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Pricing, service and preservation technology investments policy for deteriorating items under common resource constraints

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ABSTRACT

This paper addresses a joint pricing, preservation technology investment, replenishment cycle and dynamic service investment problem for deteriorating items under a common resource constraint with respect to preservation technology and service investments. The evolution of service level is considered to characterize the indirect positive effect of service investment on demand. The analytical solution for dynamic service investment is first obtained under the given sales price, preservation technology and replenishment cycle by solving an optimal control problem. An algorithm is then designed to generate the optimal joint pricing, preservation technology investment, service investment and replenishment policy to maximize the total profit per unit time. Further, a numerical example is presented to illustrate the main theoretical results and the effectiveness of the algorithm, and sensitivity analysis about key parameters is conducted to obtain managerial insights. The impact of common resource constraint on the optimal investment policy is investigated, implying that for a relatively low common resource capacity, the firm prefers to invest in service improvement rather than preservation technology.

1. Introduction

Deterioration of certain products (i.e., fruit, vegetable, medicine, electrical equipment) is commonly seen in many inventory systems, causing great losses in terms of quality and quantity. The average deteriorating rate of fruit and vegetable in China, for example, reaches up to 20–30%,[1] causing more than 100 billion yuan losses per year (Li & Zhu, 2013). As such, there calls for effective measures to reduce deterioration. An commonly applied way refers to preservation technology investment which are used to enhance advanced refrigeration technology, vacuum technology. Apart from preservation technology investment, more sophisticated strategies are needed to capture more market share. Customer service, representing all forms of demand-enhancing effort, including customer support, pre- and post-purchase services, technical and shopping assistance, and the overall quality of the shopping experience (Tsay & Agrawal, 2000), has been well viewed as relevant sources of competitive advantages (Xiao, Choi, Yang, & Cheng, 2012; Yao & Liu, 2005), which can significantly raise customer satisfaction, expand market sales, and increase revenue. Consequently, service investment should be involved to explore firms' marketing behavior. However, a firm's capital is usually limited by a capacity constraint, which confines the investments of preservation technology and service. There is, therefore, a trade-off for the firm to reasonably allocate its resources between preservation technology and service with the limited capacity.

Inspired by the research background above, we would like to propose the following questions: (1) What is the optimal pricing, service and preservation technology investments policy under resource constraints? (2) How to properly allocate the service and preservation technology investments under resource constraints? (3) How does the resource capacity affect the investments of service and preservation technology?

To answer the research questions, we consider a firm who produces and distributes a single deteriorating product to end consumers with a price and service-dependent demand. Bounded by the common resource constraints, the firm is responsible to invest in both preservation technology and service, where the former is applied to reduce the deterioration rate and the latter is carried out to boost demand. Spurred by the profit-maximization behavior, the firm aims at finding a joint optimal replenishment, pricing, preservation technology investment and dynamic service investment policy during a replenishment cycle. Adopting the optimal control theory, we first calculate the dynamic service investment

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[1] ResearchInChina, the vertical portal for Chinese business intelligence, announces the release of a new report – China Cold Chain Industry Development Report, 2010. Available at http://www.newswiretoday.com/news/83131/.

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policy under the given sales price, preservation technology investment and replenishment cycle. An algorithm is then designed to obtain the joint optimal replenishment, pricing, preservation technology and service investments policy. Furthermore, numerical examples we carry out well unveil the allocation of resources between preservation technology investment and service investment. The effect of resource constraints on the investments of preservation technology and service is discussed in detail.

The related literature with our work mainly includes the following streams: preservation technology investment, service investment, pricing and replenishment policy for deteriorating items.

Preservation technology investment, as a vital way to control deterioration rate, is drawing increasing attention from researchers. Hsu, Wee, and Teng (2010) developed a deteriorating inventory system wherein the retailer invests in preservation technology to reduce deterioration rate. The optimal replenishment cycle, shortage period, order quantity and preservation technology investment were obtained while maximizing the total profit per unit time. On this basis, Lee and Dye (2012) established an inventory model with stock-dependent selling rate and preservation technology investment, in which the shortages are allowed and partially backlogged. They first proved the existence and uniqueness of the optimal solutions, and designed an algorithm to look for the optimal preservation technology investment and replenishment schedule. Considering an inventory system for a non-instantaneous deteriorating item, Dye (2013) explored the effect of preservation technology investment on inventory decisions, which showed that a higher preservation technology investment leads to a higher optimal service rate. Hsieh and Dye (2013) established a production-inventory model for deteriorating items with time-varying demand and finite replenishment rate, where preservation technology and production rate are regarded as decision variables. A traditional particle swarm optimization was coded and used to seek the optimal production and preservation technology investment strategies. An effective algorithm, provided by Zhang, Bai, and Tang (2014), addressed the problem of pricing, preservation technology investment and inventory control for deterioration items. Assuming that the demand depends on price and quality, Liu, Zhang, and Tang (2015) studied the joint dynamic pricing and preservation technology investment strategy. Filippov-Cesari theorem was applied to prove the existence of optimal solutions, and an algorithm was designed to search for the optimal strategy. Furthermore, extending to a supply chain, Zhang, Liu, Zhang, and Bai (2015) dealt with coordination problem within a one-manufacturer-one-retailer supply chain where channel members are supposed to cooperatively invest in preservation technology to reduce deterioration rate. Algorithms were provided to obtain the corresponding pricing and preservation technology investment strategies in both integrated and decentralized scenarios. A revenue sharing and cooperative investment contract was designed to coordinate the supply chain. Researchers such as Dye and Hsieh (2012), Singh and Gupta (2014) and Yang, Dye, and Ding (2015) also delved into preservation technology investment for deteriorating items.

Service is of critical effect on customers' purchasing decision and loyalty, and eventually on their demand. Efficient service is thought to create a favorable attitude towards the provider and thus attracts consumer demand (Chiu, Choi, & Li, 2009; Dan, Xu, & Liu, 2012; Pei & Yan, 2015). More competitive advantages are followed by better service, which was supported by Hall and Porteus (2000) arguing that poor service drives consumers away while good service would increase a firm's chance to capture customers from its competitors. Extending this work by incorporating a general demand model, Liu, Shang, and Wu (2007) provided conditions under which the market share of a firm has a positive value, further demonstrating that demand patterns dictate how firms compete rationally and showing the likely outcomes of the competition. Focusing on the importance of service from manufacturers in the interactions between two competing manufacturers and their common retailer, Lu, Tsao, and Charoensiriwath (2011) compared the corresponding results in three different scenarios, finding that when the market base of one product increases, the competitor benefits at a less amount than the manufacturer of the first product. Motivated by the trend that many manufacturers are increasingly adopting a dual-channel due to the rapid development of the Internet, Dan et al. (2012) examined the optimal retail service and price in the dual-channel, and evaluated the impacts of service and degree of customer loyalty to the retail channel on the manufacturer and retailer's pricing behaviors. Furthermore, with the competition between an online channel opened by a manufacturer and a direct channel governed by a retailer, Pei and Yan (2015) built a profit-maximization model to show that supportive retail services from the manufacturer can alleviate dual-channel competition. Their results also indicated that the manufacturer is more likely to offer more financial support to the retailer to improve its service level when the product is more compatible with the web. Apart from those mentioned above, Littler and Melanthiou (2006), Chen, Kaya, and Özer (2008) and Chiu, Choi, Li, and Xu (2014), etc. also provided details about service.

Pricing and replenishment policy is still a growing area of interest in deteriorating inventory system. Wee and Law (2001) considered the time-value of money in a deteriorating inventory system with price-dependent demand, and employed heuristics and search methods to derive the optimal replenishment and pricing policy. Wee, Yu, and Law (2005) corrected an error in Wee and Shum (1999) who explored the optimal replenishment policy for deteriorating inventory in a single-level MRP system, which improved the corresponding results and analysis. Considering both ameliorating and deteriorating effects, Law and Wee (2006) developed an integrated production-inventory model to determine the optimal production and replenishment policy in the context of multiple deliveries, partial backordering and time discounting. Wee, Lo, Yu, and Chen (2008) further discussed the optimal replenishment inventory strategy with the consideration of ameliorating and deteriorating effects, time value of money and finite planning horizon, of which the amelioration and deterioration rates follow Weibull distributions. With time-dependent backlogging rate in a deterministic deteriorating inventory model, Dye (2007) assumed the demand and deterioration were known, continuous, and differentiable functions of price and time, respectively. Afterwards, he proved the existence and uniqueness of the optimal replenishment schedule and selling price, and provided an algorithm to search for the optimal solutions. Under the limited replenishment capacity for a firm, Lu, Zhang, and Tang (2016) first studied the joint dynamic pricing and replenishment policy in a deteriorating inventory system where the demand rate is dependent on stock quantity and sales price, then discussed joint static pricing and dynamic replenishment policy for this system. The comparison of numerical results under the two policies verified the advantages of the joint dynamic one. Recognizing that the quality and physical quantity of many products often deteriorate over time, Qin, Wang, and Wei (2014) discussed the pricing and lot-sizing problem for such deteriorating items with the assumption that the demand depends on price, quality as well as on-display stock level. Considering the inventory system with random disturbance, Li, Zhang, and Tang (2015) investigated a joint dynamic pricing and inventory control policy for perishable products. There are also some researchers exploring pricing and replenishment problem for non-instantaneous deteriorating items. Soni and Patel (2013), for example, assumed a price sensitive demand when the product has no deterioration, and a price and time-dependent demand while the product has deterioration, offering the optimal policy for price