Transportation Research Part E 89 (2016) 86–107

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

The price of anarchy in competitive reverse supply chains with quality-dependent price-only contracts

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ARTICLE INFO

Article history:
Received 7 September 2015
Received in revised form 16 January 2016
Accepted 3 March 2016
Available online 21 March 2016

Keywords:
Reverse supply chain
Price-only contract
Price of anarchy
Competition
Quality
Consumers' return behavior

ABSTRACT

To quantify the efficiency of decentralized competitive reverse supply chains (RSCs) with quality-dependent price-only contracts, we characterize the worst-case efficiency loss with the price of anarchy (PoA). Several scenarios with unilateral or bilateral horizontal competition under push or pull configurations of RSCs are discussed. Given the uncertainty in the returns of used products, we consider different consumers' return behaviors and investigate the effect of the quality levels of used products. We clarify the effect of horizontal competition for each scenario and find distinctive features of RSCs that differentiate them from traditional forward activities. Additional managerial insights are provided for discussion.

1. Introduction

Over the past 20 years, reverse supply chains (RSCs) have attracted considerable attention in industry and academia. Because each firm involved in the supply chain naturally desires optimal profits, many issues—such as information asymmetries and incentive misalignment—imply that RSCs require effective coordination mechanisms to achieve coordination in the optimization of supply-chain networks. To coordinate disparate incentives, contracting is essential for governing transactions in RSCs via a transfer-payment scheme. Among various contractual forms, price-only contracts (also known as wholesale price contracts) are the simplest and most commonly observed in practice because of their low administration and negotiation costs (Cachon, 2003). However, they may incur one of the most famous efficiency problems in supply chains, i.e., "double marginalization" (Spengler, 1950), which implies a decentralized supply chain that has higher final prices and lower total profits than those in a centralized system (Cachon, 2003) and does not coordinate the supply chain. There is no doubt that some "sophisticated" contracts designed to achieve coordination in forward supply chains can also be extended and applied to strive for the excellence of reverse-logistics activities, such as buyback contract (Pasternack, 1985; Padmanabhan and Png, 1997; Chen and Bell, 2011), revenue sharing contract (Gerchak and Wang, 2004; Govindan and Popiuc, 2014), two-part tariff contract (Cachon and Kök, 2010; Choi et al., 2013), and compensation contract (He, 2015). These more elaborate contracts are supposed to coordinate supply chains perfectly and with desirable flexibility, but in fact, they require much higher costs related to negotiation and administration (Cachon, 2003) and might incur additional problems related to moral hazard (Paul, 2005). For example, in the automobile and electronics industries, establishing liability with members under coordination contributes to a large part of the cost during a product's lifecycle (Corbett and

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http://dx.doi.org/10.1016/j.tre.2016.03.002
1366-5545/

Savaskan, 2003). In view of these issues, an important question arises: Which contracts are worth adopting in the RSC? Given the popularity and redeeming properties of price-only contracts, we are interested in the efficiency (the profit ratio of the decentralized system to the centralized system) of price-only contracts in RSCs. The reason is that if the efficiency loss of simple contracts is not great or the potential incremental profit of more elaborate contracts cannot cover the additional administrative and negotiating burden, a simple contract is particularly desirable for decision makers despite its incapability in optimizing the aggregate performance. The goal of this paper is to quantify the upper bound of the inefficiency of decentralized competitive RSCs that use price-only contracts and to provide further theoretical evidence for decision makers as a contracting reference.

In practice, we find three structures of competitive RSCs: the competitive collecting system (CCS), the competitive remanufacturing system (CRS) and the bilateral competitive system (BCS). CCS (Fig. 1a) characterizes the competition among upstream members (those who are nearer to the "supply side" of used products in reverse logistics). In some industries, such as mobile phones and PCs, many leading enterprises are moving toward a true circular economy by designing for recyclability. They usually acquire used products via various reverse-logistics providers or retailers (Ongondo et al., 2011). For example, in Dell's worldwide technology-recycling options, there has been an incredible number of environmental partners (EPs) onboard across the world (Dell Corporation, 2015). Similar activities are undertaken by Eastman Kodak Company and Huawei Corporation.

CRS (Fig. 1b) describes the competition among downstream members (those who are nearer to the "demand side" of used products in reverse logistics). In some industries, such as toner cartridges, automobiles and diesel engines, the original equipment manufacturer (OEM) may not be able to maintain complete control over the entire reverse-logistics chain to be responsible for gathering, classifying, segregating and finally transporting the used items. This may give rise to some opportunistic agents in the chain, particularly if the entire remanufacturing process can be duplicated. The OEM has to compete with local small remanufacturers for the supply of used items, and the reverse-logistics chain is the nucleus of competition (Majumder and Groenevelt, 2001; Jung and Hwang, 2011).

BCS (Fig. 1c) reflects a multi-channel collection to a multi-channel recycling system. The Regulation on the Administration of the Recovery and Disposal of Waste Electrical and Electronic Products, enforced in China on January 1, 2011 (Ministry of Environmental Protection of the People's Republic of China, 2011), stipulates that WEEE recycling should be collected by multiple channels and recycled intensively by qualified recycling enterprises.

In addition to the basic structures of competitive RSCs motivated from practical examples, some characteristics of reverse-logistics activities for reusing or remanufacturing may complicate the management of RSC functions, including the uncertain quantity and quality of returned used products, the need to balance the acquisition demand for remanufacturing with the supply of used products from consumers, and the behaviors of consumers in the allocation of the aggregate supply of used products.

To evaluate the effect of these characteristics on the upper bound of efficiency loss, we consider a two-stage RSC that consists of competitive collectors or/and remanufacturers and faces the newsboy problem. We suppose that members trade with quality-dependent price-only contracts under *push* or *pull* configurations. Although some literature mentions the

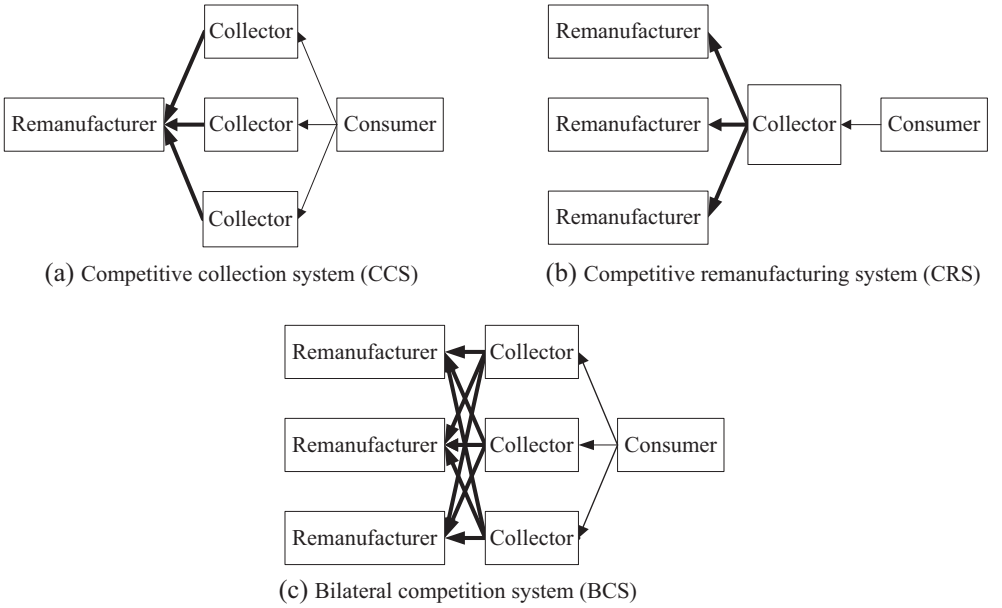

Fig. 1. Competitive RSC structures.