended the model of Hsu et al. [26] by incorporating time-varying deterioration and reciprocal time-dependent partial backlogging rates.

In this paper, we study the preservation technology investment and inventory decisions for a retailer's non-instantaneous deteriorating items, and perform a sensitivity analysis to understand how they depend on cost parameters. In particular, the generalized productivity of invested capital, deterioration and time-depend partial backlogging rates are used to obtain robust and general results on inventory management. The basic concepts and results of fractional programming are used to prove the uniqueness of the global maximum for each case. At the end, a couple of numerical examples are used to illustrate the proposed model, and concluding remarks are provided.

2. Model notation and assumptions

The mathematical model in this paper is developed on the basis of the following notation and assumptions.

2.1. Notation

D	the demand rate per unit time
K	the replenishment cost per order
c	the purchasing cost per unit
p	the selling price per unit, where $p > c$
h	the holding cost per unit per unit time
s	the backorder cost per unit per unit time
π	the goodwill cost of lost sales per unit
t_d	the length of time in which the product has no deterioration
ξ	the preservation technology cost per unit time for reducing the deterioration rate in order to preserve the products (a decision variable), $0 \leq \xi \leq w$, where w is the maximum cost of investment in preservation technology
t_1	the time at which the inventory level reaches zero (a decision variable)

T	the length of the inventory cycle (a decision variable)
Q	the ordering quantity per inventory cycle
L	the amount of lost sales per inventory cycle
$I(t)$	the level of positive inventory at time t
$m(\xi)$	the proportion of reduced deterioration rate, $0 \leq m(\xi) \leq 1$
$TP_1(t_1, T, \xi)$	the total profit per inventory cycle when $t_1 > t_d$
$TP_2(t_1, T)$	the total profit per inventory cycle when $t_1 \leq t_d$
$\Pi(t_1, T, \xi)$	the total profit per unit time.
$\Pi_1(t_1, T, \xi)$	the total profit per unit time when $t_1 > t_d$
$\Pi_2(t_1, T)$	the total profit per when $t_1 \leq t_d$.

2.2. Assumptions

1. Replenishment rate is infinite, and the lead time is zero.
2. The time horizon of the inventory system is infinite.
3. During the period, $[0, t_d]$, the product has no deterioration. After the period, the product deteriorates at a time-varying rate of deterioration $\theta(t)$, where $0 < \theta(t) < 1$. Besides, there is no repair or replacement of deteriorated units during the inventory cycle.
4. The proportion of reduced deterioration rate, $m(\xi)$, is a continuous, concave, increasing function of retailer's capital investment, where $m(0) = 0$ and $\lim_{w \rightarrow \infty} m(w) = 1$. Note that $m'(\xi) > 0$ and $m''(\xi) < 0$ imply the diminishing marginal productivity of capital.
5. The fraction of shortages backordered is a decreasing function $\beta(x)$, where x is the waiting time up to the next replenishment, and $0 \leq \beta(x) \leq 1$ with $\beta(0) = 1$. Note that if $\beta(x) = 1$ (or 0) for all x , then shortages are completely backlogged (or lost).

3. Model formulation

In this paper, the parameter t_d can be seen as exogenous variables. For the length of in-stock period, two cases regarding the model should be considered: $t_1 > t_d$ and $t_1 \leq t_d$. Given the notation and assumptions mentioned before, the inventory level follows the pattern depicted in Fig. 1. To establish the inventory model, we divide into two cases, namely Case 1: $t_d < t_1$ and Case 2: $t_d \geq t_1$.

Case 1: $t_1 > t_d$

In Case 1, the length of time in which the product has no deterioration is shorter than the length of in-stock period. During the interval $[0, t_d]$, the inventory is depleted due to the demand only. After the time t_d , the inventory level decreases due to the combined effects of demand and deterioration. Because the capital investment of preservation technology cost is ξ , the corresponding deterioration rate is $[1 - m(\xi)]\theta(t)$. Applying this,

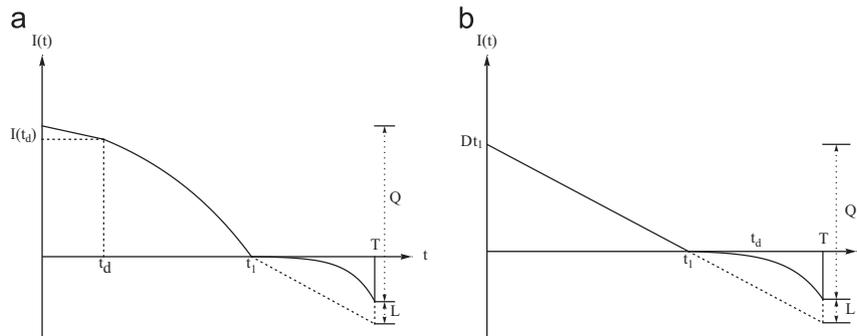


Fig. 1. Graphical representation of the inventory system: (a) $t_d < t_1$ and (b) $t_d \geq t_1$.

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