Should retailers hold a perishable product having different ages? The case of a homogeneous market and multiplicative demand model

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ABSTRACT

This paper specializes in investigating the common practice of the coexistence of multiple competing perishables, each with different age and price, all of which are associated with the same product. The fundamental postulate investigated by our model is the replacement of the policy of selling a single product-age with a policy of selling multiple product-ages. Coexistence of multiple product-ages on the shelf is associated with shorter cycle lengths as well as with providing consumers with the option of choosing between a fresher product on average and a cheaper product on average. We use a utility corresponding to the factors of price and time. We axiomatically assume the coexistence of multiple product-ages while posing several propositions which present certain difficulties in preferring this policy. With the support of a multiplicative demand with respect to price and time, and by assuming that consumers are homogeneous in their preferences, we analyze a deterministic version of the problem and derive the optimal pricing policy given any cycle length and any duration for which both types coexist on the shelf. We prove that the optimal policy is not to sell multiple product-types at all. By means of a numerical example we show that the operational mode of the coexistence of multiple product-ages reduces the retailer's profit per unit time by at least 15%. Sensitivity analysis of some of the most influential parameters is introduced. The superiority of the single product-age operational mode over the competitor mode sharply decreases as the optimal cycle length is approached.

1. Introduction

1.1. Replenishment and pricing models for perishable items

Dairy foods, meat, drugs, blood platelets, and so on are examples of perishable products. In addition, a group of products that were not traditionally considered as perishables have recently joined that category, due to technological advances that impose shortened life-cycles. Among these products are computer components, cellular phones, digital cameras, etc. Both groups of products resemble each other in the sense that their inventory can coexist with substitutable products having different ages; yet, the groups also differ from one another. In particular, new and old inventory associated with the first group are sold to customers by a retailer and consist of identical items that differ solely by age. However, in the second group, technological differences are involved; thus, products become "old" due to the arrival of newer models (and not due to deteriorated quality) and these newer models act as the substitutable products in this case. Additionally, the supplier commonly sells the products directly to retailers. Though our model refers with little modification to both groups, we limit our discussion solely to inventoried

perishables belonging to the first group, i.e., perishables that have an expiration-date stamped on them, after which their sale is prohibited. Numerous scholars have analyzed the problem of managing perishables having an identical age. The reader is referred to important reviews by Raafat (1991), Karaesmen et al. (2011), and Bakker et al. (2012). Models that deal with the pricing of perishables can be found in some excellent reviews (e.g., Elmaghraby and Keskinocak, 2003; Bitran and Caldentey, 2003). Yet, only a modest body of the existing literature analyzes perishables with different ages (Chintapalli, 2015).

1.2. Selling perishable having different ages

The majority of sales revenue of grocery stores and supermarkets comes from perishables such as food items (e.g., meats and poultry, produce, dairy, and bakery products), pharmaceuticals (e.g., drugs and vitamins), and cut flowers (Chen et al., 2014). Poor management of perishables may result in vast amounts of outdated items being discarded or in a reduction in potential profits. Such risks may increase even further when both older and newer types coexist in inventory. According to Deniz (2007), within the produce sector, the $1.7 billion U.S. apple

industry is estimated to lose $300 million annually to spoilage. According to AABB (2005), 5.8% of all components of blood processed for transfusion were outdated in 2004 in the U.S. Managing perishable products that consist of multiple ages and prices, where all of these products are substitutable, is a challenging goal. According to Chen et al. (2014), retailers such as Bruegger's Bagels offer discounts for aged items. Other retailers, such as Chesapeake Bagel, choose to dispose of old inventory as new inventory becomes available for sale.

Li et al. (2012) study the joint pricing and inventory-control problem for perishables in the case where the retailer does not sell new and old inventory at the same time. At the beginning of a period, the retailer makes replenishment and pricing decisions and at the end of a period, the retailer decides whether to dispose of remaining inventory or to carry it forward to the next period. Early work assuming different ages goes back to Pierskalla and Roach (1972). More recent works that analyze new and old inventory simultaneously deal with random demand. Parlar (1985) and Goh et al. (1993) consider only the costs of shortage and outdating. The approach of using a Markov Decision Process (MDP) that combines pricing decisions with periodic replenishment of a perishable commodity, including items of different ages in stock, can be found in Konda et al. (2003), Chandrashekar et al. (2003), and Chande et al. (2004, 2005). According to Deniz (2007), the pricing decisions considered by these models are simplified, i.e., they only decide whether to promote all the goods in stock in a given period or not. Li et al. (2009) and Chen and Sapra (2013) study pricing and inventory-replenishment decisions when old and new perishable products coexist. Li et al. (2009) assume that inventory is consumed in FIFO (first-in-first-out) order while Chen and Sapra (2013) allow inventory to be consumed in LIFO (last-in-first-out) order. Sainathan (2013) studies the problem of a perishable product with a two-period shelf-life, whereby in the first period, the product is "new" and in the next, it becomes "old." Chintapalli (2015) utilizes an MDP and assumes two states, old and new, where different prices are assigned to products with different ages. Similarly to Chintapalli (2015), we relax the LIFO and FIFO assumptions and assume that the retailer's price affects consumers' choices. Similarly to Sainathan (2013), we show that under deterministic demand, the retailer does not benefit from selling the old product. In contrast to Sainathan (2013) and Chintapalli (2015), we do not assume negligibility of either holding costs or ordering cost.

1.3. Homogeneous vs. heterogeneous demand

The majority of demand models in the existing perishable inventory literature assume homogeneity among consumers' preferences. Assigning an identical customer sensitivity response to price discounts for purchasing non-fresh items is assumed in Lazear (1986). You (2005) assumes a model whereby the entire demand declines linearly with the price and negative-exponentially with the time since replenishment. A general demand model that is separable with time and price effects under a deterministic setting, yet with identical sensitivity among all consumers is analyzed by Avinadav et al. (2014). Chen et al. (2014), who analyze an inventory system with multiple ages, use an additive demand structure characterized by a decreasing function with price that is subjected to an additive random noise. Their model enables simultaneous selling of different ages with different prices as well as disposal of inventory that has not expired. Our model assumes a demand that depends on price and also on the remaining time to expiration.

Yet, several researchers do not restrict the demand model to be identical among all consumers; that is, they allow for heterogeneity among consumers' preferences. Ishii (1993) and Ishii and Nose (1996) model two types of customer, one with high "priority" that demands only the freshest products and the other with low priority. Similarly, an efficient heuristic is developed by Haijema et al. (2005, 2007) who study a finite-horizon problem for blood platelet production with a demand model of two types of customer. However, these studies do not address pricing decisions. In their work, Herbon et al. (2011) investigate a model where the demand process is customer-oriented and is based on

heterogeneous individuals that have different utilities with respect to both price and freshness. By the method of a discrete event simulation, they study the effect of price, which is assumed to decline exponentially with time, on a deteriorating inventory system that is characterized by random lifetimes and demand. In Herbon et al. (2014), the authors investigate the effect of using radio-frequency identification (RFID)-supported time-temperature-indicator-based automatic devices (TTI-based ADs) to keep track of the age and quality of perishable items (having multiple ages) in stock and to reduce the risk of selling damaged products to customers. In particular, they first formulate the problem as a non-linear mixed integer program (NMIP) and then apply a local search algorithm to approximately solve the problem.

1.4. Information sharing

Information sharing and the value of information have been widely studied in the general supply-chain literature (Deniz et al., 2010). Many scholars highlight the importance of information sharing (e.g., Chen, 2002; Ferguson and Ketzenberg, 2006; Ketzenberg and Ferguson, 2006). Herbon (2013) analyzes the case where the retailer is unaware (e.g., uninformed) of consumer heterogeneity in sensitivity to freshness of a perishable product with a fixed shelf-life (although it exists), whereas consumers are provided with information about price and remaining shelf-life. The availability of information about the age and price of inventory enables buyers to choose whether to purchase fresher products or cheaper ones. Consumer satisfaction motivates sellers to share on-line their information about products' expiration and price. Moreover, sharing information among buyers increases competition, which is necessary to decrease prices; in fact, for this reason, regulations may be imposed to compel retailers to share information with their customers. Advances in information technologies such as RFID and information systems have enabled retailers and suppliers to share information efficiently and with barely no cost. Fransoo and Wouters (2000) discuss the benefit of sharing electronic point of sale (EPOS) information for supply chains of two perishable products (salads and ready-made pasteurized meals).

1.5. Our contribution

This paper suggests an extended deterministic EOQ model to analyze perishable inventory with different ages where the demand rate multiplicatively depends on the price and on the remaining time until expiration. Our contribution to existing literature is as follows:

(1) We obtain optimal pricing expressions given the postulate of coexistence of multiple ages.
(2) We obtain optimal ordering and leftovers expressions given the postulate of coexistence of multiple ages.
(3) The suggested model is traceable and considers maximization of the seller's profit, accumulated holding costs and an ordering cost.
(4) A reduced formulation of the suggested model coincides, for a given set of specified parameter values, with the identical-aged problem (Avinadav et al., 2013).
(5) We find that under the modeling assumptions, the optimal policy is to pose a low enough price such that consumers will pick first the remaining inventory of the older product-type in an FIFO manner.
(6) We challenge the common practice as well as the postulate of selling a single perishable with different ages.

2. Modeling assumptions and notations

The methodology described herein axiomatically assumes the coexistence of multiple product-ages, while later on, it suggests propositions that impose doubts associated with the superiority of this operational mode. In order to simplify the analysis we consider only two product