

## Coordination of a Bi-Level Closed-Loop Supply Chain Considering Economical and Green Transportation Modes

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### KEYWORDS

Supply chain coordination;  
Closed-loop;  
Game theory;  
Transportation mode;  
Collection effort.

### ABSTRACT

In recent years, comprehensive researches have provided ample support for the supply chains in the coordinated decision-making framework. However, the issue of closed-loop supply chain coordination considering various transportation modes has not yet been addressed in the literature. In this paper, a two-echelon closed-loop supply chain consisting of a manufacturer and a retailer is investigated in which the manufacturer acts as a Stackelberg leader, and the retailer plays the follower role. All transportation activities between the channel members are carried out via two transportation types including the economical and green modes. First, the proposed problem is examined under the decentralized and centralized settings. Then, a mathematical modeling is developed to coordinate the decisions related to retail price, collection effort, and the ratio of transportation mode selection. Finally, some numerical examples are applied with the aim of analyzing the performance of decentralized, centralized, and coordinated decision-making structures. The results reveal that not only the Pareto optimal solution is achievable for both channel members, but also the coordination scheme has sufficient efficiency to reach the best solution up to the centralized setting.

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### 1. Introduction

Supply chain coordination (SCC) is an effective improving approach that seeks to make some changes to inefficient decentralized decision-making structures. Following such a policy, it is possible to achieve the global optimal system

performance called “integrated” or “centralized” supply chain.

On the other hand, the joint issue of SCC and closed-loop supply chain (CLSC) is another stream of studies that has attracted the attention of many scholars. The concept of CLSC has emerged from the integration of forward and reverse logistics as traditional and modern processes, respectively [1]. As a whole, CLSC management comprises some forward and reverse operations (i.e., serving customers, remanufacturing, reusing, repairing, reworking,

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disposing, etc.) with the focus on green aims, reduction in the use of natural resources, returning the used products, and so on [2]. In recent three years, a growing number of researchers tend to address the coordination of CLSCs via various incentive mechanisms and contracts. However, they never highlighted the issue of transportation processes in their works. That is while due to the above-mentioned importance of CLSC, coordination of a CLSC system considering the transportation mode decisions is conducted in this paper, which can provide a more attractive subject in the literature. Herein, it is noteworthy to discuss the issue of why transportation is important in supply chains. According to the report published in [3], about 27% of the total greenhouse gas emissions in the U.S. is rooted in transportation processes. More importantly, the major source of launching various types of transportation systems positions is the fossil fuels family, which are the main reason for emitting CO<sub>2</sub> to the environment. Compared to the natural sources of CO<sub>2</sub> emissions, the human ones include a much smaller proportion. However, the human sources have even greater impacts on global warming, because the released gases by natural sources are completely compensated during the internal reactions. On the other hand, global warming as an important critical issue in the world strongly depends on CO<sub>2</sub> emissions and any other greenhouse gases. It should be mentioned that global warming is a serious disaster that gradually leads to some weather changes like drought, heavy storms, and so on [4]. Based on the above-mentioned facts about the importance of transportation activities in the real world, it can be concluded that the decisions related to the transportation mode selection in forward/reverse channels may play an important role in supply chain management. Furthermore, regarding the lack of the transportation mode decision in the closed-loop supply chain coordination (CLSCC) topic, we seek to investigate a new stream of researches in the SCC literature including the simultaneous pricing, collection effort, and transportation decisions in a CLSC.

In this paper, a coordination of a two-echelon CLSC consisting of a single manufacturer and a single retailer is developed. The proposed problem is a type of leader-follower Stackelberg game in which the manufacturer and the retailer are leader and follower, respectively. According to the mentioned research gaps in the field of transportation systems, coordinating the

transportation mode decisions in both forward and reverse channels of a CLSC is investigated. For more details, it should be noted that transportation modes are classified into two distinct groups: economical and green vehicles. Hereinafter, we consider the economical transportation mode as a cheap and non-clean vehicle; on the contrary, the green transportation mode is a costly and clean vehicle. As a whole, in this paper, we face an economical objective function that addresses a bi-level problem with the aim of maximizing the channel partners profit functions.

The main novelties of the current paper that differentiate it from similar studies can be mentioned as follows:

- Investigating the coordination of a novel bi-level CLSC system
- Investigating the simultaneous coordination of three decision variables including retail price, collection effort, and the ratio of transportation mode
- Considering economical and green transportation modes as two distinct categories of transportation activities in the forward and reverse logistics
- Developing an economically mathematical modeling as an efficient tool for coordinating the presented problem besides achieving a Pareto improving solution for the retailer and manufacturer

The remainder of the current paper is organized as follows. Section 2 states a brief literature review about CLSCC. Section 3 describes the proposed problem and the corresponding assumptions. In Section 4, the bi-level model is investigated under two prevalent scenarios called decentralized and centralized decision-making structures. Section 5 presents a mathematical modeling that is developed with the aim of coordinating the members' decisions. In Section 6, some sensitivity analyses besides the numerical evaluations are provided. Finally, this study is concluded in Section 7.

## 2. Literature Review

In this section, a brief literature review in the area of closed-loop supply chain coordination is provided to better distinguish the contributions of the extant study compared to the relevant research works.

In recent years, a large number of research efforts have been performed on the stream of CLSC management that mostly seek to obtain economical and green systems. Generally, CLSC

management deals with a specific type of products that are called end-of-life (EOL). This kind of products continuously flows in the forward and reverse logistics and has some unique characteristics [5]. With reference to the literature, it can be seen that some general concepts, such as supply chain network design, are comprehensively studied in the closed-loop framework. However, the growing concept of SCC has not yet been studied well in this area. Further investigations specify the fact that the stream of CLSC coordination is becoming more severe and has attracted worldwide attention over only last three years. For more details about the coordination concepts in the reverse channels or even forward/reverse networks, two interesting review works, [6] and [7], exist. [6] focused on coordination by contracts literature in the reverse and forward supply chains and classified the related studies based on the inventory risk sharing and transfer payment contractual incentive criteria. Recently, [7] presented a state-of-the-art literature review on supply chain contracts considering the reverse channels between 2006 to 2016. They mostly focused on two major factors, including the channel leadership and supply chain links, to categorize the related papers. [8] is as one of the first studies that specifically corresponds to the issue of CLSC coordination. They discussed the choice of the best structure of the reverse supply chain to collect the EOL products from customers. Three major strategies for the collection activities are proposed: (1) the manufacturer itself collects the used products; (2) the manufacturer induces the retailer to collect the used products; (3) the manufacturer signs a contract with the third party to tackle the issue of collecting used items from customers. Next, they model the problem under the mentioned scenarios in a multi-level form using the game theory approach. After a few years, to complete the previous work, [9] proposed the same problem, yet with a focus on determining which player is better to be the Stackelberg leader in the channel. Therefore, they considered a three-echelon supply chain in which the collector is responsible for collecting the returned products and examining the problem when the manufacturer, collector, and retailer are the leader, respectively. Finally, they coordinated the proposed problem via two-part tariff and novel revenue sharing contracts. [10] incorporated the issue of advertising in a CLSC and investigated the effect of cooperative advertising on reverse logistics performance, pricing decisions, total profit, and market

demand. They concluded that cooperative advertising was not able to coordinate the assumed supply chain as an incentive scheme; however, a two-part tariff could achieve SCC. Again, [11] discussed the effects of different channel leaderships on various decisions of CLSCs. They considered a price- and effort-dependent market demand and attempted to coordinate the retail price, sales effort, and collection effort decisions under different types of games and channel leadership through an extended promotion strategy. [12] investigated a two-stage CLSC in a dynamic environment in which both channel partners are involved in used products recovery plan with the aim of enhancing the return rate. Then, they studied the coordination of the designed supply chain by implementing novel incentive strategies. [13] proposed a three-echelon CLSC comprising a manufacturer, retailer, and 3PL in which the 3PL performed the remanufacturing and recycling activities of the patented products under the original manufacturer's license. They studied the efficiency of revenue sharing and two-part tariff contracts in coordinating the forward and reverse decisions. [14] coordinated the CLSC partners for the product-line-design program where both original and remanufactured products exist in the chain. They also proposed a non-dominated sorting genetic algorithm II (NSGA-II) to optimize the presented multi-objective problem under the leader-follower Stackelberg game approach. [15] developed a revenue sharing contract in order to coordinate a dual-channel CLSC with fluctuating recycle rate. They also analyzed the effects of cooperative advertising on the mentioned closed-loop system. [16] modeled a two-level CLSC by considering three environmental factors including energy usage, greenhouse gas emission, and allowable remanufacturing times under the classic and VMI coordination modes. [17] explored the issue of corporate social responsibility in a CLSC. They sought to present a model to simultaneously coordinate the economic and social decisions; to achieve this goal, they suggested a revenue sharing contract as a coordination plan to solve the existing conflicts between the chain members. According to the above-mentioned literature review, the issue of CLSC is widely surveyed between 2015 and 2017. However, some research gaps still exist in this field of study that have not yet been addressed. One important issue concerns the transportation decisions that play an important role in channels' economic and environmental objectives. Motivated by the

significant importance of transportation processes, the coordination and optimization of the transportation mode selection is investigated in this paper, which is a novel issue particularly when we face a CLSC with further decision variables such as retail price and collection effort. In other words, classifying the transportation modes into economical and green groups as well as analyzing which mode with how much selection ratio is proper make an attractive subject in the coordination literature. Finally, a novel economical-mathematical modeling is proposed to coordinate the whole supply chain, which has some differences with prevalent coordination plans such as contracts.

### 3. Notations, Problem Descriptions and Assumptions

#### 3-1. Notations

The following notations, including the parameters and decision variables, are applied to the mathematical modeling of the proposed problem.

##### Parameters

$\alpha$	Market base
$\beta$	Demand sensitivity to retail price
$\tau$	Return rate sensitivity to collection effort
$\delta$	Return rate sensitivity to transportation mode
$c_m$	Manufacturing cost per original product
$c_r$	Remanufacturing cost per returned product
$\chi$	Percentage of returned products sent for disposing
$c_d$	Disposal cost of per collected item
$c_e$	Transportation cost per shipped item by economical transportation mode
$c_g$	Transportation cost per shipped item by green transportation mode
$s$	Price of per collected item paid by retailer to the customer
$A$	Coefficient of investing on collection effort activities
$\Pi_n^m$	Profit function related to member $n$ under decision-making structure $m$

##### Decision variables

$p$	Retail price per manufactured or remanufactured unit determined by retailer
$e$	Collection effort level in the reverse channel determined by retailer
$\theta$	The transportation mode selection ratio determined by retailer
$w$	Wholesale price per manufactured or remanufactured unit determined by manufacturer
$b$	Buy-back price of per returned item in the reverse channel determined by manufacturer

Of note, superscript  $m \in \{C, DC, COO\}$  states the centralized, decentralized, and coordination models, respectively. Furthermore, subscript  $n \in \{R, M, SC\}$  represents the retailer, manufacturer, and supply chain, respectively.

#### 3-2. Problem description

This study investigates a two-echelon bi-level CLSC comprising a manufacturer and a retailer. Before the start of sales season, the retailer registers a deterministic value as the market demand. Then, the manufacturer performs two major activities including manufacturing process on raw material and remanufacturing process on used products. After the provision of the received order quantity by the manufacturer, it declares to the retailer to take the products to market. The retailer ships the ordered products to her/his own site and sells them to customers to complete the processes of the forward channel. As the nearest member to end customers, the retailer itself collects the used products from the users and again transfers them to manufacturer's site in the reverse channel. As already mentioned, the retailer itself selects the transportation mode based on some economical and green objectives. By starting the sales season, the customers visit the market and purchase the new and remanufactured products at the same retail price. It is noteworthy to mention that, in the reverse logistics, due to some environmental concerns, the retailer motivates the customers to bring back the used items which, hereinafter, we call them collection effort activities. Figure 1 shows a schematic view of the defined supply chain.

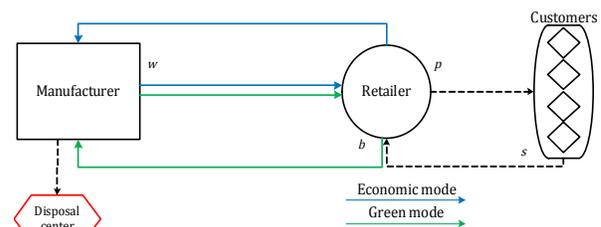


Fig. 1. Schematic view of the proposed problem

#### 3-3. Model assumptions

In this paper, It is assumed that the products obtained by the remanufacturing process are not sufficient enough for supplying the market demand. In this regard, the existence of the manufacturing process is necessary besides remanufacturing the collected items from customers [8,11]. Notice that not all of the

collected items are necessarily in proper conditions for remanufacturing activities, and only  $(1 - \chi)\%$  can be qualified for entering the forward logistics and  $\chi\%$  is transferred to the disposal center. [8,9] argued that incorporating the remanufacturing processes into the forward/reverse chains surely reduced the cost of providing raw material for manufacturing purposes.

On the other hand, the return rate of used products is sensitive to the collection effort exerted by retailer and ratio of selecting the economical or green transportation mode, which can be written as  $R(e, \theta) = \tau e + \delta(0.5 - \theta)$ . Let  $0 \leq R \leq 1$ ,  $\tau > 0$ ,  $\delta > 0$ , and  $e \geq 0$ . Note that this type of return rate is completely new in the literature and has not been investigated up to now. In other words, we try to show the important role of transportation decisions in customers' mindful decision for returning the used products with the aim of environment survival. If  $0 \leq \theta < 0.5$ , the retailer prefers to select the green transportation mode, which, then, has a positive effect on the defined return rate. However, if  $0.5 < \theta \leq 1$ , the retailer prefers to select the economical mode and will have a negative impact on the return rate. As expected, if the customers understand that the retailer has environmental concerns, they trust retailer to sell the used items to them; however, if the retailer ignores the green issue, consumers prefer not to deliver the items to him/her. Moreover, if  $\theta = 0.5$ , then the retailer is indifferent to the idea of choosing economical or green vehicles so that it has no specific impact on the return rate. Based on the general assumption in the similar studies, the market demand is considered as a linear price-sensitive function that can be written as follows:  $D(p) = \alpha - \beta p$ , where  $p < \alpha/\beta$ ,  $\alpha > 0$ , and  $\beta > 0$  [9,17,18]. In order to follow [19] and [10], we consider that the manufactured and remanufactured products have the same quality and retail price that can be sold in the same market. To guarantee the economical nature of the remanufacturing process, it is assumed that  $c_r < c_m$ . Therefore,  $\Delta = c_m - c_r$  states that unit cost saving concerns the remanufacturing execution. In this regard,  $\bar{c} = c_m - (1 - \chi)R(e, \theta)\Delta$  represents the average manufacturing/remanufacturing cost per unit.

Herein, the approach to selecting the suitable transportation mode is discussed. There are two different types of vehicles that retailers can choose: economical and green modes. The ratio  $\theta$  concerns the economical mode, and  $1 - \theta$  is

associated with green vehicles. As a whole, the value of  $\theta$  can vary in  $[0,1]$  in which the lower amounts show tendency toward the green mode; conversely, the larger values insist on economical vehicles. As already mentioned, economical vehicle is cheaper than green one, yet emits a greater amount of greenhouse gases. Therefore, we have generally  $c_e < c_g$ ; for each unit transportation cost, we have  $\theta c_e + (1 - \theta)c_g$ . Furthermore, the retailer bears a specific cost for collection effort activities which can be calculated by  $C(e) = \frac{1}{2}Ae^2 + R(e, \theta)D(p)s$  [8,9]. The condition  $s \leq c_m - c_r$  must hold to ensure the economical nature of remanufacturing processes in the proposed CLSC [9].

#### 4. Model Formulation

In this section, this study seeks to model the proposed problem under the decentralized and centralized decision-making structures. In the decentralized scenario, each chain member makes the most appropriate decisions of herself regardless of the other partners [20]. Therefore, each entity tries to maximize her own profit value, and it is not important that the other firms benefit or not. However, the centralized structure is a benchmark pattern that comprises the whole supply chain and tries to make the best decision from the supply chain's point of view. In this regard, the whole supply chain's profit is the first priority such that one member may even worse off under this situation.

To model the decentralized decision-making structure, a bi-level leader-follower problem is considered. Manufacturer plays the Stackelberg leader role in the supply chain; in the first stage, he/she decides about the wholesale and buy-back prices based on retailer's best strategies. Under the decentralized scenario, the manufacturer seeks to optimize the values of  $w$  and  $b$  to achieve her maximum profit. On the other hand, in the second stage, the retailer acts as the game follower and is responsible for deciding about the retail price, level of collection effort, and the ratio of selecting the economical transportation mode and delivers the best responses to the manufacturer. However, in the solving phase, we adopt the backward induction method, as done in [21]. Therefore, we first calculate the optimal values of  $p$ ,  $e$ , and  $\theta$ ; then, we solve the manufacturer's problem to find the optimal values of  $w$  and  $b$ .

According to the mentioned assumptions, the retailer's profit function under the decentralized scenario can be written as follows:

$$\begin{aligned} \Pi_R^{DC}(p, e, \theta) = & \\ (p - w)D(p) + bR(e, \theta)D(p) - & \quad (1) \\ (1 + R(e, \theta))D(p)(\theta c_e + (1 - \theta)c_g) - C(e) & \end{aligned}$$

The profit function of the manufacturer under the decentralized scenario can be also written as follows:

$$\begin{aligned} \Pi_M^{DC}(w, b) = & \\ (w - \bar{c})D(p) - bR(e, \theta)D(p) - & \quad (2) \\ c_d\chi R(e, \theta)D(p) & \end{aligned}$$

Now, in order to model the whole supply chain problem under the centralized setting, it is sufficient to sum the members' profit functions as  $\Pi_{SC} = \Pi_R + \Pi_M$ , resulting in:

$$\begin{aligned} \Pi_{SC}^C(p, e, \theta) = (p - \bar{c})D(p) - (1 + & \\ R(e, \theta))D(p)(\theta c_e + (1 - \theta)c_g) - & \quad (3) \\ c_d\chi R(e, \theta)D(p) - C(e) & \end{aligned}$$

Regarding the mentioned assumptions, the decentralized model can be shown as follows:

$$\begin{aligned} \text{(Leader) Max}_{w,b} \Pi_M^{DC} = (w - \bar{c})D(p) - & \\ bR(e, \theta)D(p) - c_d\chi R(e, \theta)D(p) & \\ \text{(Follower) Max } \Pi_R^{DC}(p, e, \theta) = & \\ (p - w)D(p) + & \quad (4) \\ bR(e, \theta)D(p) - & \\ (1 + R(e, \theta))D(p)(\theta c_e + & \\ (1 - \theta)c_g) - C(e) & \end{aligned}$$

$$\begin{aligned} \text{s.t.} & \\ \alpha \geq \beta p & \quad (5) \end{aligned}$$

$$\left(\tau e + \left(\frac{1}{2} - \theta\right) \delta\right) \geq 0 \quad (6)$$

$$\left(\tau e + \left(\frac{1}{2} - \theta\right) \delta\right) \leq 1 \quad (7)$$

$$p \geq w + (\theta c_e + (1 - \theta)c_g) \quad (8)$$

$$b \leq c_m - c_r \quad (9)$$

$$b \geq s + (\theta c_e + (1 - \theta)c_g) \quad (10)$$

$$w \geq c_m - \left(\tau e + \left(\frac{1}{2} - \theta\right) \delta\right) ((1 - \chi)(c_m - c_r) - b) \quad (11)$$

$$0 \leq \theta \leq 1 \quad (12)$$

$$p, e, w, b \geq 0 \quad (13)$$

Constraint (5) states that the demand function always gets positive values. Constraints (6) and (7) ensure that the return rate function gives a

positive value smaller than 1. Constraint (8) represents that the retailer has sufficient motivation to participate in the forward channel because its profit margin is positive. Constraint (9) shows the economical viability of the remanufacturing process done by the manufacturer. Constraint (10) guarantees that the retailer has sufficient incentive to participate in the reverse logistics because of the positive profit margin. Constraint (11) illustrates that the manufacturer can gain a positive profit margin from the combined forward and reverse activities. Constraint (12) states the acceptable range for the transportation mode variable. Finally, Constraint (13) expresses the standard limitations of the problem for the existing decision variables.

By conducting the backward induction, the following theorems are obtained, which are used in the simplified model subsequently.

**Theorem 1.**  $\Pi_R^{DC}$  is jointly concave in retail price, collection effort, and transportation mode selection ratio only when the following conditions are satisfied:

$$\begin{aligned} 4\beta\delta(c_g - c_e)(\alpha - \beta p) - & \\ \frac{\beta^2}{4} \left( \begin{matrix} 2(b - s)\delta + c_e(2 + 2e\tau + \delta - 4\delta\theta) \\ -c_g(2 + 2e\tau + 3\delta - 4\delta\theta) \end{matrix} \right)^2 \geq & \quad (14) \\ 0 & \end{aligned}$$

$$\begin{aligned} \frac{\beta}{4} \left( \begin{matrix} -2A + \beta\tau^2 \\ 8\delta(c_g - c_e)(\alpha - \beta p) \left( \begin{matrix} -b + s + c_g \\ +\theta c_e - \theta c_g \end{matrix} \right)^2 \end{matrix} \right) & \\ + \beta A \left( \begin{matrix} 2\delta(b - s) + c_e \left( \begin{matrix} 2 + 2e\tau \\ +\delta - 4\delta\theta \end{matrix} \right) \\ -c_g \left( \begin{matrix} 2 + 2e\tau \\ +3\delta - 4\delta\theta \end{matrix} \right) \end{matrix} \right)^2 & \quad (15) \\ 0 & \end{aligned}$$

**Proof 1.** Since the retailer's profit function is dependent on three decision variables including  $p, e,$  and  $\theta,$  the Hessian matrix is given by

$$H = \begin{pmatrix} \frac{\partial^2 \Pi_R^{DC}}{\partial p^2} & \frac{\partial^2 \Pi_R^{DC}}{\partial p \partial \theta} & \frac{\partial^2 \Pi_R^{DC}}{\partial p \partial e} \\ \frac{\partial^2 \Pi_R^{DC}}{\partial \theta \partial p} & \frac{\partial^2 \Pi_R^{DC}}{\partial \theta^2} & \frac{\partial^2 \Pi_R^{DC}}{\partial \theta \partial e} \\ \frac{\partial^2 \Pi_R^{DC}}{\partial e \partial p} & \frac{\partial^2 \Pi_R^{DC}}{\partial e \partial \theta} & \frac{\partial^2 \Pi_R^{DC}}{\partial e^2} \end{pmatrix}$$

As can be seen in the Hessian matrix, the first minor is  $\frac{\partial^2 \Pi_R^{DC}}{\partial p^2} = -2\beta$  that always has negative values. However, the second and third minors

also must be positive and negative, respectively. In this regard, after some mathematical calculations, the following conditions appear to

prove the concavity of the retailer's profit function.

$$4\beta\delta(c_g - c_e)(\alpha - \beta p) - \frac{\beta^2}{4} \left( \frac{2(b-s)\delta + c_e(2 + 2e\tau + \delta - 4\delta\theta)}{-c_g(2 + 2e\tau + 3\delta - 4\delta\theta)} \right)^2 \geq 0 \tag{16}$$

$$\frac{\beta}{4} \left( \begin{array}{l} 8\delta(c_g - c_e)(\alpha - \beta p) \left( \frac{-2A + \beta\tau^2}{(-b + s + c_g)^2 + \theta c_e - \theta c_g} \right) + \\ \beta A \left( \frac{2\delta(b-s) + c_e(2 + 2e\tau + \delta - 4\delta\theta)}{-c_g(2 + 2e\tau + 3\delta - 4\delta\theta)} \right)^2 \end{array} \right) \leq 0 \tag{17}$$

■

**Theorem 2.** The optimal decision variables of the retailer can be calculated by

$$p(e, \theta) = \operatorname{argmax}_{p,e,\theta} \Pi_R^{DC} = \frac{2\alpha + \beta \left[ \frac{(s + \theta c_e - b)(2e\tau + \delta - 2\delta\theta) + c_g(1 - \theta)(2 + 2e\tau + \delta - 2\delta\theta)}{+2(\theta c_e + w)} \right]}{4\beta} \tag{18}$$

$$e(p) = \operatorname{argmax}_{p,e,\theta} \Pi_R^{DC} = \frac{\tau(2(c_g - c_e + b\delta) - (c_e + c_g + 2s)\delta)(\alpha - \beta p)}{2[2A\delta - (c_g - c_e)\tau^2(\alpha - \beta p)]} \tag{19}$$

$$\theta(p) = \operatorname{argmax}_{p,e,\theta} \Pi_R^{DC} = \frac{2(s + c_g - b) + \frac{A[2(c_g - c_e) + \delta(2b - c_e - c_g - 2s)]}{2A\delta - (c_g - c_e)\tau^2(\alpha - \beta p)}}{2(c_g - c_e)} \tag{20}$$

**Proof 2.** By holding the sufficient conditions for the concavity of retailer's profit function, it is possible to achieve the global optimum quantities of the decision variables with the aid of taking

the first-order derivatives. After some mathematical simplification, the following equations are obtained for the decision variables.

$$\frac{\partial \Pi_R^{DC}(p, e, \theta)}{\partial p} = 0 \Rightarrow p^{DC*}(e, \theta) = \frac{2\alpha + \beta \left[ \frac{(s + \theta c_e - b)(2e\tau + \delta - 2\delta\theta) + c_g(1 - \theta)(2 + 2e\tau + \delta - 2\delta\theta)}{+2(\theta c_e + w)} \right]}{4\beta} \tag{21}$$

$$\frac{\partial \Pi_R^{DC}(p, e, \theta)}{\partial e} = 0 \Rightarrow e^{DC*}(p, \theta) = \frac{\tau(\alpha - \beta p) \left( \frac{b - s - \theta c_e}{-c_g(1 - \theta)} \right)}{A} \tag{22}$$

$$\frac{\partial \Pi_R^{DC}(p, e, \theta)}{\partial \theta} = 0 \Rightarrow \theta^{DC*}(e) = \frac{1}{4} \left( \frac{3c_g + 2s - 2b - c_e}{c_g - c_e} + \frac{2 + 2e\tau}{\delta} \right) \tag{23}$$

Now, in order to achieve Eq. (19), Eq. (23) is replaced into Eq. (22); then, the obtained equation is simplified. Similarly, by substituting Eq. (19) into Eq. (23), Eq. (20) appears. ■

Therefore, the proposed problem is formulated under the decentralized decision-making structure as in the following mathematical model.

$$\text{Max}_{w,b} \Pi_M^{DC} = (w - \bar{c})D(p) - bR(e, \theta)D(p) - c_d \chi R(e, \theta)D(p)$$

s.t.

Constraints (5)-(15) and (18)-(20)

In the next step, we seek to model the problem under the centralized setting where the whole model is considered from the supply chain's viewpoint. Under this structure, the individual members' profit is not an important issue, and the only goal is to maximize the total supply chain's profit function [22,23]. Therefore, this scenario can be a proper benchmark that must be taken into account for the next stage to design a setting to achieve the value obtained at this level. In the following, the centralized model is presented.

$$\text{Max}_{p,e,\theta} \Pi_{SC}^C = (p - \bar{c})D(p) - (1 + R(e, \theta))D(p)(\theta c_e + (1 - \theta)c_g) - c_d \chi R(e, \theta)D(p) - C(e) \quad (24)$$

$$\text{Max}_{p,e,\theta} \Pi_{SC}^C = (p - \bar{c})D(p) - (1 + R(e, \theta))D(p)(\theta c_e + (1 - \theta)c_g) - c_d \chi R(e, \theta)D(p) - C(e) \quad (25)$$

.t.

Constraints (5)-(13)

$\Pi_R^{COO}(p, e, \theta) \geq \Pi_R^{DC}(p^{DC*}, e^{DC*}, \theta^{DC*})$  can be re-written as:

$$(p - w)D(p) + bR(e, \theta)D(p) - (1 + R(e, \theta))D(p)(\theta c_e + (1 - \theta)c_g) - C(e) \geq (p^{DC*} - w^{DC*})D(p^{DC*}) + b^{DC*}R(e^{DC*}, \theta^{DC*})D(p^{DC*}) - (1 + R(e^{DC*}, \theta^{DC*}))D(p^{DC*})(\theta^{DC*}c_e + (1 - \theta^{DC*})c_g) - C(e^{DC*}) \quad (26)$$

$\Pi_M^{COO}(w, b) \geq \Pi_M^{DC}(w^{DC*}, b^{DC*})$  can be re-written as:

$$(w - \bar{c})D(p) - bR(e, \theta)D(p) - c_d \chi R(e, \theta)D(p) \geq (w^{DC*} - \bar{c}^{DC*})D(p^{DC*}) - b^{DC*}R(e^{DC*}, \theta^{DC*})D(p^{DC*}) - c_d \chi R(e^{DC*}, \theta^{DC*})D(p^{DC*}) \quad (27)$$

As mentioned before, the objective function (25) states the maximization of the total CLSC. Constraints (26) and (27) declare that the downstream and upstream players must be motivated enough to attend the proposed coordination plan.

s.t.

Constraints (5)-(13)

### 5. Coordination Plan

In this section, a coordination plan based on a mathematical programming model is developed in which the focus is on the Pareto improving solution. Unlike the usual contract models whose total chain's profit must achieve the centralized mode, in this coordination plan, there is no necessity for this issue which is similar to the approach applied by [24]. However, similar to the other coordination schemes, the Pareto optimal solution is satisfied for both channel members. It means that, under the designed coordination plan, both partners earn at least the decentralized profit, while the total chain's profit is maximized. As the total profit goes near the centralized profit, the efficiency of the coordination plan goes higher. Regarding the mentioned definitions, the coordination plan is given by

**Tab. 1. Values of parameters for different numerical experiments applied in the study**

Case	Parameter	Value										
1	$\alpha$	150	$\beta$	1.2	$\eta$	0.5	$\mu$	0.7	$\lambda$	0.2	$d$	1.5
	$c_m$	40	$c_r$	10	$c_1$	7	$c_2$	12	$C_c$	250	$j$	2
2	$\alpha$	150	$\beta$	1.5	$\eta$	0.3	$\mu$	0.8	$\lambda$	0.1	$d$	4
	$c_m$	35	$c_r$	10	$c_1$	4	$c_2$	12	$C_c$	100	$j$	6
3	$\alpha$	200	$\beta$	2.2	$\eta$	0.2	$\mu$	0.6	$\lambda$	0.15	$d$	2
	$c_m$	40	$c_r$	13	$c_1$	7	$c_2$	12	$C_c$	450	$j$	7

**Tab. 2. Evaluation of different numerical experiments under three different decision-making structures**

Case	Model	$w$	$b$	$p$	$\theta$	$e$	Demand	Return	$\Pi_R$	$\Pi_M$	$\Pi_{SC}$
1	DC	79.18	25.71	104.34	0.000	0.581	24.79	0.64	469.97	939.44	1409.41
	C	-	-	83.68	0.411	1.165	49.58	0.64	1045.47	833.41	1878.89
	COO	51.55	12.24	83.68	0.411	1.165	49.58	0.64	939.44	939.44	1878.89
2	DC	63.60	24.47	84.50	0.620	0.798	23.24	0.14	328.47	656.98	985.46
	C	-	-	69.00	0.918	1.596	46.49	0.14	546.87	767.10	1313.97
	COO	52.18	25.00	69.00	0.918	1.596	46.49	0.14	534.49	779.48	1313.97
3	DC	60.70	24.69	80.48	0.528	0.085	22.93	0.00	237.38	474.77	712.15
	C	-	-	70.06	0.557	0.170	45.86	0.00	-6.50	956.04	949.54
	COO	55.52	16.95	70.06	0.557	0.170	45.86	0.00	237.38	712.15	949.54

**6. Numerical Evaluation**

To sum up, three different decision-making structures in relation to the bi-level CLSC considering economical and green transportation modes are presented. Now, to analyze the performance of each scenario, some numerical examples are proposed. Furthermore, to achieve some managerial implications, sensitivity analysis is performed, and the results are investigated in depth. It is worth mentioning that we coded the assumed problem in GAMS software and selected the BARON solver. In the following, Table 1 shows three categories of parameter values used in the rest of paper. Table 2 shows the results of solving the proposed problem under the decentralized, centralized, and coordinated models with regard to parameters values presented in Table 1.

Figures 2 and 3 express the trend of retailer and manufacturer's profit functions toward the changes of parameter  $\beta$  under the decentralized and coordinated modes.

As can be seen in Figure 2, the retailer's profit decreases by increasing the value of  $\beta$  under both decentralized and coordinated models. Indeed, as the sensitivity of market demand to the retail price increases, retailer's profit drops down significantly. However, the coordinated plan neutralized somewhat the negative effect of  $\beta$  on retailer's profit. As expected, the profit of retailer

under the coordinated plan is larger than that in the decentralized structure in all experiments. All of the mentioned points about Figure 2 are completely true for the manufacturer side, as clearly demonstrated in Figure 3. Accordingly, simultaneous investigation of Figures 2 and 3 results in holding Pareto improving situation for both channel members under the suggested coordination scheme.

Figures 4 and 5 illustrate the changes of channel players' profit functions vs. the changes of  $\tau$  under the decentralized and coordinated plans.

Interestingly, as the sensitivity of return rate to the level of collection effort increases, retailer's profit decreases under the decentralized mode, while the same situation creates an unstable and non-decreasing trend for the coordination plan. According to Figure 4, although a large amount of  $\tau$  enhances the value of return rate, it has negative effect on retailer's profit function under the decentralized setting. Furthermore, the changes of  $\tau$  cannot disrupt the Pareto improving situation for the retailer when the coordination plan is implemented in the channel. It is worth mentioning that the larger values of  $\tau$  can better illustrate the positive performance of the coordination plan in increasing the retailer's profit.

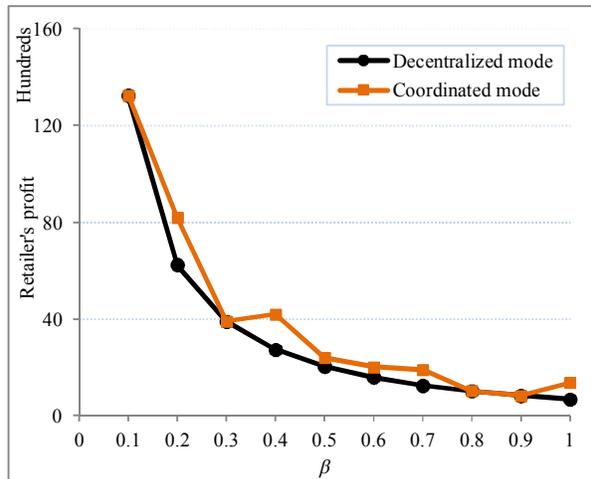


Fig. 2. Alteration of retailer's profit vs.  $\beta$

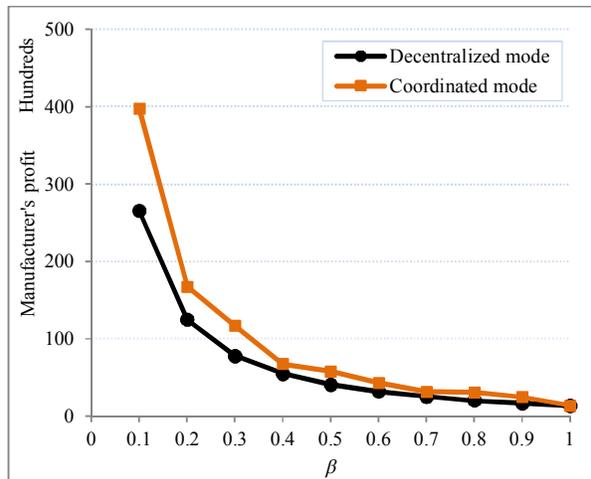


Fig. 3. Alteration of manufacturer's profit vs.  $\beta$

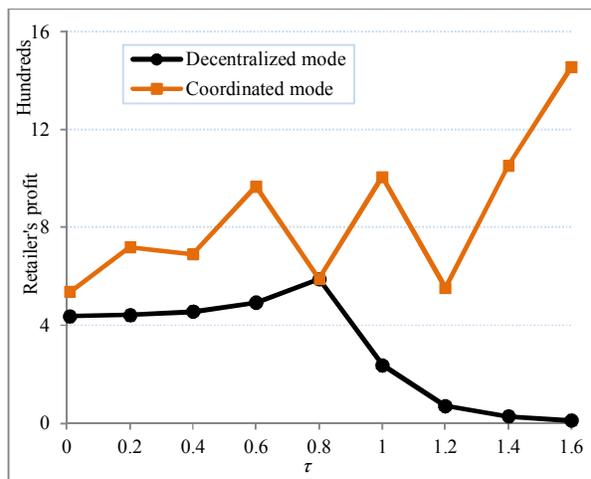


Fig. 4. Alteration of retailer's profit vs.  $\tau$

The main difference between Figures 4 and 5 lies in the effectiveness of  $\tau$  in members' profit

functions under the coordinated mode. Unlike the retailer, as  $\tau$  increases in coordination plan, the amount of manufacturer's profit still shows a decreasing trend that is similar to the decentralized structure. However, the Pareto solution is still in hand for the manufacturer in all experiments.

Figure 6 demonstrates the behavior of retailer's collection effort level under the changes of parameter  $\tau$ . The first important point can be extracted from Figure 6 is that the suggested coordination model increases the value of  $e$  compared to the decentralized structure for all evaluated numerical examples. Moreover, Figure 6 shows an interesting trend of changes for variable  $e$  by increasing parameter  $\tau$  under both decentralized and coordinated models. Indeed, it shows a specific behavior in which, for a certain amount of  $\tau$ , the collection effort level can achieve the maximum value.

Therefore, determining an appropriate value of  $\tau$  is a very important decision for the channel managers.

Figure 7 exhibits the alteration of  $\theta$  vs.  $\tau$  under two distinct decision-making structures. Again, the coordination scheme has the capability of enhancing the value of  $\theta$  compared to the decentralized mode for all experiments. Of note, the larger values of  $\theta$  indicate the tendency of retailer to choose the economical vehicles. Therefore, the economical policy of the coordination plan is obviously highlighted via Figure 7. Notice that, as the value of  $\tau$  increases, the retailer prefers to select the economical transportation modes. Therefore, the supply chain decision-makers can follow a specific policy by determining the value of  $\tau$  in the proposed model.

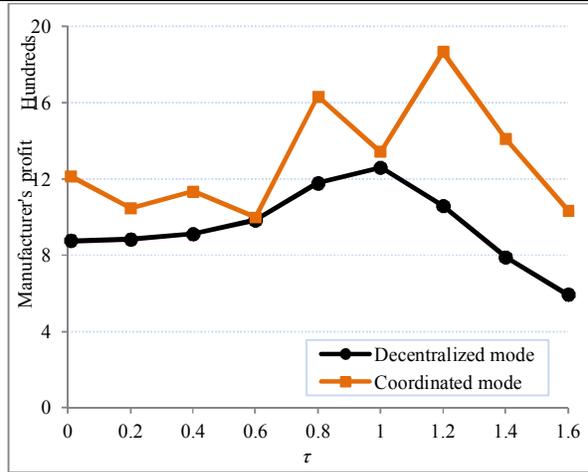


Fig. 5. Alteration of manufacturer's profit vs.  $\tau$

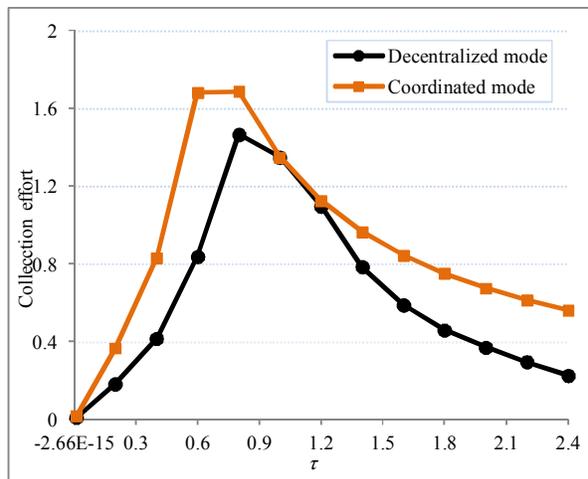


Fig. 6. Alteration of retailer's collection effort vs.  $\tau$

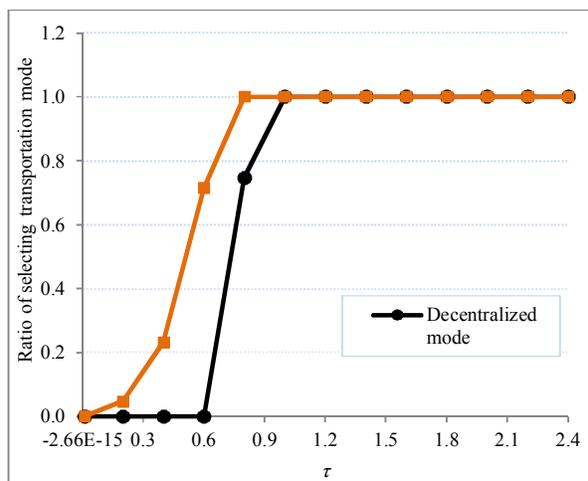


Fig. 7. Alteration of retailer's collection effort vs.  $\tau$

### 7. Conclusions

In recent years, the issue of SCC has attracted the attention of many scholars to improve the low-profit environment of decentralized decision-making and achieved the global optimization model, which is called the centralized scenario. However, one of the significant concerns of the researchers is to establish a situation in which all of the participants in the chain are better off. Despite the growing numbers of papers in the mentioned stream, coordination of a CLSC considering the transportation mode selection is a new concept that has not been investigated up to now. In this paper, a bi-level closed-loop channel composed of a manufacturer and retailer with deterministic market demand is presented where the retailer is responsible for the determination of the transportation mode selection, collection effort level, and retail price. Note that a Stackelberg game model is applied in which the manufacturer is the Stackelberg leader and retailer is the game follower. Interestingly, all of transportation activities are done by two vehicle modes: economical and green. The economical transportation mode is a cheap and highly pollutant vehicle; conversely, the green mode is an expensive and low-pollution vehicle. First, the proposed problem is modeled under the decentralized and centralized decision-making structures. Then, to coordinate the channel decisions, a mathematical model based on economical objectives is developed. Satisfying the Pareto optimal solution is the most important feature of the presented coordination plan. The comparison of the results obtained from the coordination plan with the centralized setting can illustrate the efficiency of the proposed incentive scheme. In other words, as the coordination plan gives larger values for the total profit of channel, it has higher efficiency that can ultimately lead to a perfect coordination of the whole CLSC. In the last step of the current paper, some numerical examples are taken into account to evaluate the performance of the decentralized, centralized, and coordinated plans. Furthermore, sensitivity analysis is conducted to extract some insightful implications. Although the current paper covers a specific gap in the coordination literature, it still has some limitations. In this regard, we mention some future suggestions to open some ways of improving the paper. As regards the consideration of green transportation mode, it is more applicable if the issue of green factors is highlighted in the proposed model. Other coordination plans, such as contracts, may be

appropriate tools to examine the coordination of the proposed channel with the existing features.

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