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Dynamic pricing for deteriorating products with menu cost☆

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ABSTRACT

Retail operation practice has empirically demonstrated that menu costs (i.e., the costs of adjusting a price) play a critical role in retailer pricing decisions. In this paper, we propose four dynamic pricing models for deteriorating products based on different pricing adjustment frequencies with and without menu costs. Under Poisson demand, we provide (1) the rank of these models in terms of expected profits and note that (2) the optimal prices of deteriorating products consistently decrease over time when menu costs are negligible. To investigate the impact of menu costs on dynamic pricing decisions, we conduct several numerical experiments based on different menu costs, decay rates, holding costs and initial inventories. The results demonstrate that (1) the one-time price adjustments typically employed in practice provide the most benefit from dynamic pricing when menu costs are moderate and that (2) it is typically preferable to adjust the price in the middle of the products shelf life rather than to make early or late adjustments. The same conclusions follow under compound Poisson demand and general customer utility functions.

1. Introduction

Products such as vegetables, fruits, meat products, electronics and fashion goods are assumed to deteriorate over time, resulting in deceasing utility or quantity over time. These goods are quite important to grocery retailers, as they can increase their gross marginal profits [78]. According to the North American Industry Classification System, U.S. retail grocery sales comprised 50% deteriorating foods, 30% non-deteriorating foods, and 20% nonfood items [26]. According a survey by Ketzenberg and Ferguson [37], deteriorating products represent 30% of total supermarket sales around the world. In addition, deteriorating products have become an important reason why consumers choose one supermarket over another [74]. However, deterioration, namely, spoilage, decay, pilferage, evaporation, obsolescence, and damage, causes considerable losses to supermarkets [62]. The previous literature reports two main types of losses for deteriorating products. (1) The products are not sold by the end of the shelf life, which costs the European grocery sector billions of dollars each year [49]. According to a survey from the National Supermarket Research Group, a 300-store grocery chain loses approximately $34 million per year due to spoilage [12]. (2) The continuously decreasing quality of products before sales occur also leads to significant losses in total social welfare [38]. In light of the 2012 National Supermarket Survey, approximately $30 billion is lost annually in the U.S. grocery industry because of the deterioration of goods [59]. Therefore, fully considering products deterioration characteristics and reducing mismatches between supply and demand are crucial to successful grocery retailing.

The previous literature and practical operations indicate that besides purchasing decisions, pricing is another important and effective method of increasing the profitability of deteriorating products by impacting demand [61]. The works of [20,23,25,51,75] and [18] demonstrate the benefits of the joint optimization of ordering and constant pricing for deteriorating products. Unfortunately, constant pricing is unable to adjust demand depending on the quality of the remaining inventory. In response to this problem, dynamic pricing is employed to better match the supply and the demand of deteriorating products. The majority of supermarkets dynamically adjust the prices of deteriorating products to avoid spoilage. For example, FreshDirect.com uses a “Guaranteed Fresh” tag on its product and ensures product freshness by adjusting their prices. [3,15,27,33,42,48], among others, investigate and demonstrate the benefits of dynamic pricing for deteriorating products.

Although dynamic pricing can help match supply and demand, product price changes can also involve extra costs, which are called menu costs. Indeed, two major types of price adjustment costs are identified in the economics literature: physical costs and managerial costs [13]. Physical costs are incurred by retailers, such as Walmart and Carrefour, which pay the labor costs of manually changing thousands of shelf prices in their stores [7].

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Other physical costs are associated with producing, printing and distributing price books or catalogs. Managerial costs are directly related to the time and attention required of managers to gather the relevant information and to make and implement decisions [6]. With the development of E-commerce, physical costs have been reduced by advances in information technology, whereas managerial costs might actually have increased because of the added complexity of dealing with both online and in-store prices, the additional data from customers buying through websites, and the additional knowledge and systems required to understand E-commerce [13]. Regardless of how the components of menu costs (physical costs and managerial costs) change, many empirical studies have shown that they are very significant in retailing and other industries [2,36,60,65,77]. Specifically, Levy et al. [40] show that total menu costs represent approximately 35% of the net margin among U.S. supermarkets. They also find through menu costs play a crucial role in the price-setting behavior of supermarkets, namely, excessive menu cost will keep manager from adjusting product prices. Based on this practice, some quantitative models of pricing strategies have been proposed in the economics literature, such as those of [8,63,64]. However, quantitative research on dynamic pricing with menu costs, especially for deteriorating products under stochastic demand, has been ignored in the operations management community. The purpose of this paper is to fill this gap by investigating when and how managers should adjust product prices based on different menu costs.

Motivated by above practical applications and reports, we consider a retailer that manages a category of deteriorating product in a periodic-review finite-horizon inventory system with stochastic Poisson demand and heterogeneous customer preferences with respect to quality. By controlling for the pricing adjustment frequency with and without menu costs, we develop four pricing models, namely, a dynamic pricing model without menu costs (model 1), a dynamic pricing model with menu costs (model 2), a dynamic pricing model with a one-time adjustment (model 3) and a fixed pricing model (model 4), to account for different cost structures and practices for deteriorating products. Specifically, we jointly optimize inventory and prices for each model based on a stochastic demand function that is directly derived from the arrival rate, the customers utility function and the decay process of the deteriorating products. By comparing models 1 and 2, we can examine how menu costs affect dynamic pricing decisions. By analyzing models 2 and 3, we can investigate how the number of price adjustments affects the profitability of deteriorating products. Using model 4 as benchmark for models 1 and 2, we show that the dynamic pricing method increases the profitability of deteriorating products without and with menu costs, respectively. To the best of our knowledge, this study is the first to incorporate menu costs into a dynamic pricing model with stochastic demand and to investigate the impact of menu costs on a dynamic pricing setting with deteriorating products.

By formulating and analyzing pricing models, some management insights can be obtained. When menu costs are negligible, we characterize the optimal pricing form and show that the optimal prices of deteriorating products consistently decrease over time. Through numerical experiments, we show that firm profits are increasing in the flexibility of the pricing model, as measured by the frequency of price changes. By examining the impacts of menu costs, decay rates, holding costs and inventories, we demonstrate that the price range is wider if the pricing model is more flexible. In the presence of menu costs, a one-time price adjustment can provide most of the benefits of dynamic pricing. In addition, our findings suggest that it is typically preferable to adjust a price in the middle of the product shelf life rather than to make early or late adjustments. The above conclusions hold in the compound Poisson demand and general customer utility function scenarios. These findings can help managers make price adjustment decisions for deteriorating products in practice.

The remainder of the paper is organized as follows. In Section 2, the related literature is reviewed. In Section 3, we propose four different pricing strategies. In particular, we characterize the optimal pricing strategy when there are no menu costs. The numerical experiments are conducted in Section 4. We discuss our model in the context of a compound Poisson arrival process and a general customer utility function in Section 5. In Section 6, we discuss the results of this paper and present some future research opportunities.

2. Literature review

Dynamic pricing optimization problems for non-decaying products have been pursued by many researchers. A detailed review can be found in [28]. Among all dynamic pricing studies focusing on non-decaying products, the study by Gallego and Van Ryzin [31] is the most relevant to our research. They formulate a dynamic pricing problem over a finite horizon using intensity control and obtain structural monotonicity results for the product price as a function of the stock level and the length of the horizon. Unlike their research, which has a zero menu cost for non-decaying products, we consider decaying products and positive menu costs.

Some studies also focus on dynamic pricing optimization under stochastic demand for decaying products. For example, [1] find the optimal price and inventory levels for exponentially decaying products. Considering the same product assumption used by Aggarwal and Jaggi [1], Kang and Kim [35] formulate a model for a deteriorating inventory system to determine the price and analyze the impact of product quality deterioration on the optimal price. They find that the system can increase profits by adjusting prices based on the different deterioration rates of the products. Chew et al. [16] analyze the problem of a deteriorating product with a lifetime of two periods and prove that the expected profit is a concave function of the order quantity as well as of the prices of both new and old products. By learning customer demand, [58] examine the problem of establishing a dynamic pricing policy that maximizes the revenue from deteriorating products. With the development of information and sensor technologies, managers can obtain more information about deteriorating products [24]. By keeping track of the age and quality of deteriorating products, Wang et al. [33,74] propose pricing approaches based on dynamically identified shelf lives of food products in order to reduce food spoilage and maximize food retailer profits. The above papers all assume that prices can be adjusted freely. [29] and [11] study cases where managers can only change a product's price based on a finite price set. Besides integrating dynamic pricing and inventory control decisions [12,23,43,53], dynamic pricing and other promotional methods have been studied together by Tsao and Sheen [71]. Recently, Liu et al. [26,45] propose joint dynamic pricing and preservation technology investment models for a deteriorating inventory systems.

However, all these papers focusing on the dynamic pricing problem for deteriorating products neglect menu costs. The research on menu costs is mainly concentrated in the economics and marketing fields. In operations management, few papers have studied menu costs. Aguirregabiria [2] proposes an inventory and pricing model that incorporates both fixed ordering costs and fixed price adjustment costs but focuses more on empirical studies. Netessine [52] formulates and analyzes a seasonality model to optimize the timing of price changes with menu costs. Unlike our research, the driver of price adjustments in [52] is seasonality instead of randomness. Transchel and Minner [69] consider menu costs and analyze the impact of dynamic pricing on the single product order decision of a monopolist retailer. However, in their paper, the price is drawn from a finite set. Çelik et al. [9] note