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Coordinating a supply chain for deteriorating items with a revenue sharing and cooperative investment contract ☆

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ABSTRACT

In this study, a one-manufacturer–one-retailer supply chain model for deteriorating items with controllable deterioration rate and price-dependent demand is developed, in which both players cooperatively invest in preservation technology to reduce deterioration. Algorithms are designed to obtain the pricing and preservation technology investment strategies in both integrated and decentralized scenarios. It is shown that cooperative investment strategy benefits the manufacturer but damages the profits of the retailer and the whole supply chain. A revenue sharing and cooperative investment contract, which combines revenue sharing and cost sharing mechanisms, is thus designed to coordinate the supply chain. Numerical simulations and sensitivity analysis of the equilibrium strategies and coordinating results on key system parameters are given to verify the effectiveness of the contract, and meanwhile get some managerial insights. The results show that only when the revenue sharing rate lies roughly between 1/2 and 3/4 can the contract perfectly coordinate the supply chain in most cases, which has an important guiding significance for the supply chain coordination of deteriorating items when considering preservation technology investment.

1. Introduction

Deteriorating items are assumed to deteriorate with time, resulting in a decreasing utility or quantity from the original ones. Such items include fruits, vegetables, blood, fashion goods, electronic products and so on. The phenomena of deterioration, namely vaporization, damage, spoilage, dryness, etc., take place frequently in inventory systems and cause great losses to inventory managers. In a two-echelon supply chain, manufacturer and retailer have to manage their own inventories individually due to different geographical locations. In order to cut losses caused by deteriorating items, they may cooperatively invest in preservation technology to reduce deterioration rate. A common scenario is as follows: the retailer invests in preservation technology, and the manufacturer acquires preservation technology information from the retailer and provides a subsidy to the retailer's investment. Meanwhile, to reduce the adverse impact of the double marginalization and improve supply chain efficiency, a variety of contracts have been designed in the past few decades, among which the revenue sharing contract is the most widely used scheme in improving supply chain performance. However, Cachon and Lariviere [1] show that when investment or competition occurs, a revenue sharing contract often fails to coordinate the supply chain. Therefore, when we consider a supply chain for deteriorating items with preservation technology investment, the following research questions arise: (1) Can a cooperative investment strategy improve the supply chain efficiency? (2) Can a revenue sharing contract coordinate the supply chain perfectly? If not, then (3) can a contract combining revenue sharing and cost sharing mechanisms coordinate the supply chain?

To answer the research questions above, we consider a two-echelon supply chain of deteriorating items consisting of a manufacturer and a retailer with price-dependent demand, in which pricing and preservation technology investment strategies are studied under both integrated and decentralized scenarios. In the integrated scenario, the manufacturer and the retailer jointly set retail price and preservation technology investment to maximize the whole supply chain profit. The decentralized scenario is played in a Stackelberg game, in which the manufacturer, as the leader, determines the wholesale price and the subsidy proportion of preservation technology investment, while the retailer, as the follower, decides the retail price and preservation technology investment. The complexities of the problem restrain us from acquiring analytical solutions, so we develop an algorithm for each scenario to obtain the corresponding strategies. Furthermore, we present a revenue sharing and cooperative investment contract which combines revenue sharing and cost sharing mechanisms to coordinate the supply chain. Finally, numerical study is carried out

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to illustrate the effectiveness of the algorithms and the contract, also sensitivity analysis of the solutions and the revenue sharing rate with respect to key system parameters are given to gain some valuable managerial insights.

The related literature with our work for deteriorating items involves three streams: preservation technology investment, pricing and inventory control, as well as supply chain coordination.

As the improvement of science and technology, the deterioration rate of deteriorating items can be controlled and reduced by effective capital investment such as procedural changes, specialized equipment acquisition and preservation technology investment. In practice, refrigeration equipments are commonly used to keep fruits, flowers and sea foods fresh for a long time. Hsu et al. [2] originally develop a deteriorating inventory model in which the retailer invests in the preservation technology to reduce deterioration rate. Their work provides the optimal replenishment schedule and preservation technology investment strategies while maximizing the unit time total profit. Lee and Dye [3] formulate a deteriorating inventory model with stock-dependent demand and shortage so as to decide the optimal preservation technology investment in conjunction with replacement schedule. Hsieh and Dye [4] present a production-inventory model with time-varying demand, and through particle swarm optimization algorithm, they obtain the optimal production and preservation technology investment which minimizes the total costs. Dye [5] considers a non-instantaneous deteriorating inventory model with a time-dependent partial backlogging rate, and the uniqueness of the optimal replenishment and preservation technology strategies is proved. Xue et al. [6] study the temperature control problem for quality of perishable foods, and the optimal temperature is obtained to reduce the quality deterioration rate when minimizing the total cost. Zhang et al. [7] study the problem of pricing, length of replenishment cycle and preservation technology investment for deteriorating item in the context of a single entity, and optimal solutions are obtained by an effective algorithm. Shah et al. [8] explore the impact of deploying suitable preservation technology for an inventory system where units are subject to constant rate of deterioration, and obtain the optimal preservation technology investment, retail price and purchase quantity to maximize the total profit per unit time. Researches [9–12] also look into the preservation technology investment problem for deteriorating items.

In addition, pricing, as an important factor affecting the market demand, is also taken into account in the inventory system of deteriorating items. Generally, researchers combine pricing and other strategies to study the inventory control problem for deteriorating items. Dye [13] develops a deterministic inventory model for deteriorating items with time-dependent backlogging rate, and acquires the optimal selling price and replenishment schedule through an algorithm. Maihami and Kamalabadi [14] address a joint pricing and inventory control problem for instantaneous deteriorating items involving a price and time dependent demand function. Assuming that demand is affected by adverting and retail price, Shah et al. [15] study pricing and advertising policy for non-instantaneous deteriorating items with generalized type of deterioration and holding cost rates. Sana [16] considers the optimal selling price as well as the lot size in an inventory system with time-varying deterioration and partial backlogging. Wang and Li [17] address the problem of how to reduce food spoilage waste and to maximize retailer's profit through a pricing approach based on dynamically identified food shelf life. The proposed model is evaluated through different pricing policies to exploit benefits from using accurate product shelf life information captured by tracking and monitoring technologies. Banerjee and Turner [18] study the problem of assigning optimal prices to assets whose values become zero after a fixed expiry date, e.g., a given airline flight, rooms in a hotel for a given night and so on. Their model permits consumers to arrive in groups, and the arrival follows an inhomogeneous Poisson process. Then the pricing problem is achieved by setting up coupled systems of differential equations by numerical simulation. Maihami and Karimi [19] deal with the problem of replenishment policy and pricing for non-instantaneous deteriorating items with retailer's promotional effort. They assume a price dependent stochastic demand function where shortage is allowed and partially backlogged. The optimal selling price, replenishment schedule, and order quantity are obtained by an algorithm. Liu et al. [20] study joint dynamic pricing and investment strategy for perishable foods, in which the demand is dependent on price and quality. Researches such as [21–26] also consider pricing and inventory control problem for deteriorating items.

All the above studies assume that policies are determined by one decision-maker to optimize its own performance. However, in most cases, supply chain systems are decentralized and consist of many members including manufacturers and retailers. Game theory has been viewed as one of the most prevalent approaches to address the interaction between the entities of supply chain. Dong et al. [27] develop a model for deteriorating items in a decentralized case involving competition between the manufacturer and the retailer, and propose the competitive pricing and replenishment policies. Lin et al. [28] study four scenarios concerning inventory policies between suppliers and retailers: no information is shared; suppliers are dominant during negotiations with retailers; retailers dominate the negotiations with suppliers; and suppliers and retailers cooperate. Their results indicate that the cooperation scenario with information sharing is the best to achieve a win–win situation. However, owing to the double marginalization effect in the decentralized supply chain, the total supply chain profit is lower than that in the integrated supply chain. Hence, many researchers focus on designing a contract to coordinate the supply chain, then propose various types of coordination schemes [29]. Among them, revenue sharing contract is widely used in improving supply chain efficiency. Xiao and Xu [30] develop a Stackelberg game model of a one-supplier–one-retailer supply chain for deteriorating products under vendor-managed inventory. They provide the price and service strategies under decentralized setting and integrated setting, respectively, and design a generalized revenue-sharing contract to coordinate the supply chain. This contract not only includes the revenue share of the retailer, but also involves the transfer price paid by the retailer, which makes both players simultaneously share the revenues and costs. Yu et al. [31] investigate a model for deteriorating items consisting of a retailer acting as the leader and a supplier as the follower, in which the deterioration rate follows a Weibull distribution and the retail and wholesale prices decrease over time. The retailer executes three profit-sharing mechanisms to motivate the supplier to participate in supply chain optimization. A search algorithm and numerical examples are presented to demonstrate the profitability of the three mechanisms. Bai et al. [32] consider a two-echelon supply chain composed of one manufacturer and one retailer for deteriorating items, and assume that the demand is affected by promotional effect, selling price, inventory level and time. They find that, when the manufacturer and the retailer share the investment cost of promotional effort equally, revenue sharing contract and revenue and cost sharing contract can both coordinate the supply chain perfectly, and the latter contract is easier to be accepted by the system. In addition, the studies [33,34] also investigate supply chain coordination for deteriorating items.

In the aforementioned literature, no model is proposed to consider preservation technology investment, pricing and supply chain coordination simultaneously. Our work extends the study of [7] to a two-echelon supply chain composed of a manufacturer and a retailer. Specifically, the retailer sets retail price and preservation technology investment to maximize its own profit, while the manufacturer pursues its maximum profit by determining the wholesale price as well as the subsidy proportion since it shares the preservation