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Optimal dynamic trade credit and preservation technology allocation for a deteriorating inventory model ☆

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ABSTRACT

In this paper, we examine an optimal dynamic decision-making problem for a retailer selling a single deteriorating product, the demand rate of which varies simultaneously with time and the length of credit period that is offered to the customers. The deterioration rate is time dependent and can be reduced by an investment in preservation technology. In addition, the risk of default increases with the credit period length. A generalized model is presented to determine the optimal trade credit, preservation technology investment and replenishment strategies that maximize the retailer's total profit after the default risk occurs over a finite planning horizon. Under certain conditions, we first establish a single period deteriorating inventory model, and then provide a comparative statics analysis that characterizes the impacts of key parameters on the retailer's optimal trade credit and preservation technology investment decisions by using the properties of the supermodular function. Dynamic programming is then used to solve the proposed model by employing the obtained theoretical results. At the end of this paper, some numerical examples and the results of a sensitivity analysis are used to illustrate the features of the proposed model; we then offer our concluding remarks.

1. Introduction

As reported by First Research (2005), the US retail grocery industry includes approximately 65,000 supermarkets and other grocery stores with combined annual revenue of approximately USD 550 billion. The major products sold in this industry include 50% of perishable foods, 30% of nonperishable foods and 20% of nonfood items. Today the market of perishable goods is growing fast due to the growing economy and population. However, the inevitable phenomena of deterioration of goods further erode businesses' already low profit margins. Beck, Bilby, and Chapman (2002) reported that businesses in Europe alone suffer EUR 18 billion of annual losses from stock shortages in the Fast Moving Consumer Goods sector. Ferguson, Lystad, and Alexopoulos (2006) revealed that approximately 15% of perishable goods are thrown away before reaching the consumer in the US retail grocery industry due to the deterioration of goods. As evident from these findings, the control of the deterioration of products is increasingly important in the retail grocery industry. An empirical study by The Profit Experts (2011) showed that reducing perishable waste by 20% would increase the total store profit by 33%, which highlight the pressing need for businesses to establish a more robust inventory management system to reduce their deterioration losses.

Furthermore, since grocery retailing is a dynamic and highly competitive industry, many businesses have no pricing power, and function on a small margin of profit. To avoid lasting price competition, businesses use trade credit as part of their pricing strategy and provide credit terms to their customers to gain a competitive edge. With the rapid growth of credit card adoption and usage, fewer and fewer customers are willing to pay the full price for a product or service immediately. In order to achieve more market share, today many businesses have arrangements with credit card companies and offer interest-free installment plans to their customers for a limited period. Trade credit period is an important issue in the area of cash management for businesses that are operating in today's environment because it has a significant impact on the businesses' cash flow. Although lengthening the credit period can increase sales, a longer credit period can tie up the business's capital in receivables and increase the probability of a customer default. Therefore, poorly managed trade credit may end up being more costly than profitable to a business, businesses would need to

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assess the trade-off between credit risks and the revenue potential of a marginal sale to maximize the total profit.

It is well known that the total profit can be enhanced by raising sale revenue and/or reducing costs. A longer trade credit period can stimulate sales, but the increase in demand and the consequent rise in the ordering quantity creates a greater deterioration loss. The deterioration of goods is a natural process that cannot be stopped, however, it can be slowed down by specialized equipment or processes when items are at risks of deterioration and obsolescence. For example, when food is preserved and packaged, it is not stable forever, but slowly deteriorates to the point where it is unacceptable. Low temperatures, such as refrigeration, help prevent microbial spoilage and chemical deterioration. Cold storage slows the deterioration of film and color materials. Therefore, the degree of deterioration of deteriorating items depends on the investment in the preservation technology of the inventory at the facility as well as the latter's environmental conditions. In this paper, we emphasize the importance of paying attention to trade credit and preservation technology investment when making lot sizing decisions. We integrate the effects of time and credit period dependent demand, preservation technology investment and trade credit risk into the traditional deteriorating inventory model. The objective of this paper is to determine the optimal replenishment scheme, periodic credit period and preservation technology allocation to maximize the total profit for the retailer over a finite planning horizon.

The remainder of the paper is organized as follows. In Section 2, we review the literature on time-vary demand, trade credit and preservation technology investment, respectively. In Section 3, we describe the assumptions and notation used throughout this study. In Section 4, we first establish a single period deteriorating inventory model with trade credit and preservation technology investment, and then provide structural results that characterize the sensitivity of trade credit and preservation technology allocation to model parameters. Since dynamic programming is a method for solving complex problems by breaking them down into simpler subproblems and it has been used to solve numerous complex problems in business and engineering, it is adopted to address the problem of multi-period dynamic trade credit and preservation technology allocation by employing the theoretical results obtained from this paper. In Section 5, some numerical examples and the results of a sensitivity analysis are discussed to illustrate the features of the proposed model. Finally, the conclusions and suggestions for future research are given in Section 6.

2. Literature review

The classical economic order quantity (EOQ) model is based on the implicit assumptions that the demand rate is constant over an infinite planning horizon and that payment will be made to the supplier of the goods immediately after receipt of the consignment. However, the first assumption is only valid during the maturity phase of a product life cycle. For fashion-industry goods, market demand may increase or decrease over time. Therefore, the patterns of time-varying demand, which reflect the sales in different phases of a product's life cycle, need to be considered. In the past three decades, the models for inventory replenishment policies involving time-varying demand patterns have captured researchers' attention. The fundamental result was that of Donaldson (1977) who established the classical no-shortage inventory model with a linear trend in demand over a known and finite horizon. However, as Donaldson's (1977) procedure had been too complex and tedious for computing, it led to the development of heuristic methods. Silver (1979), Phelps (1980), Ritchie (1984), Goyal (1986), Amrani and Rand (1990), Teng (1994), Hariga (1995), Teng (1996) and Wang (2002) derived simple heuristic procedures from Donaldson's problem. Recently, in order to characterize the more practical situation, Chen, Hung, and Weng (2007a, 2007b) established an inventory model under the demand function following the product-life-cycle shape. They employed the Nelder–Mead algorithm to solve the optimal number of replenishments as well as the optimal replenishment strategy. However, since the deterioration of inventory items is a common phenomenon in daily life because of poor storage and preservation quality, Dave and Patel (1981) extended Donaldson's (1977) model to consider the deterministic inventory model of deteriorating items with a linear trend in demand. Datta and Pal (1988) and Balkhi and Benkherouf (1996) then considered deterministic inventory models in which the items would deteriorate over time and the demand rate would increase over a known and finite planning horizon. In addition, Hariga (1996) and Teng, Chern, Yang, and Wang (1999) analyzed and compared the optimal EOQ models with time-varying demand for deteriorating items under various replenishment policies. Subsequently, Chang and Dye (1999) and Papachristos and Skouri (2000) extended the models of Hariga (1996) and Teng et al. (1999) to include a time-dependent partial backlogging rate. Cheng and Wang (2009) and Wang and Huang (2014) further extended the EOQ/EPQ model by considering deteriorating items with a trapezoidal type demand rate.

Furthermore, the second assumption of cash on delivery is not quite practical in real markets. Since trade credit can reduce the customer's inventory holding cost, lengthening the credit period may create reputation among potential customers and consequently gain increased market share. Therefore, trade credit is an increasingly general payment behavior in real business transactions. In recent years, a large amount of attention has been devoted to the models for inventory replenishment policies involving trade credit policy. The fundamental result in the development of the EOQ model with trade credit policy was that of Goyal (1985) who studied an EOQ model under the conditions of permissible delay in payments. Aggarwal and Jaggi (1995) and Hwang and Shinn (1997) extended the model of Goyal (1985) by considering a deterministic inventory model with a constant deterioration rate. In modifying Goyal's (1985) model, Teng (2002) then assumed that the selling price is not equal to the purchasing price. The important finding from Teng's (2002) model is that it makes economic sense for a well-established retailer to order small lot sizes to take advantage of the payment delay more frequently. Huang (2003) developed an EOQ model in which a supplier offers a retailer the permissible delay period of M, and the retailer in turn provides the trade credit period of N (with $N \leqslant M$) to the customers. Chang, Ouyang, and Teng (2003) presented an inventory model for the items with a constant demand and deterioration rate under supplier credits that are linked to ordering quantity. Liao and Huang (2010) developed an order-level inventory model for deteriorating items with capacity constraints and permissible delay in payments. In order to reflect demand in different phases of a product life cycle, Chang and Dye (2005) investigated the effects of time-varying demand and deterioration rates on the inventory model, when the credit period depends on the retailer's ordering quantity. Tsao and Sheen (2008) and Tsao (2010) adopted a price- and time-dependent demand function to model the finite time horizon inventory of deteriorating items that are subject to the supplier's trade credit. Their models were solved by dynamic programming techniques through whicn the selling price was adjusted upwards or downwards periodically. More recently, to accommodate more practical features of the real inventory systems, researchers such as Sana and Chaudhuri (2008), Geetha and Uthayakumar (2010), Maihami and Kamalabadi (2012), Sarkar (2012), Teng, Min, and Pan (2012), Tsao (2013), Khanra,