Journal of Cleaner Production 189 (2018) 406–431

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Pricing, product quality, and collection optimization in a decentralized closed-loop supply chain with different channel structures: Game theoretical approach

Ata Allah Taleizadeh [a], Mohammad Sadegh Moshtagh [a], Ilkyeong Moon [b, *]

[a] School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran
[b] Department of Industrial Engineering & Institute for Industrial Systems Innovation, Seoul National University, Seoul, Korea

ARTICLE INFO

Article history:
Received 13 May 2017
Received in revised form
1 January 2018
Accepted 20 February 2018
Available online 4 April 2018

Keywords:
Closed-loop supply chain
Dual-channel supply chain
Return policy
Sales and collection effort
Dual recycling channel

ABSTRACT

In recent years, recycling and remanufacturing functions have received increased attention because of strict environmental concerns and regulations. The aim of this paper is to investigate the pricing strategies as well as the quality level and effort decisions of the manufacturer, retailer, and third party operating in two types of closed-loop supply chains: (1) single-channel forward supply chain with a dual-recycling channel (SD model) and (2) dual-channel forward supply chain with a dual-recycling channel (DD model). On the basis of these different channel structures, two manufacturer Stackelberg game models are developed to explore the best values for prices, quality levels, and sales and collection efforts. In addition, to draw managerial insights, corresponding equilibrium solutions of the two model structures are determined and compared, and the channel structure that most benefits each supply chain member is examined. To reduce channel conflicts and increase each channel member' profits, a novel coordination mechanism is introduced and discussed. Two numerical examples are presented to simulate the strategies for choosing the best channel format for a decentralized closed-loop supply chain and examine the effectiveness of the coordination contract. The results revealed that the DD model is the best for the manufacturer, and the optimal channel structure for the retailer depends on the retailer's market share. However, by applying a novel coordination mechanism, all three members of a closed-loop supply chain can benefit from the introduction of an online selling channel. Furthermore, the results showed that the quality of products in the DD model is always greater than it is for products in the SD model. Moreover, it is observed from the sensitivity analysis that the recycling channel member with a predominant market share exerts greater collections effort and offers lower buyback prices than others in the collection channel.

1. Introduction

Over the past few decades, recycling and remanufacturing functions have received considerable attention by both academicians and practitioners because of resource shortages and requirements to implement sustainable development and environmental processes, such as waste disposal, that affect pollution levels in the air and water tables and ameliorate the natural resource depletion. In addition, government legislation has proven highly influential in saving resources, protecting ecological environments, and encouraging the development of green products. Legislation and overall environmental consciousness force companies to initiate a closed-loop supply chain (CLCS), which incorporates reverse flow into the forward flow of the supply chain and combines the processes into an integrated system that affects economic, environmental, and social performances (Guide and Wassenhove, 2003).

Studies on closed-looped supply chains (CLSCs) can be classified from the following perspectives: production planning and inventory management (Kenne et al., 2012), network design of the CLSC (Kusumastuti et al., 2008; Yi et al., 2016b), and channel management (Jiang et al., 2010), among others. Channel structure selection is one of the most important aspects of marketing decisions, which have been given considerable attention in both

* Corresponding author.
E-mail addresses: Taleizadeh@ut.ac.ir (A.A. Taleizadeh), sadegh.moshtagh@ut.ac.ir (M.S. Moshtagh), ikmoon@snu.ac.kr (I. Moon).

https://doi.org/10.1016/j.jclepro.2018.02.209

reverse and forward flows of supply chains. The main purpose of this paper is to present an exhaustive discussion on the optimal channel structures and supply chain members' profits in both forward and reverse flows in terms of the main factors affecting market demand: price, quality level, and sales and collection efforts.

In current marketing systems, several types of channel structures feature reverse or forward flow. In the forward supply chain, the structures include a retail channel; an *online channel*, in which items are sold through the Internet directly; and a dual channel, which is a hybrid of the retail and online channels. In fact, as the Internet and related information technologies developed rapidly, manufacturers have been attracted to direct channels in which products are sold directly to end users through the Internet. In addition, as a consequence of improved living standards, consumers require high quality products and services, and although some may prefer to shop in physical stores, customers are growing increasingly accustomed to online shopping. Therefore, companies have begun to sell through direct as well as traditional channels, giving rise to dual channels. For instance, in recent years, many outstanding companies in various industries (e.g., Nike, Dell, and IBM) sell directly to end users by means of an online channel (Chiang et al., 2003; Hua et al., 2010; Tedeschi, 2000; Tsay and Agrawal, 2004). However, motivated by earning more profit, other members of the supply chain, including third parties, are involved in the collection of the used products, Hence, in the reverse supply chain, several different types of channel processes have been identified, including (1) manufacturer collects used items directly from consumers, (2) manufacturer contracts with a retailer who collects used products from customers, (3) manufacturer contracts with a third party for collecting used items, and (4) manufacturer contracts with both a third party and a retailer to collect used items. For this study, a three-level supply chain was assumed in which used items are collected by both the third party and the retailer. In this paper, channel structures of both forward and reverse supply chains were taken into account.

Clearly, the emergence of dual-channel structures in both forward and reverse flow creates competition between channel members. In the forward-flow structure, manufacturers can generate demand for their goods through e-channels. However, the introduction of a dual-channel supply chain puts the retailer and manufacturer into competition (Chiang et al., 2003). This competition results in a channel conflict and forces the retailer to compete with the manufacturer. Therefore, the retailer launches local advertising and exerts sales efforts to survive. In dual-channel supply chains, sales efforts have remarkable impacts on customers' channel choices and thus on demands, profits, and pricing policies (Yan and Pei, 2009). Sales effort made by the manufacturer or the retailer is prominent factor in the competitive market of a dual channel. Through this research, to determine the efficiency of advertising, the effect of manufacturer's and retailer's sales efforts on the respective levels of demand is surveyed. Similarly, in the reverse flow, to collect used products and gain more market share, collectors may employ reverse logistics services, advertising about recycling policies, and incentives (Gao et al., 2016). Also, the investment in collection efforts can enhance the return rate. In this paper, by looking at the return quantity recovered by manufacturers and retailers, the effectiveness of collection efforts is examined. On the whole, decisions that are made about sales and collection efforts in the forward and reverse channels can be defined as effort-input decisions.

In addition to the sales and collection efforts, some other important elements affect customer preferences. Because consumers consider both price and quality of products, quality investments and price decisions play important roles in marketing strategies, and they influence the market competitiveness of the supply chains and the firms in it. In many industries, competition shifts as customers focus on quality over price in specific market segments (Gans, 2002; Ren and Zhou, 2008). As a result, competitors adopt similar price policies but offer products of unequal quality. Although those firms offering higher quality goods charge a higher price for them, they may also incur higher costs (Baiman et al., 2000; Banker et al., 1998). Based on the degree of operational inefficiency, an increase in quality may increase demand and reduce the manufacturer's or retailer's profit. This research examines the conditions under which product quality improvement offers an optimal solution for each type of channel.

This paper considers two CLSC models including a manufacturer, retailer, and third party, for which the market demand depends on the own and cross prices and the quality of products and the sales effort (The own price of a selling channel is the price offered by the corresponding channel; the cross price of a selling channel refers to the price offered by the opposing channel as well as the quality of products and the sales effort. Also, the return quantity is assumed to depend on the collection effort and the own and cross-buyback price (buyback price is the price at which customers sell their used product to the collector of the used items). The manufacturer determines the online channel and wholesale prices, the quality of products, and the sales effort to exert, and the retailer chooses the retail price and the retail channel buyback price as well as the sales and collection efforts to exert. Also, the third party decides its own buyback price and the collection effort. Two decentralized game theory models, each based on the Stackelberg game model, a centralized and a coordinated system are established to answer the following questions about two-channel structures and the coordinated system:

- What are the optimal prices, product quality levels, and effort-input decisions that generate profits in different models?
- Under which conditions do manufacturers benefit from opening direct channels or adding retailers to the reverse channel? In other words, which channel structure in the CLSC is the best in different situations?
- Is the emergence of an online channel always detrimental to the retailer?
- How does the manufacturer react to the trade-off between price and quality in two different scenarios? How do different channel structures influence product quality?
- What is the influence of sales and collection efforts on optimal solutions? What is the influence of channel strategies on sales and collection efforts?
- How can the manufacturer design a contract to eliminate channel frictions between supply chain members and increase its profits?

In general, the work presented herein contributes to the literature of CLSCs in the following ways: First, although numerous factors, including own and cross-selling prices, the quality level of products, sales and collection efforts, and own and cross-buyback prices, affect the market demand and the return quantity, prior studies have looked only into some of them, and there is no published work showing consideration of them at the same time. Therefore, in this paper, the most important factors affecting customer preferences were incorporated into two different channel-structure models to examine the effect of channel structures on these factors and supply chain members' profits comprehensively. Second, previous researchers mostly examined either forward- or reverse-channel structures. Very few works considered both the forward and the reverse channel structures simultaneously. Therefore, unlike most prior studies, this paper looks at both forward- and reverse-channel formats in the CLSC. In a dual-channel CLSC, channel conflict emerges between the chain members; however, few works in the literature addressed this problem through coordination mechanisms. To fill this gap in the literature, a novel coordination mechanism is introduced and its effectiveness is examined through two numerical examples. Finally, most published papers are based on the presumption that the buyback price is a constant parameter; however, the price of returns significantly affects the return quantity. Therefore, like that of Li et al. (2013), this research assumes that the return policy influences return quantity; however, unlike them, this study investigated a CLSC with two selling channels in which some parameters affect demand expansion. More important, unlike prior studies of the reverse supply chain, along with the competitive environment in the forward supply chain, a competitive environment in the reverse flow of CLSC is examined.

The remainder of this paper is organized as follows: In Section 2, the literature review is provided. Key assumptions and notations are outlined in Section 3. In Section 4, the formulation of the general model is explained. In Section 5, comparisons between two different models are presented. In Section 6, illustrative examples are shown that account for the applications of the results outlined in Sections 4 and 5, and concluding remarks are offered in Section 7.

2. Literature review

In recent years, studies on CLCS and remanufacturing issues considerably increased. Govindan et al. (2015) and Govindan and Soleimani (2017) presented a comprehensive review of CLSC and reverse logistics. Many analytical and scientific studies were performed in various aspects of CLSC, operations, including inventory management, production planning, network design, channel management, and so forth. In this paper, the main focus is on the issues of channel management, pricing policies, and coordination mechanisms.

Channel management is one of the most important aspects of marketing decisions, and it is investigated by many researchers, many of whom recognized that establishment of a direct channel leads to new problems. Previous works that feature investigations of dual-channel models have shown extensive study on pricing policies by taking competition into account. For instance, Moriarty and Moran (1990) declared an undeniable competition between direct and traditional channels. Chiang et al. (2003), as well as Tsay and Agrawal (2004), pointed out that channel friction in the dual-channel system is problematic for channel members.

To suggest means of reducing channel conflict between manufacturers and retailers, many researchers have investigated pricing strategies within both direct and traditional channels. Chiang et al. (2003) demonstrated that introducing an e-channel may allow a manufacturer to monitor the pricing behavior of the retailer, which could reduce conflict. Using the Pareto zone, they indicated that addition of an online channel can benefit members of both channels. In a study similar to that of Chiang et al. (2003), Yan and Pei (2009) looked at the issue of retail services in a supply chain with two selling channels and showed that the online channel may not invariably harm the retailer who improves services in response. Fruchter and Tapiero (2005) showed that the optimal decisions of the manufacturer lead to adoption of consistent pricing policies and establishment of the same price in both channels. By considering both single- and dual-channel supply chains, Cai (2010) examined the ways the channel structures and coordination affect the optimal decisions of the supplier and the retailer. By contemplating both centralized and decentralized systems, Dan et al. (2012) determined the optimum strategies for prices and retail services in a supply chain with two selling channels. Also, they examined the effects of retailer market share and services on the pricing behaviors of the supply chain members. In a recent work considering single- and dual-channel distribution structures, Lu and Liu (2015) discussed the way the introduction of e-commerce influences the behavior of manufacturers and retailers. Recently, Li et al. (2016) presented a dual-channel supply chain model for the case of green products, and by considering a consistent pricing policy, they analyzed the pricing and greening policies for the retailer and the manufacturer. Taleizadeh et al. (2014) developed a multiple product single machine system with quality considerations and rework and remanufacturing processes.

Departing from studies of the forward supply chain, many researchers have discussed channel structure selection in the context of the reverse supply chain. Savaskan et al. (2004) proposed three decentralized models characterized by manufacturer, retailer, and third party collections to decide the most appropriate decision for the reverse-channel. Their results indicate that retailer recycling is the most beneficial structure for the manufacturer. Yao and Chen (2007) extended the work of Savaskan et al. (2004) by looking at manufacturer sales of products to end users. They also analyzed different reverse-channel formats from the manufacturer's perspective.

Although the cited studies relate the issue of choosing collection channels, they disregard the impact of competition on the best decisions for implementing CLSCs. Therefore, Savaskan and Van Wassenhove (2006) investigated the interactions between manufacturers and retailers who are deciding the specifics of forward and reverse channels under retailer competition. Hong et al. (2013) proposed a CLSC model with a hybrid dual-collection channel in which the manufacturer has three options. Their results showed that for the manufacturer, collection by both the manufacturer and the retailer is the best reverse-channel format. Recently, Huang et al. (2013) extended both decentralized and centralized models with a dual-collection channel to investigate the optimal channel choice in the reverse flow of a CLSC. They also showed that the best choice for the reverse channel is related to the intensity of competition between members of the collection channel. Hong et al. (2015) elaborated a joint pricing, advertising, and collection model by considering three reverse-collection modes. Yi et al. (2016a) developed a retailer-led CLSC consisting of two recycling channels for construction machinery remanufacturing.

As the buyers of manufactured and remanufactured products and the main resource of used items, customer perspectives are considered vital in CLSC management research. In recent years, many scholars have investigated consumer-related factors, such as price, quality, and advertising, that significantly influence customer preferences, and subsequently, market demand. However, the literature lacks single articles in which all of these influential factors are considered simultaneously. Accordingly, in this paper, we explore consumer-related factors jointly with regard to different channel structures.

Among the critical factors contributing to customer preferences, quality issues have garnered increased attention in recent years. Singer et al. (2003) investigated a distribution channel of disposable products in which the supplier and the retailer decide the optimal investment in quality as a function of customer demand. Xie et al. Xie et al. (2011) presented a selection model of two competing supply chains to investigate the issue of quality improvement. De Giovanni (2011) studied a dynamic optimization model of advertising, pricing, and quality improvement strategies under both cooperative and non-cooperative scenarios. De Giovanni also assumed that demand depends on price and goodwill. By considering uncertainty in the quality of used items, Huang et al. (2015) presented a modal interval based method with multi-dimensional reverse channel in which the retailer is predominant. Recently, Moshtagh and Taleizadeh (2017) discussed an inventory model of a CLSC by considering the stochastic qualities of returns, shortage, and reworked products. Yu and Ma (2013) investigated the effects of different decision sequences on the quality investment, product price, and supply chain profit in a two-level assembly system under demand uncertainty. Recently, by assuming that the demand of products depends on the quality level, Maiti and Giri (2015) proposed a three-echelon CLSC model to determine the best values for the price and quality level of items in five scenarios.

In the CLSC setting, sales and collection efforts play pivotal roles in augmenting market demand and promoting a recycling program. Recently, many studies have been performed on ways sales efforts affect market demand and ways to exert such effort efficiently. However, current papers on the CLSC give little attention to the momentous influence of advertising on demand and return quantity expansion.

By considering sales effort-dependent demand expansion, Taylor (2002) studied supply chain coordination through contracts of targeted rebates and returns. Ma et al. (2013b) determined the optimal decisions of effort levels and channel strategies by considering the impact of quality and marketing efforts under three different power formats. Their results indicated that in the most profitable strategies, the retailer invests in marketing under a retailer Stackelberg, and the manufacturer invests in quality efforts under a manufacturer Stackelberg. Hong et al. (2015) proposed a two-echelon CLCS model to survey optimal pricing policies, advertising levels, and return rates under different collection-channel formats. Chen (2015) analyzed the influence of pricing policies and cooperative advertising mechanisms on the competitive manufacturer-led supply chain with dual selling channels. In a recent work, Gao et al. (2016) studied a two-level CLSC model by investigating different channel power modes in which the market demand is relevant to used-product collection efforts as well as retail and sales prices. Recently, Taleizadeh et al. (2017) optimized price, quality, effort level, and return policy in a three-echelon CLSC according to various games by applying different game models.

In addition to the collection effort, the return quantity of used products in a CLCS is directly influenced by return policies. Previous researchers addressed the effect of different return policies on customers, whose behavior has been analyzed (Ai et al., 2012; Davis et al., 1998; Hess and Mayhew, 1997; Shulman et al., 2009). Mukhopadhyay and Setoputro (2004) proposed a direct sales model to survey the impact of return and pricing policies on customer decisions to purchase and return. Using a direct sales model, Yu and Wang (2008) determined optimal marketing and return strategies. Bonifield et al. (2010) extended a direct sales model and analyzed the relationship between quality and return policies. In a recent work, Li et al. (2013) extended a model of online direct selling with the joint considerations of the pricing, product quality, and return strategies.

In recent years, the issue of coordination has been receiving increasing attention in the literature. Majumder and Srinivasan (2006) applied a two-part tariff contract to coordinate a serial supply chain with different leadership policies. Hong et al. (2015) extended four different models to derive the optimal value of advertising investment, used-product collection, and pricing in both centralized and decentralized systems. They also pointed out that using a two-part tariff contract, members of a decentralized CLSC can attain a coordinated system, while this is impossible under cooperative advertising. By considering the impact of quality and marketing effort, Ma et al. (2013a) developed a novel coordination contract to coordinate manufacturer and the retailer efforts. Gao et al. (2016) explored the influence of different channel power formats on pricing and effort decisions. They also introduced a low-price promotion strategy to coordinate the manufacturer Stackelberg model. To coordinate a CLSC under different channel leadership, Choi et al. (2013) developed the two-tariff and new revenue-sharing contract.

On the basis of the highlighted literature, the conclusion was made that no one has looked at CLSCs while simultaneously considering the effects of own and cross prices, quality level of products, and sales efforts on demand expansion. In addition, very few studies designed or established an effective coordination contract for the elimination of channel conflict in a dual-channel CLCS with a dual-recycling channel, which highlights the research objectives and contributions of this paper.

3. Model assumptions and notations

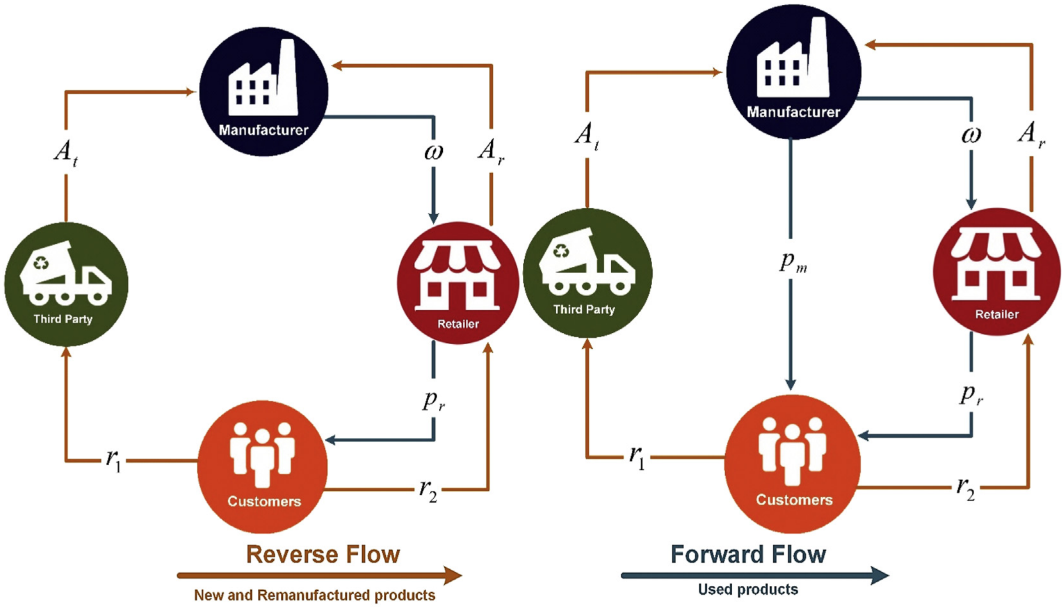
In order to formulate the problems, the following notations are utilized throughout the paper:

ω: Unit wholesale price
p_r: Unit retail price
p_m: Unit manufacturer price
r_1: Average buy-back price of used items collected by a third party
r_2: Average buy-back price of used items collected by a retailer
y_1: Collection effort of the third party
y_2: Collection effort of the retailer
g_1: Sales effort of the retailer
g_2: Sales effort of the manufacturer
q: Product quality of newly produced items
q_r: Product quality of returned products
D_r: The demand faced by the retailer
D_m: The demand faced by the manufacturer
R_r: The quantity of returned used items in the retail channel
R_t: The quantity of returned used items in the third party channel
c_m: Unit cost of producing a new item from raw materials
c_r: Unit cost of producing a new item using returns
c_1: Sales effort cost coefficient
c_2: Collection effort cost coefficient
Δ: Saving unit cost by recycling ($\Delta = c_m - c_r$)
c_q: Quality improvement cost of the manufacturer
A_r: Average recycling price of returned items paid by the manufacturer to the retailer
A_t: Average recycling price of returned items paid by the manufacturer to the third party
Π_i^k: Profit function for supply chain member $i$in model k

Superscript $k \in \{SD, DD, C, Co\}$ refers to the decentralized single-channel supply chain with a dual-collection channel system, decentralized dual-channel supply chain with a dual-collection channel, and centralized DD model, and coordinated DD model, respectively. Subscript $i \in \{M, R, T, C\}$ signifies the manufacturer, retailer, third party, and entire supply chain, respectively. In addition, the following assumptions are made:

Assumption 1. We consider a CLCS comprised of a manufacturer, retailer, and third party with two options for forward- and reverse-channel structures: (1) single-channel forward supply chain with a dual-recycling channel (SD) model (see Fig. 1a) or (2) dual-channel forward supply chain with a dual-recycling channel (DD) model (see Fig. 1b).

In the reverse flow of both models, the manufacturer compiles returns collected by the retailer and the third party. In the SD forward supply chain, the manufacturer sells the goods to a single



(a) SD model (b) DD model

Fig. 1. Channel structures of the forward and reverse supply chain in two models.

retailer, and the retailer sells them to end users. (See Fig. 1a) In the DD forward supply chain, the manufacturer sells the goods to a single retailer, and the retailer sells them to end users; also, the manufacturer can sell products to customers directly (See Fig. 1b).

Assumption 2. The demands faced by the manufacturer (only in the DD model) and the retailer are linear functions of the own, cross, and buyback prices as well as quality of the product and sales effort in which $\alpha, \beta, \gamma, k, \delta > 0$. It is noteworthy that the demand for a direct channel is defined only for the DD model, and in the SD model it is equal to zero. The literature shows a direct channel as representative of quality considerations (Maiti and Giri, 2015), and sales effort (Gao et al., 2016). Therefore, the demand expansions in the traditional and direct channels are as follows:

$$D_r = (1-\rho)d - \alpha p_r + \beta p_m + \gamma q + k g_1 \quad (1)$$

$$D_m = \rho d - \alpha p_m + \beta p_r + \gamma q + k g_2 \quad (2)$$

Where D_r and D_m represent the demands faced by the manufacturer and the retailer, respectively. d represents the basic market demand of the products. It is considerably greater than the other parameters of the model. ρ denotes the market share of the direct channel, and $1-\rho$ is the market share of the retail channel; $0 \le \rho \le 1$. α is the self-price elastic coefficient, which specifies the influence of the own price on the demand of the channels. β represents the sensitivity of demand to the cross-price, meaning the demand is shifted between two channels on the basis of price. γ is a quality sensitivity parameter denoting demand sensitivity to the quality of products. k is the degree of demand sensitivity to sales effort; it measures the impact of sales effort on demand. It is also assumed that $\alpha \ge \beta$ meaning that the demand depends more on the own selling price than on the cross-price sensitivity parameter. This assumption is reasonably applicable to real-world situations.

Assumption 3. The returned quantities of used products from the third party and retailer are linear functions of the own and cross buyback price (Li et al., 2013) and collection effort (Gao et al., 2016), as identified in the literature. Thus, the returned quantity functions in the third party and retail channels in which $\varphi, \theta, l > 0$, can be written, respectively, as follows:

$$R_r = \psi\phi + \varphi r_2 - \theta r_1 + l y_2 \quad (3)$$

$$R_t = (1-\psi)\phi + \varphi r_1 - \theta r_2 + l y_1 \quad (4)$$

where R_t and R_r are the quantities of used products returned from the third party and the retailer, respectively. ϕ represents a base return quantity that is smaller than the basic demand of the items and is larger than the other parameters of the model. ψ is the proportion of customer sales of used items to the third party channel, and $1-\psi$ is the proportion of customer sales of used products to the retail channel; $0 \le \psi \le 1$. φ describes the self-buyback price elastic coefficient. θ denotes the sensitivity of the returned quantity to the cross-buyback price. l is the degree of sensitivity of the returned quantity to collection effort; it measures the impact of collection efforts on return quantity. It is also assumed that $\varphi \ge \theta$, which means that the quantity of returns depends more on the own buyback price than on the cross buyback price. This assumption is in reasonable harmony with real-world situations. In both the SD and DD models, the quantities of used products returned from both third party and retailer must be non-negative such that the following assumption can be considered:

$$\max\{\psi_{\min}, 0\} \le \psi \le \min\{\psi_{\max}, 1\} \quad (5)$$

where $\psi_{\min}$ and $\psi_{\max}$ can be obtained as

$$\psi_{\min} = \frac{\theta r_1 - \varphi r_2 - l y_2}{\phi} \quad (6)$$

$$\psi_{\max} = \frac{\phi - (\theta r_2 - \varphi r_1 - l y_1)}{\phi} \quad (7)$$

Assumption 4. The unit cost of producing a new item is greater than reproducing returns; that is, $c_m > c_r$.

Assumption 5. Reproduced items are as good as new ones, and there is no difference between them. Therefore, remanufactured items have the same price as new ones. A similar assumption is made in Maiti and Giri (2015), Gao et al. (2016), Hong et al. (2015), Choi et al. (2013), Savaskan et al. (2004) and others. For example, the Kodak single-use cameras are sold on the basis of this assumption, and both manufactured and remanufactured items are sold to the retailer at the same price (Atasu et al., 2013). Another example for this case is Xerox copiers, which are remanufactured from returned copiers and sold as new copiers.

Assumption 6. The quality of a produced item is q while the quality of a returned item is $q_r < q$. That is, returned products are suitable for remanufacturing if they satisfy the minimum allowed quality level q_r. However, the quality of a remanufactured item is the same as the quality of a newly produced item and is equal to q.

Assumption 7. All players of the CLSC are interested in cooperating in an integrated system. For feasibility of the model, it is assumed that $p_r > \omega > 0, \quad \Delta > A_t > r_1, \quad \Delta > A_r > r_2$.

Assumption 8. In reality, the buyback price, or any other parameter, may be variable and dependent on the quality of returns. However, to simplify the model and generate more managerial insights, this paper follows the extensive literature of related remanufacturing topics and builds our model under the deterministic setting (Gao et al., 2016; Huang et al., 2013; Maiti and Giri, 2015).

Assumption 9. The information is symmetric.

4. Model formulation and solution

As explained in Assumption 1, in this paper, two channel formats are studied. The CLSC has a forward and reverse supply channel. In the SD model, a forward supply chain, goods are sold to the retailer by the manufacturer only at wholesale price, ω, but in the DD model, goods are sold to the retailer and to end users directly by the manufacturer. Also, in the reverse flow, used items are either obtained from customers by a third party or by a retailer. Then, they are taken to a warehouse facility where they are inspected and sorted so that high-quality components are reused and low-quality components are repaired, replaced, or upgraded. Eventually, all the components are reproduced and stocked as serviceable good-as-new products to satisfy a portion of customer demand.

A CLSC including a manufacturer, retailer, and third party is considered. In the forward flow of the CLSC, products are sold to the retailer through the traditional retail channel at wholesale price, ω. and to users through direct channel at the manufacturer price per unit, p_m. The retailer and manufacturer invest in sales effort activities, which can increase the market demand. The retailer's and manufacturer's investments in sales efforts, g_1 and g_2, are presumed to be ascending and convex functions of g_1 and g_2 ; they are expressed as quadratic cost functions and defined as $0.5c_1g_1^2$ and $0.5c_1g_2^2$, respectively. Such a quadratic cost function has been employed in the previous works as well (Ghosh and Shah, 2012; Liu et al., 2012; Ma et al., 2013b). The third party collects the used products at an average price, r_1, and delivers them to the manufacturer at an average price, A_t. In the reverse flow of CLSC, the retailer collects the used products at an average price, r_2, and delivers them to the manufacturer at an average price, A_r.

The third party and retailer invest in collecting effort activities, which can increase the return quantity. The third party's and retailer's investments in collection effort y_1 and y_2 are assumed to be ascending and convex functions of y_1 and y_2, which are expressed as quadratic cost functions and defined as $0.5c_2y_1^2$ and $0.5c_2y_2^2$, respectively. Then the manufacturer remanufactures returned products at an average cost c_r, which is less than the unit cost of producing a new item from raw materials. Therefore, the unit cost savings of remanufacturing is $c_m - c_r$. Because the produced items are not of perfect quality and contain some impurities, it is assumed that the quality of the produced items is $q(0 < q < 1)$. Because the quality of products decreases during consumption, we also assume that the average quality of the returned products is q_r, which is smaller than the quality of items produced and upgraded to q during remanufacturing. Because product improvements are sequentially difficult and costly, we assume the investment for quality as a quadratic cost function expressed as $\frac{1}{2}c_q q_r^2$.

In this section, based on Stackelberg, two game theory models are established. The Stackelberg game is a type of strategic game in which at least one player is noted as the leader who makes decisions before other players who are defined as followers. Then, these game models are applied to decentralized CLSCs to obtain the optimal solutions in SD and DD models. In a decentralized supply chain, the individual entities make their own decisions, which differs from a centralized supply chain in which a single decision maker makes an integrated decision.

4.1. Case 1: single channel forward supply chain with a dual-recycling channel

As shown in Fig. 1a, through the SD model, consumers can buy a product only through the retail channel. Also, either a retailer or third party buys back remanufacturable used products from the customer. Therefore, the demand faced by a retailer is as follows:

$$D_r = d - \alpha p_r + \gamma q + k g_1 \tag{8}$$

Also, the returned quantity of used products in the retail and third party channel can be written as the following:

$$R_r = \psi\phi + \varphi r_2 - \theta r_1 + l y_2 \tag{9}$$

$$R_t = (1-\psi)\phi + \varphi r_1 - \theta r_2 + l y_1 \tag{10}$$

Also, it is assumed that $R = R_r + R_t$.

The profit function of the manufacturer, retailer and third party in the SD model are expressed as the following:

$$\Pi_M^{SD} = D_r\omega - (D_r - R)c_m - Rc_r - R_rA_r - R_tA_t - (D_r - R)c_q q^2 - Rc_q\left(q^2 - q_r^2\right) \tag{11}$$

$$\Pi_R^{SD} = D_r(p_r - \omega) + R_r(A_r - r_2) - \frac{1}{2}c_1 g_1^2 - \frac{1}{2}c_2 y_2^2 \tag{12}$$

$$\Pi_T^{SD} = R_t(A_t - r_1) - \frac{1}{2}c_2 y_1^2 \tag{13}$$

To ensure that the return quantity is smaller than the total market demand, $R \le D_r$ is assumed. By solving the above inequality with respect to ϕ, the maximum amount of ϕ can be obtained as

$$\phi_{\max} = d - \alpha p_r^{SD*} + \gamma q^{SD*} + k g_1^{SD*} - l\left(y_1^{SD*} + y_2^{SD*}\right) - (\varphi - \theta)\left(r_1^{SD*} + r_2^{SD*}\right) \tag{14}$$

4.1.1. Retailer's reaction

We first derive the optimal reaction of the retailer.

Proposition 1. *When Condition (15) is satisfied, Π_R^{SD} is concave in* $p_r, g_1, y_2,$ and r_2 *, and there is a unique optimal reaction of the retailer.*

$$c_1 > \frac{2g_1kp_r - 2\alpha p_r^2 - 2\varphi r_2^2 - c_2y_2^2 - 2lr_2y_2}{g_1^2} \tag{15}$$

$$r_1^{SD*} = \frac{A_tl^4 + c_2^2\left[2A_t\varphi^2 - 2(1-\psi)\phi\varphi - \theta(\psi\phi - A_r\varphi)\right] + c_2\left[(1-\psi)\phi l^2 - 3A_t\varphi l^2 - A_r\theta l^2\right]}{\left(2c_2\varphi - c_2\theta - l^2\right)\left(2c_2\varphi + c_2\theta - l^2\right)} \tag{23}$$

$$r_2^{SD*} = \frac{A_tl^4 + c_2^2\left[2A_r\varphi^2 - 2(1-\psi)\phi\theta + A_t\varphi\theta - 2\psi\phi\varphi\right] + c_2\left[\psi\phi l^2 - 3A_r\varphi l^2 - A_t\theta l^2\right]}{\left(2c_2\varphi - c_2\theta - l^2\right)\left(2c_2\varphi + c_2\theta - l^2\right)} \tag{24}$$

Proof. See Appendix A.

By solving the first-order conditions $\frac{\partial \Pi_R^{SD}}{\partial r_2^{SD}} = 0, \frac{\partial \Pi_R^{SD}}{\partial p_r^{SD}} = 0,\ \frac{\partial \Pi_R^{SD}}{\partial y_2^{SD}} = 0,$ and $\frac{\partial \Pi_R^{SD}}{\partial g_1^{SD}} = 0$, the best reaction of the retailer can be expressed in the following functions:

$$p_r^{SD*} = \frac{c_1[d + \gamma q + \alpha\omega] - \omega k^2}{2\alpha c_1 - k^2} \tag{16}$$

$$g_1^{SD*} = \frac{k[d + \gamma q - \alpha\omega]}{2\alpha c_1 - k^2} \tag{17}$$

$$y_2^{SD*} = \frac{l[A_r\varphi + \psi\phi - \theta r_1]}{2c_2\varphi - l^2} \tag{18}$$

$$r_2^{SD*} = \frac{c_2\theta r_1 + c_2A_r\varphi - c_2\psi\phi - A_rl^2}{2c_2\varphi - l^2} \tag{19}$$

4.1.2. Third party's reaction

After solving the retailer's problem, the optimal third party's reaction can be derived.

Proposition 2. *When Condition (20) is satisfied, Π_T^{SD} is concave in* r_1 and y_1, *and there is a unique optimal reaction for the third party.*

$$c_1 > \frac{l^2}{2\varphi} \tag{20}$$

Proof. See Appendix B.

Therefore, the optimal marginal profit of the third party can be obtained through the first-order conditions of Equation (13). The result is as follows:

$$r_1^{SD*} = \frac{-A_tl^2 - c_2\phi + c_2A_t\varphi + c_2\psi\phi + c_2\theta r_2}{2c_2\varphi - l^2} \tag{21}$$

$$y_1^{SD*} = \frac{l[A_t\varphi + (1-\psi)\phi - \theta r_2]}{2c_2\varphi - l^2} \tag{22}$$

By solving Equations (19) and (21) simultaneously, the optimal values of r_1^{SD} and r_2^{SD} can be obtained as follows:

4.1.3. Manufacturer's optimal decisions

After getting the optimal decisions of the retailer and the third party, the manufacturer maximizes the profit function and determines optimal decisions.

Proposition 3. *When Condition (25) is satisfied, Π_M^{SD} is concave in* $q, \omega, A_r,$ and A_t, *and there is a unique optimal decision for the manufacturer.*

$$c_q > \max\left\{\frac{\gamma\omega}{q(d + g_1k - \alpha p_r + 3\gamma q)},\ \frac{\gamma}{2\alpha}\right\} \tag{25}$$

By solving $\frac{\partial \Pi_M^{SD}}{\partial q^{SD}}$ and $\frac{\partial \Pi_M^{SD}}{\partial \omega^{SD}}$ simultaneously, the manufacturer's best solutions can be obtained as follows:

$$q^{SD*} = \frac{\gamma}{2\alpha c_q} \tag{26}$$

$$\omega^{SD*} = \frac{4\alpha c_q(d + \alpha c_m) + 3\gamma^2}{8\alpha^2 c_q} \tag{27}$$

$$A_t^{SD*} = \frac{\left(c_m - c_r + c_qq_r^2\right)\left(\varphi^2 - \theta^2\right) - (1-\psi)\phi\varphi - \psi\phi\theta}{2\left(\varphi^2 - \theta^2\right)} \tag{28}$$

$$A_r^{SD*} = \frac{\left(c_m - c_r + c_qq_r^2\right)\left(\varphi^2 - \theta^2\right) - (1-\psi)\phi\theta - \psi\phi\varphi}{2\left(\varphi^2 - \theta^2\right)} \tag{29}$$

Proof. See Appendix C.

Also, the profits of the manufacturer, retailer, and third party can be obtained by replacing the optimal solutions in Equations (11)–(13), respectively.

4.2. Case 2: dual-channel forward supply chain with a dual-recycling channel

As shown in Fig. 1b, customers in the DD model can buy product either through the traditional or direct channel. Also, a third party or a retailer buys back remanufacturable used products from customers. In this case, the demand faced by the retailer and the manufacturer are given by:

$$D_r = (1-\rho)d - \alpha p_r + \beta p_m + \gamma q + kg_1 \quad (30)$$

$$D_m = \rho d - \alpha p_m + \beta p_r + \gamma q + kg_2 \quad (31)$$

In addition, it is assumed that $D = D_r + D_m$.

The returned quantity of used products in the retail and third party channel can be written as follows:

$$R_r = \psi\phi + \varphi r_2 - \theta r_1 + ly_2 \quad (32)$$

$$R_t = (1-\psi)\phi + \varphi r_1 - \theta r_2 + ly_1 \quad (33)$$

Also, it is assumed that $R = R_r + R_t$.

The profit functions of the manufacturer, retailer, third party in this case are as follows:

$$\Pi_M^{DD} = D_r\omega + D_m p_m - (D-R)c_m - Rc_r - R_rA_r - R_tA_t - (D-R)c_q q^2 - Rc_q\left(q^2 - q_r^2\right) - \frac{1}{2}c_1 g_2^2 \quad (34)$$

$$\Pi_R^{DD} = D_r(p_r - \omega) + R_r(A_r - r_2) - \frac{1}{2}c_1 g_1^2 - \frac{1}{2}c_2 y_2^2 \quad (35)$$

$$\Pi_T^{DD} = R_t(A_t - r_1) - \frac{1}{2}c_2 y_1^2 \quad (36)$$

In this case, the demand in both channels must be non-negative so that the following assumption can be made:

$$\max\{\rho_{\min}, 0\} \le \rho \le \min\{\rho_{\max}, 1\} \quad (37)$$

Where $\rho_{\min}$ and $\rho_{\max}$ can be obtained as

$$\rho_{\min} = \frac{\alpha p_r^{DD*} - \beta p_m^{DD*} - \gamma q^{DD*} - kg_1^{DD*}}{d} \quad (38)$$

$$\rho_{\max} = \frac{d - \left(\alpha p_r^{DD*} - \beta p_m^{DD*} - \gamma q^{DD*} - kg_1^{DD*}\right)}{d} \quad (39)$$

In addition, to ensure that the return quantity is smaller than the total market demand, $R \le D$ is assumed. By solving the above inequality with respect to ϕ, the maximum amount of ϕ can be obtained as

$$\phi_{\max} = d - (\alpha-\beta)\left(p_r^{DD*} + p_m^{DD*}\right)\alpha + 2\gamma q^{DD*} + k\left(g_1^{DD*} + g_2^{DD*}\right) - l\left(y_1^{DD*} + y_2^{DD*}\right) - (\varphi - \theta)\left(r_1^{DD*} + r_2^{DD*}\right) \quad (40)$$

4.2.1. Retailer's reaction

The retailer observes the wholesale price and quality of products before deciding the retail price and the sales effort.

Proposition 4. *When Condition (41) is satisfied,* Π_R^{DD} *is concave in* r_2, p_r, g_1, *and* y_2, *and there is a unique optimal reaction of the retailer.*

$$c_1 > \frac{2g_1kp_r - 2\alpha p_r^2 - 2\varphi r_2^2 - c_2y_2^2 - 2lr_2y_2}{g_1^2} \quad (41)$$

By solving the first-order conditions $\frac{\partial\Pi_R^{DD}}{\partial r_2^{DD}} = 0$, $\frac{\partial\Pi_R^{DD}}{\partial p_r^{DD}} = 0$, $\frac{\partial\Pi_R^{DD}}{\partial y_2^{DD}} = 0$, and $\frac{\partial\Pi_R^{DD}}{\partial g_1^{DD}} = 0$, the best reaction of the retailer can be expressed as the following functions:

$$p_r^{DD*} = \frac{c_1[d + \gamma q + \beta p_m + \alpha\omega - \rho d] - \omega k^2}{2\alpha c_1 - k^2} \quad (42)$$

$$g_1^{DD*} = \frac{k[d + \gamma q + \beta p_m - \alpha\omega - \rho d]}{2\alpha c_1 - k^2} \quad (43)$$

$$y_2^{DD*} = \frac{l(A_r\varphi + \psi\phi - \theta r_1)}{2c_2\varphi - l^2} \quad (44)$$

$$r_2^{DD*} = \frac{c_2(\theta r_1 + A_r\varphi - \psi\phi) - A_r l^2}{2c_2\varphi - l^2} \quad (45)$$

Proof. See Appendix A.

4.2.2. Third party's reaction

After obtaining the best retailer's reaction, the optimal third party's reaction can be derived.

Proposition 5. *When Condition (46) is satisfied, the profit function* Π_T^{DD} *is concave in r* and y_1, *and there is a unique optimal reaction for the third party.*

$$c_1 > \frac{l^2}{2\varphi} \quad (46)$$

Therefore, the optimal response functions of the third party can be concluded by the first-order conditions of Equation (36) as follows:

$$r_1^{DD*} = \frac{c_2[\theta r_2 + A_t\varphi - (1-\psi)\phi] - A_t l^2}{2c_2\varphi - l^2} \quad (47)$$

$$y_1^{DD*} = \frac{l[A_t\varphi + (1-\psi)\phi - \theta r_2]}{2c_2\varphi - l^2} \quad (48)$$

Proof. See Appendix B.

By solving Equations (45) and (47), simultaneously, the optimal values can be obtained as follow:

$$r_1^{DD*} = \frac{A_t l^4 + c_2^2\left[2A_t\varphi^2 - 2(1-\psi)\phi\varphi - \theta(\psi\phi - A_r\varphi)\right] + c_2\left[(1-\psi)\phi l^2 - 3A_t\varphi l^2 - A_r\theta l^2\right]}{\left(2c_2\varphi - c_2\theta - l^2\right)\left(2c_2\varphi + c_2\theta - l^2\right)} \quad (49)$$

$$r_2^{DD*} = \frac{A_t l^4 + c_2^2\left[2A_r\varphi^2 - 2(1-\psi)\phi\theta + A_t\varphi\theta - 2\psi\phi\varphi\right] + c_2\left[\psi\phi l^2 - 3A_r\varphi l^2 - A_t\theta l^2\right]}{\left(2c_2\varphi - c_2\theta - l^2\right)\left(2c_2\varphi + c_2\theta - l^2\right)} \quad (50)$$

4.2.3. Manufacturer's optimal decisions

Using the retailer's and third party's decisions and substituting them into Equation (34), the manufacturer determines optimal decisions:

Proposition 6. *When Condition (51) is satisfied, Π_M^{DD} is concave in $p_m, g_1, q, \omega, A_r,$ and A_t , and there is a unique optimal decision of the manufacturer.*

$$c_q > \max\left\{\frac{\left[2p_m(kg_2-\alpha p_m+\gamma q+\beta\omega)-c_1g_2^2+2\gamma q\omega\right]}{2q^2[d-(\alpha-\beta)(p_r+3p_m)+k(g_1+3g_2)+6\gamma q]}, \frac{\gamma}{2(\alpha-\beta)}\right\} \tag{51}$$

When Condition (51) is satisfied, the optimal decisions of the manufacturer are given by

$$p_m^{DD*} = \frac{4c_q(\alpha-\beta)^2\left[c_mk^4\left(2\alpha^2-\beta^2\right)+4\alpha c_1k^2\left[c_m\begin{pmatrix}6\alpha^2-3\beta^2\\+\alpha\beta\end{pmatrix}-d\begin{pmatrix}(1-\rho)\beta\\+2\alpha\rho\end{pmatrix}\right]+16\alpha^2c_1d\right]+16\alpha^2c_1^2c_q(\alpha-\beta)^3[c_m(\alpha+\beta)+d\rho]+12\alpha^2c_1^2\gamma^2\left(\alpha^2-\beta^2\right)+\gamma^2k^4\left(2\alpha^2-\beta^2\right)-c_1\gamma^2k^2\left(10\alpha^3-5\alpha\beta^2-\alpha^2\beta\right)}{4c_q(\alpha-\beta)^2\left[8\alpha^2c_1^2\left(\alpha^2-\beta^2\right)-k^2\left(2\alpha^2-\beta^2\right)(4\alpha c_1-k^2)\right]} \tag{52}$$

$$g_2^{DD*} = \frac{4\alpha kc_q(\alpha-\beta)^2[4\alpha c_1[d\rho-c_m(\alpha+\beta)]+c_mk^2(2\alpha+\beta)]+4\alpha^2kc_1\gamma^2(\alpha+\beta)+4\alpha kc_qd(\alpha-\beta)\left[4\alpha\beta c_1-k^2\begin{pmatrix}(1-\rho)\beta\\+2\alpha\rho\end{pmatrix}\right]-\alpha\gamma^2k^3(2\alpha+\beta)}{4c_q(\alpha-\beta)\left[8\alpha^2c_1^2\left(\alpha^2-\beta^2\right)-k^2\left(2\alpha^2-\beta^2\right)(4\alpha c_1-k^2)\right]} \tag{53}$$

$$q^{DD*} = \frac{\gamma}{2c_q(\alpha-\beta)} \tag{54}$$

$$\omega^{DD*} = \frac{\begin{array}{l}4c_q(\alpha-\beta)^2\left[\alpha k^4(\alpha c_m+d)+4\alpha^3c_1^2d-c_1k^2\left[d\left(4\alpha^2+\beta^2\right)-d\rho(2\alpha-\beta)^2+c_m\left(4\alpha^3-\alpha\beta^2+\beta^3\right)\right]\right]-\gamma^2k^2\left[c_1\left(12\alpha^3-\beta^3-7\alpha\beta^2\right)-k^2\left(3\alpha^2-2\beta^2\right)\right]\\+(\alpha-\beta)^3\left[4c_qd\rho\left(4\alpha^2c_1^2+k^4\right)+16\alpha^2c_1^2c_mc_q(\alpha+\beta)\right]+12\alpha^2\gamma^2\left(\alpha^2-\beta^2\right)\end{array}}{4c_q(\alpha-\beta)^2\left[8\alpha^2c_1^2\left(\alpha^2-\beta^2\right)-k^2\left(2\alpha^2-\beta^2\right)(4\alpha c_1-k^2)\right]} \tag{55}$$

$$A_t^{DD*} = \frac{(c_m-c_r+c_qq_r^2)\left(\varphi^2-\theta^2\right)-(1-\psi)\phi\varphi-\psi\phi\theta}{2\left(\varphi^2-\theta^2\right)} \tag{56}$$

$$A_r^{DD*} = \frac{(c_m-c_r+c_qq_r^2)\left(\varphi^2-\theta^2\right)-(1-\psi)\phi\theta-\psi\phi\varphi}{2\left(\varphi^2-\theta^2\right)} \tag{57}$$

Proof. See Appendix D.

The profits of manufacturer, retailer, and third party can be obtained by substituting the optimal solutions in Functions (34), (35) and (36), respectively.

5. Strategies for choosing the channel structure of a CLSC

To encourage a better understanding of CLSC channel structures, several managerial implications about the results derived in Section 4 are discussed. First, we compare the optimal values and the profit of each of the supply chain members as described by the SD and DD model. Second, we discuss the best choice of channel structure from the point of view of the manufacturer, retailer, third party, and customer.

When the concavity conditions are satisfied, the equilibrium results in the SD and DD models can be compared to obtain solutions. However, ϕ must satisfy Conditions (14) and (40), ρ must satisfy Conditions (37), (38), and (39), and ψ must satisfy Conditions (5), (6), and (7); therefore, some expressions in Propositions 7–16 may be infeasible.

Proposition 7. *The optimal qualities of the products in the SD and DD models satisfy the following relationship*:

$$q^{SD} < q^{DD} \tag{58}$$

Proof. See Appendix E.

Proposition 7 infers that the quality of products under the DD model is greater than it is under the SD model. This finding is the result of emergent competition between the retailer and manufacturer in the DD model; however, in the SD model, the manufacturer and retailer do not compete. Because the product quality plays a significant role in customer preference, increasing quality may increase the demand faced by the retailer and manufacturer. Therefore, customers always prefer the DD model in terms of quality. Also, because quality improvements raise total costs, the price of the product may increase through quality improvements. The result is a trade-off between quality and price.

Proposition 8. *The optimal wholesale prices in the SD and DD models satisfy the following relationships*:

$$\begin{cases}\omega^{SD} < \omega^{DD} & \rho < \rho_1\\ \omega^{DD} \le \omega^{SD} & \rho \ge \rho_1\end{cases} \tag{59}$$

Proof. See Appendix F. Also, ρ_1 is given in Appendix F.

Proposition 8 suggests that wholesale prices must be compared in both the SD and DD models. Because the quality of products in the DD model is greater than it is in the SD model, it is expected that the product price is higher in the DD system than in the SD system. However, through the DD model, the manufacturer can diminish channel friction by reducing the wholesale price. In this case, when ρ is relatively small, implying that in the online channel the basic market demand is comparatively small, the manufacturer offers the products at higher wholesale prices. As a result, if $\rho < \rho_1$, then $\omega^{SD} < \omega^{DD}$. By increasing the market share of the manufacturer such that it falls in the range of $\rho_1 \leq \rho$, the manufacturer decreases the whole sale price to minimize conflicts and the relationship $\omega^{DD} \leq \omega^{SD}$ is satisfied. Therefore, according to Proposition 8, retailers can drive the channel structure such that the lower price is offered under either channel format.

Proposition 9. *The relationships of the optimal retail prices in the SD and DD models are presented as follows*:

$$\begin{cases} p_r^{SD} < p_r^{DD} & \rho < \rho_2 \\ p_r^{DD} \leq p_r^{SD} & \rho \geq \rho_2 \end{cases} \tag{60}$$

Proof. See Appendix G. Also, the value of ρ_2 is given in Appendix G.

The relationship between retail prices in the SD and DD models is similar to that between wholesale prices.

According to Proposition 9, customers can drive the channel structure that offers the lower price under each channel format. The purchase price is one of the key parameters in customer purchasing, but it is not the only effective parameter. Quality and buyback price, among parameters, influence customer preferences. According to Propositions 7, 9, and 10, customers can consider either the SD or DD model the best channel structure.

Proposition 10. *The relationship between the optimal buyback prices and collection efforts in the SD and DD models satisfy the following equations*:

$$r_1^{SD} = r_1^{DD} \text{ and } r_2^{SD} = r_2^{DD} \tag{61}$$

$$y_1^{DD} = y_1^{SD} \text{ and } y_2^{DD} = y_2^{SD} \tag{62}$$

Proof. See Appendix H.

Proposition 10 suggests that the buyback price and collection effort of both the third party and the retailer is the same in the DD and SD models. This finding is based on the identical structures of reverse supply chains in both the DD and SD setting. As noted, return policy is another parameter that can influence channel selection from the customer's perspective. Proposition 10 implies that customers perceive no difference between the DD and SD models in terms of buyback price.

Proposition 11. *The optimal sales effort satisfies the following relationship*:

$$\begin{cases} g_1^{SD} < g_1^{DD} & \rho < \rho_3 \\ g_1^{DD} \leq g_1^{SD} & \rho \geq \rho_3 \end{cases} \tag{63}$$

Proof. See Appendix I. Also, the value of ρ_3 is given in Appendix I.

Proposition 11 indicates that, when the market share of the retail channel is greater than the limit, $1 - \rho > 1 - \rho_3$, the retailer's sales effort in the DD model is greater than it is in the SD model. However, when the market share of the retail channel is smaller than the threshold $(1 - \rho < 1 - \rho_3)$, the retailer's sales effort in the DD model is smaller than it is in the SD model.

Proposition 12. *The relationship between the optimal manufacturer's profit in the SD and DD systems is given as follows*:

$$\Pi_M^{SD} < \Pi_M^{DD} \tag{64}$$

Proof. See Appendix J.

Proposition 12 indicates that the manufacturer's profit in the DD model is always better than it is in the SD model; that is, $\Pi_M^{DD} > \Pi_M^{SD}$. In the DD model, the manufacturer sells items through the direct channel in addition to the traditional channel; therefore, the manufacturer's profit in the DD system is significantly greater than it is in the SD system. In the DD model, the manufacturer benefits from introducing a direct channel to augment profits from the retail channel in the forward supply chain.

Proposition 13. *The optimal retailer's profits in the SD and DD models satisfy the following relationships*:

$$\begin{cases} \Pi_R^{SD} < \Pi_R^{DD} & \rho < \rho_3 \\ \Pi_R^{DD} \leq \Pi_R^{SD} & \rho \geq \rho_3 \end{cases} \tag{65}$$

Proof. See Appendix K. The value of ρ_3 is given in Appendix I.

In the DD model, the market share of the retailer decreases, but in addition to market share, some other factors, such as quality and buyback price (among others), also influence the demand faced by the retailer. Therefore, market share can partially affect the retailer's profit. When ρ is relatively small, which implies that in the online channel, the basic market demand is comparatively small, the manufacturer earns less profit and the retailer can earn more profit. Therefore, if $\rho < \rho_3$, then $\Pi_R^{SD} < \Pi_R^{DD}$. In contrast, by increasing ρ such that it falls in the range of $\rho > \rho_3$, the retailer loses some profits and $\Pi_R^{DD} < \Pi_R^{SD}$.

Proposition 14. *The third party's optimal profits in the SD and DD models satisfy the following equation*:

$$\Pi_T^{SD} = \Pi_T^{DD} \tag{66}$$

Proof. See Appendix L.

Proposition 14 indicates that the third party's profit earned under the SD model is equal to the profit earned under the DD model; that is, $\Pi_T^{SD} = \Pi_T^{DD}$, because the reverse supply chain in both DD and SD models has the same structure.

Propositions 7–14 suggest that we can derive the beneficial choices of channel structures from the perspective of the manufacturer, retailer, and third party according to Propositions 12, 13, and 14, respectively. Furthermore, because the selling and buyback prices as well as quality of products influence their preferences, customers prefer a channel format in which products with relatively high quality and buy-back price are sold at relatively low prices. According to the above propositions, the *DD* model offers the best quality, but both models show similar buyback prices. Also, when $\rho \geq \rho_2$, the selling price in retail channel in the *DD* model is lower than it is in the *SD* model. Therefore, when $\rho \geq \rho_2$, customers benefit the most through the *DD* model.

Proposition 15. *The relationship between optimal buyback prices in retail and third-party channels under both SD and DD models satisfy the following equations*:

$$\begin{cases} r_1 < r_2 & \psi < 1/2 \\ r_2 \leq r_1 & \psi \geq 1/2 \end{cases} \tag{67}$$

Proof. See Appendix M. Also, the value of ψ_1 is given in Appendix M.

When ψ is relatively small, implying that the proportion of customers who sale their used items to the retail party channel is relatively small, the retailer collects the used products at a higher price than the third party does. That is, if $\psi < 1/2$, then $r_1 < r_2$. In contrast, by increasing ψ such that it falls in the range of $\psi \geq 1/2$, the retailer collects the used products at a lower price than the third party does and the following condition is obtained: $r_2 \leq r_1$. The result indicates that as the proportion of customers who sell their used items to the retailer or third party channel increases, the buyback prices of these items decrease.

Proposition 16. *The optimal third party's and retailer's collection efforts in both the SD and DD models satisfy the following equation*:

$$\begin{cases} y_2 < y_1 & \psi < 1/2 \\ y_1 \leq y_2 & \psi \geq 1/2 \end{cases} \tag{68}$$

Proof. See Appendix N. Also, the value of ψ_2 is provided in Appendix N.

Proposition 16 indicates that, when the proportion of customers who sell their used products to the retail party channel (ψ) is smaller than the limit, $\psi < 1/2$, the retailer's collection effort is smaller than the third party's collection effort. However, when ψ is greater than the threshold ($\psi < 1/2$), the retailer's collection effort is greater than the third party's collection effort. The result indicates that as the proportion of customers who sell their used items to the retailer or third party channel increases, the collection efforts by both retailer and third party also increase.

6. Coordinating a dual-channel CLSC with a dual-recycling channel by an integrated two-tariff and cooperative advertising contract

In this section, to improve the performance of the dual-channel CLSC with a dual-collection channel and to decrease channel conflict between the members of the CLCS, a novel contract is designed such that the optimal decisions of the CLSC members in the decentralized DD model are equal to those made in the centralized DD model. Therefore, first, the optimal values of the decision variables are obtained under the centralized DD model.

By integrating Equations (34)–(36), the total profit of the centralized DD model can be written as follows:

$$\begin{aligned} \Pi_C = {} & D_r p_r + D_m p_m - (D - R)c_m - Rc_r - R_t r_1 - R_r r_2 \\ & - (D - R)c_q q^2 - Rc_q\left(q^2 - q_r^2\right) - \frac{1}{2}c_1 g_1^2 - \frac{1}{2}c_1 g_2^2 - \frac{1}{2}c_2 y_1^2 \\ & - \frac{1}{2}c_2 y_2^2 \end{aligned} \tag{69}$$

Proposition 17. *When Condition (70) is satisfied, Π_C is concave in* $p_r, p_m, q, g_1, g_2, r_1, r_2, y_1,$ and y_2, *and there is a unique optimal reaction for a unique decision maker.*

$$c_q > \max\left\{ \frac{2p_r(kg_1 - \alpha p_r + \gamma q) + 2p_m(kg_2 - \alpha p_m + \gamma q) + 4\beta p_r p_m + c_1\left(g_1^2 + g_2^2\right) - 2\varphi\left(r_1^2 + r_2^2\right) + 4\theta r_1 r_2 - 2l(r_1 y_1 + r_2 y_2) + c_2\left(y_1^2 + y_2^2\right)}{2q^2[d - 3\alpha(p_r + p_m) + 3k(g_1 + g_2) + 6\gamma q]}, \ \frac{\gamma}{2(\alpha - \beta)} \right\} \tag{70}$$

Proof. See Appendix O.

By solving the first-order conditions, the equilibrium results of a centralized DD model can be obtained follows:

$$p_m^{C*} = \frac{4c_q(\alpha-\beta)^2\left[c_1 d(2\beta c_1 - \rho k^2) - c_m k^2\left[c_1(3\alpha+\beta) - k^2\right]\right] + 6c_1^2\gamma^2\left(\alpha^2 - \beta^2\right) + 8c_1^2 c_q(\alpha-\beta)^3\left[c_m(\alpha+\beta) + d\rho\right] - \gamma^2 k^2\left[c_1(5\alpha-\beta) - k^2\right]}{4c_q(\alpha-\beta)^2\left[2(\alpha-\beta) - k^2\right]\left[2(\alpha+\beta) - k^2\right]} \tag{71}$$

$$p_r^{C*} = \frac{4c_q(\alpha-\beta)^2\left[c_1 d\left(2(\alpha+\beta)c_1 - (1-\rho)k^2\right) - c_m k^2\left[c_1(3\alpha+\beta) - k^2\right]\right] + 8c_1^2 c_q(\alpha-\beta)^3\left[c_m(\alpha+\beta) - d\rho\right] - \gamma^2 k^2\left[c_1(5\alpha-\beta) - k^2\right] + 6c_1^2\gamma^2\left(\alpha^2 - \beta^2\right)}{4c_q(\alpha-\beta)^2\left[2(\alpha-\beta) - k^2\right]\left[2(\alpha+\beta) - k^2\right]} \tag{72}$$

$$g_1^{C*} = \frac{4kc_q(\alpha-\beta)^2\left(c_m k^2 - 2c_1 d\rho\right) - 4kc_q d(\alpha-\beta)\left((1-\rho)k^2 - 2\alpha c_1\right) + 2kc_1\gamma^2(\alpha+\beta) - \gamma^2 k^3}{4c_q(\alpha-\beta)^2\left[2(\alpha-\beta)-k^2\right]\left[2(\alpha+\beta)-k^2\right]} \tag{73}$$

$$g_2^{C*} = \frac{4kc_q(\alpha-\beta)^2\left(c_m k^2 - 2c_1 d\rho\right) + 4kc_q d(\alpha-\beta)\left(2\beta c_1 - \rho k^2\right) + 2kc_1\gamma^2(\alpha+\beta) - \gamma^2 k^3}{4c_q(\alpha-\beta)^2\left[2(\alpha-\beta)-k^2\right]\left[2(\alpha+\beta)-k^2\right]} \tag{74}$$

$$y_1^{C*} = \frac{l\left(c_m - c_r + c_q q_r^2\right)\left[2c_2\left(\varphi^2-\theta^2\right) - l^2(\varphi-\theta)\right] + \phi l\left[2c_2(\psi\theta + (1-\psi)\varphi) - (1-\psi)l^2\right]}{4c_2^2\left(\varphi^2-\theta^2\right) - 4c_2\varphi l^2 + l^4} \tag{75}$$

$$y_2^{C*} = \frac{l\left(c_m - c_r + c_q q_r^2\right)\left[2c_2\left(\varphi^2-\theta^2\right) - l^2(\varphi-\theta)\right] + \phi\left[2c_2(\psi\varphi + (1-\psi)\theta) - \psi l^2\right]}{4c_2^2\left(\varphi^2-\theta^2\right) - 4c_2\varphi l^2 + l^4} \tag{76}$$

$$r_1^{C*} = \frac{c_2\left(c_m - c_r + c_q q_r^2\right)\left[2c_2\left(\varphi^2-\theta^2\right) - l^2(3\varphi+\theta) + l^4\right] + c_2\phi\left[2\psi c_2(\varphi-\theta) - 2c_2\varphi + l^2(1-\psi)\right]}{4c_2^2\left(\varphi^2-\theta^2\right) - 4c_2\varphi l^2 + l^4} \tag{77}$$

$$r_2^{C*} = \frac{c_2\left(c_m - c_r + c_q q_r^2\right)\left[2c_2\left(\varphi^2-\theta^2\right) - l^2(3\varphi+\theta) + l^4\right] - c_2\phi\left[2\psi c_2(\varphi-\theta) + 2c_2\varphi - \psi l^2\right]}{4c_2^2\left(\varphi^2-\theta^2\right) - 4c_2\varphi l^2 + l^4} \tag{78}$$

The results in Table 1 reveal that the total profit of the centralized CLSC is higher than that of the decentralized CLSC. To achieve better profit in the CLSC, the manufacturer tries to motivate the retailer and the third party to take the optimal values of the centralized system as their optimal policies.

After obtaining the optimal decisions of the centralized system as a benchmark model, a hybrid contract, which is a mixture of cooperative advertising and two-tariff contracts is established. This new contact is introduced because of the number of decision variables. Neither the two-tariff nor the cooperative advertising contract can coordinate both the forward and reverse supply chains individually, so in this paper, these two contracts are integrated as a new contract. This coordination mechanism contains three sub-contracts: a forward contract and two reverse contracts. In the former, the manufacturer incurs a part of retailer's sales effort and sets lower wholesale prices. In return, the retailer pays the fixed fee F_1 to the manufacturer. Therefore, putting the retailer's decisions in the coordinated decentralized CLSC equal to the corresponding values in the centralized CLSC, the manufacturer determines the optimal values of the wholesale price (i.e., ω) and determines the manufacturer participation rate in the retailer's sales effort (i.e., u). The retailer benefits from the decline in the wholesale price and the

Table 1
Values that yield maximum profits in the numerical example.

Decision Variable	SD model	DD model		Centralized model		Coordinated Model	
	$\rho=0.3/\rho=0.5$	$\rho=0.3$	$\rho=0.5$	$\rho=0.3$	$\rho=0.5$	$\rho=0.3$	$\rho=0.5$
ω	175.27	192.77	176.11	–	–	130.28	138.52
p_r	212.87	224.19	195.01	193.00	176.32	193.00	176.32
p_m	–	159.57	176.26	159.63	176.32	159.63	176.32
b_t	9.50	9.50	9.50	–	–	20.15	20.15
b_r	10.50	10.50	10.50	–	–	19.82	19.82
r_1	3.19	3.19	3.19	10.44	10.44	10.44	10.44
r_2	4.77	4.77	4.77	9.44	9.44	9.44	9.44
q	0.3		0.6	0.6	0.6	0.6	0.6
y_1	0.10	0.10	0.10	0.26	0.26	0.26	0.26
y_2	0.09	0.09	0.09	0.24	0.24	0.24	0.24
g_1	0.23	0.20	0.12	0.58	0.47	0.58	0.47
g_2	–	0.37	0.47	0.37	0.47	0.37	0.47
u	–		–	–	–	0.00	0.50
m	–		–	–	–	0.36	0.36
n	–		–	–	–	0.31	0.31
F_1	–		–	–	–	$[19636.31, 30230.73]$	$[7179.48, 11497.05]$
F_2	–		–	–	–	$[20755.32 - F_1, 1119.01]$	$[8298.49 - F_1, 1119.01]$
Π_m	30,950.89	48,308.49	52,528.93	–	–	$27553.17 + F_1 + F_2$	$44230.43 + F_1 + F_2$
Π_r	14,610.26	10,343.69	4058.08	–	–	$40574.42 - F_1$	$15555.13 - F_1$
Π_t	595.10	595.10	595.10	–	–	$1714.12 - F_2$	$1714.12 - F_2$
Π	46,156.25	57,182.11	57,182.11	69,841.70	61,499.68	69,841.70	61,499.68

sales effort investment, and the manufacturer benefits from receiving the fixed fee F_1.

In similar fashion, in the reverse contracts, the manufacturer designs one reverse contract with the retailer and another reverse contract with a third party. In these contracts, the manufacturer incurs a part of the third party's and retailer's collection efforts and sets a relatively high transfer price for returning the used products from the retailer and the third party. In return, the retailer pays the fixed fee, F_1, and the third party pays the fixed fee, F_2, to the manufacturer. Therefore, by placing the retailer and third party values that correspond to those in the centralized CLSC into the coordinated decentralized CLSC, the manufacturer determines the optimal values for the transfer prices paid to the retailer and the third party (i.e., A_r and A_t, respectively). In this process, the manufacturer also determines the participation rate in the retailer's and third party's collection efforts (i.e., m and n, respectively). The retailer and the third party benefit from the incremental transfer prices and the decline in their collection effort investments. Also, the manufacturer benefits from receiving fixed fees F_1 and F_2.

Then, according to the bargaining power of the manufacturer, retailer, and third party, the values of F_1 and F_2 are determined such that the profits of the manufacturer, retailer, and third party in the cooperative DD model are greater or equal to those in the non-cooperative DD model.

In a cooperative sales effort scheme, u percent of the retailer's sales effort investment is charged by the manufacturer and $(1-u)$ percent of it is charged by the retailer. Also, in a cooperative collection effort scheme, m percent of the retailer's collection effort investment and n percent of the third party's collection effort investment is charged by the manufacturer, and $(1-m)$ percent of the retailer's collection effort and $(1-n)$ percent of the third party's collection effort is charged by the retailer and the third party, respectively

$$\Pi_M^{Ce} = D_r\omega + D_m p_m - (D-R)c_m - Rc_r - R_rA_r - R_tA_t - (D-R)c_q q^2 - Rc_q\left(q^2 - q_r^2\right) - \frac{1}{2}c_1 g_2^2 - \frac{1}{2}uc_1 g_1^2 - \frac{1}{2}mc_2 y_2^2 - \frac{1}{2}nc_2 y_1^2 \tag{79}$$

$$\Pi_R^{Ce} = D_r(p_r - \omega) + R_r(A_r - r_2) - \frac{1}{2}(1-u)c_1 g_1^2 - \frac{1}{2}(1-m)c_2 y_2^2 \tag{80}$$

$$\Pi_T^{Ce} = R_t(A_t - r_1) - \frac{1}{2}(1-n)c_2 y_1^2 \tag{81}$$

The fixed costs F_1 and F_2 are the negotiated values influenced by the bargaining power of each member, so the values of F_1 and F_2 can be determined such that the profits of the manufacturer, retailer, and third party in the decentralized system are higher or equal to those in the centralized system. Thus, under this contract, the profits of the manufacturer, retailer, and third party, can be given as follows:

$$\Pi_M^{Co} = D_r\omega + D_m p_m - (D-R)c_m - Rc_r - R_rA_r - R_tA_t - (D-R)c_q q^2 - Rc_q\left(q^2 - q_r^2\right) - \frac{1}{2}c_1 g_2^2 - \frac{1}{2}uc_1 g_1^2 - \frac{1}{2}mc_2 y_2^2 - \frac{1}{2}nc_2 y_1^2 + F_1 + F_2 \tag{82}$$

$$\Pi_R^{Co} = D_r(p_r - \omega) + R_r(A_r - r_2) - \frac{1}{2}(1-u)c_1 g_1^2 - \frac{1}{2}(1-m)c_2 y_2^2 - F_1 \tag{83}$$

$$\Pi_T^{Co} = R_t(A_t - r_1) - \frac{1}{2}(1-n)c_2 y_1^2 - F_2 \tag{84}$$

By solving the first-order conditions $\frac{\partial \Pi_R^{Co}}{\partial r_2^{Co}} = 0, \frac{\partial \Pi_R^{Co}}{\partial p_r^{Co}} = 0, \frac{\partial \Pi_R^{Co}}{\partial y_2^{Co}} = 0,$ and $\frac{\partial \Pi_R^{Co}}{\partial g_1^{Co}} = 0$, the optimal reactions of the retailer can be can be obtained as follows:

$$p_r^{Co*} = \frac{c_1(1-u)[d + \gamma q + \beta p_m + \alpha\omega - \rho d] - \omega k^2}{2(1-u)\alpha c_1 - k^2} \tag{85}$$

$$g_1^{Co*} = \frac{k[d + \gamma q + \beta p_m - \alpha\omega - \rho d]}{2(1-u)\alpha c_1 - k^2} \tag{86}$$

$$y_2^{Co*} = \frac{l(A_r\varphi + \psi\phi - \theta r_1)}{2(1-m)c_2\varphi - l^2} \tag{87}$$

$$r_2^{Co*} = \frac{c_2(1-m)(\theta r_1 + A_r\varphi - \psi\phi) - A_r l^2}{2(1-m)c_2\varphi - l^2} \tag{88}$$

In addition, by solving the first-order conditions $\frac{\partial \Pi_T^{Co}}{\partial y_1^{Co}} = 0$ and $\frac{\partial \Pi_T^{Co}}{\partial r_1^{Co}} = 0$, the optimal reactions of the third party can be written as follows:

$$r_1^{Co*} = \frac{c_2(1-n)[\theta r_2 + A_t\varphi - (1-\psi)\phi] - A_t l^2}{2(1-n)c_2\varphi - l^2} \tag{89}$$

$$y_1^{Co*} = \frac{l[A_t\varphi + (1-\psi)\phi - \theta r_2]}{2(1-n)c_2\varphi - l^2} \tag{90}$$

Then, in the forward contract, by solving equations $p^{Co*} = p^{C*}$ and $g_1^{Co*} = g_1^{C*}$, the optimal values of ω^{Co} and u^{Co} can be determined as follows:

$$\omega^{Co*} = \frac{4c_q(\alpha-\beta)^2\left[c_1 d\left[2\beta^2 c_1 - k^2\rho(4\alpha - 3\beta)\right] + dk^4(2\rho-1) + c_m k^2\left[\alpha k^2 - c_1\left(4\alpha^2 + \beta^2 - \alpha\beta\right)\right]\right] + c_1\gamma^2\left[2c_1\left(\alpha^2 - \beta^2\right)(2\alpha+\beta) - k^2\left(4\alpha^2 - \beta^2 + \alpha\beta\right)\right] + 8c_1c_q(\alpha-\beta)^3\left[c_1c_m(2\alpha-\beta)(\alpha+\beta) + dk^2 + \beta c_1 d\rho\right] + \alpha\gamma^2 k^4}{4\alpha c_q(\alpha-\beta)^2\left[4c_1^2\left(\alpha^2-\beta^2\right) - 4\alpha c_1 k^2 + k^4\right]} \tag{91}$$

$$u^{Co*} = \frac{4c_q d(\alpha-\beta)\left[k^2(2\rho-1) + c_1\left[k^2(3\alpha - 2\beta) - 2c_1\left(\alpha^2 - \beta^2 - \alpha\beta\right)\right]\right] + \beta c_1\gamma^2\left[2c_1(\alpha+\beta) - k^2\right] + 4c_1c_q(\alpha-\beta)^2\left[d\rho(2\alpha+\beta)\left(2c_1 - 3k^2\right) + \beta c_m\left[c_q k^2 - 2c_1(\alpha+\beta)\right]\right]}{\alpha c_1\left[\gamma^2\left[2(\alpha+\beta)c_1 - k^2\right] + 4c_q d(\alpha-\beta)\left[2\beta c_1 - k^2\rho\right] + (\alpha-\beta)^2\left[8c_1c_q d\rho - 4c_m c_q\left(2c_1(\alpha+\beta) - k^2\right)\right]\right]} \tag{92}$$

Also, in the reverse contract between the manufacturer and the third party, by solving the equations $y_1^{Co*} = y_1^{C*}$ and $r_1^{Co*} = r_1^{C*}$, the manufacturer determines the optimal values of n^{Co} and A_t^{Co} as follows:

$$n^{Co*} = \frac{\theta\left(c_m - c_r + c_q q_r^2\right)\left[2c_2\left(\varphi^2 - \theta^2\right) - l^2(\varphi - \theta)\right] + \phi\theta\left[2c_2(\psi\varphi + (1-\psi)\theta) - \psi l^2\right]}{\varphi\left(c_m - c_r + c_q q_r^2\right)\left[2c_2\left(\varphi^2 - \theta^2\right) - l^2(\varphi - \theta)\right] + \phi\varphi\left[2c_2(\psi\theta + (1-\psi)\varphi) - (1-\psi)l^2\right]} \tag{93}$$

$$A_t^{Co*} = \frac{\left(c_m - c_r + c_q q_r^2\right)\left[2c_2(2\alpha - \beta)(\alpha - \beta)(\alpha + \beta) - c_2 l^2\left(4\varphi^2 + \theta^2 - \varphi\theta\right) + \varphi l^4\right] - c_2\phi\theta\left[2c_2(\psi\varphi + (1-\psi)\theta) - \psi l^2\right]}{\varphi\left[4c_2^2\left(\varphi^2 - \theta^2\right) - 4c_2\varphi l^2 + l^4\right]} \tag{94}$$

Similarly, in the reverse contract between the manufacturer and the third party, by solving the equations $y_2^{Co*} = y_2^{C*}$ and $r_2^{Co*} = r_2^{C*}$, the manufacturer determines the optimal values of m^{Co} and A_r^{Co} as follows:

$$m^{Co*} = \frac{\theta\left(c_m - c_r + c_q q_r^2\right)\left[2c_2\left(\varphi^2 - \theta^2\right) - l^2(\varphi - \theta)\right] + \phi\theta\left[2c_2(\psi\theta + (1-\psi)\varphi) - (1-\psi)l^2\right]}{\varphi\left(c_m - c_r + c_q q_r^2\right)\left[2c_2\left(\varphi^2 - \theta^2\right) - l^2(\varphi - \theta)\right] + \phi\varphi\left[2c_2(\psi\varphi + (1-\psi)\theta) - \psi l^2\right]} \tag{95}$$

$$A_r^{Co*} = \frac{\left(c_m - c_r + c_q q_r^2\right)\left[2c_2(2\alpha - \beta)(\alpha - \beta)(\alpha + \beta) - c_2 l^2\left(4\varphi^2 + \theta^2 - \varphi\theta\right) + \varphi l^4\right] - c_2\phi\theta\left[2c_2(\psi\theta + (1-\psi)\varphi) - (1-\psi)l^2\right]}{\varphi\left[4c_2^2\left(\varphi^2 - \theta^2\right) - 4c_2\varphi l^2 + l^4\right]} \tag{96}$$

It is noteworthy that $\omega^{Co*} \le \omega^{D*}$, $A_t^{Co*} \ge A_t^{D*}$, and $A_r^{Co*} \ge A_r^{D*}$. In fact, if there are no values for F_1 and F_2, then the retailer and the third party gain more profit and the manufacturer loses more profit than they do in the non-cooperative system. Therefore, the sizes of F_1 and F_2 guarantee the success of this contract. When F_1 satisfies $\Pi_R^{Ce*}(\omega^{Co*}, u^{Co*}, A_r^{Co*}, m^{Co*}) - F_1 \ge \Pi_R^{DD^*}$, the retailer is willing to accept the contract, and the following is obtained:

$$F_1 \le \Pi_R^{Ce*}\left(\omega^{Co*}, u^{Co*}, A_r^{Co*}, m^{Co*}\right) - \Pi_R^{DD*} \tag{97}$$

Thus, the upper limit of F_1 can be written as: $\overline{F_1} = \Pi_R^{Ce*}(\omega^{Co*}, u^{Co*}, A_r^{Co*}, m^{Co*}) - \Pi_R^{DD*}$.

When F_2 satisfies $\Pi_T^{Ce*}(A_t^{Co*}, n^{Co*}) - F_2 \ge \Pi_T^{DD*}$ the third party is willing to accept the contract, and the following is obtained:

$$F_2 \le \Pi_T^{Ce*}\left(A_t^{Co*}, n^{Co*}\right) - \Pi_T^{DD*} \tag{98}$$

Thus, the upper limit of F_2 can be written as: $\overline{F_2} = \Pi_T^{Ce*}(A_t^{Co*}, n^{Co*}) - \Pi_T^{DD*}$.

Also, when F_1 and F_2 satisfy $\Pi_M^{Ce*}(\omega^{Co*}, u^{Co*}, A_r^{Co*}, m^{Co*}, A_t^{Co*}, n^{Co*}) + F_1 + F_2 \ge \Pi_M^{DD*}$, the manufacturer is willing to offer the contract and the following is obtained:

$$F_1 + F_2 \ge \Pi_M^{Ce*}\left(\omega^{Co*}, u^{Co*}, A_r^{Co*}, m^{Co*}, A_t^{Co*}, n^{Co*}\right) - \Pi_M^{DD*} \tag{99}$$

According to Inequality (99), by setting $F_2 = \overline{F_2} = \Pi_T^{Ce*}(A_t^{Co*}, n^{Co*}) - \Pi_T^{DD*}$, the minimum value of F_1 is obtained as $\underline{F_1} = \Pi_M^{Ce*}(\omega^{Co*}, u^{Co*}, A_r^{Co*}, m^{Co*}, A_t^{Co*}, n^{Co*}) - \Pi_M^{DD*} - \overline{F_2}$.

Therefore, the feasible range of F_1, which can be used to coordinate the CLSC can be written as $F_1 \in \left[\underline{F_1}, \overline{F_1}\right]$ where $\underline{F_1} = \Pi_M^{Ce*}(\omega^{Co*}, u^{Co*}, A_r^{Co*}, m^{Co*}, A_t^{Co*}, n^{Co*}) - \Pi_M^{DD*} - \overline{F_2}$ and $\overline{F_1} = \Pi_R^{Ce*}(\omega^{Co*}, u^{Co*}, A_r^{Co*}, m^{Co*}) - \Pi_R^{DD*}$.

Then, with regard to the value of F_1, the feasible range of F_2 satisfying Inequality (99) can be written as $F_2 \in \left[\underline{F_2}, \overline{F_2}\right]$ where $\underline{F_2} = \Pi_M^{Ce*}(\omega^{Co*}, u^{Co*}, A_r^{Co*}, m^{Co*}, A_t^{Co*}, n^{Co*}) - \Pi_M^{DD*} - F_1$ and $\overline{F_2} = \Pi_T^{Ce*}(A_t^{Co*}, n^{Co*}) - \Pi_T^{D*}$.

6.1. Coordination mechanism for elimination of channel conflicts

Under the contracts described in the previous section, the profits of the manufacturer, retailer, and third party are always better or equal to those under the decentralized DD model. However, these contracts do not guarantee that the retailer's profit in the coordinated DD model is greater than it is in either the SD or DD model or that the retailer benefits from the emergence of the online channel.

According to Proposition 13, in some situations, the retailer loses profit from the introduction of an online channel, which may result in channel conflict. To reduce any conflict, the manufacturer should assure the retailer that introduction of the online selling channel will not diminish the retailer's profit. To achieve this purpose, the manufacturer can use the contracts described. However, in this case, for the determination of F_1, the manufacturer uses the following relation instead of the Inequality (97).

$$F_1 \le \Pi_R^{CA*}\left(\omega^{Co*}, u^{Co*}, b_r^{Co*}, m^{Co*}\right) - \max\left\{\Pi_R^{D*}, \Pi_R^{SD*}\right\} \tag{100}$$

Thus, the upper limit of F_1 can be written as: $\overline{F_1} = \Pi_R^{CA*}(\omega^{Co*}, u^{Co*}, b_r^{Co*}, m^{Co*}) - \max\{\Pi_R^{D*}, \Pi_R^{SD*}\}$.

Also, other calculations are exactly the same as in the previous

Table 2
Sensitivity analysis of the key parameters of the SD model.

Parameter	Value	Value												
		ω^*	p_r^*	b_t^*	b_r^*	r_1^*	r_2^*	q^*	y_1^*	y_2^*	g_1^*	Π_m^*	Π_R^*	Π_T^*
α	8	206.67	259.97	9.50	10.50	3.20	4.77	0.38	0.11	0.10	0.33	48,078.69	23,174.16	595.10
	10	175.27	212.87	9.50	10.50	3.20	4.77	0.30	0.11	0.10	0.24	30,950.89	14,610.26	595.10
	12	154.35	181.50	9.50	10.50	3.20	4.77	0.25	0.11	0.10	0.17	20,382.05	9325.84	595.10
	14	139.42	159.11	9.50	10.50	3.20	4.77	0.21	0.11	0.10	0.12	14,500.09	5912.40	595.10
	16	128.23	142.32	9.50	10.50	3.20	4.77	0.19	0.11	0.10	0.09	10,080.83	3667.01	595.10
φ	10	175.27	212.87	6.84	8.17	0.57	2.70	0.30	0.10	0.09	0.24	30,295.67	14,415.79	391.25
	12	175.27	212.87	8.34	9.52	2.05	3.92	0.30	0.10	0.09	0.24	30,536.15	14,493.64	473.71
	14	175.27	212.87	9.20	10.25	2.89	4.55	0.30	0.11	0.09	0.24	30,808.64	14,571.39	554.85
	16	175.27	212.87	9.75	10.71	3.44	4.94	0.30	0.11	0.10	0.24	31,095.68	14,649.13	635.21
	18	175.27	212.87	10.14	11.01	3.83	5.19	0.30	0.11	0.10	0.24	31,390.55	14,726.90	715.06
ϕ	25	175.27	212.87	11.75	12.00	6.41	6.81	0.30	0.09	0.09	0.24	30,311.82	14,522.33	426.57
	50	175.27	212.87	11.00	11.50	5.34	6.13	0.30	0.09	0.09	0.24	30,514.90	14,550.68	479.64
	100	175.27	212.87	9.50	10.50	3.20	4.77	0.30	0.11	0.10	0.24	30,950.89	14,610.26	595.10
	125	175.27	212.87	8.75	10.00	2.12	4.09	0.30	0.11	0.10	0.24	31,183.80	14,641.49	657.50
	150	175.27	212.87	8.00	9.50	1.05	3.41	0.30	0.12	0.10	0.24	31,426.65	14,673.68	723.01
γ	8	175.12	212.70	9.50	10.50	3.20	4.77	0.20	0.11	0.10	0.23	30,913.30	14,591.46	595.10
	10	175.19	212.78	9.50	10.50	3.20	4.77	0.25	0.11	0.10	0.23	30,930.21	14,599.92	595.10
	12	175.27	212.87	9.50	10.50	3.20	4.77	0.30	0.11	0.10	0.24	30,950.89	14,610.26	595.10
	14	175.37	212.99	9.50	10.50	3.20	4.77	0.35	0.11	0.10	0.24	30,975.34	14,622.48	595.10
	16	175.48	213.12	9.50	10.50	3.20	4.77	0.40	0.11	0.10	0.24	31,003.56	14,636.59	595.10

Table 3
Sensitivity analysis for the key parameters of the DD model.

Parameter	Value	Value														
		ω^*	p_r^*	p_m^*	b_t^*	b_r^*	r_1^*	r_2^*	q^*	y_1^*	y_2^*	g_1^*	g_2^*	Π_m^*	Π_R^*	Π_T^*
α	8	261.50	291.53	261.91	9.50	10.50	3.20	4.77	1.00	0.11	0.10	0.19	1.00	141,276.16	7692.84	595.10
	10	176.11	195.01	176.26	9.50	10.50	3.20	4.77	0.60	0.11	0.10	0.12	0.47	52,528.93	4058.08	595.10
	12	139.84	151.38	139.91	9.50	10.50	3.20	4.77	0.43	0.11	0.10	0.07	0.25	21,377.77	2087.26	595.10
	14	119.78	126.08	119.81	9.50	10.50	3.20	4.77	0.33	0.11	0.10	0.04	0.12	8500.09	1046.38	595.10
	16	107.04	109.41	107.05	9.50	10.50	3.20	4.77	0.27	0.11	0.10	0.01	0.04	3580.83	581.91	595.10
φ	10	176.11	195.01	176.26	6.84	8.17	0.57	2.70	0.60	0.10	0.09	0.12	0.47	51,873.71	3863.62	391.25
	12	176.11	195.01	176.26	8.34	9.52	2.05	3.92	0.60	0.10	0.09	0.12	0.47	52,114.19	3941.47	473.71
	14	176.11	195.01	176.26	9.20	10.25	2.89	4.55	0.60	0.11	0.09	0.12	0.47	52,386.68	4019.21	554.85
	16	176.11	195.01	176.26	9.75	10.71	3.44	4.94	0.60	0.11	0.10	0.12	0.47	52,673.72	4096.96	635.21
	18	176.11	195.01	176.26	10.14	11.01	3.83	5.19	0.60	0.11	0.10	0.12	0.47	52,968.59	4174.73	715.06
ϕ	25	176.11	195.01	176.26	11.75	12.00	6.41	6.81	0.60	0.09	0.09	0.12	0.47	51,889.86	3970.16	426.57
	50	176.11	195.01	176.26	11.00	11.50	5.34	6.13	0.60	0.09	0.09	0.12	0.47	52,092.94	3998.50	479.64
	100	176.11	195.01	176.26	9.50	10.50	3.20	4.77	0.60	0.11	0.10	0.12	0.47	52,528.93	4058.08	595.10
	125	176.11	195.01	176.26	8.75	10.00	2.12	4.09	0.60	0.11	0.10	0.12	0.47	52,761.84	4089.31	657.50
	150	176.11	195.01	176.26	8.00	9.50	1.05	3.41	0.60	0.12	0.10	0.12	0.47	53,004.69	4121.50	723.01
γ	8	175.51	194.36	175.66	9.50	10.50	3.20	4.77	0.40	0.11	0.10	0.12	0.47	52,264.87	4039.18	595.10
	10	175.78	194.65	175.93	9.50	10.50	3.20	4.77	0.50	0.11	0.10	0.12	0.47	52,383.61	4047.68	595.10
	12	176.11	195.01	176.26	9.50	10.50	3.20	4.77	0.60	0.11	0.10	0.12	0.47	52,528.93	4058.08	595.10
	14	176.50	195.43	176.65	9.50	10.50	3.20	4.77	0.70	0.11	0.10	0.12	0.47	52,700.94	4070.40	595.10
	16	176.95	195.92	177.10	9.50	10.50	3.20	4.77	0.80	0.11	0.10	0.12	0.47	52,899.79	4084.63	595.10
ρ	0	217.78	267.96	134.54	9.50	10.50	3.20	4.77	0.60	0.11	0.10	0.31	0.21	61,531.49	25,634.53	595.10
	0.2	201.11	238.78	151.22	9.50	10.50	3.20	4.77	0.60	0.11	0.10	0.24	0.32	50,109.00	14,658.98	595.10
	0.4	184.44	209.60	167.91	9.50	10.50	3.20	4.77	0.60	0.11	0.10	0.16	0.42	49,115.13	6810.06	595.10
	0.6	167.78	180.42	184.60	9.50	10.50	3.20	4.77	0.60	0.11	0.10	0.08	0.52	58,549.88	2087.76	595.10
	0.8	151.11	151.24	201.29	9.50	10.50	3.20	4.77	0.60	0.11	0.10	0.00	0.63	78,413.24	492.09	595.10

coordination mechanism. It should be noted that, when the value of $\overline{F_1}$ is lower than the value of $\underline{F_1}$, the channel coordination contract for elimination of channel conflicts would be infeasible.

7. Numerical examples and sensitivity analysis

7.1. Numerical examples

This section provides two numerical examples to demonstrate the results derived in prior sections and examine the effectiveness of the introduced coordination mechanism. Numerical examples are solved for two decentralized CLSC, namely SD and DD models, a DD centralized system, and a coordinated model. After that, conclusions on the SD and DD models are offered and two channel structures are compared. Then, sensitivity analyses are performed to survey the effects of the main parameters on the behavior in both models. The numerical values of the parameters in a CLCS are $d = 25000$, $\phi = 100$, $\alpha = 10$, $\beta = 5$, $l = 5$, $k = 5$, $\gamma = 12$, $\varphi = 15$, $\theta = 5$, $c_m = 100$, $c_r = 75$, $q_r = 0.05$, $c_q = 2$, $c_1 = 800$, and $c_2 = 300$. By substituting these parameter values under concavity conditions, all conditions for this data set are satisfied, and therefore, all models are concave. Because the demand in both the online and traditional channels must be non-negative, Conditions (37), (38), and (39) can be applied to derive the value of ρ that satisfies $0.00 \le \rho \le 0.80$ and Conditions (5), (6), and (7) to derive a value of ψ that satisfies $0 \le \psi \le 1$. Also, by applying Conditions (14) and (40), the feasible range of ϕ in the SD and the DD model can be obtained as $0 \le \phi \le$

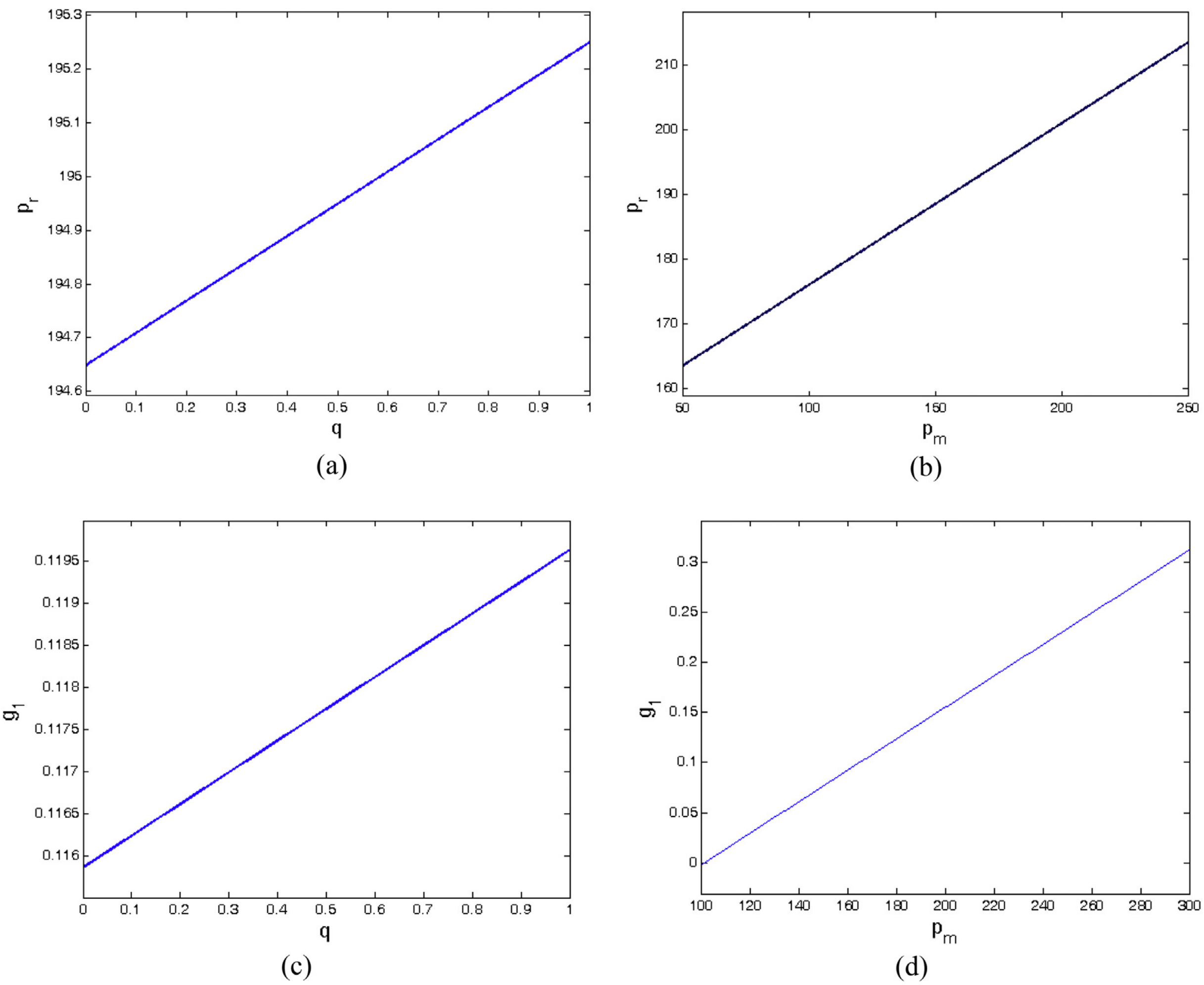


Fig. 2. Relationships between selling price, sales effort, and quality level.

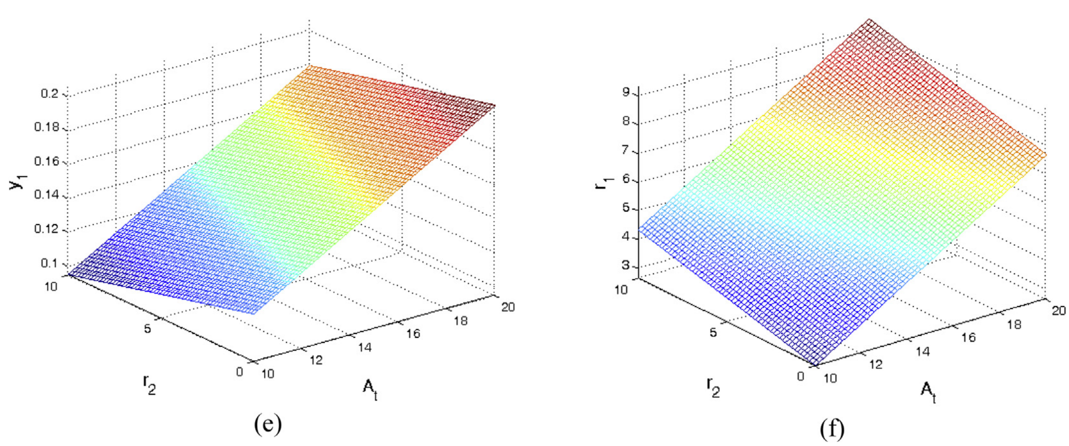


Fig. 3. Relationships between transfer price, self-buyback price, cross-buyback price, and collection effort.

749.18 and $0 \le \phi \le 1695.96$, respectively.

Example 1. In this example, $\psi = 0.3$ and $\rho = 0.3$ are assumed, which fall into the proper ranges for ρ and ψ. By using the solutions proposed in Section 4, the values for the decision variables that yield the maximum total profits can be obtained, as presented in Table 1. As Table 1 shows, the total profit under the centralized DD model is greater than it is under the decentralized DD model. Therefore, the manufacturer tends to design appropriate contracts to improve each member's profit and the total profit of the CLSC. In addition, it is clear that, by considering $\rho = 0.3$, the retailer loses from the emergence of an online selling channel, and the retailer profit in the SD model is greater than it is in the DD model. The lost retailer profit leads to the channel friction, so by applying a

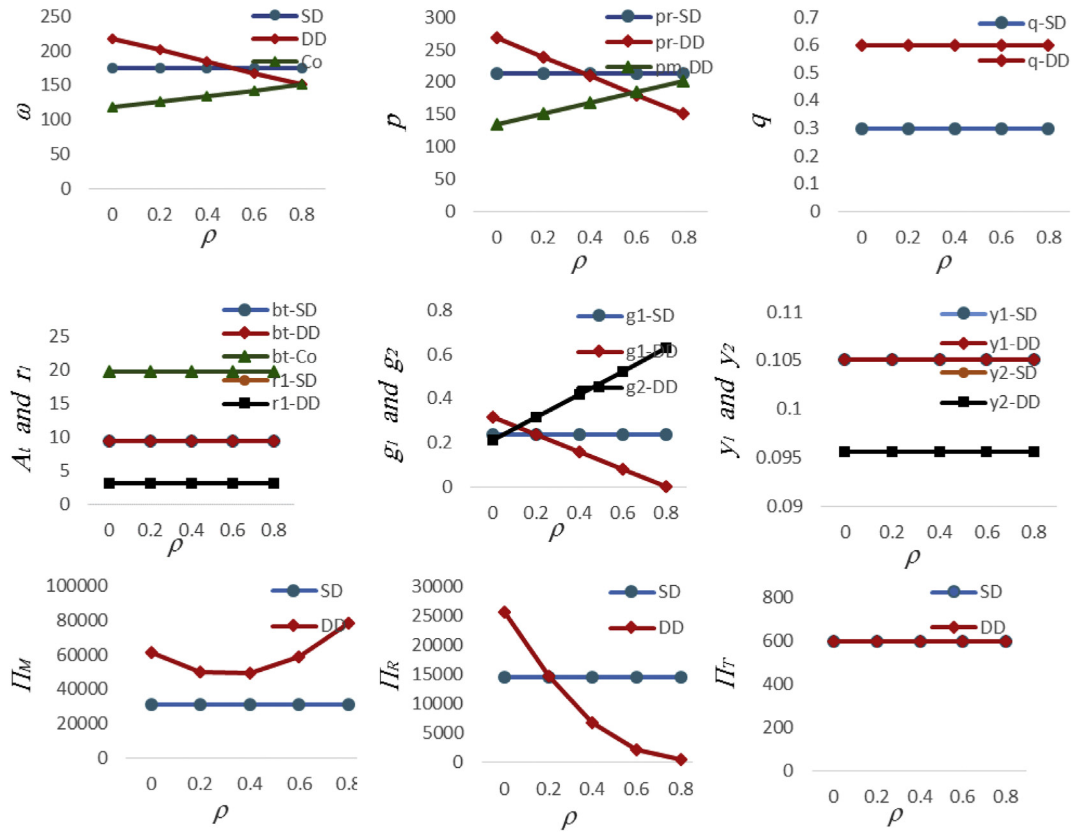


Fig. 4. Effects of ρ on optimal solutions and profits.

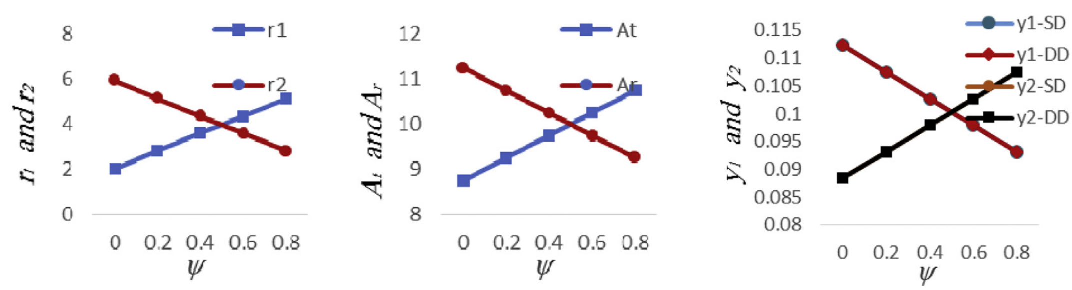


Fig. 5. Effects of ψ on buyback prices, transfer prices, and collection efforts.

coordination mechanism, the manufacturer tends to eliminate channel conflicts and obtain the consent of retailer for introducing the online selling channel.

By applying the joint cooperative advertising and two-tariff contract proposed in Section 6, the optimal values for $\omega^{Co*}, u^{Co*}, b_r^{Co*}, m^{Co*}, b_t^{Co*}$, and n^{Co*} can be determined as 130.28, 0.00, 19.82, 0.36, 20.15, and 0.31, respectively.

Also, by using the feasible range for F_1 and F_2, the optimal range of F_1 and F_2 under which the DD model is coordinated can be obtained as $\{F_1 \in [19636.31, 30230.73]$and $F_2 \in [20755.32 - F_1, 1119.01]\}$. Under this coordination mechanism, the DD model can be effectively coordinated. However, the channel conflict might remain between the retailer and the manufacturer, because when $F_1 \in [25964.16, 30230.73]$, the retailer's profit in the DD model is lower than it is in the SD model. Therefore, to reduce channel friction, the manufacturer offers a contract under which the retailer has assurance that the profits in the coordinated model are greater than they are in either the SD and DD models. Therefore, by applying the channel coordination described in Section 6.1, the optimal range of F_1 that eliminates the channel conflict can be obtained as $F_1 \in [19636.31, 25964.16]$. For instance, by considering F_1 and F_2 as 20,000 and 500, the optimal values of Π_M^{Co*}, Π_R^{Co*}, and Π_T^{Co*} can be obtained as 48,053.16, 20,574.42, and 1214.12, respectively.

Example 2. It is assumed that $\psi = 0.3$ and $\rho = 0.3$, which fall into the proper ranges for ρ and ψ. By using the solutions proposed in Section 4, the values for the decision variables that yield the maximum total profits can be obtained, as shown in Table 1. In addition, by applying the joint cooperative advertising and two-tariff contract proposed in Section 5, the optimal values of $\omega^{Co*}, u^{Co*}, b_r^{Co*}, m^{Co*}, b_t^{Co*}$, and n^{Co*} can be determined as 138.52, 0.50, 19.82, 0.36, 20.15, and 0.31, respectively. Also, by using the feasible ranges for F_1 and F_2, the optimal ranges of F_1 and F_2 under which DD model is coordinated are

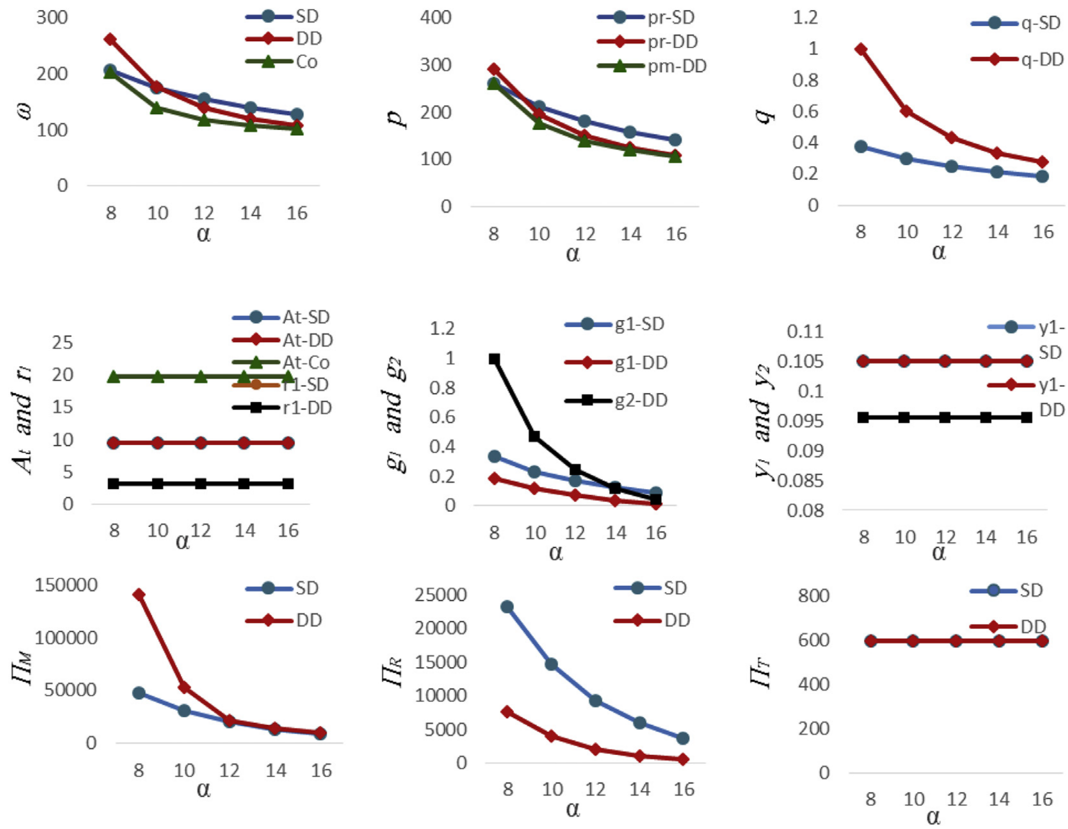


Fig. 6. Effects of α on optimal solutions and profits.

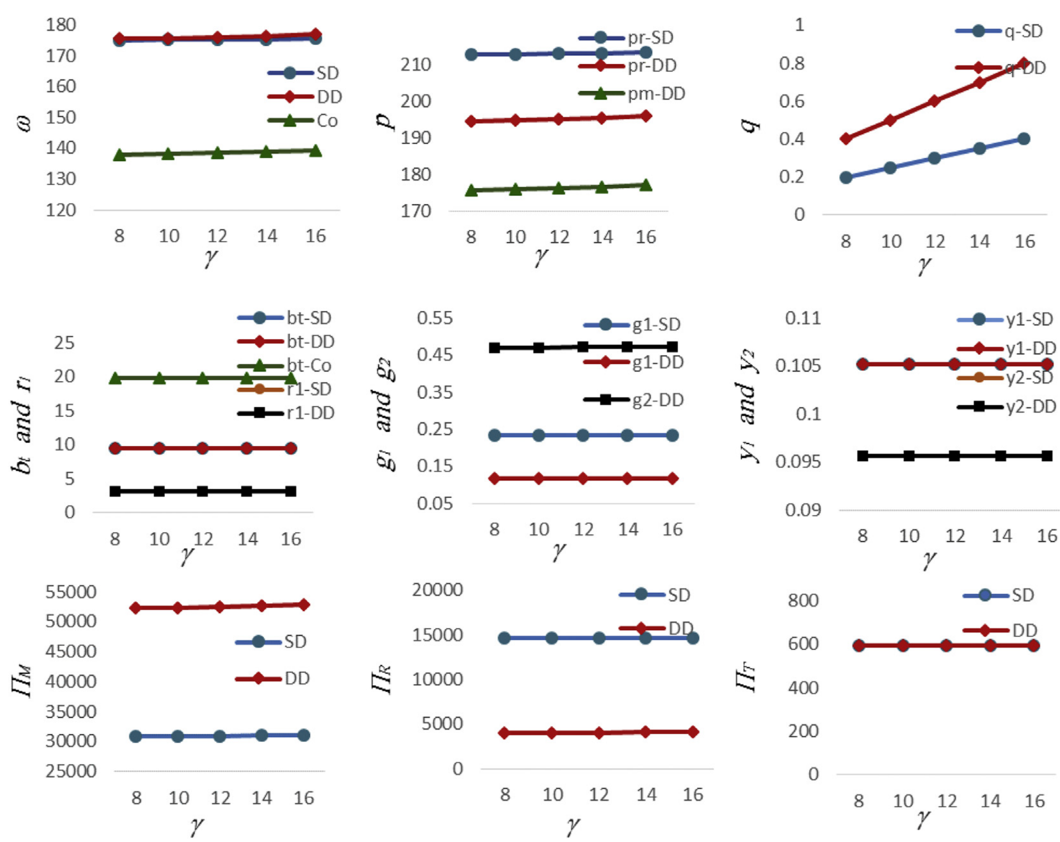


Fig. 7. Effects of γ on optimal solutions and profits.

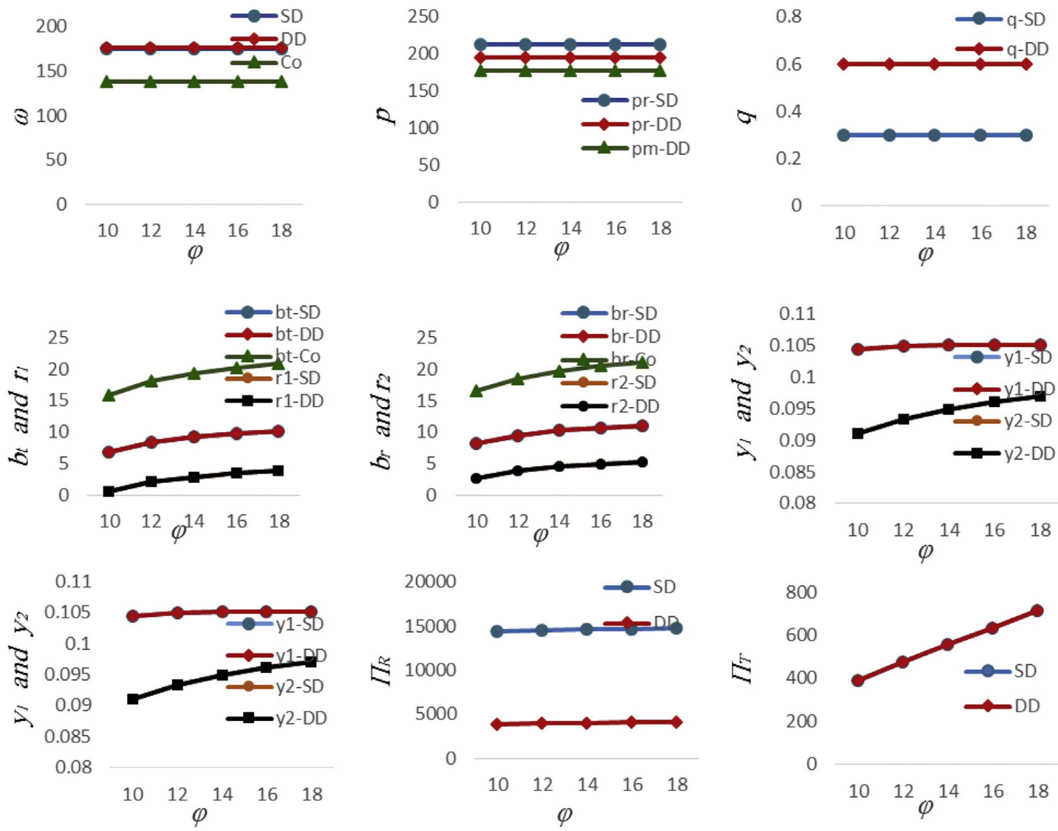


Fig. 8. Effects of φ on optimal solutions and profits.

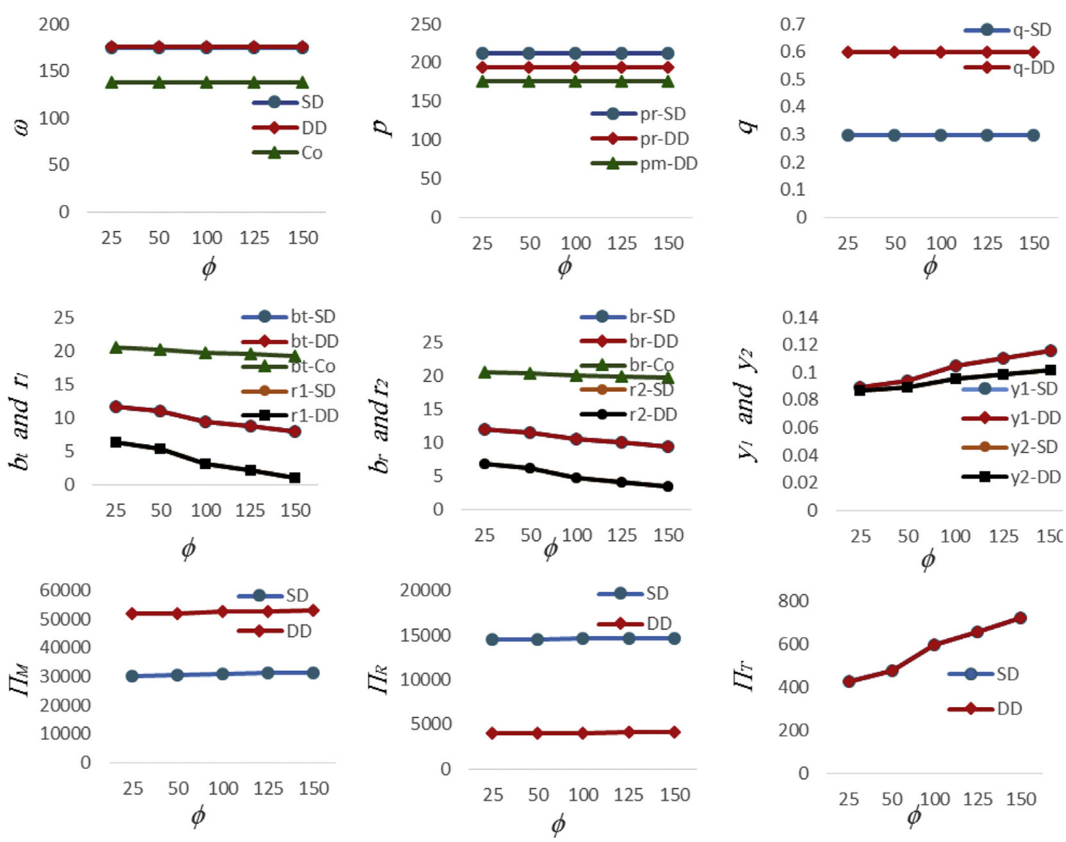


Fig. 9. Effects of ϕ on optimal solutions and profits.

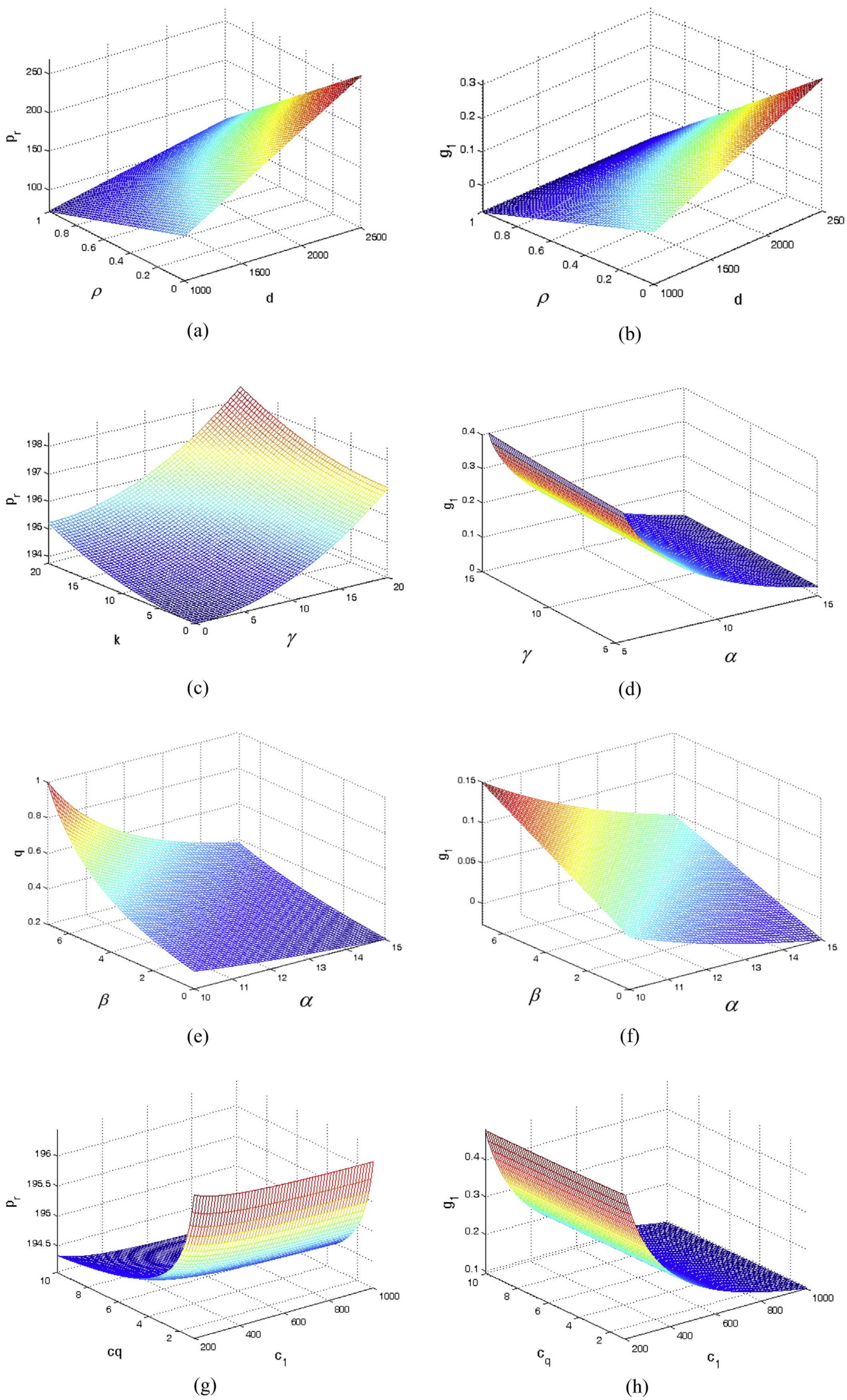


Fig. 10. Changes of the selling price, the quality level, and the sales and collection efforts with respect to various parameters.

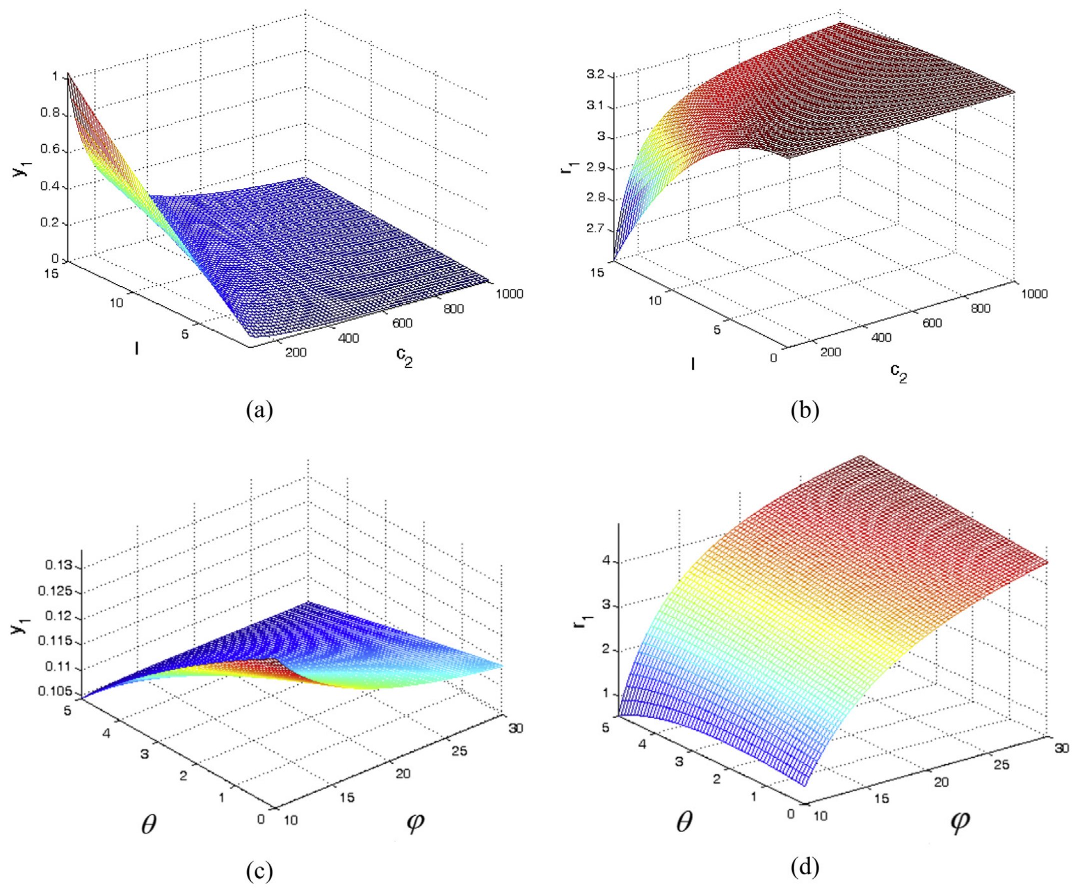


Fig. 11. Changes of the buyback price and the collection effort with respect to various parameters.

$\{F_1 \in [7179.48, 11497.05]$ and $F_2 \in [8298.49 - F_1, 1119.01]\}$. Under this coordination mechanism, the DD model can be effectively coordinated. However, in this example, the channel conflict between the retailer and the manufacturer cannot be eliminated completely, and in this coordinated system, the retailer can only be more satisfied than it can in a situation without the coordination mechanism.

In fact, in this example, by using the relationship proposed in Section 6.1 and using $\overline{F_1} = \Pi_R^{CA*}(\omega^{Co*}, u^{Co*}, b_r^{Co*}, m^{Co*}) - \max\{\Pi_R^{D*}, \Pi_R^{SD*}\}$, the value of $\overline{F_1}$ is obtained as 944.87, which does not satisfy the relationship $\overline{F_1} \geq \underline{F_1}$. Therefore, in this example, the retailer's profit in this coordinated system can only be greater than that of the DD model. For instance, by considering F_1 and F_2 as 7200 and 500, the optimal values of Π_M^{Co*}, Π_R^{Co*}, and Π_T^{Co*} are obtained as 51,930.43, 20,574.42, and 8355.12, respectively.

7.2. Sensitivity analysis

By considering the numerical values of the parameters in Example 2, sensitivity analysis is performed on the key parameters α, δ, φ, ϕ, γ, ψ, and ρ of the models to survey their effects on the values that lead to optimal profits for each supply chain member. Problems were solved with selected values, and the results are shown in Tables 2 and 3.

To illustrate the behavior of the decision variables and the profits for increasing values of the various parameters, the optimal values and total profits were determined. Figs. 2–11 show the outcomes of the parameters changed in both decentralized models.

By using Propositions 7–16, the optimal values of ρ_1, ρ_2, and ρ_3 are 0.510, 0.378, and 0.20, respectively. According to Fig. 4 and Proposition 7, the quality of products in the DD model is always better than that of the products in the SD model. Using Proposition 8, one sees that $\rho_1 = 0.510$. To compare ω^{DD} with ω^{SD}, the value of ρ was changed within the feasible range, as shown in Fig. 4. When ρ is lower than $\rho_1 = 0.510$, the relationship $\omega^{SD} < \omega^{DD}$ is satisfied, and when ρ falls in the range of $0.510 \leq \rho \leq 0.80$, one can conclude that $\omega^{DD} \leq \omega^{SD}$. According to Fig. 4, when ρ is lower than $\rho_2 = 0.378$, the market share of the retailer is high, and the selling price offered by the retailer in the SD model is lower than that in the DD model (i.e., $p_r^{SD} < p_r^{DD}$). However, when ρ exceeds a threshold ρ_2, the relationship $p_r^{DD} \leq p_r^{SD}$ is satisfied. In addition, according to Fig. 4 and Propositions 11 and 13, when the market share of the retailer is lower than 0.20, the retailer exerts greater sales effort in the DD model than in the SD model (i.e., $g_1^{SD} < g_1^{DD}$) and the retailer's profit in the DD model is greater than it is in the SD model (i.e., $\Pi_R^{SD} < \Pi_R^{DD}$). However, when $0.20 \leq \rho \leq 0.80$, $g_1^{DD} \leq g_1^{SD}$ and $\Pi_R^{DD} \leq \Pi_R^{SD}$ are satisfied. Fig. 4 shows changes to the value of ρ within the feasible range. The results indicate that Π_M^{DD} is always greater than Π_M^{SD}; therefore, it is concluded that $\Pi_M^{SD} < \Pi_M^{DD}$. In addition, according to Fig. 5, in the reverse flow, if $0.00 \leq \psi < 0.50$, then $r_1 < r_2$, and $y_1 > y_2$. If $0.50 \leq \psi < 1.00$, then $r_1 > r_2$ and $y_1 < y_2$. Actually, the channel that has more market share exerts more collection efforts and offers a lower buyback price than the other channel.

Fig. 2 illustrates relationships between the selling price, sales effort, and quality level. According to Fig. 2a, as the quality of the products increase, selling price also increases. Fig. 2b shows that by increasing the manufacturer's selling price, the retailer's selling price increases, indicating that the selling prices of both are related to each other. According to Fig. 2c, an incremental increase in the quality of the products results in increasing sales efforts. In other words, as the quality of products increases the manufacturer or the retailer invest more in the advertisement. Fig. 2d indicates that as the selling price of the online channel increases, the retailer exerts more sales effort.

Fig. 3a and b shows that when the transfer price for returning products from the third party increases, the third party increases the collection effort and buyback price. In addition, when the buyback price of the retailer increases, the collection effort of the third party decreases and the third party buyback price increases.

As shown in Tables 2 and 3, when the self-price coefficient (α) increases, ω^*, p_r^*, p_m^*, q^*, g_1^*, g_2^*, Π_M^*, and Π_R^* decrease and r_1^*, r_2^*, y_1^*, y_2^*, and Π_T^* do not change. In fact, when α is increased, the sensitivity of customers to price increases; therefore, according to Fig. 10e, the optimal strategy shifts from production of high-quality goods at high prices to production of goods with relatively low quality at low prices, which leads to decreasing profits for the manufacturer and retailer. Also, the results reveal that as the own price effect increases, sales effort decreases $\left(\frac{\partial g_1^{DD}}{\partial \alpha} = \frac{-k[2c_1(1-\rho)d-\omega k^2+2c_1\beta p_m+2c_1\gamma q]}{(2\alpha c_1-k^2)^2} < \frac{-2c_1 kD_r}{(2\alpha c_1-k^2)^2} < 0\right)$. The effects of α on optimal solutions and profits are shown in Fig. 6.

In addition, Fig. 10e indicates that, as the cross-selling price increases and the competition between channels intensifies, the quality level of products increases. According to Fig. 10f, the increased increments of competition between two selling channels result in increased sales effort. Because of the competition, each channel member tries to exert more effort to increase its profit $\left(\frac{\partial g_1^{DD}}{\partial \beta} = \frac{kp_m}{2\alpha c_1-k^2} > 0\right)$.

When the quality sensitivity parameter (γ) increases in the DD and SD models in which the parameters apply, ω^*, p_r^*, p_m^*, q^*, Π_M^*, and Π_R^* increase and r_1^*, r_2^*, y_1^*, y_2^*, g_1^*, g_2^*, and Π_T^* do not change.

According to Fig. 10c, when the sensitivity of customers to the quality level, γ ,increases, the price of the products increases $\left(\frac{\partial p_r^{DD}}{\partial \gamma} = \frac{c_1\gamma}{2\alpha c_1-k^2} > 0\right)$, and the optimal strategy shifts such that the production of goods with relatively high quality and offered at high prices increase the profits of the manufacturer and the retailer. The effects of γ on the optimal solutions and profits are shown in Fig. 7.

In addition, according to Equation (42), $\frac{\partial p_r^{DD}}{\partial k} = \frac{2c_1 k[(1-\rho)d-\alpha\omega+\beta p_m+\gamma q]}{(2\alpha c_1-k^2)^2} > \frac{2c_1 kD_r}{(2\alpha c_1-k^2)^2} > 0$, which indicates that by increasing the sales effort impact, the prices of the products increase. The effects of γ and k on selling price are shown in Fig. 10c. Also, the effects of α and γ on sales effort are presented in Fig. 10d.

Fig. 10a and b shows that when the basic market demand faced by the retailer, $(1-\rho)d$, increases, the retailer's sales effort and selling price increase as well. In fact, the incremental increase of the potential market demand for the retailer's product motivates the retailer to exert more sales effort and increase the retailer selling price. However, when there is a lack of demand, the retailer prefers to decrease the selling price and exert lower sales effort.

According to Fig. 10g and h, by increasing the quality improvement cost, the selling price of the products decreases. In fact, as the quality improvement cost increases, the quality of the products decreases and as a result, the selling price of the products and the sales effort decrease. In addition, by increasing the sales-effort cost coefficient, the sales effort and the selling price of the products slightly decrease $\left(\frac{\partial p_r^{DD}}{\partial c_1} = \frac{-k^2[(1-\rho)d-\alpha\omega+\beta p_m+\gamma q]}{(2\alpha c_1-k^2)^2} < \frac{2c_1 kD_r}{(2\alpha c_1-k^2)^2} < 0\right.$ and $\left.\frac{\partial g_1^{DD}}{\partial c_1} = \frac{-2\alpha k[(1-\rho)d-\alpha\omega+\beta p_m+\gamma q]}{(2\alpha c_1-k^2)^2} < \frac{2c_1 kD_r}{(2\alpha c_1-k^2)^2} < 0\right)$.

According to Fig. 11a and b, the increment of the sensitivity of customers to the collection effort results in increasing collection effort and decreasing buyback price, and by increasing the collection effort cost coefficient, the collection effort decreases and the buyback price increases. In other words, when the customers are more sensitive to the collection effort, the third party and the retailer prefer to decrease their buyback prices and instead invest in exerting more collection effort. In addition, by increasing l, the sensitivity of the collection effort to the collection-effort cost coefficient increases.

When the self-buyback price effect (φ) increases, the following findings are found in the respective model in which the parameters apply: r_1^*, y_1^*, and y_2^* decrease, r_1^*, Π_M^*, Π_R^*, and Π_T^* increase, and ω^*, p_r^*, p_m^*, g_1^*, g_2^*, and q^* do not change. The results reveal that as the effect of self-buyback price on the return quantity expansion increases, the third party buys used products at high prices and the retailer buys them at low prices and both of them make less effort to collect them. As a result, investments in collection effort decrease and quantity of returns increases, and as a consequence, all three supply chain members earn more profit than when the buyback price is not increased. The effects of φ on optimal solutions and profits are shown in Fig. 8.

Furthermore, according to Fig. 11c and d, when the competition between reverse channels intensifies and the cross-buyback price effect increases, self-buyback price increases $\left(\frac{\partial r_1^{DD}}{\partial \theta} = \frac{c_2 r_2}{2c_2\varphi - l^2} > 0\right)$ and the collection effort decreases $\left(\frac{\partial y_1^{DD}}{\partial \theta} = \frac{-lr_2}{2c_2\varphi - l^2} < 0\right)$. In fact, in this situation, the collector should increase the buyback price and decrease its collection effort.

When the basic return quantity (ϕ) is increased in the DD and SD models in which the parameters apply, r_1^* and r_2^* decrease, y_1^*, y_2^*, Π_M^*, Π_R^*, and Π_T^* increase, and ω^*, p_r^*, p_m^*, g_1^*, g_2^*, and q^* do not change. The results show that as the basic return quantity increases, both the third party and retailer buy used products at high prices and make extensive effort to collect them. As a result, the quantity of returns increases and all three supply chain members earn more profit than when the buyback price remains unchanged. The effects of ϕ on optimal solutions and profits are shown in Fig. 9.

8. Conclusions

In this paper, a joint optimization model of the pricing, return, and quality policies as well as sales and collection efforts, were presented in CLCSs with two types of channel structures that include a manufacturer, retailer, and third party in a Stackelberg situation. Specifically, customer demand was assumed to depend on the cross and buyback prices, quality of products, and the sales effort. Furthermore, customer returns depend on the buyback price and collection effort. Two different channel structures were established to discuss the influence of different channel formats on the manufacturer, retailer, third party, and the entire CLSC. These structures include a single-channel forward supply chain with a dual-recycling channel (SD model) and dual-channel forward supply chain with a dual-recycling channel (DD model) in a decentralized system. Because the emergence of an online selling channel leads to channel conflict, a novel and effective coordination mechanism was introduced to either eliminate or reduce this friction between the retailer and the manufacturer. Furthermore, the equilibrium solutions of two different structures were compared and the results were analyzed. In addition, sensitivity analyses on the main parameters using numerical studies were carried out and thereby several instructive managerial insights were derived. Also, the beneficial choice of channel structure was discussed from the standpoint of the manufacturer, retailer, third party, and customer. The conclusions suggest that customers can select the best structure with respect to the parameters of selling and buyback prices, product quality, and sales effort.

Through the analyses, the following important managerial insights are offered: (1) the manufacturer's profit in the DD model is invariably better than it is in the SD system; (2) the best choice model (SD or DD) for the retailer depends on the level of customer loyalty to the direct channel; (3) the third party's profits in the SD and the DD models are equal; (4) selling and wholesale prices depend on the market share of the direct channel; (5) the quality of products in the DD model is always greater than it is in the SD model; (6) for both the third party and the retailer, the buyback prices in the DD system are equal to the buyback price in the SD system; (7) as the effect of the self-buyback price on the return quantity expansion increases, the third party buys used products at high prices, the retailer buys them at low prices, and both make relatively little effort to collect them, and as a consequence, all three supply chain members earn greater profits than when the buyback price is unchanged; (8) the collection channel member with a predominant market share exerts greater collection effort and offers lower buyback price than the other collection channel; (9) as the competition between selling channels intensifies, the quality of products and the sales effort increase because by intensification of the competition, each channel member tends to exert more effort to increase its profit; furthermore, as the competition between reverse channels intensifies and the cross-buyback price effect increases, the self-buyback price increases and the collection effort decreases; (10) as the quality improvement cost increases, the selling price of the products and the sales effort decrease, and by increasing the sales-effort cost coefficient, the sales effort and the selling price of the products slightly decrease; (11) the increment of the sensitivity of customers to the sales effort results in increasing the price of the products. In addition, when the customers are more sensitive to the collection effort, the third party and the retailer prefer to decrease their buyback prices and instead invest in exerting more collection effort.

The model developed in this paper has a few limitations that should be ameliorated in future research. The CLCS featured one retailer, so future studies could look at a circumstance with multiple retailers. An interesting extension to this work includes consideration of coordination mechanisms, such as revenue sharing. Another possible study direction specifies game models with asymmetric information.

Acknowledgment

The second author would like to thank the financial support of University of Tehran for this research under grant number 30015-1-04. The authors are grateful to four reviewers whose comments were helpful to improve the earlier version of the manuscript.

Appendix A. Proof of Propositions 1 and 4

The Hessian matrix Π_R^{SD} or Π_R^{DD} with respect to $p_r, g_1,$ and y_2 is given by

$$H_R^{SD} = H_R^{DD} = \begin{bmatrix} -2\alpha & k & 0 & 0 \\ k & -c_1 & 0 & 0 \\ 0 & 0 & -c_2 & -l \\ 0 & 0 & -l & -2\varphi \end{bmatrix} \tag{101}$$

To prove that the joint total profit is concave in p_r, g_1, and y_2, we must show that $x \cdot H_R^{SD} \cdot x^T < 0$ or $x \cdot H_R^{DD} \cdot x^T < 0$ where $x = [p_r, g_1, y_2, r_2]$. By Solving $x \cdot H_R^{SD} \cdot x^T < 0$ or $x \cdot H_R^{DD} \cdot x^T < 0$, we can obtain the following condition:

$$c_1 > \frac{2g_1kp_r - 2p_r^2\alpha - 2\varphi r_2^2 - c_2y_2^2 - 2lr_2y_2}{g_1^2} \tag{102}$$

Therefore, if Condition (70) is satisfied, H_R^{SD} or H_R^{DD} will be a negative definite Hessian matrix.

Appendix B. Proof of Propositions 2 and 5

The Hessian matrix associated with the profit function Π_T^{SD} or Π_T^{DD} is given by:

$$H_T^{SD} = H_T^{DD} = \begin{bmatrix} -c_2 & -l \\ -l & -2\varphi \end{bmatrix} \tag{103}$$

To prove that the joint total profit is concave in r_1 and y_1, we need to show that $|H_{1T}| < 0$ and $|H_{2T}| > 0$. Because $c_2 > 0$, $|H_{1T}| = -c_2 < 0$ is always satisfied. Also, by solving $|H_{2T}| = 2c_2\varphi - l^2 > 0$, the following condition is obtained:

$$c_1 > \frac{l^2}{2\varphi} \tag{104}$$

Therefore, if Condition (73) is satisfied, Π_T^{SD}, and Π_T^{DD} will be negative definite Hessian matrices.

Appendix C. Proof of Proposition 3

The Hessian matrix associated with the profit function H_M^{SD} is given by

$$H_M^{SD} = \begin{bmatrix} 0 & \gamma & 0 & 0 \\ \gamma & -2c_q(d + kg_1 - \alpha p_r + 3\gamma q) & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{105}$$

To prove that the Π_M^{SD} joint total profit is concave in ω and q, $x \cdot H_M^{SD} \cdot x^T < 0$ where $x = [\omega, q, A_t, A_r]$ must be proven.

By solving $x \cdot H_M^{SD} \cdot x^T < 0$, we obtain the following condition:

$$c_q > \frac{\gamma\omega}{q(d + g_1k - \alpha p_r + 3\gamma q)} \tag{106}$$

Moreover, to ensure $0 < q^* < 1$, $0 < q^* = \frac{\gamma}{2\alpha c_q} < 1$ is solved to yield the following expression:

$$c_q > \frac{\gamma}{2\alpha} \tag{107}$$

By integrating Conditions (76) and (77), the following is obtained

$$c_q > \max\left\{ \frac{\gamma\omega}{q(g_1 k - (\alpha+\delta)p_r + \delta r_r + 3\gamma q)}, \quad \frac{\gamma}{2\alpha} \right\} \tag{108}$$

Appendix D. Proof of Proposition 6

For Π_M^{DD} The Hessian matrix can be written as follows:

$$H_M^{DD} = \begin{bmatrix} -2\alpha & \beta & \gamma + 2c_q q(\alpha-\beta) & k & 0 & 0 \\ \beta & 0 & \gamma & 0 & 0 & 0 \\ \gamma + 2c_q q(\alpha-\beta) & \gamma & -2c_q(d - (\alpha-\beta)(p_r+p_m) + k(g_1+g_2) + 6\gamma q) & -2c_q kq & 0 & 0 \\ k & 0 & -2c_q kq & -c_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{109}$$

To prove that the joint total profit is concave in $\omega, p_m, q,$ and y_2, $\omega, p_m, q,$ and y_2 where $x = [p_m, \omega, q, g_2, A_t, A_r]$ should be proven. By Solving $x \cdot H_M^{DD} \cdot x^T < 0$, the following condition is obtained:

$$c_q > \frac{\left[2p_m(kg_2 - \alpha p_m + \gamma q + \beta\omega) - c_1 g_2^2 + 2\gamma q\omega\right]}{2q^2[d - (\alpha-\beta)(p_r + 3p_m) + k(g_1 + 3g_2) + 6\gamma q]} \tag{110}$$

Therefore, if Condition (80) is satisfied, H_M^{DD} will be a negative definite Hessian matrix.

Thus, q^{SD} can be obtained by solving the first-order condition as follows:

$$q^{DD*} = \frac{\gamma}{2c_q(\alpha-\beta)} \tag{111}$$

To ensure $0 < q^{DD*} < 1$, we solve $0 < q^{DD*} = \frac{\gamma}{2c_q(\alpha-\beta)} < 1$, which yields the following expression:

$$c_q > \frac{\gamma}{2(\alpha-\beta)} \tag{112}$$

Therefore, Conditions (80) and (82) are integrated as follows:

$$c_q > \max\left\{ \frac{\left[2p_m(kg_2 - \alpha p_m + \gamma q + \beta\omega) - c_1 g_2^2 + 2\gamma q\omega\right]}{2q^2[d - (\alpha-\beta)(p_r + 3p_m) + k(g_1 + 3g_2) + 6\gamma q]}, \frac{\gamma}{2(\alpha-\beta)} \right\} \tag{113}$$

Appendix E. Proof of Proposition 7

To show that $q^{SD} < q^{DD}$, $\frac{q^{DD}}{q^{SD}} > 1$ should be proven. The following condition is used

$$\frac{q^{DD}}{q^{SD}} = \frac{\alpha+\delta}{\alpha-\beta+\delta} > 1 \tag{114}$$

According to Equation (84), $q^{SD} < q^{DD}$ is proven.

Appendix F. Proof of Proposition 8

Fig. 2 shows that there is a possibility that $\omega^{DD} = \omega^{SD}$. Because $\frac{\partial\omega^{DD}}{\partial\rho} > 0$ and $\frac{\partial\omega^{SD}}{\partial\rho} = 0$, ρ_1 may exist in the feasible range of ρ, making $\omega^{DD} = \omega^{SD}$. ρ_1 can be obtained by solving $\omega^{DD} = \omega^{SD}$. So, ρ_1 is given by

$$\rho_1 = \frac{\begin{array}{l} 4\alpha\beta^2 c_q(\alpha-\beta)^2\left[\alpha d c_1\left[8\alpha c_1 + 6k^2\right] + k^4[\alpha c_m + d] - 2\alpha c_m c_1 k^2(\alpha+\beta)\right] - 2\alpha\beta c_1\gamma^2 k^2\left(24\alpha^3 + 13\alpha^2\beta + 13\alpha\beta^2 + 6\beta^2\right) \\ +24\alpha^2\beta c_1^2\gamma^2(2\alpha-\beta)(\alpha+\beta)(\alpha-\beta) + \beta\gamma^2 k^4\left(12\alpha^3 - 7\alpha^2\beta - 6\alpha\beta^2 + 3\beta^3\right) \end{array}}{8\alpha^2 c_q d(\alpha-\beta)^2\left[(\alpha-\beta)\left[4\alpha c_1(\alpha c_1 - k^2) + k^4\right] - \beta^2 c_1 k^2\right]} \tag{115}$$

Appendix G. Proof of Proposition 9

Fig. 2 shows that there is a possibility that $p_r^{DD} = p_r^{SD}$. Because $\frac{\partial p_r^{DD}}{\partial\rho} > 0$ and $\frac{\partial p_r^{SD}}{\partial\rho} = 0$, ρ_2 may exist in the range of $\max\{\rho_{\min}, 0\} \le \rho \le \min\{\rho_{\max}, 1\}$ making $p_r^{DD} = p_r^{SD}$. ρ_2 can be obtained by solving $p_r^{DD} = p_r^{SD}$. Therefore, ρ_2 is given as follows:

$$\rho_2 = \frac{\begin{array}{l} 4\alpha\beta c_q(\alpha-\beta)^2\left[16\alpha^2\beta d c_1^2\left(\alpha c_1 - k^2\right) - \alpha^2 c_1 c_m k^2\left[4c_1\left(3\alpha^2 + \alpha\beta - \beta^2\right) - k^2(4\alpha+3\beta)\right] + 7c_1\alpha\beta d k^4 - \beta k^6(\alpha c_m + d) + 8\alpha^3 c_m c_1^3(\alpha-\beta)(\alpha+\beta)\right] - \beta\gamma^2 k^6\left(12\alpha^3 - 7\alpha^2\beta - 6\alpha\beta^2 + 3\beta^3\right) \\ -\alpha\beta c_1\gamma^2 k^2\left[4\alpha c_1\left(37\alpha^3 - 21\alpha^2\beta - 25\alpha\beta^2 + 13\beta^3\right) - k^2\left(72\alpha^3 - 41\alpha^2\beta - 38\alpha\beta^2 + 19\beta^3\right)\right] + 8\alpha^3\beta c_1^3\gamma^2(13\alpha - 7\beta)\left(\alpha^2 - \beta^2\right) \end{array}}{8\alpha^2 c_q d(\alpha-\beta)^2(2\alpha c_1 - k^2)\left[(\alpha-\beta)\left[2\alpha c_1^2(3\alpha+\beta) + k^4\right] - \alpha c_1 k^2(5\alpha - 3\beta)\right]} \tag{116}$$

Appendix H. Proof of Proposition 10

According to the optimal buyback prices in the SD and DD models, $r^{SD} = r^{DD}$. Also, according to the optimal values for the collection efforts in the SD and DD models, $y_1^{SD} = y_1^{DD}$.

Appendix I. Proof of Proposition 11

Fig. 2 shows that there is a possibility that $g_1^{DD} = g_1^{SD}$. Because $\frac{\partial g_1^{DD}}{\partial \rho} > 0$ and $\frac{\partial g_1^{SD}}{\partial \rho} = 0$, ρ_3 may exist in the range of $\max\{\rho_{\min}, 0\} \le \rho \le \min\{\rho_{\max}, 1\}$, making $g_1^{DD} = g_1^{SD}$, ρ_3 obtainable by the solution of $g_1^{DD} = g_1^{SD}$. Therefore, $\rho_3$is given by:

$$\rho_3 = \frac{4\beta(\alpha-\beta)\left[c_m c_q k^2\left[4\alpha c_1\left(3\alpha^2-2\beta^2\right)-k^2\left(4\alpha^2-\alpha\beta-2\beta^2\right)\right]-\alpha\beta c_q d k^2(4\alpha c_1-k^2)\right]+4\alpha\beta c_1\gamma^2k^2\left(\alpha^2-\alpha\beta-\beta^2\right)-8\alpha^2\beta c_1^2(\alpha-\beta)(\alpha+\beta)[4\alpha c_m c_q(\alpha-\beta)+\gamma^2]+\beta\gamma^2k^4(\alpha+\beta)}{8\alpha c_q d(\alpha-\beta)(2\alpha c_1-k^2)\left[k^2\left(\alpha^2+\alpha\beta-\beta^2\right)-2\alpha c_1\left(\alpha^2-\beta^2\right)\right]} \tag{117}$$

Appendix J. Proof of Proposition 12

In the DD model, the manufacturer sells products through the direct channel and retailers; therefore, the manufacturer's profit in the DD model is greater than it is in the SD model (as shown in Fig. 4). To prove this proposition, $\Pi_M^{DD} - \Pi_M^{SS} < 0$ and $\Pi_M^{DD} - \Pi_M^{SD} < 0$ must be proven. Because the Proof of this expression is similar to the previous proofs and is huge, it is omitted.

Appendix K. Proof of Proposition 13

Fig. 2 shows that there is a possibility that $\Pi_R^{SD} = \Pi_R^{DD}$. Because $\frac{\partial \Pi_R^{DD}}{\partial \rho} < 0$ and $\frac{\partial \Pi_R^{SD}}{\partial \rho} = 0$, ρ_3 may exist in the feasible range of ρ, making $\Pi_R^{SD} = \Pi_R^{DD}$. Solving $\Pi_R^{SD} = \Pi_R^{DD}$ yields ρ_3 (see Appendix I).

Appendix L. Proof of Proposition 14

According to the optimal profit of the third party in the SD and DD models, $r_1, r_2, y_1,$ and y_2 in the DD model are equal to those in the SD model, and thus, it is concluded that $\Pi_T^{SD} = \Pi_T^{DD}$. The result comes from the reverse supply chain in DD and SD models having the same structure.

Appendix M. Proof of Proposition 15

Fig. 2 shows that there is a possibility that $r_1 = r_2$. Because $\frac{\partial r_1}{\partial \psi} > 0$ and $\frac{\partial r_2}{\partial \psi} < 0$, ψ_1 may exist in the range of $\max\{\psi_{\min}, 0\} \le \psi \le \min\{\psi_{\max}, 1\}$ making $r_1 = r_2$. Therefore, By solving $r_1 = r_2$, ψ_1 can be obtained as $\psi_1 = 1/2$.

Appendix N. Proof of Proposition 16

Fig. 2 shows that there is a possibility that $y_1 = y_2$. Because $\frac{\partial y_1}{\partial \psi} < 0$ and $\frac{\partial y_2}{\partial \psi} > 0$, ψ_2 may exist in the range of $\max\{\psi_{\min}, 0\} \le \psi \le \min\{\psi_{\max}, 1\}$ making $y_1 = y_2$. By solving $y_1 = y_2$, ψ_2 can be obtained as $\psi_2 = 1/2$.

Appendix O. Proof of Proposition 17

For Π_C, the Hessian matrix is obtained as follows:

$$H_C = \begin{bmatrix} -2\alpha & 2\beta & \gamma+2c_q q(\alpha-\beta) & k & 0 & 0 & 0 & 0 & 0 \\ 2\beta & -2\alpha & \gamma+2c_q q(\alpha-\beta) & 0 & k & 0 & 0 & 0 & 0 \\ \gamma+2c_q q(\alpha-\beta) & \gamma+2c_q q(\alpha-\beta) & -2c_q(d-(\alpha-\beta)(p_r+p_m)+k(g_1+g_2)+6\gamma q) & -2c_q kq & -2c_q kq & 0 & 0 & 0 & 0 \\ k & 0 & -2c_q kq & -c_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & k & 0 & 0 & -c_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -2\varphi & 2\theta & -l & 0 \\ 0 & 0 & 0 & 0 & 0 & 2\theta & -2\varphi & 0 & -l \\ 0 & 0 & 0 & 0 & 0 & -l & 0 & -c_2 & 0 \\ & 0 & 0 & 0 & 0 & 0 & -l & 0 & -c_2 \end{bmatrix} \tag{118}$$

In order to prove that the joint total profit is concave in $p_r^C, p_m^C, q^C, g_1^C, g_2^C, r_1^C, r_2^C, y_1^C,$ and y_2^C, $x \cdot H_C \cdot x^T < 0$, where $x = [p_r^C, p_m^C, q^C, g_1^C, g_2^C, r_1^C, r_2^C, y_1^C, y_2^C]$ must be proven.

By solving $x \cdot H_C \cdot x^T < 0$, the following condition is obtained:

$$c_q > \frac{2p_r(kg_1-\alpha p_r+\gamma q)+2p_m(kg_2-\alpha p_m+\gamma q)+4\beta p_r p_m+c_1(g_1^2+g_2^2)-2\varphi(r_1^2+r_2^2)+4\theta r_1 r_2-2l(r_1y_1+r_2y_2)+c_2(y_1^2+y_2^2)}{2q^2[d-3\alpha(p_r+p_m)+3k(g_1+g_2)+6\gamma q]} \tag{119}$$

Therefore, similar to Appendix D, by considering quality level condition, the following condition is obtained:

$$c_q > \max\left\{\frac{2p_r(kg_1 - \alpha p_r + \gamma q) + 2p_m(kg_2 - \alpha p_m + \gamma q) + 4\beta p_r p_m + c_1\left(g_1^2 + g_2^2\right) - 2\varphi\left(r_1^2 + r_2^2\right) + 4\theta r_1 r_2 - 2l(r_1 y_1 + r_2 y_2) + c_2\left(y_1^2 + y_2^2\right)}{2q^2[d - 3\alpha(p_r + p_m) + 3k(g_1 + g_2) + 6\gamma q]}, \quad \frac{\gamma}{2(\alpha - \beta)}\right\} \tag{120}$$

References

Ai, X., Chen, J., Zhao, H., Tang, X., 2012. Competition among supply chains: implications of full returns policy. Int. J. Prod. Econ. 139 (1), 257–265.

Atasu, A., Toktay, L.B., Van Wassenhove, L.N., 2013. How collection cost structure drives a manufacturer's reverse channel choice. Prod. Oper. Manag. 22 (5), 1089–1102.

Baiman, S., Fischer, P.E., Rajan, M.V., 2000. Information, contracting, and quality costs. Manag. Sci. 46 (6), 776–789.

Banker, R.D., Khosla, I., Sinha, K.K., 1998. Quality and competition. Manag. Sci. 44 (9), 1179–1192.

Bonifield, C., Cole, C., Schultz, R.L., 2010. Product returns on the Internet: a case of mixed signals? J. Bus. Res. 63 (9), 1058–1065.

Cai, G.G., 2010. Channel selection and coordination in dual-channel supply chains. J. Retailing 86 (1), 22–36.

Chen, T.-H., 2015. Effects of the pricing and cooperative advertising policies in a two-echelon dual-channel supply chain. Comput. Ind. Eng. 87, 250–259.

Chiang, W.-y.K., Chhajed, D., Hess, J.D., 2003. Direct marketing, indirect profits: a strategic analysis of dual-channel supply-chain design. Manag. Sci. 49 (1), 1–20.

Choi, T.-M., Li, Y., Xu, L., 2013. Channel leadership, performance and coordination in closed loop supply chains. Int. J. Prod. Econ. 146 (1), 371–380.

Dan, B., Xu, G., Liu, C., 2012. Pricing policies in a dual-channel supply chain with retail services. Int. J. Prod. Econ. 139 (1), 312–320.

Davis, S., Hagerty, M., Gerstner, E., 1998. Return policies and the optimal level of "hassle". J. Econ. Bus. 50 (5), 445–460.

De Giovanni, P., 2011. Quality improvement vs. advertising support: which strategy works better for a manufacturer? Eur. J. Oper. Res. 208 (2), 119–130.

Fruchter, G.E., Tapiero, C.S., 2005. Dynamic online and offline channel pricing for heterogeneous customers in virtual acceptance. Int. Game Theor. Rev. 7 (02), 137–150.

Gans, N., 2002. Customer loyalty and supplier quality competition. Manag. Sci. 48 (2), 207–221.

Gao, J., Han, H., Hou, L., Wang, H., 2016. Pricing and effort decisions in a closed-loop supply chain under different channel power structures. J. Clean. Prod. 112, 2043–2057.

Ghosh, D., Shah, J., 2012. A comparative analysis of greening policies across supply chain structures. Int. J. Prod. Econ. 135 (2), 568–583.

Govindan, K., Soleimani, H., 2017. A review of reverse logistics and closed-loop supply chains: a Journal of Cleaner Production focus. J. Clean. Prod. 142, 371–384.

Govindan, K., Soleimani, H., Kannan, D., 2015. Reverse logistics and closed-loop supply chain: a comprehensive review to explore the future. Eur. J. Oper. Res. 240 (3), 603–626.

Guide, V.D.R., Wassenhove, L.N., 2003. Business Aspects of Closed-loop Supply Chains. Carnegie Mellon University Press, Pittsburgh, PA.

Hess, J.D., Mayhew, G.E., 1997. Modeling merchandise returns in direct marketing. J. Interact. Market. 11 (2), 20–35.

Hong, X., Wang, Z., Wang, D., Zhang, H., 2013. Decision models of closed-loop supply chain with remanufacturing under hybrid dual-channel collection. Int. J. Adv. Manuf. Technol. 68 (5–8), 1851–1865.

Hong, X., Xu, L., Du, P., Wang, W., 2015. Joint advertising, pricing and collection decisions in a closed-loop supply chain. Int. J. Prod. Econ. 167, 12–22.

Hua, G., Wang, S., Cheng, T.E., 2010. Price and lead time decisions in dual-channel supply chains. Eur. J. Oper. Res. 205 (1), 113–126.

Huang, M., Song, M., Lee, L.H., Ching, W.K., 2013. Analysis for strategy of closed-loop supply chain with dual recycling channel. Int. J. Prod. Econ. 144 (2), 510–520.

Huang, M., Yi, P., Shi, T., Guo, L., 2015. A modal interval based method for dynamic decision model considering uncertain quality of used products in remanufacturing. J. Intell. Manuf. 1–11.

Jiang, C., Xu, F., Sheng, Z., 2010. Pricing strategy in a dual-channel and remanufacturing supply chain system. Int. J. Syst. Sci. 41 (7), 909–921.

Kenne, J.-P., Dejax, P., Gharbi, A., 2012. Production planning of a hybrid manufacturing–remanufacturing system under uncertainty within a closed-loop supply chain. Int. J. Prod. Econ. 135 (1), 81–93.

Kusumastuti, R.D., Piplani, R., Lim, G.H., 2008. Redesigning closed-loop service network at a computer manufacturer: a case study. Int. J. Prod. Econ. 111 (2), 244–260.

Li, B., Zhu, M., Jiang, Y., Li, Z., 2016. Pricing policies of a competitive dual-channel green supply chain. J. Clean. Prod. 112, 2029–2042.

Li, Y., Xu, L., Li, D., 2013. Examining relationships between the return policy, product quality, and pricing strategy in online direct selling. Int. J. Prod. Econ. 144 (2), 451–460.

Liu, Z.L., Anderson, T.D., Cruz, J.M., 2012. Consumer environmental awareness and competition in two-stage supply chains. Eur. J. Oper. Res. 218 (3), 602–613.

Lu, Q., Liu, N., 2015. Effects of e-commerce channel entry in a two-echelon supply chain: a comparative analysis of single-and dual-channel distribution systems. Int. J. Prod. Econ. 165, 100–111.

Ma, P., Wang, H., Shang, J., 2013a. Contract design for two-stage supply chain coordination: integrating manufacturer-quality and retailer-marketing efforts. Int. J. Prod. Econ. 146 (2), 745–755.

Ma, P., Wang, H., Shang, J., 2013b. Supply chain channel strategies with quality and marketing effort-dependent demand. Int. J. Prod. Econ. 144 (2), 572–581.

Maiti, T., Giri, B., 2015. A closed loop supply chain under retail price and product quality dependent demand. J. Manuf. Syst. 37, 624–637.

Majumder, P., Srinivasan, A., 2006. Coordination in serial supply chains. Prod. Oper. Manag. 15 (1), 22–39.

Moriarty, R.T., Moran, U., 1990. Managing hybrid marketing systems. Harv. Bus. Rev. 146–156.

Moshtagh, M.S., Taleizadeh, A.A., 2017. Stochastic integrated manufacturing and remanufacturing model with shortage, rework and quality based return rate in a closed loop supply chain. J. Clean. Prod. 141, 1548–1573.

Mukhopadhyay, S.K., Setoputro, R., 2004. Reverse logistics in e-business: optimal price and return policy. Int. J. Phys. Distrib. Logist. Manag. 34 (1), 70–89.

Ren, Z.J., Zhou, Y.-P., 2008. Call center outsourcing: coordinating staffing level and service quality. Manag. Sci. 54 (2), 369–383.

Savaskan, R.C., Bhattacharya, S., Van Wassenhove, L.N., 2004. Closed-loop supply chain models with product remanufacturing. Manag. Sci. 50 (2), 239–252.

Savaskan, R.C., Van Wassenhove, L.N., 2006. Reverse channel design: the case of competing retailers. Manag. Sci. 52 (1), 1–14.

Shulman, J.D., Coughlan, A.T., Savaskan, R.C., 2009. Optimal restocking fees and information provision in an integrated demand-supply model of product returns. Manuf. Serv. Oper. Manag. 11 (4), 577–594.

Singer, M., Donoso, P., Traverso, P., 2003. Quality strategies in supply chain alliances of disposable items. Omega 31 (6), 499–509.

Taleizadeh, A.A., Moshtagh, M.S., Moon, I., 2017. Optimal decisions of price, quality, effort level and return policy in a three-level closed-loop supply chain based on different game theory approaches. Eur. J. Ind. Eng. 11 (4), 486–525.

Taleizadeh, A.A., Cardenas-Barron, L.E., Mohammadi, B., 2014. Multi product single machine EPQ model with backordering, scraped products, rework and interruption in manufacturing process. Int. J. Prod. Econ. 150, 9–27. April 2014.

Taylor, T.A., 2002. Supply chain coordination under channel rebates with sales effort effects. Manag. Sci. 48 (8), 992–1007.

Tedeschi, B., 2000. Compressed data; big companies go slowly in devising net strategy. N. Y. Times 27.

Tsay, A.A., Agrawal, N., 2004. Channel conflict and coordination in the e-commerce age. Prod. Oper. Manag. 13 (1), 93–110.

Xie, G., Wang, S., Lai, K.K., 2011. Quality improvement in competing supply chains. Int. J. Prod. Econ. 134 (1), 262–270.

Yan, R., Pei, Z., 2009. Retail services and firm profit in a dual-channel market. J. Retailing Consum. Serv. 16 (4), 306–314.

Yao, W., Chen, M., 2007. Comparison among closed-loop supply chain models. Commer. Res. 1, 51–53.

Yi, P., Huang, M., Guo, L., Shi, T., 2016a. Dual recycling channel decision in retailer oriented closed-loop supply chain for construction machinery remanufacturing. J. Clean. Prod. 137, 1393–1405.

Yi, P., Huang, M., Guo, L., Shi, T., 2016b. A retailer oriented closed-loop supply chain network design for end of life construction machinery remanufacturing. J. Clean. Prod. 124, 191–203.

Yu, C.-C., Wang, C.-S., 2008. A hybrid mining approach for optimizing returns policies in e-retailing. Expert Syst. Appl. 35 (4), 1575–1582.

Yu, J., Ma, S., 2013. Impact of decision sequence of pricing and quality investment in decentralized assembly system. J. Manuf. Syst. 32 (4), 664–679.