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Pricing and effort decisions in a closed-loop supply chain under different channel power structures

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ABSTRACT

This paper aims to explore the influence of different channel power structures on the optimal decisions and performance of a closed-loop supply chain (CLSC) with price and effort dependent demand, to identify the most profitable channel power structure and to propose coordination strategy for the decentralized CLSC. Considering the demand expansion effectiveness of collection effort and sales effort, centralized and decentralized game theoretic models of a CLSC with one manufacturer and one retailer are built, to investigate optimal decisions of collection effort, sales effort and pricing under different channel power structures, namely manufacturer Stackelberg, vertical Nash and retailer Stackelberg. Through a systematic comparison and numerical analysis, the results show that with dominant power shifting from the manufacturer to the retailer, the retailer's profit always increases and the manufacturer may also benefit when the demand expansion effectiveness of collection effort is large enough. The symmetric channel power structure is the most favorable for both the CLSC and consumers when the demand expansion effectiveness of collection effort is relatively low; otherwise, the CLSC with dominant retailer is the most profitable. Moreover, the proposed low price promotion strategy can effectively enhance the performance of decentralized CLSC.

1. Introduction

The intensifying pressure of environmental deterioration and natural resource shortages highlights the importance of closed-loop supply chain (CLSC) management. Government legislations, oversight from non-governmental organizations, consumer environmental awareness and corporate social responsibility are important drivers for enterprises to participate in CLSC, while the economic benefits may be the key factor that attracts enterprises to incorporate reverse logistics in their supply chain (Chen and Chang, 2013; Shi et al., 2011; Wu, 2012; Wu and Pagell, 2011; Zhu et al., 2008). In many industries, such as automobiles, copiers and computers, CLSC management has been successfully practiced, with the establishment of economically viable production and collection systems that enable remanufacturing of used products in parallel with the manufacturing of new units (Savaskan et al., 2004). Motivated by the significance of CLSC management in practice and open questions in channel decision-making, CLSC has also been a critical research topic in the academic area. The objective of this paper is to present a comprehensive discussion on the influence of channel power structure on optimal channel strategies and profitability of CLSC with the price and effort dependent demand, analyze which channel power structure is the most favorable one for the CLSC and consumers, and coordinate the decentralized CLSC.

Manufacturers have realized that CLSC management can be used to gain competitive advantage and achieve sustainable development. In a common form of a CLSC, a manufacturer collects used products and appropriates the benefits (De Giovanni and Zaccour, 2014). For example, Xerox has been a leader in reusing their high-value, end-of-lease copiers in the manufacturing of new copiers. Similar activities are undertaken by Hewlett Packard Corporation with their used computers and peripherals (Savaskan and Van Wassenhove, 2006). To facilitate collecting, the manufacturer usually exerts collection effort such as product design and process modification towards recycle, advertising and communication campaigns about the recycling policies, reverse logistics services, monetary and symbolic incentives, and employees-training programs. These activities reflect firm's environmentally responsible features and enhance the firm's reputation, satisfy the consumers'

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environmental concerns and simplify their disposal process (Hong and Yeh, 2012). With economic and environmental benefits, in practice, it is noted that the investment in collection effort can not only positively influence the return rate but also enhance the market demand. Despite of this, most previous studies merely pay attention to the effectiveness of collection effort on the return. Thus this paper investigates the optimal effort-input and pricing decisions, considering the demand expansion effectiveness of collection effort.

On the other hand, the retailer's sales effort is crucial for winning the market share. For instance, the retailer can stimulate demand by advertising the products' features, providing attractive shelf space, and point-of-sale demonstrations by salespeople. Since the sales effort also incurs significant investment, it is vital for the retailer to make the optimal sales effort decision and retail margin decision in the channel. Based on this, the collection effort and sales effort are simultaneously taken into account in this paper when exploring the optimal strategies and profitability of CLSC, and proposing coordination mechanism.

Moreover, channel power structure, which depends on the member's ability to control the decision making process in the channel, will have a substantial effect on the channel performance. From a single firm perspective, most firms would arguably want to become the channel leaders, and get a lion share of the supply chain profit (Choi et al., 2013). Traditionally, many manufacturers enjoy sufficient power to be the channel leader who will anticipate the retailer's response and make decisions at first. However, the increasing power of some retailers such as Wal-Mart and Tesco leads to the symmetric channel power structure or even the retailer-dominated power structure. Therefore, a more thorough understanding of the impact of channel power structure on optimal pricing, effort decisions and profitability is necessary and interesting. Furthermore, companies have also increasingly realized the importance of coordinating the supply chain to achieve higher performance. It hence raises the question that how to coordinate the CLSC with price and effort dependent demand.

This paper explores a CLSC with one manufacturer and one retailer, where the market demand is sensitive to retail price, collection effort and sales effort. The manufacturer decides the collection effort and wholesale price, while the retailer chooses the sales effort and retail margin. Game theoretic models of centralized CLSC and decentralized CLSC under three channel power structures, i.e., manufacturer Stackelberg (MS), vertical Nash (VN) and retailer Stackelberg (RS), are established to answer the following questions:

What are the optimal pricing, effort-input decisions and profits in different models?
What is the influence of channel power structure and demand expansion effectiveness on channel strategies and profits?
Which channel power structure is the best, from the view of the CLSC and consumers, respectively?
What role does low price promotion strategy play in enhancing the performance of decentralized CLSC?

Therefore, the contributions of this paper to literature are in the following aspects. First, the impact of channel power structure on optimal CLSC decisions and profits is examined when the demand expansion effectiveness of collection effort and sales effort are considered simultaneously. Second, the best channel power structure is analyzed from the perspective of the CLSC and consumers. Third, a strategy is proposed to coordinate the decentralized CLSC with price and effort dependent demand. The remainder of this paper is organized as follows. Section 2 reviews the related literature. Section 3 gives model description and presents different CLSC models with equilibrium results. Section 4 discusses optimal results with the impact of power structure and demand expansion effectiveness. Section 5 presents the low price promotion strategy to coordinate the CLSC. Section 6 provides the numerical examples to examine the propositions and shed more implications. Section 7 concludes the study and outlines the future research directions.

2. Relevant literature

Over the past decades, many researchers have shown interest in decision-making and coordination of the CLSC. A detailed review of earlier efforts on CLSC research can be found in Guide and Van Wassenhove (2009). An overview of the literature on coordination contract can be found in Govindan et al. (2013). Govindan et al. (2015) presents a systematic classified analysis of recent papers on reverse logistics and CLSC to spot future avenues.

In recent years, Wei et al. (2010) explore the optimal pricing decisions for the CLSC with retail competing by the use of game theory and fuzzy theory, considering the collecting price, wholesale price and retail prices as triangular fuzzy numbers. Shi et al. (2011) analyze the optimal decisions of production quantities, selling price and acquisition price for a closed loop system with uncertain demand and return, where the manufacturer can manufacture brand-new products and remanufacture returns into as-new products. Wei and Zhao (2011) focus on the decision-making process of the wholesale price, retail prices and remanufacturing rate in a fuzzy CLSC with retail competition. Wei et al. (2012) study the pricing problem for a CLSC consisting of a manufacturer and a retailer in a fuzzy environment and show the effect of bargaining power on the results by establishing the MS game and VN game. Wu (2012) identifies the equilibrium characteristics with respect to the remanufacturer's effort and price and service decisions for all members of the supply chain, and investigates the profits of chain members by considering different interactions of prices and service competition between the manufacturer and the remanufacturer.

Choi et al. (2013) examine the implications of different channel leaderships on the performance of CLSC with a manufacturer, a retailer and a collector, given the price-dependent demand, and present the two-part tariff and novel revenue-cost sharing contract to coordinate the CLSC. De Giovanni and Zaccour (2014) investigate the pricing, collection effort decisions and members' profitability to compare several CLSC configurations of collection process. Tseng et al. (2014) evaluate the close-loop and open hierarchical structures in the multi-criteria decision making analysis of green supply chain management using hybrid fuzzy set theory and analytical network process techniques, and find that the close-loop hierarchical structure more closely resembles the real situation. Maiti and Giri (2014) investigate the effect of channel power structures on the quality of manufactured and remanufactured products, the pricing strategy, the collection rate, and the profits of the CLSC, finding that the centralized policy is always the best and the retailer-led decentralized policy is more acceptable among the decentralized policies. Wei et al. (2015) study the optimal wholesale price, retail price, collection rate decisions and member's bargaining powers by examining a CLSC under symmetric and asymmetric information conditions.

Most of the above papers focus on the pricing, collection effort or collection rate decisions of CLSC under certain channel power structure. In particular, despite the fact that the collection effort can not only facilitate the collection of used products but also exert positive influence on the market demand, little research has been done. Wu (2012) incorporates the impact of service on demand; however, the study draws attention to the competition between the manufacturer and the remanufacturer rather than the influence of channel power structure. Choi et al. (2013) provides a comparison among manufacturer-led, retailer-led and collector-led CLSC models, and Maiti and Giri (2014) investigate the centralized, different Stackelberg games and Nash game, while the researchers do not consider the demand expansion effectiveness of the collection effort and sales effort, and do not investigate the coordination of CLSC with price and effort dependent demand.

In forward supply chain management, both sales effort-dependent demand and channel power structure have attracted great attention of researchers (Ertek and Griffin, 2002; Ghosh and Shah, 2012; Karray, 2013; Li et al., 2002; Ma et al., 2013a,b; Saha, 2013; Taylor, 2002; Xing and Liu, 2012; Yue et al., 2013; Zhang et al., 2012; Zhao and Wei, 2014). To cite a few, Taylor (2002) focuses on the supply chain coordination when demand is influenced by sales effort, which can be achieved with target rebate and returns contract. Ertek and Griffin (2002) explore the impact of power structure on price, sensitivity of market price, and profits in a two-stage supply chain by analyzing both the supplier-driven and the buyer-driven cases. Ma et al. (2013a) identify the optimal effort level decisions and the corresponding profits under different supply chain power structures, given quality and marketing effort-dependent demand. Their research shows that investing in marketing efforts is most profitable to the retailer under RS, while investing in quality efforts is most profitable to the manufacturer under MS. Ma et al. (2013b) propose a new contract that integrates the endeavors of the manufacturer and the retailer in the two-part tariff contract to coordinate the manufacturer-dominated supply chain with quality and marketing effort-dependent demand. Yue et al. (2013) study the pricing and advertising decisions in a manufacturer-retailer supply chain considering price discounts offered by both parties, with manipulative power shifting from the manufacturer to both parties. Their study shows that the manufacturer always prefers Stackelberg equilibrium, but there is no definitive conclusion for the retailer. The key difference between our work and the aforementioned studies is that our work investigates the collection effort, sales effort and pricing decisions in the CLSC context with the price and effort dependent demand.

To the best of our knowledge, very few research results on price and effort decisions in a CLSC under different channel power structures have been established, which highlights the research objectives and contributions of this paper. Therefore, this paper should provide useful theoretical and managerial insights on the operation of CLSC.

3. Models of CLSC under different channel power structures

Consider a CLSC composed of one manufacturer and one retailer, the manufacturer incorporates the remanufacturing process for used products into its original production system. It enables to manufacture a new product directly from raw materials and to remanufacture part or whole of a returned unit into a new product. Remanufactured products have no distinction with brand-new products and can be sold in the same market at the same price (Savaskan et al., 2004). The manufacturer sells its product with unit wholesale price w to the exclusive independent retailer. The manufacturer has ample capacity to meet the retailer's order quantity. The retailer sets the unit retail margin t and sells the product to consumers with unit retail price p.

The manufacturer directly collects used products from consumers for remanufacturing. The manufacturer invests in collecting effort activities such as product design towards recycle, advertisement of recycling policies, reverse logistics services, monetary incentives and employees-training programs, which can enhance both the market demand and return rate. Let g denote the level of a composite index of collection effort input by the manufacturer and assume that the return rate α is proportional to g, i.e., $\alpha = \lambda g$. λ is a positive scaling parameter measuring the consumer's response to the collection effort, defined as collection effectiveness coefficient. The manufacturer's investment in collection effort g is assumed to be an increasing and convex function of g, which is defined as $(1/2)c_1 g^2$ for simplicity with c_1 symbolizing the collection effort cost coefficient.

In manufacturing, the unit production cost of brand-new product c_m is more costly than the unit remanufacturing cost of used product c_r, i.e., $c_m > c_r$. The unit remanufacturing cost includes the cost for disassembling, inspection, quality assurance, remanufacturing, and other activities (Shi et al., 2011). Although the collected products will be sorted by different quality levels and only part of them can be remanufactured, for focusing on pricing and effort decisions and without loss of generality, all collected products can be remanufactured successfully in this study (Choi et al., 2013). To take advantage of the cost-saving, the manufacturer makes use of returned products in manufacturing at first. Usually, remanufactured products are not enough to satisfy the demand, and brand-new products are also produced. Thus the average unit cost of manufacturing can be written as $c_m(1-\alpha) + c_r\alpha$. In addition, for remanufacturing to be economically viable, the unit collection cost m is not higher than the unit cost savings of remanufacturing, i.e., $m \le c_m - c_r$, where m comprises all unit variable costs that an end-of-use product is acquired till it is delivered to the manufacturer's plant.

In retailing, the retailer can positively influence the market demand by exerting sales effort y, for example, advertising the products' features, providing attractive shelf space, and point-of-sale demonstrations. The retailer's sales effort cost is also assumed as an increasing and convex function of sales effort y, defined as $(1/2)c_2 y^2$. Such a quadratic cost function is commonly used in previous literature (e.g. Ghosh and Shah, 2012; Liu et al., 2012; Wu, 2012; Ma et al., 2013a,b).

The market demand function D is $D = a - bp + kg + ly$, where $a, b, k, l > 0$, $a > bp$. a represents the initial market potential when the price is zero with no impact of collection effort and sales effort on demand expansion. b is the sensitivity of demand to price. k is the demand expansion effectiveness coefficient of the collection effort, measuring impact of collection effort on demand. l is the demand expansion effectiveness coefficient of sales effort. The assumption of linear demand function with respect to price and non-price variables has been widely used in supply chain models (e.g. Savaskan et al., 2004; Liu et al., 2012; Ghosh and Shah, 2012).

Members are risk-neutral and profit seeking, and have access to the same information. Therefore, the profits of the manufacturer, the retailer and the CLSC can be defined as:

$$\pi_m = [a - b(w+t) + kg + ly][w - c_m(1-\lambda g) - c_r\lambda g - m\lambda g] - \frac{1}{2}c_1 g^2, \tag{1}$$

$$\pi_r = [a - b(w+t) + kg + ly]t - \frac{1}{2}c_2 y^2, \tag{2}$$

$$\pi_{sc} = (a - bp + kg + ly)[p - c_m(1-\lambda g) - c_r\lambda g - m\lambda g] - \frac{1}{2}c_1 g^2 - \frac{1}{2}c_2 y^2. \tag{3}$$

In the following, the paper presents the centralized CLSC model (Model C) and three decentralized CLSC models with different channel power structures, which are the manufacturer Stackelberg

(MS), the vertical Nash (VN) and the retailer Stackelberg (RS). The equilibrium results for each model are derived, and please refer to Appendix A for all proofs of propositions in this paper.

3.1. Centralized CLSC model (Model C)

The centralized CLSC model is considered as the benchmark in which the manufacturer and the retailer reach a binding agreement and make decisions in the principle of maximizing the total profit of CLSC. The optimization problem can be defined as

$$\underset{p,g,y}{\text{Max}}\ \pi_{sc}^{c} = (a - bp + kg + ly)[p - c_m(1-\lambda g) - c_r\lambda g - m\lambda g] - \frac{1}{2}c_1 g^2 - \frac{1}{2}c_2 y^2, \tag{4}$$

subject to: $p, g, y > 0$, $0 < \alpha = \lambda g < 1$ and $a > bp$.

Proposition 1. *When the condition $c_1 > \{(c_2[k + b\lambda(c_m - c_r - m)][k + \lambda(a - bc_r - bm)])/(2bc_2 - l^2), (c_2k[k + b\lambda(c_m - c_r - m)])/(bc_2 - l^2)\}_{\max}$ is satisfied, there is a unique optimal solution for the optimization problem of centralized CLSC.*

The equilibrium results are given as follows.

$$p^{c*} = \frac{(a - bc_m)c_2\{c_1 - \lambda(c_m - c_r - m)[k + b\lambda(c_m - c_r - m)]\}}{2bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2} + c_m \tag{5}$$

$$g^{c*} = \frac{c_2(a - bc_m)[k + b\lambda(c_m - c_r - m)]}{2bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2} \tag{6}$$

$$y^{c*} = \frac{c_1 l(a - bc_m)}{2bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2} \tag{7}$$

Therefore, the return rate and market demand can be derived, as well as the maximum profit of CLSC.

$$\alpha^{c*} = \frac{\lambda c_2(a - bc_m)[k + b\lambda(c_m - c_r - m)]}{2bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2} \tag{8}$$

$$D^{c*} = \frac{bc_1c_2(a - bc_m)}{2bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2} \tag{9}$$

$$\pi_{sc}^{c*} = \frac{c_1c_2(a - bc_m)^2}{2\left\{2bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2\right\}}. \tag{10}$$

It is inferred that the recycling is costly since the collection cost coefficient c_1 should be sufficiently large to satisfy the condition, thus it is not economically viable to manufacture all units from used products (Savaskan et al., 2004). In the subsequent part of the analysis, the condition in Proposition 1 should hold to guarantee the existence of a unique solution for each optimization problem. It is also noted that the demand expansion effectiveness coefficients of collection effort and sales effort will not be infinite. The bounds for k and l are $k \in (0, \bar{k})$ and $l \in (0, \bar{l})$ respectively, $\bar{k} = \{\sqrt{bc_1 + ((b^2\lambda^2(c_m - c_r - m)^2)/4)} - ((b\lambda(c_m - c_r - m))/2), ((\sqrt{8bc_1 + \lambda^2(a - bc_m)^2} - \lambda(a + bc_m - 2bc_r - 2bm))/2)\}_{\min}$, $\bar{l} = \{\sqrt{bc_2 - ((c_2k(k + b\lambda(c_m - c_r - m)))/c_1)}, \sqrt{2bc_2 - ((c_2(k + b\lambda(c_m - c_r - m))(k + \lambda(a - bc_r - bm)))/c_1)}\}_{\min}$.

3.2. Decentralized CLSC models

In the decentralized CLSC, the manufacturer and the retailer make decisions independently in order to maximize their own profits. The manufacturer decides the collection effort and the wholesale price. The retailer determines the sales effort and the retail margin. In order to investigate the impact of different channel power structures, the manufacturer Stackelberg (MS), the vertical Nash (VN) and the retailer Stackelberg (RS) are investigated.

3.2.1. Manufacturer Stackelberg (MS)

Under the MS, the manufacturer has sufficient channel power over the retailer to act as a Stackelberg leader. The manufacturer takes the retailer's response functions into consideration to decide the wholesale price and collection effort; the retailer decides the retail margin and sales effort based on manufacturer's decisions. Backward induction is adopted in pursuit of equilibrium decisions.

The retailer's optimization problem is defined as:

$$\underset{t_r,y_r}{\text{Max}}\ \pi_r^{ms} = [a - b(w + t_r) + kg + ly_r]t_r - \frac{1}{2}c_1 y_r^2, \tag{11}$$

t_r and y_r are the retailer's optimal reaction functions given w and g.

Hence, the manufacturer's objective function can be defined as

$$\underset{w,g}{\text{Max}}\ \pi_m^{ms} = [a - b(w + t_r) + kg + ly_r][w - c_m(1-\lambda g) - c_r\lambda g - m\lambda g] - \frac{1}{2}c_1 g^2, \tag{12}$$

subject to $w, g > 0$ and $0 < \alpha = \lambda g < 1$.

Proposition 2. *π_r^{ms} is jointly concave in t_r and y_r, and the retailer's best response functions are given by $t_r = ((c_2(a + kg - bw))/(2bc_2 - l^2))$, $y_r = (l(a + kg - bw))/(2bc_2 - l^2)$; π_m^{ms} is concave in w and g, and the optimal decisions for the manufacturer are*

$$w^{ms*} = \frac{(a - bc_m)\{2bc_1c_2 - c_1l^2 - bc_2\lambda(c_m - c_r - m)[k + b\lambda(c_m - c_r - m)]\}}{b\left\{4bc_1c_2 - 2c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2\right\}} + c_m, \tag{13}$$

$$g^{ms*} = \frac{c_2(a - bc_m)[k + b\lambda(c_m - c_r - m)]}{4bc_1c_2 - 2c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2}. \tag{14}$$

The optimal decisions for the retailer are:

$$t^{ms*} = \frac{c_1c_2(a - bc_m)}{4bc_1c_2 - 2c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2}, \tag{15}$$

$$y^{ms*} = \frac{c_1 l(a - bc_m)}{4bc_1c_2 - 2c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2}. \tag{16}$$

The retailer's response t_r and y_r increase as the collection effort g increases. In contrast, t_r and y_r decrease as the wholesale price w increases. It is inferred that if the dominant manufacturer inputs low collection effort or sets high wholesale price, the retailer prefers to decrease the retail margin to avoid pushing up the retail price, and decrease the sales effort to save expenses. Furthermore, the retail price and market demand can be derived from optimal decisions.

$$p^{ms*} = \frac{(a - bc_m)\{3bc_1c_2 - c_1l^2 - bc_2\lambda(c_m - c_r - m)[k + b\lambda(c_m - c_r - m)]\}}{b\left\{4bc_1c_2 - 2c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2\right\}} + c_m \tag{17}$$

$$D^{ms*} = \frac{bc_1c_2(a - bc_m)}{4bc_1c_2 - 2c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2} \tag{18}$$

The profits of the manufacturer, the retailer and the CLSC are listed as follows.

$$\pi_m^{ms*} = \frac{c_1c_2(a - bc_m)^2}{2\left\{4bc_1c_2 - 2c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2\right\}} \tag{19}$$

$$\pi_r^{ms*} = \frac{c_1^2c_2(a - bc_m)^2\left(2bc_2 - l^2\right)}{2\left\{4bc_1c_2 - 2c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2\right\}^2} \tag{20}$$

$$\pi_{sc}^{ms*} = \frac{c_1c_2(a - bc_m)^2\left\{6bc_1c_2 - 3c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2\right\}}{2\left\{4bc_1c_2 - 2c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2\right\}^2} \tag{21}$$

3.2.2. Vertical Nash (VN)

Here both the manufacturer and the retailer are not in a position to dominate the channel. As such, the manufacturer and the retailer simultaneously maximize each party's own profits and independently make decisions. In this set-up, the following optimization problems are solved simultaneously.

$$\max_{w,g} \pi_m^{vn} = [a - b(w + t) + kg + ly][w - c_m(1 - \lambda g) - c_r\lambda g - m\lambda g] - \frac{1}{2}c_1g^2, \tag{22}$$

subject to $w, g > 0$, $0 < \alpha = \lambda g < 1$.

$$\max_{t,y} \pi_r^{vn} = [a - b(w + t) + kg + ly]t - \frac{1}{2}c_2y^2, \tag{23}$$

subject to: $t > 0$ and $y > 0$

Proposition 3. *π_m^{vn} is concave in w and g. π_r^{vn} is jointly concave with respect to t and y. The unique equilibrium solutions in model VN are*

$$w^{vn*} = \frac{(a - bc_m)c_2\{c_1 - \lambda(c_m - c_r - m)[k + b\lambda(c_m - c_r - m)]\}}{3bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2} + c_m, \tag{24}$$

$$g^{vn*} = \frac{c_2(a - bc_m)[k + b\lambda(c_m - c_r - m)]}{3bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2}, \tag{25}$$

$$t^{vn*} = \frac{c_1c_2(a - bc_m)}{3bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2}, \tag{26}$$

$$y^{vn*} = \frac{c_1l(a - bc_m)}{3bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2}. \tag{27}$$

Based on them,

$$p^{vn*} = \frac{(a - bc_m)c_2\{2c_1 - \lambda(c_m - c_r - m)[k + b\lambda(c_m - c_r - m)]\}}{3bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2} + c_m, \tag{28}$$

$$D^{vn*} = \frac{bc_1c_2(a - bc_m)}{3bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2}, \tag{29}$$

$$\pi_m^{vn*} = \frac{c_1c_2^2(a - bc_m)^2\left\{2bc_1 - [k + b\lambda(c_m - c_r - m)]^2\right\}}{2\left\{3bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2\right\}^2}, \tag{30}$$

$$\pi_r^{vn*} = \frac{c_1^2c_2(a - bc_m)^2\left(2bc_2 - l^2\right)}{2\left\{3bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2\right\}^2}, \tag{31}$$

$$\pi_{sc}^{vn*} = \frac{c_1c_2(a - bc_m)^2\left\{4bc_1c_2 - c_1l^2 - c_2[k + \lambda(c_m - c_r - m)]^2\right\}}{2\left\{3bc_1c_2 - c_1l^2 - c_2[k + b\lambda(c_m - c_r - m)]^2\right\}^2}. \tag{32}$$

3.2.3. Retailer Stackelberg (RS)

In this case, the retailer plays the dominant role in the CLSC and becomes the leader of Stackelberg game. The retailer first decides the retail margin and sales effort. Second, the manufacturer chooses the collection effort and wholesale price, taking the retail margin and sales effort into account. Similar to the model MS, the optimization problem is solved with backward induction.

The manufacturer first maximizes the profit function to derive best response functions.

$$\underset{w_m, g_m}{\text{Max}}\ \pi_m^{rs} = [a - b(w_m + t) + kg_m + ly][w_m - c_m(1 - \lambda g_m) - c_r\lambda g_m - m\lambda g_m] - \frac{1}{2}c_1 g_m^2, \tag{33}$$

where w_m and g_m characterize the response functions. Based on these, the retailer's optimization problem is as follows,

$$\underset{t,y}{\text{Max}}\ \pi_r^{rs} = [a - b(w_m + t) + kg_m + ly]t - \frac{1}{2}c_2 y^2, \tag{34}$$

subject to $t > 0$ and $y > 0$.

Proposition 4. *π_m^{rs} is concave in w_m and g_m, and the best response functions are given by $w_m = (((a - bc_m - bt + ly)[c_1 - \lambda(c_m - c_r - m)[k + \lambda(c_m - c_r - m)])/(2bc_1 - [k + b\lambda(c_m - c_r - m)]^2)) + c_m$ and $g_m = ((a - bc_m - bt + ly)[k + b\lambda(c_m - c_r - m)])/(2bc_1 - [k + b\lambda(c_m - c_r - m)]^2)$. π_r^{rs} is jointly concave in t and y. The retailer's optimal solutions are*:

$$t^{rs*} = \frac{\left(a - bc_m\right)c_2\left\{2bc_1 - [k + b\lambda(c_m - c_r - m)]^2\right\}}{b\left\{4bc_1c_2 - c_1 l^2 - 2c_2[k + b\lambda(c_m - c_r - m)]^2\right\}}, \tag{35}$$

$$y^{rs*} = \frac{c_1 l(a - bc_m)}{4bc_1c_2 - c_1 l^2 - 2c_2[k + \lambda(c_m - c_r - m)]^2}. \tag{36}$$

The manufacturer's optimal solutions are:

$$w^{rs*} = \frac{c_2(a - bc_m)\{c_1 - \lambda(c_m - c_r - m)][k + b\lambda(c_m - c_r - m)]\}}{4bc_1c_2 - c_1 l^2 - 2c_2[k + b\lambda(c_m - c_r - m)]^2} + c_m, \tag{37}$$

$$g^{rs*} = \frac{c_2(a - bc_m)[k + b\lambda(c_m - c_r - m)]}{4bc_1c_2 - c_1 l^2 - 2c_2[k + b\lambda(c_m - c_r - m)]^2}, \tag{38}$$

It is found that the manufacturer's best response functions, w_m and g_m, decrease as the retail margin t increases, while w_m and g_m increase as the sales effort y increases. Therefore, the low retail margin and high sales effort can motivate the manufacturer to exert high collection effort, and set high wholesale price to cover costs.

Therefore,

$$p^{rs*} = \frac{(a - bc_m)c_2\{3bc_1 - k^2 - b\lambda(c_m - c_r - m)]\,[3k + 2b\lambda(c_m - c_r - m)]\}}{b\left\{4bc_1c_2 - c_1 l^2 - 2c_2[k + b\lambda(c_m - c_r - m)]^2\right\}} + c_m. \tag{39}$$

$$D^{rs*} = \frac{bc_1c_2(a - bc_m)}{4bc_1c_2 - c_1 l^2 - 2c_2[k + b\lambda(c_m - c_r - m)]^2}, \tag{40}$$

$$\pi_m^{rs*} = \frac{c_1 c_2^2(a - bc_m)^2\left\{2bc_1 - [k + b\lambda(c_m - c_r - m)]^2\right\}}{2\left\{4bc_1c_2 - c_1 l^2 - 2c_2[k + b\lambda(c_m - c_r - m)]^2\right\}^2}, \tag{41}$$

$$\pi_r^{rs*} = \frac{c_1c_2(a - bc_m)^2}{2\left\{4bc_1c_2 - c_1 l^2 - 2c_2[k + b\lambda(c_m - c_r - m)]^2\right\}}, \tag{42}$$

$$\pi_{sc}^{rs*} = \frac{c_1c_2(a - bc_m)^2\left\{6bc_1c_2 - c_1 l^2 - 3c_2[k + b\lambda(c_m - c_r - m)]^2\right\}}{2\left\{4bc_1c_2 - c_1 l^2 - 2c_2[k + b\lambda(c_m - c_r - m)]^2\right\}^2}. \tag{43}$$

4. Discussions

In this section, the equilibrium values of different models are compared to understand the influence of channel power structure and demand expansion effectiveness.

4.1. Comparisons between centralized and decentralized CLSC

Proposition 5. *Compared with decentralized CLSC models, the retail price in model C is lower; the collection effort and sales effort in Model C are higher; the total profit of CLSC in model C is higher.*

Proposition 5 shows centralized CLSC not only gains the greatest profits, but also offers the greatest welfare to consumers with the lowest retail price, and to the environment with the highest collection effort. It reveals that the double marginalization in decentralized CLSC leads to relatively low performance. Channel strategy should be developed to motivate members' collaboration, hence to enhance the performance of decentralized CLSC towards the performance level of centralized CLSC.

4.2. Comparisons among decentralized CLSC models under different power structures

Proposition 6. *Both the collection effort g and sales effort y are positively related to the demand expansion effectiveness k and l. g and y satisfy the following relationship*:

(i) $g^{ms*} < g^{rs*} < g^{vn*}$ *and* $y^{ms*} < y^{rs*} < y^{vn*}$, *if* $0 < k < \sqrt{bc_1} - b\lambda(c_m - c_r - m)$ *and* $0 < l < [k + b\lambda(c_m - c_r - m)]\sqrt{c_2/c_1}$;

(ii) $g^{rs*} \le g^{ms*} < g^{vn*}$ *and* $y^{rs*} \le y^{ms*} < y^{vn*}$, *if* $0 < k < \sqrt{bc_1} - b\lambda(c_m - c_r - m)$ *and* $l \ge [k + b\lambda(c_m - c_r - m)]\sqrt{c_2/c_1}$;

(iii) $g^{ms*} < g^{vn*} \le g^{rs*}$ *and* $y^{ms*} < y^{vn*} \le y^{rs*}$, *if* $k \ge \sqrt{bc_1} - b\lambda(c_m - c_r - m)$.

The proposition suggests that with the increasing demand expansion effectiveness, the CLSC members will correspondingly improve their effort level. It implies that the market demand is the key driver of further development.

When $0<k<\sqrt{bc_1}-b\lambda(c_m-c_r-m)$ and $0<l<[k+b\lambda(c_m-c_r-m)]\sqrt{c_2/c_1}$, which means the consumers are not sensitive to the effort-input, it is under the symmetric channel power structure (VN) that the effort decisions are the highest. In the asymmetric channel power structure, members play the sequential game. The best responses in MS or RS show that the effort decisions are positively correlated with each other. When the benefit of effort-input is not large enough, the first-mover in MS or RS is prone to taking advantage of the dominant power to choose lower level of effort, and the follower will also set correspondingly low effort level. When the demand expansion effectiveness of sales effort increases and exceeds the threshold, the effort decisions in MS are respectively higher than those in RS. The dominant manufacturer in MS prefers to set higher collection effort in order to encourage the retailer exerting more sales effort.

When the demand expansion effectiveness of collection effort exceeds the threshold, both the collection effort and the sales effort will increase with the dominant channel power shifting to the retailer. It is wise for the dominant retailer, who is closer to the consumer, to exert great sales effort to motivate the manufacturer for mutual benefit.

Proposition 7. *The wholesale prices and retail margins satisfy the following order*:

(i) $w^{rs*}<w^{vn*}<w^{ms*}$ *and* $t^{ms*}<t^{vn*}<t^{rs*}$, *if* $0<k<\sqrt{bc_1}-b\lambda(c_m-c_r-m)$;
(ii) w^{vn*} *is the lowest and* t^{vn*} *is the highest*, *if* $k\geq\sqrt{bc_1}-b\lambda(c_m-c_r-m)$.

When the demand expansion effectiveness of collection effort is low, it is intuitive to note that the wholesale price will decrease with the dominant power shifting to the retailer, while the retail margin increase with it. The dominant retailer has strong incentive to lower the wholesale price, while raise the retail margin. It indicates that benefiting through one's pricing strategy is the great motivation for one player to be the channel leader. However, when the demand expansion effectiveness of collection effort is large enough, the symmetric power structure (VN) is most favorable to the retailer. The retailer in RS, will not set the retail margin much too high, to avoid pushing the manufacturers' collection effort down and negatively influencing the demand. The observation here provides an interesting finding on the retail price discussed in the next proposition.

Proposition 8. *The retail prices and market demand are in the following order*:

(i) $p^{vn*}<p^{rs*}<p^{ms*}$ *and* $D^{ms*}<D^{rs*}<D^{vn*}$, *if* $0<k<\sqrt{bc_1}-b\lambda(c_m-c_r-m)$ *and* $0<l<[k+b\lambda(c_m-c_r-m)]\sqrt{c_2/c_1}$;
(ii) $p^{vn*}<p^{ms*}\leq p^{rs*}$ *and* $D^{rs*}\leq D^{ms*}<D^{vn*}$, *if* $0<k<\sqrt{bc_1}-b\lambda(c_m-c_r-m)$ *and* $l\geq[k+b\lambda(c_m-c_r-m)]\sqrt{c_2/c_1}$;
(iii) $p^{rs*}\leq p^{vn*}<p^{ms*}$ *and* $D^{ms*}<D^{vn*}\leq D^{rs*}$, *if* $k\geq\sqrt{bc_1}-b\lambda(c_m-c_r-m)$.

Proposition 8 *shows that when the demand expansion effectiveness of collection effort is low, CLSC in VN charges the lowest retail price and enjoys the largest sales volume. When the demand expansion effectiveness of sales effort is also low, the retail price in MS is the highest. It is because the dominant manufacturer in MS sets the highest wholesale price as shown in* Proposition 7, *which plays the key role in pushing up the retail price. As the increasing of demand expansion effectiveness of sales effort, the retail price in RS gradually becomes the highest. Since the level of sales effort increases (as mentioned in* Proposition 6*), the retailer seeks to improve the retail margin to cover the cost, which increases the retail price.*

When the demand expansion effectiveness of collection effort is high, it is interesting to observe that the retail price decreases with the dominant channel power shifting to the retailer. Hence, the demand increases in this case with decreasing retail price and increasing effort decisions (as shown in Proposition 6*), which contributes to the increasing recovered products. The increasing sales volume and returns are favorable to the CLSC and the environment.*

Proposition 9. *The profits of the manufacturer and the retailer satisfy the following order*:

(i) $\pi_m^{rs*}<\pi_m^{vn*}<\pi_m^{ms*}$, *if* $0<k<\sqrt{bc_1}-b\lambda(c_m-c_r-m)$; *otherwise*, $\pi_m^{vn*}\leq\pi_m^{rs*}$, $\pi_m^{vn*}\leq\pi_m^{ms*}$.
(ii) $\pi_r^{ms*}<\pi_r^{vn*}\leq\pi_r^{rs*}$.

The proposition suggests that if the consumers are not sensitive to the collection effort, the profit of the manufacturer will decrease with the dominant position shifting to the retailer; otherwise, the manufacturer may benefit because of the great effectiveness of the effort. However, winning the channel leadership is always beneficial to the retailer.

Proposition 10. *The profits of CLSC are positively related to the demand expansion effectiveness of collection and sales effort*, *which are in the following order*:

(i) $\pi_{sc}^{ms*}<\pi_{sc}^{rs*}<\pi_{sc}^{vn*}$, *if* $0<k<\sqrt{bc_1}-b\lambda(c_m-c_r-m)$ *and* $0<l<[k+b\lambda(c_m-c_r-m)]\sqrt{c_2/c_1}$;
(ii) $\pi_{sc}^{rs*}\leq\pi_{sc}^{ms*}<\pi_{sc}^{vn*}$, *if* $0<k<\sqrt{bc_1}-b\lambda(c_m-c_r-m)$ *and* $l\geq[k+b\lambda(c_m-c_r-m)]\sqrt{c_2/c_1}$;
(iii) $\pi_{sc}^{ms*}<\pi_{sc}^{vn*}\leq\pi_{sc}^{rs*}$, *if* $k\geq\sqrt{bc_1}-b\lambda(c_m-c_r-m)$.

Proposition 10 *reveals that whatever the CLSC channel power structure is, greater demand expansion effectiveness is conducive to the CLSC. It is also noticed that when the demand expansion effectiveness of collection effort is low, CLSC under VN will be the most profitable. This can be attributed to the role of the greatest effort-input and the lowest retail price in boosting the sales volume, as demonstrated in the above propositions. In this case, with the increasing demand expansion effectiveness of sales effort, CLSC under MS can gain more profits than the CLSC under RS. However, it is observed that when the demand expansion effectiveness of collection effort is high, CLSC under RS will gain the highest profit by charging the lowest retail price and exerting greatest effort. The comparison result of equilibrium values in a decentralized CLSC under different channel power structures are summarized in* Table 1.

In summary, there is no power structure which can always be the most favorable one for the CLSC with price and effort-dependent demand, as demonstrated in Table 1. *When the demand expansion effectiveness of collection effort is low, CLSC under VN will gain the highest profit and consumers will get the most welfare from it. When the demand expansion effectiveness of collection effort is high enough, that is, when consumers proactively respond to the collection effort, CLSC under RS will make the best performance. Whatever the demand expansion effectiveness is, it is a bit counter-intuitive that the performance of CLSC under MS is relatively low. Shifting the dominant channel power from upstream manufacturer to downstream retailer may be beneficial for the CLSC.*

5. Coordinating CLSC with low price promotion strategy (Model L)

The discussion in Section 4 reveals that the performance of CLSC under different channel power structures differs and the double marginalization in decentralized CLSC leads to lower performance than centralized CLSC. It is hence important to propose the strategy

Table 1
Comparison of equilibrium results in decentralized CLSC models.

k	$0<k<k_0(\text{if } k_0<\overline{k})$ or $0<k<\overline{k}(\text{if } \overline{k}<k_0)$[a]		$k_0 \le k<\overline{k}$ (if $k_0<\overline{k}$)
l	$0<l<l_0(\text{if } l_0<\overline{l})$ or[b] $0<l<\overline{l}(\text{if } \overline{l}<l_0)$	$l_0 \le l<l$ (if $l_0<\overline{l}$)	$0<l<\overline{l}$
g^*	$g^{ms*}<g^{rs*}<g^{vn*}$	$g^{rs*} \le g^{ms*}<g^{vn*}$	$g^{ms*}<g^{vn*} \le g^{rs*}$
y^*	$y^{ms*}<y^{rs*}<y^{vn*}$	$y^{rs*} \le y^{ms*}<y^{vn*}$	$y^{ms*}<y^{vn*} \le y^{rs*}$
w^*	$w^{rs*}<w^{vn*}<w^{ms*}$	$w^{rs*}<w^{vn*}<w^{ms*}$	$w^{vn*} \le w^{rs*}, w^{vn*}<w^{ms*}$
t^*	$t^{ms*}<t^{vn*}<t^{rs*}$	$t^{ms*}<t^{vn*}<t^{rs*}$	$t^{ms*}<t^{vn*}, t^{rs*} \le t^{vn*}$
p^*	$p^{vn*}<p^{rs*}<p^{ms*}$	$p^{vn*}<p^{ms*} \le p^{rs*}$	$p^{rs*} \le p^{vn*}<p^{ms*}$
D^*	$D^{ms*} \le D^{rs*}<D^{vn*}$	$D^{rs*} \le D^{ms*}<D^{vn*}$	$D^{ms*}<D^{vn*} \le D^{rs*}$
π_m^*	$\pi_m^{rs*}<\pi_m^{vn*}<\pi_m^{ms*}$	$\pi_m^{rs*}<\pi_m^{vn*}<\pi_m^{ms*}$	$\pi_m^{vn*} \le \pi_m^{rs*}, \pi_m^{vn*}<\pi_m^{ms*}$
π_r^*	$\pi_r^{ms*}<\pi_r^{vn*}<\pi_r^{rs*}$	$\pi_r^{ms*}<\pi_r^{vn*}<\pi_r^{rs*}$	$\pi_r^{ms*}<\pi_r^{vn*} \le \pi_r^{rs*}$
π_{sc}^*	$\pi_{sc}^{ms*}<\pi_{sc}^{rs*}<\pi_{sc}^{vn*}$	$\pi_{sc}^{rs*} \le \pi_{sc}^{ms*}<\pi_{sc}^{vn*}$	$\pi_{sc}^{ms*}<\pi_{sc}^{vn*} \le \pi_{sc}^{rs*}$

[a] $k_0=\sqrt{bc_1}-b\lambda(c_m-c_r-m), \overline{k}=\{\sqrt{bc_1+((b^2\lambda^2(c_m-c_r-m)^2)/4)}-((b\lambda(c_m-c_r-m))/2), ((\sqrt{8bc_1+\lambda^2(a-bc_m)^2}-\lambda(a+bc_m-2bc_r-2bm))/2)\}_{\min}$.
[b] $l_0=[k+b\lambda(c_m-c_r-m)]\sqrt{c_2/c_1}, \overline{l}=\{\sqrt{bc_2-((c_2k(k+b\lambda(c_m-c_r-m)))/c_1)}, \sqrt{2bc_2-((c_2(k+b\lambda(c_m-c_r-m))(k+\lambda(a-bc_r-bm)))/c_1)}\}_{\min}$.

to coordinate the players, so as to enhance the performance of decentralized CLSC.

Based on the two-part tariff contract, i.e., the manufacturer offers the retailer a low wholesale price and charges a fixed franchise fee (Govindan et al., 2013), the low price promotion strategy is proposed. In this strategy, the retailer sells products with the wholesale price set by the manufacturer and exerts great sales effort as much as that in centralized CLSC, while the retailer charges the manufacturer a fixed fee F as channel allowance. To achieve supply chain coordination, all the pricing and effort decisions of the decentralized CLSC should be the same as those in the centralized model. The fixed fee F is the negotiated value and influenced by the bargaining power that each member carries. To ensure the smooth implementation of the strategy, profits of the manufacturer and the retailer should be no less than those derived in decentralized CLSC.

The profits of the manufacturer and the retailer are as follows:

$$\pi_m^l=(a-bw+kg+ly)[w-c_m(1-\lambda g)-c_r\lambda g-m\lambda g]-\frac{1}{2}c_1g^2-F, \tag{44}$$

$$\pi_r^l=F-\frac{1}{2}c_2y^2. \tag{45}$$

Proposition 11. *In the low price promotion strategy, the manufacturer's optimal decisions are*

$$w^{l*}=\frac{(a-bc_m)c_2\{c_1-\lambda(c_m-c_r-m)[k+b\lambda(c_m-c_r-m)]\}}{2bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2}+c_m, \tag{46}$$

$$g^{l*}=\frac{c_2(a-bc_m)[k+b\lambda(c_m-c_r-m)]}{2bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2}. \tag{47}$$

Substituting Eqs. (46) and (47) into Eqs. (44), (45) and (3), the profits are:

$$\pi_m^{l*}=\frac{c_1c_2^2(a-bc_m)^2\left\{2bc_1-[k+b\lambda(c_m-c_r-m)]^2\right\}}{2\left\{2bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}^2}-F^{l*}, \tag{48}$$

$$\pi_r^{l*}=F^{l*}-\frac{c_1^2c_2l^2(a-bc_m)^2}{2\left\{2bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}^2}, \tag{49}$$

$$\pi_{sc}^{l*}=\frac{c_1c_2(a-bc_m)^2}{2\left\{2bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}}. \tag{50}$$

Comparing the profits of the manufacturer and the retailer with those in model MS, VN, RS respectively, the feasible range of F can be derived. In the CLSC under manufacturer Stackelberg, $F^{lms*} \in [\underline{F}^{lms*}, \overline{F}^{lms*}]$, where

$$\underline{F}^{lms*}=\frac{c_1^2c_2(a-bc_m)^2\left(2bc_2-l^2\right)}{2\left\{4bc_1c_2-2c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}^2}+\frac{c_1^2c_2l^2(a-bc_m)^2}{2\left\{2bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}^2}, \tag{51}$$

$$\overline{F}^{lms*}=\frac{c_1c_2^2(a-bc_m)^2\left\{2bc_1-[k+b\lambda(c_m-c_r-m)]^2\right\}}{2\left\{2bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}^2}-\frac{c_1c_2(a-bc_m)^2}{2\left\{4bc_1c_2-2c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}}. \tag{52}$$

In the CLSC under vertical Nash, $F^{lvn*} \in [\underline{F}^{lvn*}, \overline{F}^{lvn*}]$, where

$$\underline{F}^{lvn*}=\frac{c_1^2c_2(a-bc_m)^2\left(2bc_2-l^2\right)}{2\left\{3bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}^2}+\frac{c_1^2c_2l^2(a-bc_m)^2}{2\left\{2bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}^2}, \tag{53}$$

Table 2
Equilibrium results under different models in different cases.

Case	Model	w^*	t^*	p^*	g^*	y^*	α^*	π_m^*	π_r^*	π_{sc}^*
Case 1	C	N/A	N/A	70.7	0.7	1.3	21.8%	N/A	N/A	1499.5
	MS	65.9	20.3	86.1	0.3	0.6	10.3%	709.4	373.8	1083.1
	VN	55.2	26.6	81.8	0.4	0.8	13.5%	640.6	642.8	1283.4
	RS	49.3	36.8	86.1	0.3	0.6	10.3%	373.9	710.6	1084.5
Case 2	C	N/A	N/A	69.4	1.2	1.5	96.7%	N/A	N/A	1717.9
	MS	65.0	21.6	86.6	0.5	0.6	42.5%	754.7	423.2	1177.9
	VN	53.2	28.9	82.0	0.7	0.9	56.8%	668.5	757.5	1426.1
	RS	48.5	37.1	85.6	0.6	0.7	45.5%	428.0	808.0	1235.9
Case 3	C	N/A	N/A	68.5	0.4	0.8	13.1%	N/A	N/A	1392.8
	MS	65.5	19.2	84.8	0.2	0.4	6.3%	673.3	347.8	1021.1
	VN	54.5	25.4	79.9	0.3	0.5	8.4%	604.8	605.1	1209.9
	RS	48.6	36.2	84.8	0.2	0.4	6.3%	347.8	673.4	1021.3
Case 4	C	N/A	N/A	67.6	0.7	0.9	55.2%	N/A	N/A	1508.6
	MS	65.0	20.0	85.0	0.3	0.4	25.6%	699.2	375.1	1074.3
	VN	53.3	26.7	80.0	0.4	0.5	34.1%	620.6	669.0	1289.5
	RS	48.1	36.3	84.4	0.3	0.4	26.6%	379.7	727.4	1104.1

$$\overline{F}^{lvn*} = \frac{c_1c_2^2(a-bc_m)^2\left\{2bc_1-[k+b\lambda(c_m-c_r-m)]^2\right\}}{2\left\{2bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}^2} - \frac{c_1c_2^2(a-bc_m)^2\left\{2bc_1-[k+b\lambda(c_m-c_r-m)]^2\right\}}{2\left\{3bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}^2}. \tag{54}$$

In the CLSC under retailer Stackelberg, $F^{lrs*}\in[\underline{F}^{lrs*},\overline{F}^{lrs*}]$, where

$$\underline{F}^{lrs*} = \frac{c_1c_2(a-bc_m)^2}{2\left\{4bc_1c_2-c_1l^2-2c_2[k+b\lambda(c_m-c_r-m)]^2\right\}} + \frac{c_1^2c_2l^2(a-bc_m)^2}{2\left\{2bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}^2}, \tag{55}$$

$$\overline{F}^{lrs*} = \frac{c_1c_2^2(a-bc_m)^2\left\{2bc_1-[k+b\lambda(c_m-c_r-m)]^2\right\}}{2\left\{2bc_1c_2-c_1l^2-c_2[k+b\lambda(c_m-c_r-m)]^2\right\}^2} - \frac{c_1c_2^2(a-bc_m)^2\left\{2bc_1-[k+b\lambda(c_m-c_r-m)]^2\right\}}{2\left\{4bc_1c_2-c_1l^2-2c_2[k+b\lambda(c_m-c_r-m)]^2\right\}^2}. \tag{56}$$

Proposition 12. *The low price promotion strategy effectively coordinates the decentralized CLSC under different channel power structures, i.e., $p^{l*}=p^{c*}, g^{l*}=g^{c*}, y^{l*}=y^{c*}, \pi^{l*}=\pi^{c*}$.*

Proposition 12 *implies that the low price promotion strategy can improve the performance of CLSC under different channel power structures to the level of centralized CLSC. The manufacturer and the retailer agree on F which ensures that their profits will not be lower than decentralized decision-making models. Although there is no retail margin, the retailer covers the input in promotion with the manufacturer's payment F. The manufacturer benefits from the increasing market demand, getting more sales and returns. In addition, the consumers purchase the product at a lower retail price, more used products will be recycled. On the whole, low price promotion strategy is beneficial for the CLSC, the consumers and the environment. It sheds great implication that chain members' collaboration can facilitate sustainable operation of the CLSC in the long run.*

6. Numerical analysis

In this section, numerical examples are utilized to analyze the equilibrium results in different models and the efficiency of the proposed coordination strategy. The impact of demand expansion effectiveness on pricing and profits are also investigated in different cases to provide more insights. The data adopted in numerical examples are estimated from the engine remanufacturing companies, while these data have been manipulated before being employed to

Table 3
Equilibrium results under coordination strategies in different cases.

Case	Model	w^* (p^*)	g^*	Y^*	α^*	F^*	π_M^*	π_r^*	π_{sc}^*
Case 1	LMS	70.7	0.7	1.3	21.8%	[539.0, 955.4]	[709.4, 1125.7]	[373.8, 790.2]	1499.5
	LVN	70.7	0.7	1.3	21.8%	[808.0, 1024.1]	[640.6, 856.8]	[642.8, 858.9]	1499.5
	LRS	70.7	0.7	1.3	21.8%	[875.8, 1290.9]	[373.9, 788.9]	[710.6, 1125.7]	1499.5
Case 2	LMS	69.4	1.2	1.5	96.7%	[640.0, 1180.0]	[754.7, 1194.8]	[423.2, 963.2]	1717.9
	LVN	69.4	1.2	1.5	96.7%	[974.4, 1266.2]	[668.5, 960.4]	[757.5, 1049.4]	1717.9
	LRS	69.4	1.2	1.5	96.7%	[1024.8, 1506.8]	[428.0, 909.9]	[808.0, 1289.9]	1717.9
Case 3	LMS	68.5	0.4	0.8	13.1%	[442.8, 814.6]	[673.3, 1045.0]	[347.8, 719.6]	1392.8
	LVN	68.5	0.4	0.8	13.1%	[700.1, 883.1]	[604.8, 787.7]	[605.1, 788.1]	1392.8
	LRS	68.5	0.4	0.8	13.1%	[768.5, 1140.0]	[347.8, 719.4]	[673.4, 1045.0]	1392.8
Case 4	LMS	67.6	0.7	0.9	55.2%	[486.62, 920.89]	[699.2, 1133.5]	[375.1, 809.4]	1508.6
	LVN	67.6	0.7	0.9	55.2%	[780.43, 999.53]	[620.6, 839.7]	[669.0, 888.1]	1508.6
	LRS	67.6	0.7	0.9	55.2%	[838.91, 1243.42]	[376.7, 781.2]	[727.4, 1131.9]	1508.6

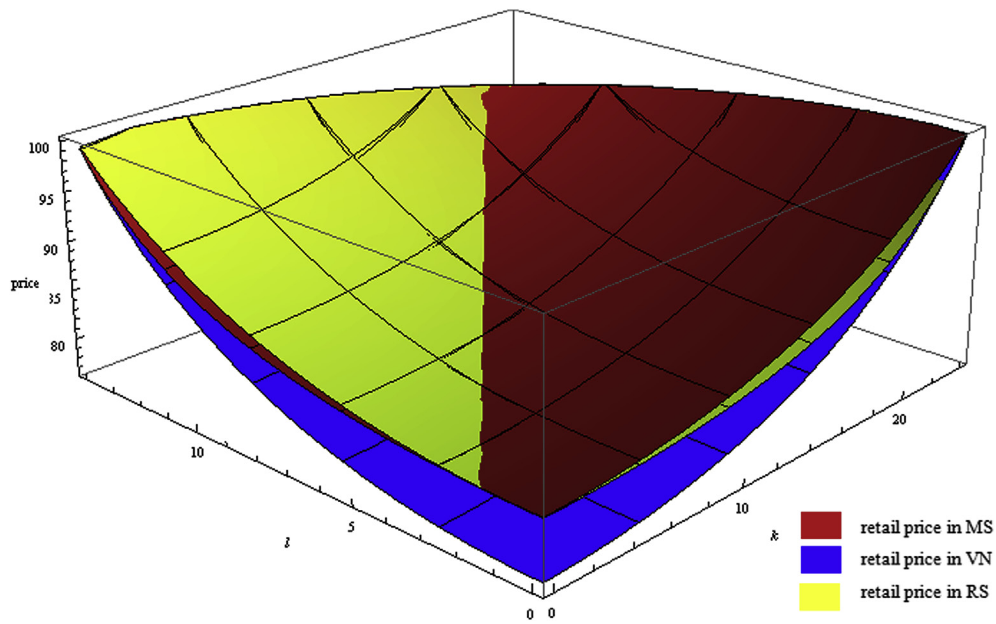

Fig. 1. Influence of k and l on the retail price in case 1. The influence of demand expansion effectiveness coefficient of collection effort (k) and the demand expansion effectiveness coefficient of sales effort (l) on the retail price (p) in the decentralized CLSC under manufacturer Stackelberg (MS), vertical Nash (VN) and retailer Stackelberg (RS) in case 1.

closely comply with certain assumptions of this study. Considering the influence of effort cost on effort decisions and the importance of collection efficiency in reverse logistics, four cases are demonstrated.

The parameters in common are as follows: $a = 100$, $b = 1$, $k = 8$, $l = 6$, $c_m = 30$, $c_r = 15$, $m = 5$. In case 1, the effort cost coefficients and the collection efficiency are low where $c_1 = 650$, $c_2 = 200$ and $\lambda = 0.3$. In case 2, the effort cost coefficients are low and the collection efficiency is high, where $c_1 = 650$, $c_2 = 200$, $\lambda = 0.8$. In case 3, the effort cost coefficients are high and the collection efficiency is low, where $c_1 = 1000$, $c_2 = 300$, $\lambda = 0.3$. In case 4, the effort cost coefficients and the collection efficiency are high, where $c_1 = 1000$, $c_2 = 300$, $\lambda = 0.8$.

6.1. Analysis of equilibrium results

The corresponding equilibrium results under centralized and decentralized models in different cases are summarized in Table 2. As shown in Table 2, the performance of CLSC in model C is much better than those in decentralized CLSC models. With regarding to

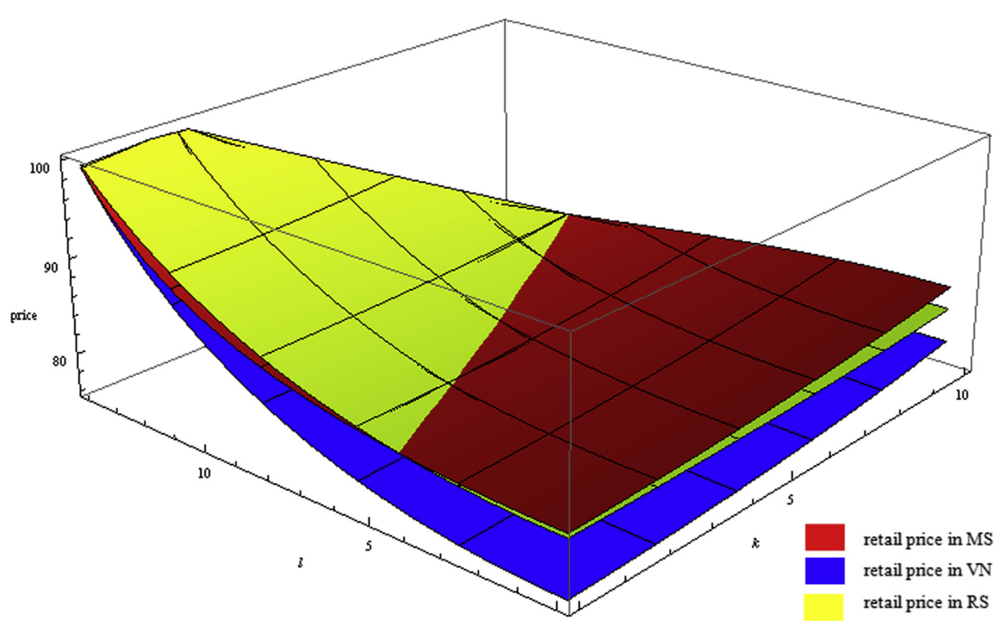

Fig. 2. Influence of k and l on the retail price in case 2. The influence of demand expansion effectiveness coefficient of collection effort (k) and the demand expansion effectiveness coefficient of sales effort (l) on the retail price (p) in the decentralized CLSC under manufacturer Stackelberg (MS), vertical Nash (VN) and retailer Stackelberg (RS) in case 2.

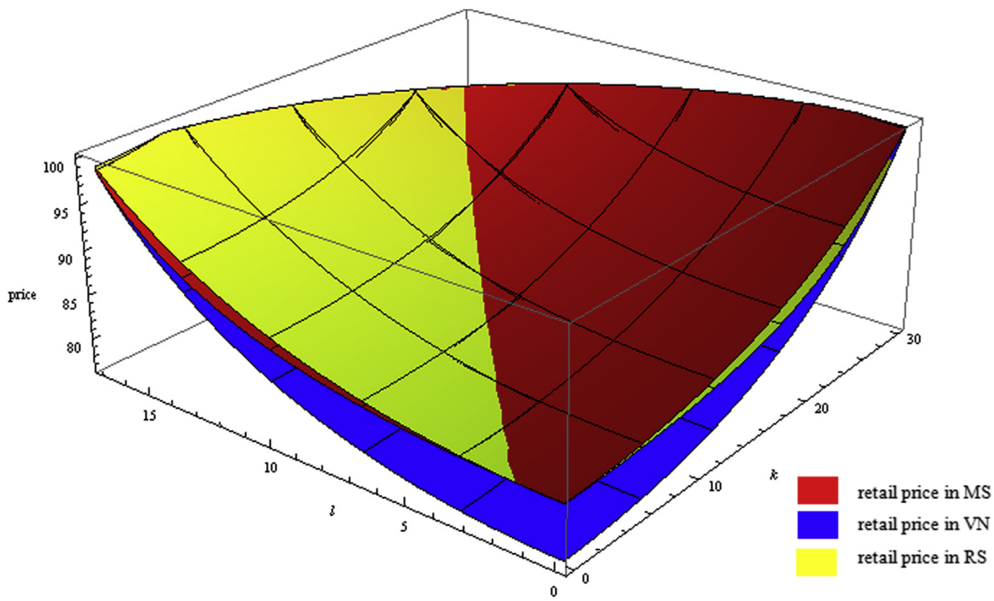

Fig. 3. Influence of k and l on the retail price in case 3. The influence of demand expansion effectiveness coefficient of collection effort (k) and the demand expansion effectiveness coefficient of sales effort (l) on the retail price (p) in the decentralized CLSC under manufacturer Stackelberg (MS), vertical Nash (VN) and retailer Stackelberg (RS) in case 3.

decentralized CLSC models, $w^{rs*} < w^{vn*} < w^{ms*}$, $t^{ms*} < t^{vn*} < t^{rs*}$, $p^{vn*} < p^{rs*} \le p^{ms*}$, $g^{ms*} \le g^{rs*} < g^{vn*}$, $y^{ms*} \le y^{rs*} < y^{vn*}$, $\pi_m^{rs*} < \pi_m^{vn*} < \pi_m^{ms*}$, $\pi_r^{ms*} < \pi_r^{vn*} < \pi_r^{rs*}$ and $\pi_{sc}^{ms*} < \pi_{sc}^{rs*} < \pi_{sc}^{vn*}$ hold in all the four cases. As stated in Proposition 10, when the demand expansion effectiveness of collection effort is low, CLSC under VN will be the most profitable. Table 2 also demonstrates that each member prefers to hold the dominant channel power to gain the larger portion of total profit, while the symmetric channel power structure is the best for the CLSC and consumers in this scenario. Moreover, the low cost coefficient and high collection efficiency can be beneficial to the total CLSC. Under the same channel power structure, the CLSC in case 2 gains the highest profits and the CLSC in case 3 gains the lowest profits.

The efficiency of coordination strategy in different cases is shown in Table 3. With low price promotion strategy, the equilibrium decisions and overall profit of decentralized CLSC under different channel power structures are equal to those in centralized CLSC in all four cases. The profits of the manufacturer and the retailer under different channel power structures are no less than theirs in corresponding decentralized models. Furthermore, with the power shifting to the retailer, the lower bound and upper bound of the fixed fee F which is paid by the manufacturer to the retailer increase gradually. It provides an insight that the dominant member should be proactive in facilitating the implementation of the contract.

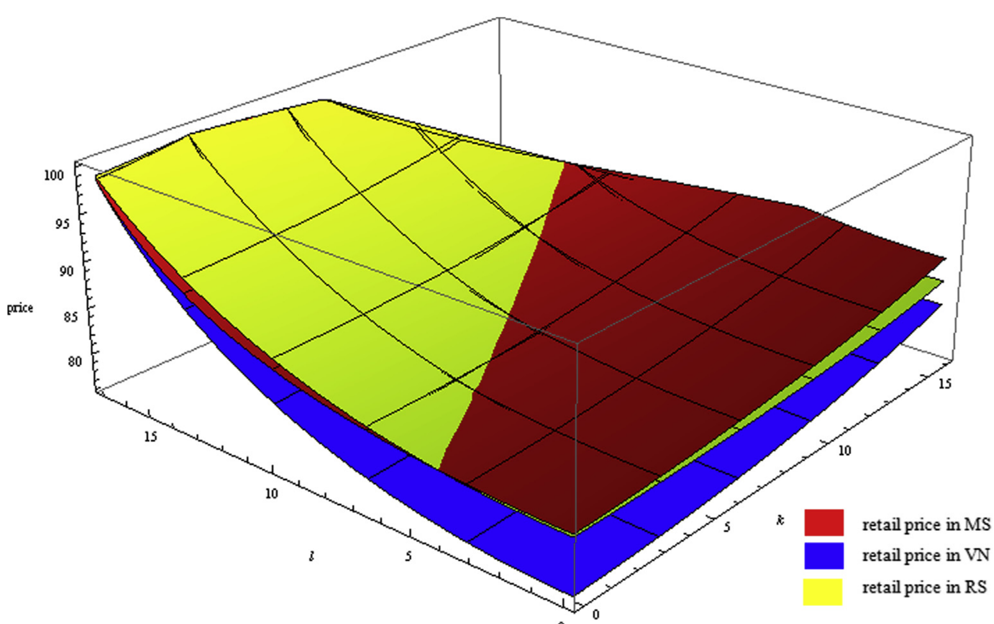

Fig. 4. Influence of k and l on the retail price in case 4. The influence of demand expansion effectiveness coefficient of collection effort (k) and the demand expansion effectiveness coefficient of sales effort (l) on the retail price (p) in the decentralized CLSC under manufacturer Stackelberg (MS), vertical Nash (VN) and retailer Stackelberg (RS) in case 4.

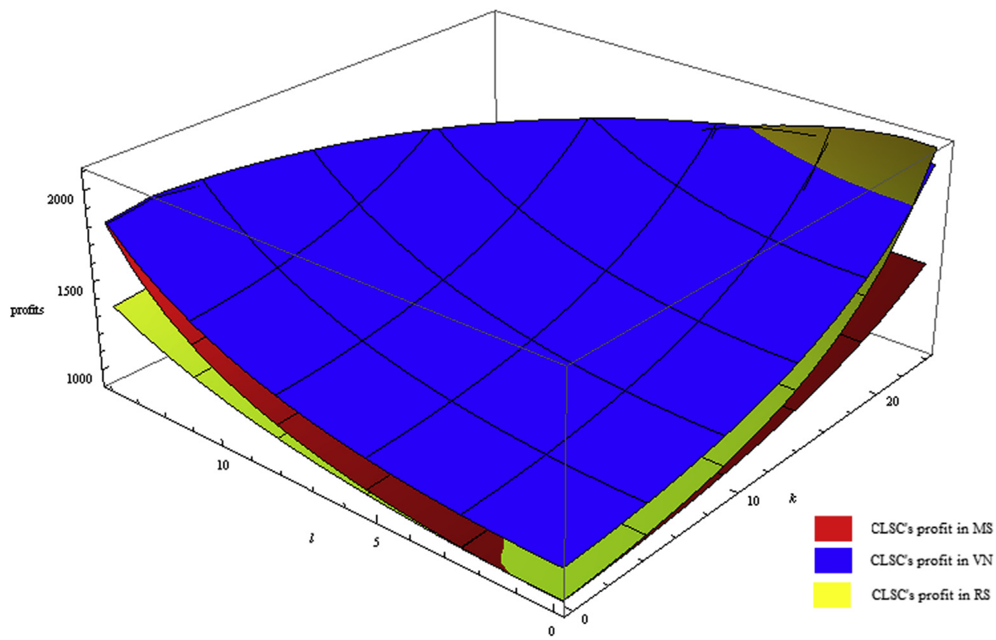

Fig. 5. Influence of k and l on profits of the decentralized CLSC in case 1. The influence of demand expansion effectiveness coefficient of collection effort (k) and the demand expansion effectiveness coefficient of sales effort (l) on profits of the decentralized CLSC under manufacturer Stackelberg (MS), vertical Nash (VN) and retailer Stackelberg (RS) in case 1.

6.2. The impact of demand expansion effectiveness coefficients

The impact of demand expansion effectiveness of collection effort and sales effort on pricing and profits will be demonstrated under decentralized models with different channel power structures. With k and l varying in the feasible ranges, pricing decisions in the decentralized models of four cases are illustrated in Figs. 1–4 respectively.

Figs. 1–4 show that the demand expansion effectiveness of both collection effort and sales effort has a positive effect on pricing decision under different power structures. It implies that when the demand expansion effectiveness is low, the CLSC mainly relies on the low price to enhance demand; when the demand expansion effectiveness is high, the CLSC will take advantage of the consumer's proactive response to the effort and increase the price to cover the cost in increasing the effort (effort decisions are positively related to the demand expansion effectiveness, as demonstrated in Proposition 6). Specifically, the retail price in MS is prone to be the highest one with high demand expansion effectiveness of collection effort k, for the dominant manufacturer will charge high

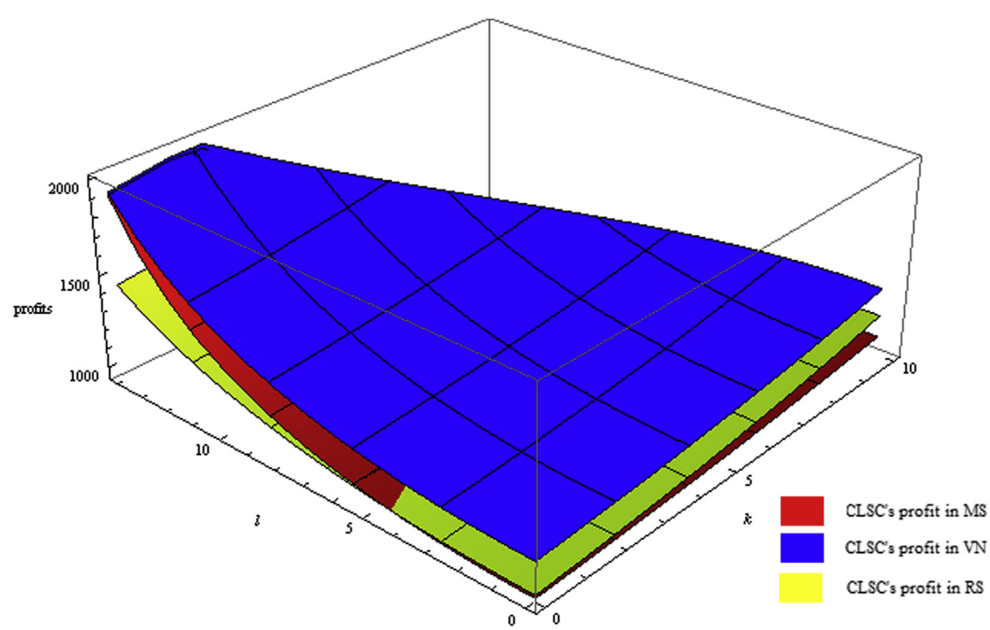

Fig. 6. Influence of k and l on profits of the decentralized CLSC in case 2. The influence of demand expansion effectiveness coefficient of collection effort (k) and the demand expansion effectiveness coefficient of sales effort (l) on profits of the decentralized CLSC under manufacturer Stackelberg (MS), vertical Nash (VN) and retailer Stackelberg (RS) in case 2.

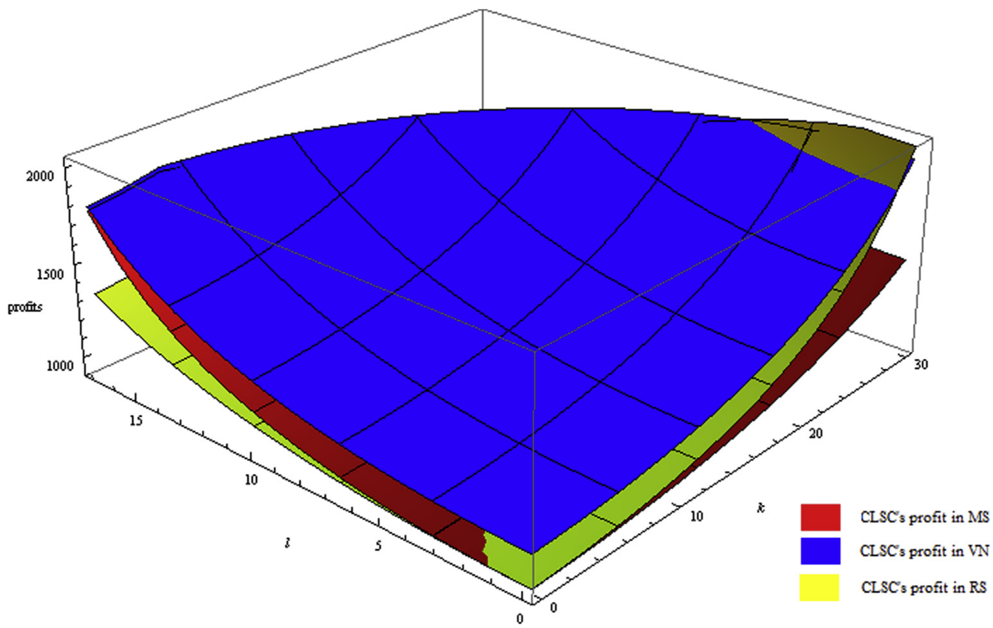

Fig. 7. Influence of k and l on profits of the decentralized CLSC in case 3. The influence of demand expansion effectiveness coefficient of collection effort (k) and the demand expansion effectiveness coefficient of sales effort (l) on profits of the decentralized CLSC under manufacturer Stackelberg (MS), vertical Nash (VN) and retailer Stackelberg (RS) in case 3.

wholesale price at first to cover the cost on improving the collection effort, which pushes up the retail price. Similarly, the retail price in RS is prone to be the highest one with high demand expansion effectiveness of sales effort.

Comparing Fig. 1 with Fig. 2, it is found that the feasible range of k in Fig. 2 is smaller than that in Fig. 1. If the collection efficiency is high, the collection rate will be easier to reach the maximum level, which requires less collection effort. Therefore, the range of demand expansion effectiveness of collection effort in Fig. 2 is smaller. The similar situation also holds in Figs. 3 and 4.

It is worth noting the price is not sensitive to the changes of k in Figs. 2 and 4, where the collection efficiency is high. The reason is that the collection effort input by the manufacturer will go up if k increases, and the product collected for remanufacturing will increase greatly with high collection efficiency, which bring considerable cost-savings. In Figs. 1 and 3, it is illustrated that the retail price in RS can be lower than that in VN when the demand expansion effectiveness of collection effort exceeds the threshold and the demand expansion effectiveness of sales effort is low. The reason is that the dominant retailer will set the low retail margin to motivate the manufacturer to input greater collection effort to take advantage of the high demand expansion effectiveness. Thus when the demand expansion effectiveness of collection effort is low, the CLSC under VN is the most beneficial to the consumers; otherwise, the CLSC under RS is the favorable one to the consumers.

As k and l varies, profits of the CLSC in the decentralized models of four cases are illustrated in Figs. 5–8, respectively.

Figs. 5–8 show that the demand expansion effectiveness of both collection effort and sales effort exerts positive influence on profits of the CLSC under different power structures. It is also noted that the profits of CLSC is not sensitive to the changes of k in Figs. 6 and 8, which can be partly explained by the insensitive retail price. The CLSC in MS tends to gain the lowest profit with the increasing of k and the CLSC in RS tends to gain the lowest profit with the increasing of l, since the dominant member usually makes low effort decision at first and charge high price, which will hinder the profitability of total CLSC. When the demand expansion effectiveness of collection effort is low, the CLSC in VN is the most profitable. However, the CLSC in RS gains the most profits with high demand expansion effectiveness of collection effort (Figs. 5 and 7), charging the lowest retail price (Figs. 1 and 3) and inputting the greatest efforts (Proposition 6).

7. Conclusions

Great advances have been made in the research on CLSC management. However, less attention has been given on the influence of channel power structure on optimal channel strategies and profitability of CLSC with the price and effort dependent demand. This paper presents a comprehensive discussion on the CLSC under different channel power structures, when the market demand is sensitive to collection effort, sales effort and the price. In a CLSC with one manufacturer and one retailer, the optimal pricing and effort decisions are explored by establishing game theoretic models of centralized CLSC and decentralized CLSC under three channel power structures, i.e., manufacturer Stackelberg (MS), vertical Nash (VN) and retailer Stackelberg (RS). This research examines the decision-making process considering the demand expansion effectiveness of both sales effort and collection effort. The contribution of this paper is threefold.

Firstly, by comparing equilibrium results under different models, the influence of different channel power structures on optimal decisions and profits of CLSC is examined. The retailer's profit always increases with the dominant channel power shifting from the manufacturer to the retailer, whereas the manufacturer's profit decreases with it just in the case of low demand expansion effectiveness of collection effort. When the demand expansion effectiveness of collection effort is high, the manufacturer under symmetric power structure gains the lowest profit.

Secondly, the best channel power structure from the viewpoint of the CLSC and consumers is analyzed. The best channel power structure for the CLSC varies with the demand expansion effectiveness of the collection effort. When the demand expansion effectiveness of collection effort is relatively low, the CLSC under VN

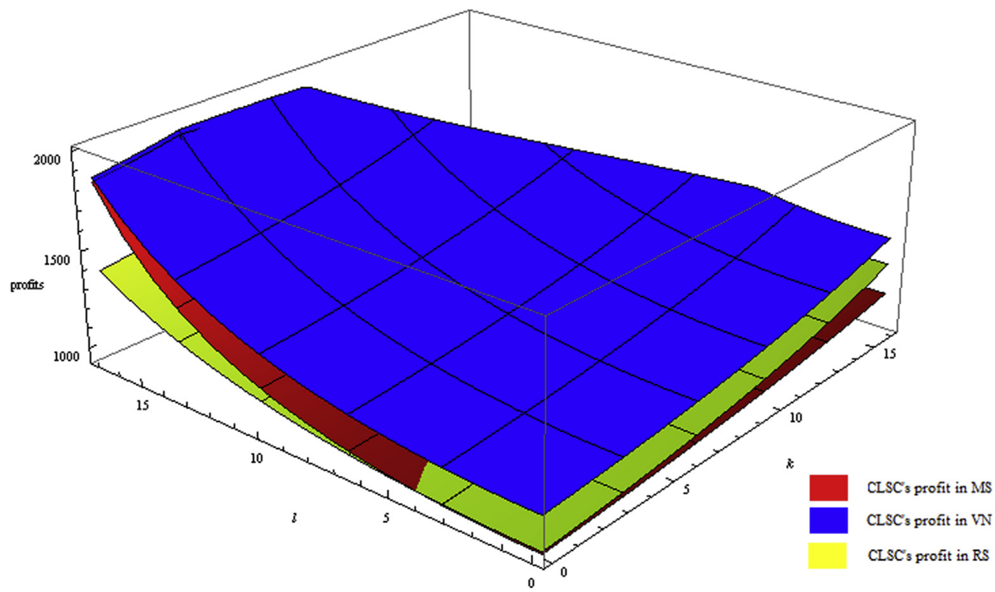

Fig. 8. Influence of k and l on profits of the decentralized CLSC in case 4. The influence of demand expansion effectiveness coefficient of collection effort (k) and the demand expansion effectiveness coefficient of sales effort (l) on profits of the decentralized CLSC under manufacturer Stackelberg (MS), vertical Nash (VN) and retailer Stackelberg (RS) in case 4.

will make the best performance, charging the lowest retail price and exerting the highest efforts, which brings the most welfare to consumers and collects largest quantity of used products to reduce the negative effect on environment; otherwise, the CLSC under RS will perform best and be the most favorable to consumers and the environment.

Thirdly, the low price promotion strategy is proposed to enhance the performance of decentralized CLSC to reach the level of centralized CLSC, without damaging chain members' profits. It is beneficial for the manufacturer, the retailer and consumers, while the allocation of the profit depends on CLSC members' channel power.

These findings provide some insights on the CLSC management in academic research and practice. Although many previous studies assume that the manufacturer is the channel leader, it is not the best channel power structure for the total CLSC with price and effort dependent demand. This encourages more researches in the context of the retailer-led CLSC, and sheds light on the support of building up the strength of the retailer in practice. It is the fact that members of CLSC can benefit from being the dominant player, however, no power structure is always the best. The highlight is that the high demand expansion effectiveness and members' collaboration are conducive to both parties. The manufacturer and the retailer should endeavor to help consumers increase their eco-friendly awareness and understand the potential benefit of recycling or closed-loop operations. Consumers' active response can not only inspire their purchasing initiative, but also facilitate the collection activity. The high collection effort, in turn, will benefit both the consumers and the environment in the long run. Measures such as modular design, efficient reprocess, and the governments' technical and economic assistance can facilitate the implementation of CLSC in view of cost reduction. Driven by closing the loop and exerting sales effort, enterprises simultaneously gain more profits and social reputation, further strides towards sustainable operation.

Although our model is well-supported by the literature, several assumptions in the model settings can be relaxed for further study. For example, the demand is assumed to be deterministic, thus an extension of this paper would investigate the stochastic demand to get better understanding. Information asymmetry also points to an interesting future research, which contributes to better comprehend members' interactions, since manufacturer may possess more information on production cost while the retailer is likely to understand the market demand better. Moreover, introducing competition into the chain or considering multi-echelons CLSC can provide a more comprehensive picture. The CLSC management still has a long road to travel in both research and practice.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jclepro.2015.01.066.

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