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Pricing, collecting and contract design in a reverse supply chain with incomplete information

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ABSTRACT

The significance of the reverse supply chain management and remanufacturing operations has been gaining increased attention in the literature and in practice. In this paper, we address the problem of how to make pricing, collecting and contract design decisions in a reverse supply chain, which consists of a collector and a remanufacturer. Two non-cooperative game models are established under complete and incomplete information scenarios, respectively. To begin with, we obtain the equilibrium pricing and effort decisions under complete information case. Then, the first-order conditions that the optimal acquisition price, optimal collection effort, optimal wholesale price and optimal retailing price satisfy are given under incomplete information. The result shows that the incomplete information structure might lead to an efficiency loss in the reverse supply chain. Hence, we then introduce a two-part tariff contract for the remanufacturer to motivate the collector to reveal private information, which can effectively improve the channel performance. Finally, we conduct numerical examples to compare the equilibrium solutions under different models and make the sensitivity analysis for some model parameters.

1. Introduction

Recently, consumers' increasing awareness of environmental quality and more stringent legislation introduced by governments heavily affect firms' marketing and operations strategies (Govindan & Popiuc, 2014). To meet these requirements, many companies have increasingly focused on establishing reverse supply chains and developing remanufacturing practices in order to obtain more economic benefits and positive environmental outcomes. The reverse supply chain can be seen as the series of activities to retrieve a used product, which aims to recover its remaining value (Huang & Su, 2013; Prahinski & Kocabasoglu, 2006).

In fact, remanufacturing can be a potentially promising choice compared with new manufacturing under some cases, at the same time, requires less energy usage than new manufacturing (Galbreth, Boyaci, & Verter, 2013). In many manufacturing industries, such as automobile, textile, mobile phone and high-tech manufacturing, the reverse supply chain and remanufacturing operations have been successfully implemented. For example, Xerox can utilize 90 percentage of the recycled materials in manufacturing new toner cartridges (Shi & Min, 2013). According to a report by Global Industry Analysts (2010), the global automotive remanufacturing is predicted to add up to US $104.8 billion in 2015 (Wu, 2012). In summary, the potential prospect of remanufacturing has been widely recognized by business managers and the academic business community.

However, the uncertainty in quality, quantity and timing of the used product market often leads to many firms passively to implement collecting and remanufacturing activities; firms are not willing to align the corresponding remanufacturing costs and sales opportunities (Guide, Harrison, & Van Wassenhove, 2003). According to a Chinese e-waste market analysis report, the total recycling rate of electronic products is less than 20%, and the recycling and remanufacturing efficiency is also very low as a result of the restrictions from old recycling technology and the defects of the construction of the recycling channel (Wang, Kuehr, Ahlquist, & Li, 2013; Wang, Zhang, Yin, & Zhang, 2011; Zhang et al., 2015). One of the most important reasons is that, from a reverse supply chain perspective, the asymmetric information between manufacturing firms and collectors lowers the recycling efficiency. For example, in a reverse supply chain, the collector might be better informed of the used product supply market information, as well as firm's collection effort cost. However, many existing models regarding reverse supply chain assume that all supply chain members have complete information and all decisions are made in a

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certain environment. How the incomplete information influences channel players' decisions and profits in the reverse supply chain is worth substantial study.

The uncertainty of the cost and used product market information makes it difficult for remanufacturing firms to make some operations and marketing strategies (Li, Li, & Cai, 2015). Savaskan, Bhattacharya, and Van Wassenhove (2004) and Zhao and Zhu (2015) point out that there are two main challenges in the management of the reverse supply chain: how to match the supply of the used product and the demand for the remanufactured product and how to collaborate with the collector. Many well-known companies have achieved great success in product recycling and reuse by collaborating with collectors. For example, firms (such as Apple, HP and Dell) have built cooperative recycling programs with collectors to facilitate used product collection (Esenduran & Kemahlgoglu-Ziya, 2015; Govindan & Popiuc, 2014). Rahman and Subramanian (2012) also point out that the integration between manufacturing firms and collectors in reverse supply chain can effectively improve collection efficiency and the profitability of the firm. Hence, it is necessary to design appropriate collaborative mechanism between the collector and the remanufacturer in a reverse supply chain to improve channel performance. However, Govindan, Popiuc, and Diabat (2013) claim that the incentives used to coordinate the reverse supply chain are very limited, particularly in an uncertain environment. When the collector in a reverse supply chain has private information, it is practically significant to investigate how the remanufacturer designs an effective incentive mechanism to motivate the collector to reveal private information and to reach a win-win situation. To the best of our knowledge, this problem has not been explored in the existing literature, and we aim to fill this gap by studying the contract design in a reverse supply chain with incomplete information.

Motivated by the above facts, in this paper, we present a theoretical model to investigate the pricing, collecting and contract design in a reverse supply chain with complete and incomplete information. The collector is better informed about the base supply of the used product and the collection effort cost scale, which are unknown to the remanufacturer. Hence, this study addresses the situation in a reverse supply chain where information is incomplete. Through establishing two non-cooperative models, we compare the equilibrium outcomes and profits of channel players under complete and incomplete information. Furthermore, we design a two-part tariff contract in which the remanufacturer provides a higher wholesale price at the cost of charging a fixed payment to the collector. The contribution of this study includes the following three aspects. First, we consider the joint effects of the acquisition price and collection effort on collection quantity and further explore the uncertainty of the collector's effort cost on equilibrium decisions and profits. Second, we analyze and compare the optimal decisions of the remanufacturer and the collector under complete and incomplete information cases and show that the incomplete information decision structure reduces the efficiency of the reverse supply chain system compared with complete information case. Third, we use a two-part tariff contract to coordinate the decentralized reverse supply chain, the contract ensures the collector to share private information with the remanufacturer and the channel performance is also improved.

The remainder of this paper is organized as follows. In the following section, we briefly review the relevant literature. Section 3 shows the basic model and key assumptions. In Sections 4 and 5, we present two different reverse supply chain models and derive the details of our analytical results under complete and incomplete information structures. Section 6 presents the two-part tariff contract to improve the channel performance under incomplete information. Section 7 provides some numerical examples to examine the propositions and the final section concludes the study, including some managerial insights and suggestions for future research.

2. Literature review

We review the literature closely related to our research. The first body of research examines pricing and remanufacturing decisions in reverse supply chains. Savaskan et al. (2004) address the pricing and reverse channel selection decisions and show that the retailer collecting model is the most effective mode of product collection for the manufacturer. Savaskan and Van Wassenhove (2006) later extend the model to allow retail competition and explore the reverse channel structure selection strategies between the direct and indirect collection systems. Ferrer and Swaminathan (2010) examine pricing and remanufacturing strategies in a differentiated product market for a monopolistic firm when facing different periods. Atasu, Toktay, and Van Wassenhove (2013) explore the impact of collection cost structure on the manufacturer's optimal reverse channel choice. They show that the manufacturer's optimal channel choice hinges on the cost structure that moderates the collection and sale quantities. Jena and Sarmah (2014) examine the cooperation and competition strategies in closed-loop supply chains when two manufacturers compete to sell their products. Wei and Zhao (2015) study the pricing and remanufacturing strategies with two competing supply chains. Wu and Zhou (2017) explores the manufacturer's optimal reverse channel selection strategy under two competing closed loop supply chains. Meanwhile, some other relevant studies explore the network design and optimization problems in the reverse supply chain (Alshamsi & Diabat, 2015; Santibanez-Gonzalez & Diabat, 2013; Batarfi, Jaber, & Aljazzar, 2017; Diabat, Abdallah, & Henschel, 2015; Diabat & Al-Salem, 2015). However, these papers all assume that channel members have complete information over others' strategies in the reverse supply chain and do not focus on incomplete information.

The second stream of research related to our study is about reverse supply chain strategies under incomplete/asymmetric information. As we know, numerous studies on forward supply chain management with incomplete information have been made (Esmaeili & Zeephongsekul, 2010; Ha & Tong, 2008; Li, Gilbert, & Lai, 2014; Sucky, 2006). However, very few studies consider the decisions of the reverse supply chain with incomplete information structure. Bakal and Akcali (2006) investigate the effect of the random recovery yield rate on pricing decisions in reverse supply chains and analyze the influence of yield variation on the profitability of remanufacturing. Teunter and Flapper (2011) consider the effect of quality uncertainty on the optimal acquisition and remanufacturing policies for both deterministic and uncertain demand environment. Li et al. (2015) study the pricing and remanufacturing decisions when both the demand for remanufactured products and remanufacturing yield are random. Xu et al. (2017) proposes a robust model for global reverse supply chain design under uncertain waste collection rate and carbon emission constraint. Wei, Govindan, Li, and Zhao (2015) investigate the pricing and collecting decisions in manufacturing and remanufacturing closed-loop supply chain with one manufacturer and one retailer under symmetric and asymmetric information environments. Our research differs from Wei et al. (2015) in the following aspects. First, we focus on the analysis of the reverse supply chain structure with complete and incomplete information, which shows the interplay between the collector and the remanufacturer. Second, we explore a two-part tariff contract provided by the remanufacturer to motivate the collector to reveal private information, which, in turn, improves the channel performance.