Sustainable development by waste recycling under a three-echelon supply chain: A game-theoretic approach

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A B S T R A C T

In this study, the economic and environmental aspects of sustainability are considered on the waste recycling process under a three-echelon dual-channel supply chain containing one collector, one recycler, and one manufacturer. To our knowledge, this study is the first one focused on the recyclables under a dual-channel structure. Under the considered structure, the customers' demand for the finished product is specified. Then, the manufacturer procures the product from a recyclable waste with a specific recyclability degree. The collector collects the waste while the recycler recycles it. The manufacturer is also capable to recycle the waste. Thus, he can purchase the recycled materials from the recycler or gets the non-recycled waste from the collector and then recycles it. Under the various power structures, the game-theoretic models are established among the members. Then, the equilibrium strategies are obtained and various managerial insights are revealed. It is found that under the various games, the manufacturer selects the collector when some thresholds are met. When the collector and recycler have similar decision powers, the manufacturer gets higher profit than the situation that they make decisions with different decision powers. Moreover, more the recyclability degree of the waste leads to higher profits for the members.

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1. Introduction

Recently, the importance of product sustainability in the business environment has been increasingly adopted by both academy and industry (Lozano and Huisingh, 2011). Many studies have provided various approaches for sustainable development. These include environmental management, design for environment, green purchasing, reverse logistics, reusing, remanufacturing, recycling, etc. (Luchs et al., 2010; Grimmer and Bingham, 2013; Salimifard and Raeesi, 2014). Among these approaches, recycling can be considered as a more pragmatic way, due to its low compromise requirements (Chen et al., 2015).

Recycling is a process to turn waste materials into new products. It as a key component of the modern waste reduction can make the environment friendlier (Kreiger et al., 2014). Some benefits of recycling are as follows (Agunwamba, 2003):

- Makes the environment sustainable for future generations.

- Reduces pollution by decreasing the need to collect raw materials.
- Reduces greenhouse gas emissions that lead to global climate change.
- Saves energy.
- Saves natural resources through the reduction of the consumption of fresh raw materials.
- Creates new jobs in recycling and manufacturing industries.
- Prevents the waste of potentially useful materials.

Supply chain management aims to facilitate better material and information flows among chain parties to establish better relationships (Handfield and Nichols, 2002; Ashby et al., 2012). With increasing global resource scarceness, waste becomes a resource that should be globally managed (Bing et al., 2015). A reverse supply chain is one in which helps companies to enhance the credibility of sustainability policies via reusing, remanufacturing, and recycling of wastes (Dekker et al., 2013). In other words, unlike the forward supply chain in which managers have focused on improving forward processes, as the business environment becomes more competitive, managers in the reverse supply chain attempt to focus on improving backward loop.

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Dual-channel supply chain is one in which an upstream agent sells his materials or products to a downstream agent both directly (hereafter referred to as "direct channel") and through a mediator agent indirectly (hereafter referred to as "indirect channel") (Takahashi et al., 2011). Fig. 1 depicts the structure of a dual-channel supply chain.

Game theory is a mathematical tool for investigating complicated relationships among rational players in the competitive environments (Huang, 2010). Recently, it is extensively applied in the sustainable supply chain management to give the equilibrium decisions (e.g., see: Mishra, 2006; Dong et al., 2010; Jalali Naini et al., 2011; Kamiński, 2014).

The aim of the current study is to investigate pricing and ordering decisions on the waste recycling process under a three-echelon dual-channel supply chain using the game-theoretic framework. Sustainable supply chain management investigates economic, environmental, and social aspects of sustainability in supply chains (Carter and Rogers, 2008). This paper considers the economic and environmental directions of sustainability and involves technical and management conceptions, which are beneficial for companies to adopt the concepts of sustainability and cleaner production.

The reminder of this paper is organized as follows: Related literature is discussed in Section 2. In Section 3, a detailed description of the considered three-echelon dual-channel supply chain is provided. Equilibrium strategies are given under the various game-theoretic models in Section 4. Section 5 deals with a discussion of the equilibrium strategies obtained from the models. Moreover, conclusions and directions for future studies are presented in Section 6. Finally, proofs of the lemmas and propositions are provided in the appendices.

2. Literature review

This paper aims to perform a game-theoretic analysis for pricing and ordering decisions of a recyclable waste under a three-echelon dual-channel supply chain. Thus, the related literature can be grouped into two streams: The first reviews the sustainable supply chain particularly recycling issue, and another one studies the game-theoretic analysis of pricing and ordering decisions under the dual-channel supply chain.

2.1. Research on environmental sustainability and recycling issues

Brundtland (1987) presented a definition for sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Different approaches have been proposed for sustainable development. Some of them are: green purchasing (e.g., see: Diabat and Govindan, 2011; Green et al., 2012; Tian et al., 2014; Li et al., 2015), design for environment (e.g., see: Kurk and Eagan, 2008; Bevilacqua et al., 2012; Arnette et al., 2014), pollution control (e.g., see: Aramyan et al., 2011; Sheu and Chen, 2012; Fahimnia et al., 2013), remanufacturing (e.g., see: Tsoulfas and Pappis, 2006; Zhu et al., 2007), and recycling.
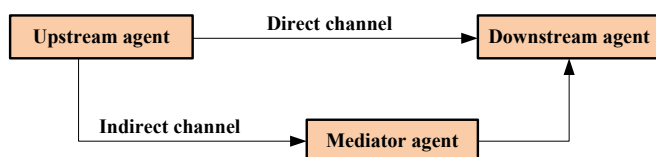

Fig. 1. The graphical structure of a dual-channel supply chain.

The development of cleaner environmental technologies leads to saving energy and resources (Dovì et al., 2009). In this point of view, recycling is one of the major avenues to improve waste management systems (Chen et al., 2015). Several studies have investigated this issue. Below, some of the related studies are briefly addressed.

Krikke et al. (2003) analyzed decisions concerning the recyclability of a product, i.e., the structure of a product including the percentage of recyclable materials in 1 kg of finished product. Chen and Sheu (2009) studied how to improve products' recyclability using a differential game theoretical model. Nagurney and Nagurney (2010) and Nagurney and Woolley (2010) developed a multi-criteria network model for a sustainable supply chain by focusing on profit maximization. Sheu (2011) investigated competition between a supplier and a manufacturer under a green supply chain, whereas Sheu and Chen (2012) considered a similar problem and used a game-theoretic model to tackle the problem. Li and Li (2014) analyzed the game-theoretic model of two sustainable supply chains under competition in product sustainability. Moreover, Dong et al. (2014) analyzed investment on sustainability of a product under the centralized and decentralized cases.

Recycling of electronic waste (i.e., e-waste) is known as e-cycling (Nagurney and Toyasaki, 2005). The concept of e-cycling has been introduced by Sodhi and Reimer (2001). Nagurney and Toyasaki (2003) and Nagurney and Ke (2003) are some studies done in this field.

2.2. Research on pricing decisions in the dual-channel structure

Price is the most important competitive factor in the markets (Mankiw, 2014). Thus, managerial strategy on setting prices derives critical decisions in supply chains. To our knowledge, studies on how to investigate the issue of pricing policy in the dual-channel structure via the game-theoretic framework are still limited that are discussed below.

Yao and Liu (2005) analyzed price competition between the direct and indirect channels. Huang et al. (2012, 2013) proposed a game model to price a product when production cost is disrupted, while Dai et al. (2005) discussed pricing policies under deterministic and stochastic demands. Mukhopadhyay et al. (2008), Liu et al. (2010), and Cao et al. (2013) examined the impact of asymmetric information on pricing strategy in which players have private information about demands. Chen et al. (2013) analyzed pricing decision where a retailer sells manufacturer's product as well as a substitute product produced by another manufacturer. Hsieh et al. (2014) set prices in a structure consisting of multiple competitor manufacturers and a common retailer. Zhang et al. (2012) investigated the effect of product substitutability on price competition. In a more recent study, Li et al. (2015) have examined a dual-channel structure in which a manufacturer produces a green sustainable product for the environmental conscious. They analyze pricing and greening decisions under the decentralized and centralized cases. Some other studies in this area are: Tsay and Agrawal, 2004; Kumar and Ruan, 2006; Hua et al. (2010); Xiong et al. (2012); Li and Ma, 2015.

The objective of the current study is to consider a perspective of sustainable supply chain management by investigating the pricing and ordering decisions on the waste recycling process. In this setting, the issue of channel selection is investigated on a three-echelon dual-channel supply chain containing one collector, one recycler, and one manufacturer.

Under the considered supply chain, based on the customers' demand, the manufacturer produces a product that the main portion of its required raw material is one type of the recyclable waste. In this setting, the collector collects the non-recycled waste,