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Optimal dynamic pricing and preservation technology investment for deteriorating products with reference price effects ☆

Chung-Yuan Dye [a], Chih-Te Yang [b,*]

[a] Graduate School of Business and Administration, Shu-Te University, Yen-Chao, Kaohsiung 824, Taiwan
[b] Department of Industrial Management, Chien Hsin University of Science and Technology, Taoyuan 320, Taiwan

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ABSTRACT

Marketing and consumer behavior literature has empirically demonstrated that reference prices play a critical role in customer purchase decisions. In this paper, we propose a joint dynamic pricing and preservation technology investment model for a deteriorating inventory system with time-and-price sensitive demand and reference price effects. A generalized model is presented to jointly determine the optimal selling price, preservation technology investment and replenishment strategies that maximize the retailer's total profit over a finite planning horizon. Beginning with mild assumptions, we derive theoretical results to demonstrate the existence of an optimal solution for the deteriorating inventory problem, and reveal the sensitivities of optimal pricing and preservation technology investment decisions to an initial reference price. A simple iterative algorithm is then used to solve the proposed model by employing the theoretical results. Numerical examples and sensitivity analysis are then provided to illustrate the features of the proposed model. Finally, concluding remarks are offered.

1. Introduction

Deterioration, because of poor storage and preservation quality, is a common phenomenon in daily life. For example, environmental factors such as temperature, humidity, oxygen, light, enzymes, and microorganisms can trigger several chemical reactions that may cause the deterioration of food. Electronic equipments may lose functionality because of slight bumps, shocks, vibration, or compression in one or more components. Because of inevitable deterioration, goods may not be able to fulfill their intended purposes, and thus may lose their value over time. As reported by [1], U.S. retail grocery sales comprised 50% perishable foods, 30% nonperishable foods, and 20% nonfood items. Beck et al. [2] reported that, in Europe alone, stock shortages cost the fast moving consumer goods sector 18 billion euros annually. Ferguson et al. [3] revealed that approximately $30 billion is lost annually in the U.S. grocery industry because of the deterioration of goods. Hence, for retailers to reduce their deterioration losses, establishing a more reasonable inventory model is crucial.

Ghare and Schrader [4] first addressed the deteriorating inventory problem with constant demand and deterioration rates. In the past two decades, numerous studies have examined how the deterioration of goods affects various inventory systems. However, many environmental factors may influence the deterioration rate of food products, with the deterioration rate of perishable food items being particularly unstable. Likewise, electronic components deteriorate more quickly with aging and temperature cycling. Therefore, Covert and Philip [5] and Tadikamalla [6] extended the model of Ghare and Schrader [4] by using Weibull and Gamma distributed deterioration rates, respectively. Furthermore, because the stage of a product's life cycle influences market demand, Dave and Patel [7] extended the model of Ghare and Schrader [4] to consider the deterministic inventory model for deteriorating items with a linear increasing demand rate over a finite planning horizon. To render the model mathematically tractable, Dave and Patel [7] stipulated equally sized replenishment periods. Relaxing the assumption of equal length for the replenishment periods, Benkherouf [8], Hariga [9] and Benkherouf and Mahmoud [10] studied the deterministic inventory model for items deteriorating at a constant rate with log-concave demand over a known and finite planning horizon. They also proved the uniqueness of the optimal replenishment scheme and presented an iterative procedure to obtain it. Subsequently, Benkherouf and Balkhi [11] generalized the finite planning horizon inventory models to allow for time-vary demand and deterioration rates.

Grocery retailing is a highly competitive industry in which pricing is the main strategy for a retailer to maximize profit.

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* Corresponding author.
E-mail addresses: chungyuandye@gmail.com (C.-Y. Dye), ctyang@uch.edu.tw (C.-T. Yang).

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Instead of setting the selling price as a parameter, Wee [12] proposed a deteriorating inventory model with multiplicative demand over a finite planning horizon in which the demand decreases exponentially with time and increases linearly in price. Unlike the model of Wee [12] that assumed equal replenishment period, Chang et al. [13] presented a deteriorating inventory model for a retailer to determine its optimal selling price and replenishment schedule with unequal periods and with the optimal replenishment number over the finite planning horizon. However, both the Wee [12] and Chang et al. [13] models used the fixed-pricing policy. For seasonal goods, the market demand may increase or decrease rapidly over time, the retailer should adjust the selling price periodically during the planning horizon to influence market demand and improve revenue. Because of the nonlinear nature of the problem, inherent difficulty exists in analyzing pricing and replenishment schemes simultaneously over the finite planning horizon. To solve this problem, Chen and Chen [14,15] used dynamic programming techniques to study optimal pricing and production/replenishment decisions over a finite planning horizon. Their numerical studies also revealed that major benefits can be derived by complementing a replenishment strategy by dynamically adjusting the commodity's price. Subsequently, Tsao and Sheen [16,17] extended this approach to dynamic versions of the joint pricing and replenishment decisions over the finite time horizon inventory problem for deteriorating items subject to the supplier's trade credit. Recently, Dye and Hsieh [18] and Dye and Ouyang [19] studied different deteriorating inventory problems with price- and time-dependent demand for specific business applications. They utilized particle swarm optimization to determine the replenishment number, scheduling and periodic selling price to optimize the total profit. Furthermore, experimental results have shown that the particle swarm optimization algorithm offers acceptable efficiency and accurate search capability. Applying the concept of $L^\natural$-convexity, Chen et al. [20] analyzed a joint inventory-pricing problem for a perishable product with a fixed lifetime in a stochastic periodic review inventory system involving positive lead time. They also proposed an approximate dynamic programming scheme for finite-horizon problems with both backlogging and lost sales cases.

However, although the aforementioned studies have introduced the deterioration rate of products into inventory models as an exogenous variable, they have neglected the difficulties relating to the preservation investment for inventory items. In various situations, the degree of deterioration depends on the preservation of inventory in a facility and the environmental conditions of the facility. The deterioration of goods is an unstoppable natural process but might be slowed by specialized equipment or processes. For example, preserved and packaged food will not remain stable forever rather, it will slowly deteriorate until it is unfit for consumption. Low temperatures, such as those provided by refrigeration, prevent microbial spoilage and chemical deterioration. Cold storage slows the deterioration of film and color materials. Hsu et al. [21] considered how preservation technology investment affects an exponentially decaying inventory model involving partial backorders. However, Hsu et al. [21] assumed the rates of deterioration and productivity of invested capital to be specific functions. In addition, the preservation technology cost was assumed to be a constant regardless of inventory cycle length. Recently, Dye and Hsieh [22] generalized the model of Hsu et al. [21] to consider the arbitrary deterioration rate and productivity function of invested capital. In particular, the preservation technology cost was incorporated into the study by using an equivalent cost per replenishment period or a leasing fee rather than a cost that is independent of the period length. Dye [23] analyzed the joint preservation technology investment and inventory decisions of non-instantaneous deteriorating items. The author mathematically proved that a retailer can reduce economic losses and improve customer service by investing in preservation technology. He and Huang [24] and Zhang et al. [25] extended the model of Hsu et al. [21] by using price as an additional decision variable. However, the demand rate in these studies was assumed to be a constant and a linear function of selling price.

Furthermore, the studies on joint pricing and deteriorating inventory management have assumed that demand depends only on the time and current price, and have not considered the scenario in which situation that customers know a retailer's pricing history. In fact, consumers are sensitive to price changes in the short term. In the marketing literature, consumers have long been recognized as using standards or reference points to evaluate the purchase price of a product which is called the reference price. The reference price can be seen as an internal price that aids consumers in determining whether the current price is high or low, or fair or unfair. When the current price exceeds the reference price, consumers may feel that the attractiveness of the price has decreased, causing reduced demand. Conversely, when the price is lower than the reference price, customers are more attracted to the product, causing increased excess demand. Kalyanaram and Winer [26] found that reference prices exert a consistent and substantial impact on consumer's decision making and translated the cumulative evidence into an empirical generalization. By using adaptation-level theory, Greenleaf [27] first proposed an optimal dynamic pricing policy for a monopolist to analyze how the reference price affects a single-period promotion. Kopalle and Winer [28] generalized the result of Greenleaf [27] to both reference and product quality, and suggested that “high-low” prices are optimal when customer is loss seeking. Fibich et al. [29] developed a methodology for calculating explicitly the optimal pricing strategy when the reference price is an exponentially weighted average of past prices. Fibich et al. [30] extended their previous model to incorporate the effect of price promotion. They also calculated the optimal depth and duration of a price promotion and revealed that reference price can affect price rigidity and flexibility. Popescu and Wu [31] studied the dynamic pricing problem with a reference price in a more general case in a discrete time model. They showed that the results of Fibich et al. [29] are not simply a consequence of linearity but hold for more general demand models. Furthermore, they proved that optimal pricing policies induce a perception of monotonic prices, whereby consumers always perceive a discount or surcharge relative to their expectation. Because customers judge their experience according to its highest or lowest point and its final moments, Nasiry and Popescu [32] extended the model of Popescu and Wu [31] by using a different model of reference price formation, called peak-end anchoring. They also found that optimal prices converge monotonically for loss-averse customers. Recently, retailers have used advertising to form a higher reference price in the minds of customers, Zhang et al. [33] examined how the reference price affected the cooperative advertising program of a manufacturer and a retailer supply chain. Assuming that customers are loss neutral and the selling price is fixed, they observed that a steady reference price usually exceed the market price. Zhang et al. [34] derived the equilibrium prices of a supply chain comprising one manufacturer and one retailer, both of whom face a reference-price effect over an infinite selling horizon. They developed the model with loss-neutral customers in two different supply chain scenarios. One is the integrated scenario, whose goal is to maximize the sum of the manufacturer's and retailer's profits. The other is the decentralized scenario, in which the manufacturer selects the wholesale price first, and then the retailer observes this decision and makes its own.

However, none of these studies in the field of dynamic pricing and revenue management with reference price effects considered