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Multi-dimensional Reverse Channel Decision under Different Collection Strategies

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Abstract: In this paper, a remanufacturer-driven closed-loop supply chain with multi-dimensional reverse channel is modeled. In which, the used products are acquired simultaneously in the following ways by the remanufacturer: signing contacts with a proportion of the customers to return the used products with cash refund; buying from the original equipment manufacturer; subcontracting the third party to collect the returns. Taken the differentiation in collection strategies (pick-up strategy or drop-off strategy) of these collection agents into account, we explore the optimal collection choices of the decision-maker exhaustively by the game theory.

Keywords: closed-loop supply chain; reverse logistics; channel; remanufacturing; collection strategies.

1. INTRODUCTION

The research on closed-loop supply chain (CLSC) with remanufacturing has gained significant momentum in academia and industry over the last few years for the financial and environmental benefits in products remanufacturing. CLSCs consisting of the movement of the products from the upstream suppliers to the downstream customers and the flow of used ones back to the remanufacturers, combine the reverse logistics and the forward logistics. And to the decision-makers, how to design the reverse logistics (RL) network which collects used products from the end users is one of the most crucial components of CLSCs to be taken into account.

Savaskan et al. (2004) addressed that all the original equipment manufacturer (OEM), the retailer, and the third party can take on the collection activities in a RL network. To efficiently collect enough quantities of used products from all kinds of customers, many firms engaging in remanufacturing have adopted more than one reverse channel. For example, ReCellular Inc., the largest cell phone remanufacturer in the USA, chooses to collect the used phones both form the retailers and the third party collectors (Teunter and Flapper 2011). In addition, facing with the challenge of economic globalization, more and more OEMs in the field of construction machinery devote themselves to the development and research of the manufacturing process, and are likely to outsource the processing of end-of-life vehicles to other agents (Karakayali et al. 2007). However, the research on the design of the associated RL network is just getting started.

As observed in practice, there are different kinds of reverse logistic network structures, it indicates that all the original equipment manufacturer, retailer, and the third party can respectively or jointly actively engage in used-product acquisition and recovery operations in a closed-loop supply chain. Huang et al. (2013) analysed the optimal strategies of a closed-loop supply chain with dual recycling channel and gave macro-control policy making suggestions. Hong et al. (2013) investigated three reverse hybrid collection channel structures, and concluded that the manufacturer and the retailer hybrid collection channel was the most effective one. These two works may be the first to investigate the reverse logistic network structures with jointly using different reverse channel, but they ignored the effects of the collection strategies adopted by the collection agents.

Ferguson and Souza (2010) pointed out that the used products can be picked-up from the end users or collected by setting up drop-off facilities, such that one would observe diseconomies of scale or economies of scale in the collection cost structures. Under a pick-up strategy, the products are collected from the end users, whereas under a drop-off strategy, the end users make the travel effort to a central point to return the used products. Atasu et al. (2013) investigated how the collection cost structure of these two different collection strategies influenced a manufacturer's profit, and described under what conditions each reverse channel choice should be preferred. Chuang et al. (2014) further extended the work of Souza et al. (2013) to study the choice of reverse channel structures for high-tech product featured with a short life-cycle and volatile demand. In summary, the models discussed in Huang et al. (2013), Hong et al. (2013), Atasu et al. (2013), and Chuang et al. (2014) have explored the reverse logistic network structures from different perspectives. However, the multi-dimensional reverse channel under different collection strategies generally adopted by the firms engaging in remanufacturing in practice but, to the best of our knowledge, is still unexplored, which motivates us to work on this problem.

In order to study the multi-dimensional reverse channel decision under different collection cost structures, we investigate a remanufacturer-driven CLSC for construction

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machinery remanufacturing. The CLSC consists of an OEM, a retailer, and a third party, where the retailer is authorized by the OEM to remanufacture his own products. In the reverse channel, the OEM and the retailer collect the used products with drop-off strategy, and the third party collects the used products with pick-up strategy. The different collection strategies result in different collection cost structures for the agents. Based on the work of Atasu et al. (2013), we use the game theory to analyse the optimal collection decision of the remanufacturer under different reverse logistics cost coefficients under the multi-dimensional reverse channel, and provide insights for the decision-maker.

The rest of this paper is organised as follows. Section 2 provides the definition of symbols used throughout this paper and gives the basic assumptions. In Section 3, we describe the remanufacturer-driven multi-dimensional reverse channel system and propose the solving method. Section 4 gives the numerical study and result discussions. Section 5 summarizes the contribution of this paper and gives the direction of future research.

2. PROBLEM FORMULATION

2.1 Definition of Symbols

P Sales price of the remanufactured products

A Average acquisition cost

b_M Unit transfer price paid to the OEM by the retailer for the collected used products, $b_M > A$

b_T Unit transfer price paid to the OEM by the retailer for the collected used products, $b_T > A$

C_r Unit remanufacturing cost

Q_R The amount of used products dropped-off to the retailer by the customers

Q_M The amount of used products picked-up by the OEM

Q_T The amount of used products picked-up by the third party

Q_C Total remanufactured products sold to the customers by the retailer

B_P Reverse logistics cost coefficient of the pick-up collector

B_D Reverse logistics cost coefficient of the drop-off collector

j Scale economies coefficient of the pick-up collector, $j > 1$

k Scale economies coefficient of the drop-off collector, $0 < k < 1$

π The profit

We note that the total remanufactured products sold to the customer are equal to the sum of the used products collected by the retailer, OEM, and the third party, namely, $Q_C = Q_R + Q_M + Q_T$. It is obvious that $Q_R \geq 0$, $Q_M \geq 0$, and $Q_T \geq 0$, which satisfies the logistic limitation. For ease of presentation, let subscripts R, M, and T denote the retailer/remanufacturer, the OEM, and the third party, respectively.

2.2 Basic Assumptions

Assumptions in this paper are similar to those in Karakayali et al. (2007) and Atasu et al. (2013), and they are stated as following.

(1) The supply of used products in the market is sufficient. Therefore we do not consider upper bounds on the quantity of used products available to simplify the presentation. This assumption is reasonable as there is huge quantity of used products in the construction machinery industry, the collector can collect as many used products as he can if it is profitable.

(2) All the used products collected by the remanufacturer can be remanufactured.

(3) The information is symmetric. There is a Stackelberg game among the OEM, the retailer, and the third party, the retailer acts as the leader, the OEM and the third party act as the followers (Savaskan et al. 2004).

(4) The demand for the remanufactured products is modelled as a deterministic linear function of the selling price p, and we have $P(Q) = \alpha - \beta Q$, where $\alpha, \beta > 0$ and $Q \geq 0$. In the construction machinery industry, the OEM's products market and the market of remanufactured products that are retrieved from end-of-life vehicles are independent. Thus, in this paper, we only focus on the remanufactured products selling market to analyse the multi-dimensional reverse channel decision puzzle.

(5) The total collection cost is modelled as a function of the used products collected, that $C(Q) = AQ + BQ^n, n = j, k$, where $j > 1$ and $0 < k < 1$. In this model, $j > 1$ captures diseconomies of scale for pick-up strategy in used products collection, while $0 < k < 1$ captures economies of scale for drop-off strategy in used products collection. In this paper, the retailer and OEM accept the used products "dropped-off" by the customers, while the third party "picks-up" the used products from the customers. This assumption makes sense, as we have observed it in practice from a construction machinery remanufacturing firm in China.

3. MODEL DEVELOPMENT AND ANALYSIS

In this section, we develop models and solution methods to identify the optimal decisions of the retailer/remanufacturer on used products collection activities allocation to the agents.

In this remanufacturer-driven CLSC with multi-dimensional reverse channel we investigate, the OEM outsources the remanufacturing activity to the retailer, the retailer acts as the Stackelberg leader while the OEM and the third party are the followers. All the OEM, the retailer, and the third party collect the used products, but they adopt different collection strategies. In the new products selling market, the retailer has signed contracts with a proportion of the customers to return the used products with cash refund. Which implies that the retailer has