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Closed-loop supply chain models for a high-tech product under alternative reverse channel and collection cost structures

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ABSTRACT

In this paper we study closed-loop supply chain models for a high-tech product which is featured with a short life-cycle and volatile demand. We focus on the manufacturer's choice of three alternative reverse channel structures for collecting the used product from consumers for remanufacturing: (1) the manufacturer collects the used product directly; (2) the retailer collects the used product for the manufacturer; and (3) the manufacturer subcontracts the used product collection to a third-party firm. We characterize and compare the manufacturer's optimal production quantities and profits under the three alternative reverse channel structures. We also investigate the impacts of collection cost structures and implementations of product take-back laws on the manufacturer's choice of reverse channel structures.

1. Introduction

With the fast developments in product remanufacturing to improve economic and environmental performance, an increasing number of manufacturers in the automobile, machinery, appliances, electronics, personal computers, etc., are offering remanufactured goods and associated services. It is estimated that $100 billion of remanufactured goods are sold each year in the U.S. and more than 500,000 people are employed in the remanufacturing industry (Hagerty and Glader, 2011).

In this paper, we focus on the remanufacturing of a high-tech product (e.g., GPS, cell phones, MP3 players, computers, digital camera, and video game systems) which is featured with a short life-cycle and volatile demand due to rapid technology innovation and frequent new product introductions. If the manufacturer is unwilling to collect the used product, consumers often discard the obsolete high-tech product when a technically advanced version is introduced to the market. For example, it is estimated consumers in the United States scrap 400 million electronic products per year (Daly, 2006). To minimize the amount of electronic waste (e-waste) that goes into landfills and to save the cost for materials, many high-tech manufacturers have begun to collect the used product from consumers and explore the value-added product recovery through remanufacturing, whereby worn-out components are replaced, whereas durable components are reused in the making of a remanufactured product.

We next discuss three key features of the closed-loop supply chain (CLSC) for the high-tech product in Section 1.1; provide a literature review and highlight our research contributions in Section 1.2; and summarize our main research findings in Section 1.3.

1.1. Key features of the CLSC for the high-tech product

1.1.1. Reverse channel structures

In a traditional forward-only supply chain, a manufacturer sells the product via a retailer to consumers and does not collect the used product. However, in a CLSC, the manufacturer not only sells the original product to consumers through her forward channel, but also collects the used product for remanufacturing and recycling through her reverse channel. Hence, the choice of an appropriate reverse channel structure is important to the manufacturer's overall profit in the CLSC.

In practice, there are generally three alternative reverse channel structures that have been deployed by high-tech manufacturers for collecting the used product. First, some high-tech manufacturers collect the used product directly from consumers. For example, Samsung collects televisions, monitors, cell phones, and other consumer electronic products by offering the consumers a free mail-back option and a permanent drop-off option over 200 locations. Second, some high-tech manufacturers collect the used product from consumers through their retailers. For example, Sony has created the GreenFill Program that provides its retailers collection kiosks for used electronics. Similarly, Dell offers consumers free recycling for all its

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computers, printers, monitors, and peripheral items for free at Staples. Third, some high-tech manufacturers collect the used product from consumers through a third-party firm. For example, LG Electronics partnered with Waste Management to establish the LG Electronics Recycling Program. Waste Management provides the collection services for LG-brand electronic products.

Motivated by the above reverse channel examples in the high-tech CLSCs, in this paper we consider the manufacturer's choice of three alternative reverse channel structures: (1) the manufacturer collects the used product directly; (2) the retailer collects the used product for the manufacturer; and (3) the manufacturer subcontracts the used product collection to a third-party firm.

1.1.2. Collection cost structures

There are generally two alternative collection cost structures that have been observed in practice and studied in the CLSC literature. In the first alternative, the collection cost exhibits *economies of scale* in the total collection volume, i.e., the more used products collected, the lower the per unit collection cost. Such a collection cost structure is more appropriate when the collecting firm uses a simple *drop-off* collection method, i.e., consumers either drop off the used products to the collection site or mail them back in prepaid mailboxes provided by the collecting firm, whereas the collection firm focuses on efforts to raise consumer awareness of the use product collection program (Atasu et al., 2013; Savaskan et al., 2004). In the second alternative, the collection cost exhibits *diseconomies of scale* in the total collection volume, i.e., the more used products collected, the higher the per unit collection cost. Such a collection cost structure is more appropriate when the firm uses a relatively more complex *pick-up* collection method, i.e., the collection firm prefers to collect used products from closer or cheaper sources or more densely populated areas first and it would be more costly to collect additional used products from consumers farther away (Atasu et al., 2013; Ferguson and Toktay, 2006; Guide, 2003). Motivated by the above collection cost structures, in this paper we study the CLSC models under two alternative collection cost structures with economies and diseconomies of scale.

1.1.3. Take-back laws

Since high-tech products are highly perishable, consumers often distinguish between the original and remanufactured products. The remanufactured high-tech product is often sold at a low margin to less technology-driven or more price-sensitive consumers. As pointed out in Atasu et al. (2013), an e-waste processing cost of up to 3% of the revenue could have a significant impact on the high-tech manufacturer's profitability. As a result, an economically interested manufacturer often chooses a low used product collection rate which is far from environmentally optimal. This phenomenon is known as the *tragedy of the commons dilemma* that arises when the common good does not align perfectly with the good of individual entities (Hardin, 1968; Chopra and Meindl, 2013). To overcome this dilemma, product take-back legislation has been popular in recent years, especially for high-tech products that often generate large amount of e-waste to landfills. For example, in Europe, the European Commission has enacted the Waste Electrical and Electronic Equipment (WEEE) Directive (Directive 2003/108/EC) such that European Union member states must establish collection systems for e-waste. In the U.S., there are currently more than 25 states that have passed product take-back legislations mandating statewide e-waste collection and recycling (Electronics Takeback Coalition, 2011). Since the product take-back legislation has played an important role in aligning the high-tech manufacturer's economic interest with the environmental interest of the public, in this paper we also investigate the impact of the product take-back law on the manufacturer's choice of reverse channel structures.

1.2. Related literature and research contributions

Recently, we have seen a growing body of research on CLSCs. We refer interested readers to Savaskan and Van Wassenhove (2006), Atasu et al. (2008), and Guide and Van Wassenhove (2009) for complete reviews of this part of literature. Within this research stream, there are two papers that are most closely related to this research. Savaskan et al. (2004) is the first to study the manufacturer's choice of reverse channel structures for collecting used products from consumers. They assume the collection cost exhibits economies of scale and find that the reverse channel structure with retailer collecting is optimal to the manufacturer. Atasu et al. (2013) further extend Savaskan et al. (2004) by studying the manufacturer's choice of reverse channel structures under two alternative collection cost structures that exhibit economies and diseconomies of scale. They further show if there are diseconomies of scale in collection cost, then the reverse channel structure with manufacturer collecting is optimal to the manufacturer.

Compared to those two papers, this research offers two main contributions. First, both Savaskan et al. (2004) and Atasu et al. (2013) focus on the CLSC models for a relatively *long life-cycle* product with *deterministic* demand. However, in this paper we focus on the CLSC models for a *short life-cycle* high-tech product with *uncertain* demand. Our stochastic newsvendor modeling framework is more appropriate for the high-tech product and our model analysis is significantly different from the deterministic modeling framework in those two papers. As far as we know, there is no previous research that uses the newsvendor model to study the manufacturer's choice of reverse channel structures for the high-tech product in the CLSCs.

Second, both Savaskan et al. (2004) and Atasu et al. (2013) assume that the collection rate of the used product is *endogenously* determined by the collecting firm. However, in practice, especially for high-tech products that often generate large amount of e-waste to landfills, the collection rate of the used high-tech product is often mandated by the take-back legislation (e.g., WEEE Directive) to avoid the *tragedy of the commons dilemma* that arises when an economically interested high-tech manufacturer chooses a low used product collection rate that is far from environmentally optimal. In view of this, in this paper we assume that the collection rate is *exogenously* mandated by the take-back law. As far as we know, there is no previous research that studies the impact of the product take-back law on the manufacturer's choice of reverse channel structures in the CLSCs.

Finally, our research is also closely related to the newsvendor literature on the traditional forward-only supply chains for a short life-cycle product with uncertain demand. We refer interested readers to Cachon (2003) for a complete review of this part of literature. Within this research stream, this paper is most closely related to Lariviere and Porteus (2001) who study a forward-only supply chain comprised of a single manufacturer and a single retailer selling a short life-cycle product with uncertain demand. This research extends Lariviere and Porteus (2001) by introducing three types of reverse channel structures to the supply chain and we show how the addition of a reverse channel will affect the manufacturer's forward channel decisions and overall profits in the CLSCs.

1.3. Main research findings

In summary, in this paper we study both centralized and decentralized CLSC models for a short life-cycle high-tech product with uncertain demand under three alternative reverse channel structures. We also investigate the impact of collection cost structures and product take-back laws on the manufacturer's choice of reverse channel structures. This paper provides the following main research