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Designing contracts for a closed-loop supply chain under information asymmetry

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ABSTRACT

This paper studies the problem of designing contracts in a closed-loop supply chain when the cost of collection effort is the retailer's private information. We investigate four cases: two contracts (a two-part nonlinear contract and a collection effort requirement contract), each under complete information and asymmetric information. We derive the manufacturer's optimal contracts for all four cases and analyze the impact of information on the equilibrium results of supply chain members.

1. Introduction

Driven by economic incentives, social pressure and legislation, a large number of companies such as Xerox, Hewlett Packard and Kodak are engaging in remanufacturing operations in addition to the traditional operations management. As a part of remanufacturing operations, some manufacturers rely on retailers for collecting their used products. A classic case is that Kodak receives single-use cameras from large retailers and recovers 76% of the weight of a returned camera in the production of a new one. For this indirect collection system, the performance of the reverse channel strongly relies on the retailer's investment on the promotional/advertising activities, which may be needed to motivate consumers to return their products [7]. Generally, the investing activities are the retailer's private information, and are hard to be monitored by the manufacturer. Hence, it is difficult for the manufacturer to influence the collection effort of the retailer and to allocate the profit of the supply chain.

In this paper, we consider a closed-loop supply chain with one manufacturer and one retailer. In the forward supply chain, the manufacturer sells the products to the consumers through the retailer, and in the reverse supply chain, the manufacturer also utilizes the retailer for collecting used products which can be remanufactured into new products. The collection rate of used products relies strictly on the retailer's product collection effort which is the retailer's private information and cannot be observed exactly by the manufacturer. The manufacturer designs contracts to maximize his profit and two common forms of contract are investigated: One is a two-part nonlinear schedule with wholesale price and a fixed payment depending on quantity ordered by the retailer, the other is a collection effort requirement contract which the manufacturer set requirement on the collection effort of the retailer in addition to the two-part nonlinear schedule. The questions we are interested in are as follows: How to design contracts in the closed-loop supply chain with information asymmetry? What is the impact of asymmetric information on the equilibrium profits and strategies of both manufacturer and retailer?

We derive the manufacturer's optimal contracts under complete information and asymmetric information, respectively. It is shown that in the case of complete information, the two-part nonlinear contract cannot coordinate the supply chain, while the collection effort requirement contract can do it. We also find that in the case of asymmetric information, neither of the contracts can coordinate the supply

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chain. Besides, compared with the case of complete information, the manufacturer always suffers from the asymmetric information, while the retailer always benefits from the private cost information. Moreover, regardless of which contract is implemented, the wholesale price and the retail price in the complete information case are lower than those in the asymmetric information case, and the return rate of the complete information case is higher than that of the asymmetric information case. We have also compared the two forms of contract and have found that the retailer exerts more (less) collection effort under the two-part nonlinear contract than that under the collection effort requirement contract if the remanufacturing operations yield small (large) economic benefits.

Our paper is most relevant to close-loop supply chain management and contract design under information asymmetry. The theme of close-loop supply chain with remanufacturing has received much attention in the past few years. Savaskan et al. [6,7] investigate the optimal reverse channel structure in the closed-loop supply chain with single-manufacturer–single-retailer scenario and single-manufacturer–two-retailer scenario. Webster and Mitra [8] study the impact of different take-back laws on the strategies of manufacturer, remanufacturer and policy-maker in a competitive environment. Xiong et al. [9] demonstrate the impact of the interaction between a key component supplier and a non-integrated manufacturer on the economic and environmental implications of remanufacturing. Zhou et al. [10] study the bride side of the decentralized control mode which the original equipment manufacturer manages its manufacturing and remanufacturing activities separately. Based on these literature, we assume that the retailer's collection effort is the asymmetric information and contribute to designing contracts for the manufacturer with remanufacturing operations.

Our paper also belongs to the contract design in the present of information asymmetry. Ha [4] studies the optimal contracts and cutoff policy in a one-supplier–one-buyer supply chain when the buyer's marginal cost is hard to monitor by the supplier. Corbett et al. [1] consider a buyer's variable costs to be private and investigate the value of information and of more general contracts to the supply chain members. Mukhopadhyay et al. [5] examine the optimal contract in a dual-channel supply channel when the value-added cost of retailer is private information. Dai and Chao [2] study the problem of incentive and inventory planning when the firm has incomplete information about the risk attitude of sales agents. These studies, however, are limited to the forward supply chain and without considering the collection and remanufacturing operations. We, therefore, complement to study the contract design in a closed-loop supply chain.

The rest of this paper is organized as follows. Section 2 describes the notation and assumptions of the model. Section 3 derives the optimal two-part nonlinear contract under complete and asymmetric information. Section 4 studies the optimal collection effort requirement contract and compares the two forms of contracts. Some potential future research topics are outlined in Section 5. All proofs are served as electronic supplementary material and provided at http://www.journals.elsevier.com/operations-research-letters (see Appendix A). All Proofs are also available from the authors for the interested reader.

2. Model notation and assumptions

We consider a closed-loop supply chain which integrates the forward supply chain and the reverse supply chain, and we analyze the decisions of the closed-loop supply chain in a single-period setting. In the forward supply chain, let c_m denotes the unit cost of manufacturing a new product directly from raw materials, and c_r denotes the unit cost of remanufacturing a returned product into a new one. The final market's demand $D(p) = \phi - \beta p$, where ϕ ($\phi > \beta c_m$) represents the potential market demand, p is the retail price of retailer (he) and β represents the price sensitiveness of demand. We give the following assumptions in the forward supply chain: Firstly, consumer could not distinguish the remanufactured product between the new product because of the advanced remanufacturing technology; secondly, let $\Delta = c_m - c_r > 0$, which implies that the manufacturer (she) can obtain economic benefits from the remanufacturing operations.

In the reverse supply chain, the retailer collects used products from consumers, and then delivers to the manufacturer. Let b represents the exogenous buy-back price of a returned product which transfers from the manufacturer to the retailer ($b < \Delta$), and τ ($0 \le \tau \le 1$) denotes the return rate of used products, which could be also interpreted as the fraction of current generation products remanufactured from returned units. Correspondingly, the total collection cost is given by $\theta\tau^2$, where θ represents the retailer's cost type and reflects the collection efficiency of the retailer. From the above assumptions, the average unit cost of manufacturing can be written as $c = (1-\tau)c_m + \tau c_r$ or $c_m - \tau\Delta$. In fact, the above notation and assumptions are similar to [6,7].

The asymmetric information we modeled in this paper is the retailer's collection efficiency parameter θ. The manufacturer does not know θ, but has a prior distribution $F(\theta)$ with continuous density $f(\theta)$, defined on $\left[\underline{\theta}, \overline{\theta}\right]$. We consider two forms of contract, first is the two-part nonlinear contract $\{w(q), L(q)\}$, i.e., the manufacturer specifies the unit wholesale price $w(q)$ and a lump-sum side payment $L(q)$, where $L(q) > 0$ represents a franchise fee charged by the manufacturer, and $L(q) < 0$ represents the subsidies give to the retailer. Second is the collection effort requirement contract $\{w(q), \tau(q), L(q)\}$, in which the manufacturer specifies the return rate that the retailer must collect from consumers apart from the two-part nonlinear contract. This is maybe possible when the take-back legislation is strict or the economic benefits of collection are large. Let $\Pi_{\bar{M}}$ and $\Pi_{\bar{R}}$ denote the reservation profit level of the manufacturer and the retailer, respectively. Only when both parties earn more profit than their reservation profit will the contract be signed. Moreover, we will see that both parties' profits are always decreasing in θ, so they can follow a cutoff policy: They will not sign the contract if $\theta > \alpha$, where α ($\alpha \in \left[\underline{\theta}, \overline{\theta}\right]$) is the cutoff point. Ha [4] shows that such a policy is optimal for contract signing.

The goal of this paper is to investigate the impact of information, and we will study each contract under complete or asymmetric information, respectively. Hence, four cases will be considered. In Case F1 and F2, the manufacturer knows the value of θ and offers the contract $\{w, L\}$ and the contract $\{w, \tau, L\}$, respectively. However, in Case A1 and A2, the manufacturer does not know the exact value of θ, correspondingly, he offers a menu of contracts, i.e. $\{w(q), L(q)\}$ and $\{w(q), \tau(q), L(q)\}$, which can also be reformulated as $\{w(\theta), L(\theta)\}$ and $\{w(\theta), \tau(\theta), L(\theta)\}$ by the revelation principle [3].

3. The two-part nonlinear contract

To provide a benchmark, we first analyze the decisions of the integrated supply chain. From the notation and assumptions of Section 2, we know the central planner optimizes

$$\max_{p,\tau} \Pi_C = (\phi - \beta p)(p - c_m + \tau\Delta) - \theta\tau^2. \tag{1}$$