RAIRO-Oper. Res. 54 (2020) 1515–1535
https://doi.org/10.1051/ro/2019073

RAIRO Operations Research
www.rairo-ro.org

COORDINATION CONTRACT FOR A COMPETITIVE PHARMACEUTICAL SUPPLY CHAIN CONSIDERING CORPORATE SOCIAL RESPONSIBILITY AND PRICING DECISIONS

Maryam Johari[1] and Seyyed-Mahdi Hosseini-Motlagh[1,*]

Abstract. Corporate social responsibility (CSR) and pricing decisions are proposed for a competitive two-level pharmaceutical supply chain (PSC) comprising two pharma-manufacturers and one pharma-retailer. In the investigated PSC, the pharma-manufacturers competitively invest in the CSR effort to produce a new medicine and sell two substitutable products to the market through the pharma-retailer, deciding on selling prices of manufacturers' products. The PSC under consideration is modeled in three decision-making structures, *i.e.*, decentralized, centralized, and coordinated models. In the decentralized model, the pricing and CSR decisions are individually obtained using a pharma-manufacturers–Stackelberg game structure. In the centralized model as a benchmark, the best performance of the entire PSC system is achieved. Finally, to encourage all PSC members to agree on the coordination plan, a CSR cost-sharing contract is proposed. Our results reveal that under competitive environment, the proposed CSR cost-sharing contract is able to increase market demand by significantly decreasing selling prices and increasing level of the CSR efforts.

Mathematics Subject Classification. 91A40, 91A80, 91B24.

Received March 15, 2019. Accepted July 23, 2019.

1. Introduction

In today's competitive environment, companies aim to engage in some strategies to influence customers' demand. For instance, manufacturers may compete on the corporate social responsibility (CSR) effort to achieve more market share. By investing in the CSR effort, the manufacturers take responsibilities towards a wide groups of stakeholders, *i.e.*, the environment and customers [9]. As noted by Cruz and Wakolbinger [5]; Fombrun [10]; Sen and Bhattacharya [46], CSR effort can increase company's reputation and sales volume, decrease imperfect products and risk, build customer loyalty, and provide new markets. Furthermore, retailers close to end consumers can provide pricing strategy to impact on market demand. In addition, powerful retailers usually sell several substitutable products of manufacturers to customers. Under such a case, decisions on the CSR effort made by manufacturers and retail prices of substitutable products can affect entire supply chain (SC) performance along with other SC members' profit. Although in traditional business, each SC member

Keywords. Pharmaceutical supply chain coordination, corporate social responsibility (CSR), pricing, Stackelberg game, substitutable products, CSR cost-sharing contract.

[1] School of Industrial Engineering, Iran University of Science and Technology, University Road, Hengam Street, Resalat Square, Narmak, Tehran, Iran.
[*]Corresponding author: motlagh@iust.ac.ir

Article published by EDP Sciences

individually decides on its own decisions such that its own profit is maximized, these individual decision-making model may lead to an inefficient system. Accordingly, designing a coordination mechanism to align different SC decisions on the pricing of retailer and CSR effort of competitive manufacturers is of high importance, for it can improve whole SC performance and increase all SC members' profit.

*Corporate social responsibility (*CSR*)* efforts have been investigated by different kinds of mechanism such as consumer surplus and performance level on the customer demand in the related supply chain literature. Ni and Li [37] analyzed the impact of CSR effort invested by both firm and supplier on the customer demand through a game theoretic approach. They investigated simultaneous-move and sequential-move games to find the equilibrium solution of CSR through a wholesale price contract as an incentive scheme. Panda [40] addressed CSR issue through consumer surplus for a manufacturer-retailer SC considering retailer's CSR effort and manufacturer's CSR effort through a revenue-sharing contract. In another study, Hsueh [19] considered a two-echelon SC in which the impact of CSR level on the demand function was examined through a revenue-sharing contract. Modak *et al.* [29] investigated the effect of CSR in the form of consumer surplus in a dual-channel SC through all unit quantity discount contract. Panda *et al.* [42] addressed CSR using consumer surplus in a three-stage SC under coordination contract and bargaining model. Panda and Modak [41] proposed channel coordination through subgame perfect equilibrium for a manufacturer-retailer chain in which both SC members exhibit CSR effort through consumer surplus. Modak *et al.* [30] analyzed CSR using consumer surplus in a three-echelon SC including one manufacturer, multiple distributors and retailers through revenue-sharing contract. Panda *et al.* [43] investigated CSR in the form of consumer surplus in a manufacturer-retailer SC under two cases: when the retailer is socially responsible and when the manufacturer is socially concerned through quantity discount contract. Modak *et al.* [31] examined the impact of CSR in the form of consumer surplus in a competitive two-echelon SC using two-part tariff contract and Nash bargaining model. Panda *et al.* [44] coordinated a socially responsible manufacturer-retailer closed-loop SC in which the manufacturer invested in CSR effort through consumer surplus. Nematollahi *et al.* [34] developed a collaborative model to coordinate a supplier-retailer chain under a newsvendor inventory system in which the supplier concerned with CSR activities to enhance the brand recognition of its product and increase market share. Nematollahi *et al.* [35] proposed a social collaborative approach for a pharmaceutical supply chain (PSC) through providing essential service level to patients. Nematollahi *et al.* [36] investigated social and economic objectives of a collaborative models for one pharma-distributor-one pharma-retailer chain to improve service level. Although the above-reviewed papers investigated CSR effort through channel coordination, they all have neglected CSR competition existing among socially responsible manufacturers in supply chain coordination.

Although coordination of pricing decisions have been significantly investigated in the supply chain literature, few studies have analyzed *pricing competition* through coordination contracts. Zhao *et al.* [53] explored a distribution system in which two competitive manufacturers compete on the service level of two substitutable products provided to consumers. Yang *et al.* [51] considered a supplier-retailers chain of a perishable good in which two competitive retailers compete on the price offered to customers. Modak *et al.* [32] considered price competition between two competitive retailers for a three-level supply chain through a coordination model. Huang *et al.* [20] coordinated pricing decisions for a competitive supplier-retailers chain. Jafari *et al.* [21] analyzed pricing competition among multiple retailers for a dual-channel SC through coordination contract. Gao *et al.* [11] investigated pricing competition among multiple firms with substitutable products. Li and Chen [28] studied pricing decisions through horizontal competition between two manufacturers and vertical competition between retailers and manufacturers for a supply chain with two products in quality-differentiated brands. However, in the above-reviewed studies, CSR efforts has been ignored in addition to channel coordination models have received less attention.

Supply chain coordination models have been developed to solve conflicts of objectives which are incurred due to the individually decision-making of SC members and align SC decisions such that all SC members' profits are improved [36]. In the supply chain literature, various coordination contracts have been developed to coordinate different decisions in the supply chains, *i.e.*, quantity discount [3, 25, 26, 38], buy back [7, 52], grove wholesale price [4], bi-level wholesale price contract [17], delay in payment [8, 22], collaborative models [15], revenue-sharing [12], two-part tariff [31, 32, 47], multilateral two-part tariff [18], two-way two-part tariff [24], bi-level credit period [27], compensation-based wholesale price [14, 39], and cost-sharing [23]. Several studies investigated coordination of CSR efforts made by channel members through coordination contracts.

Raj *et al.* [45] modeled a two-echelon SC under a price-greening-CSR dependent demand and optimized pricing, greening, and CSR decisions under different coordination contracts. Hosseini-Motlagh and Ebrahimi [13] studied supply chain coordination in a single manufacturer-duopolistic retailers green SC in which retailers competitively decide on CSR efforts. Sinayi and Rasti-Barzoki [48] also considered social welfare in the form of consumer surplus in a two-stage SC under government intervention and analyzed the optimal decisions on pricing, greening, and social welfare of SC agents. Furthermore, Hosseini-Motlagh *et al.* [16] investigated CSR effort in a manufacturer-retailer supply chain under periodic review replenishment system through cost-sharing contract. Recently, Modak *et al.* [33] investigated a two-echelon closed-loop SC considering corporate social responsibility and recycling efforts under two-part tariff contract. However, to the best of our knowledge, simultaneous coordination of pricing and corporate social responsibility decisions for a competitive pharmaceutical supply chain comprising two duopolistic manufacturers and one retailer through a CSR cost-sharing contract has not been investigated in the existing literature.

This paper is motivated by the issue of life quality development of cancer patients. In fact, since in the current situation of the pharmaceutical market, gastrointestinal cancer is cured by chemical medicines that have side effects on cancer patients' health, in the investigated pharmaceutical supply chain, pharma-manufacturers aim to produce herbal medicine instead of chemical one to take into account cancer patients' health improvement. Accordingly, producing herbal medicine, which is a new medicine in the pharmaceutical market, is considered as the CSR effort made by pharmaceutical manufacturers as it shows the social responsibility of pharmaceutical manufacturers towards the society (*i.e.*, patients). Currently, producing chemical medicine for cancer patients can be considered as non-CSR effort of the pharma-manufacturers in the pharmaceutical market, since it has side effects on the patients' health. Therefore, in this study, we consider the production of herbal medicine, which is a new medicine for curing gastrointestinal cancer, as CSR practice of pharmaceutical manufacturers. Specifically, pharma-manufacturers aim to improve cancer patients' health by producing innovative herbal medicine that does not have side effects on the cancer patients' health. In fact, pharma-manufacturers take care of cancer patients' health through producing innovative herbal medicine which is considered as their corporate social responsibility towards society. Accordingly, cancer patients' health can be enhanced by consuming such herbal medicine compared to the chemical medicine. Therefore, the life quality of cancer patients can be developed. To this end, nowadays, the aim of a pharmaceutical supply chain is to provide a new herbal medicine for curing gastrointestinal cancer that using it has not any side effects for patients compared to the current chemical medicines. For instance, BIOGEN is a pharmaceutical corporation producing the most innovative medicines for rare diseases in the market and engages in all areas of corporate social responsibility such as protection of the environment, stakeholder engagement, and diversity and inclusion (`www.biogen.com`) and [49]. To achieve competitive advantage, BIOGEN competes with its competitors (*i.e.*, Abbott Laboratories, Amgen, Inc., Bristol-Myers Squibb, GlaxoSmithKline Plc) on producing innovative medicines. As another example for competitive CSR activities, GlaxoSmithKline, Johnson and Johnson (Janssen), Merck & Co., Novartis, Pfizer, Roche, and Sanofi, which are among the top 10 largest multinational pharmaceutical firms conducted CSR practices such as differential pharmaceutical pricing, strengthening developing country drug distribution infrastructure, mHealth initiatives, and targeted research and development to achieve competitive advantage [6]. Therefore, due to the competitive market of pharmaceutical, pharma-manufacturers should invest in CSR effort as competitiveness strategy through producing innovative medicines indicating pharma-manufacturers' responsibility towards society (*i.e.*, patients). In our investigated case study, two pharma-manufacturers competitively engage in CSR effort through producing new substitutable herbal medicines. To be more precise, by considering stakeholder engagement, competing pharma-manufacturers invest in producing innovative herbal medicine to care patients' health. Such investment in CSR activities to produce the innovative herbal medicine can influence the cancer patients' health improvement, thus enhancing consumer social preferences and market share. Pharma-manufacturers sell their medicines to a powerful pharma-retailer in the pharmaceutical market. The

Table 1. Literature review of CSR efforts and price competition and the proposed model.

Reference	Pricing decision	CSR effect on	SC Structure	Competition	Product	Coordination approach
Modak *et al.* [33]	✓	Demand	1 manufacturer 1 retailer	No	1	Two-part tariff
Sinayi and Rasti-Barzoki [48]	✓	Consumer surplus	1 manufacturer 1 retailer	No	1	Two-part tariff
Hosseini-Motlagh and Ebrahimi [13]	–	Demand	1 manufacturer 2 retailers	Yes	1	Environmental and CSR cost-sharing
Raj *et al.* [45]	✓	Demand	1 supplier 1 buyer	No	1	Revenue and greening-cost sharing
Hosseini-Motlagh *et al.* [16]	–	Demand	1 manufacturer 1 retailer	No	1	Promotional and CSR cost-sharing
Li and Chen [28]	✓	–	2 manufacturer 1 retailer	Yes	2	–
Nematollahi *et al.* [36]	–	Customer fill rate	1 distributer 1 retailer	No	1	Collaborative
Gao *et al.* [11]	✓	–	multiple firms	Yes	2	–
Nematollahi *et al.* [34]	–	Demand	1 supplier 1 retailer	No	1	Collaborative
Nematollahi *et al.* [35]	–	Customer fill rate	1 supplier 1 retailer	No	1	Collaborative
Panda *et al.* [44]		Consumer surplus	1 manufacturer 1 retailer	No	1	Revenue-sharing
Modak *et al.* [30]	✓	Consumer surplus	1 manufacturer multiple distributors multiple retailers	Yes	1	Revenue-sharing
Modak *et al.* [31]	✓	Consumer surplus	1 manufacturer 2 retailers	Yes	1	Two-part tariff
Modak *et al.* [32]	✓	–	1 manufacturer 1 distributor 2 retailers	Yes	1	Two-part tariff
Panda and Modak [41]	✓	Consumer surplus	1 manufacturer 1 retailer	No	1	Subgame equilibrium
Panda *et al.* [43]	✓	Consumer surplus	1 manufacturer 1 retailer	No	1	Quantity discount
Panda *et al.* [42]	✓	Consumer surplus	1 manufacturer 1 distributor 1 retailer	No	1	Wholesale price and bargaining model
Yang *et al.* [51]	✓	–	1 supplier 2 retailers	Yes	1	–
Modak *et al.* [29]	✓	Consumer surplus	1 manufacturer 1 retailer	Yes	1	all unit quantity discount
Hsueh [19]		Demand	1 manufacturer 1 retailer	No	1	New Revenue-sharing
Panda [40]	✓	Consumer surplus	1 manufacturer 1 retailer	No	1	Revenue-sharing
Zhao *et al.* [53]	✓	–	2 manufacturers 1 retailer	Yes	2	–
Ni and Li [37]	✓	Demand	1 supplier 1 firm	No	1	Wholesale price
Proposed model	✓	Demand	2 pharma-manufacturers 1 pharma-retailer	Yes	2	CSR cost-sharing

pharma-retailer decides on the pricing of two substitutable herbal medicines affecting consumers demand. In the current situation, each pharma-manufacturer individually makes decision on the investment level of the CSR effort. Moreover, the pharma-retailer independently decides on the price of substitutable medicines offered to consumers. However, these individual decision-making of PSC members affect the entire PSC and other pharma members. Hence, there is a need to design a coordination plan to align pricing and CSR decisions of all PSC members and make the best performance of the system.

According to the above-reviewed literature and Table 1, the following research gaps are identified:

- Few studies such as Modak *et al.* [32] has investigated pricing competition in supply chain coordination. However, in their study, price competition is considered between two duopolistic retailers. In other words, pricing competition of two substitutable products has been neglected in their model. In addition, in their study, CSR effort of manufacturer has been ignored.
- Although some studies in the existing literature such as Nematollahi *et al.* [36], Panda *et al.* [44], Hsueh [19], and Ni and Li [37] have addressed coordination of CSR effort in supply chains, they have ignored the impact of CSR competition in their models.
- To the best of our knowledge, this study for the first time proposes a coordination contract named "CSR cost-sharing" to coordinate competitive CSR efforts and pricing of two substitutable products for a pharma-manufacturers-pharma-retailer supply chain.

This study aims to fill the above research gaps and contributes to the existing literature by considering coordination of competitive socially concerned pharma-manufacturers' CSR efforts and pricing of two substitutable products. In this paper, a two-echelon PSC including two competitive pharma-manufacturers and one pharma-retailer is studied. In the investigated PSC, two competitive pharma-manufacturers compete with each other on CSR efforts to produce herbal medicines. The pharma-retailer sells two substitutable medicines of two pharma-manufacturers to consumers. The market demand of two substitutable medicines depends not only on the CSR efforts of pharma-manufacturers but also on the retail prices offered by the pharma-retailer. The investigated PSC is modeled in three decision-making structures, *i.e.*, (1) decentralized, (2) centralized, and (3) coordination models. The decentralized structure is modeled in the pharma-manufacturers–Stackelberg game structure. In addition, in the decentralized model, CSR efforts of pharma-manufacturers and retail prices of two substitutable products are individually optimized from each PSC member's point of view. In the centralized model as a benchmark, the pricing and CSR decisions are optimized from the entire PSC perspective such that the best performance of the entire PSC is achieved. Finally, a CSR cost-sharing contract as a coordination mechanism is proposed which is able to coordinate pricing and CSR decisions in a way that all PSC members profit along with whole PSC profit are improved. The rest of this paper is organized as follows. Section 2 defines the studied problem and provides notations. In Section 3, investigated PSC is modeled in three different decision-making structures. Numerical examples and sensitivity analysis are carried out in Section 4. Section 5 provides the main findings of the study and discusses managerial insights. Finally, Section 6 concludes the paper and discusses future research directions.

2. Problem definition

In this paper, a two-echelon PSC including two competitive pharma-manufacturers and one pharma-retailer is studied. In the investigated PSC, each pharma-manufacturer produces a single product (*i.e.*, medicine). It is considered that two products are substitutable with each other. Furthermore, the pharma-retailer sells these substitutable products to the market. In addition, two pharma-manufacturers competitively invest in CSR effort affecting the customer demand. Therefore, the market demand is dependent on the CSR investment of the pharma-manufacturers and the selling prices of two products. In the investigated PSC, the pharma-manufacturers have dominant powers and thus they are Stackelberg game leaders and the pharma-retailer is their follower. The pharma-manufacturers make decisions on the CSR efforts and the pharma-retailer determines the selling prices of two substitutable products. The PSC under consideration is modeled in three decision-making structures: (1) decentralized, (2) centralized, and (3) coordinated models. In the decentralized model, each PSC member individually optimizes its own decision without considering the other PSC participants' performances. In the decentralized model, Cournot behavior of the pharma-manufacturers is investigated in which the pharma-manufacturers simultaneously decide on the CSR investment. In the centralized model as benchmark, decisions on the CSR and pricing are optimized from the whole PSC perspective. Finally, to coordinate the CSR and pricing decisions of all PSC members, a CSR cost-sharing contract is proposed. Figure 1 illustrates the investigated pharmaceutical supply chain.

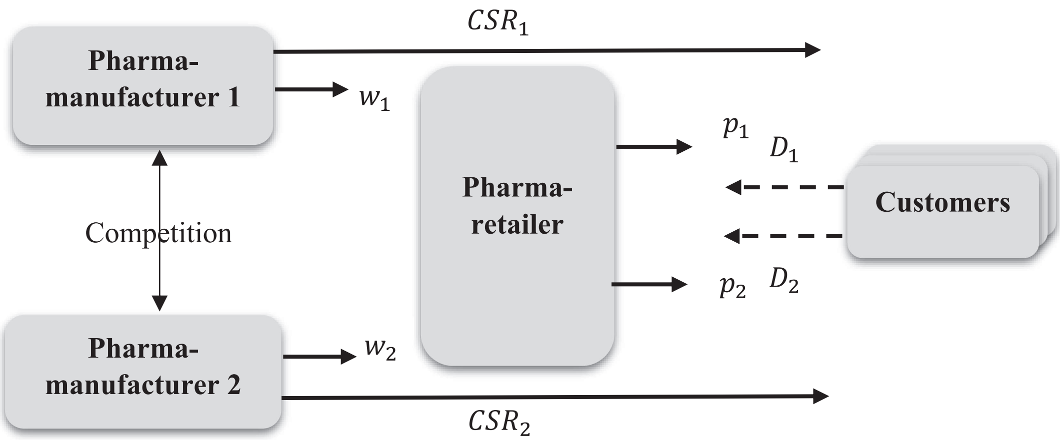


FIGURE 1. The framework of the investigated pharmaceutical supply chain.

2.1. Notations

The following notations are used in the investigated PSC.

Decision variables

CSR_i CSR effort by pharma-manufacturer i.
p_i Unit retail price of product i (\$/unit).

Parameters

d_i Primary demand of product i (units).
τ_1 Pharma-manufacturer's CSR effort elasticity coefficient of demand.
τ_2 Competitor's CSR effort elasticity coefficient of demand.
μ_1 Self-price coefficient of demand.
μ_2 Cross-price coefficient of demand.
w_i Unit wholesale price of pharma-manufacturer i (\$/unit).
e_i Unit production cost of product i for pharma-manufacturer i (\$/unit).
β_i CSR effort coefficient of pharma-manufacturer i.

3. MODEL FORMULATION

In this section, three decision-making structures are analyzed. Firstly, the profit functions of PSC members are modeled. To model the profit function of the pharma-retailer, demand of product i which is affected by both CSR investment and retail prices is as follows:

$$D_i\left(p_i, p_j, \mathrm{CSR}_i, \mathrm{CSR}_j\right) = d_i + \tau_1 \mathrm{CSR}_i - \tau_2 \mathrm{CSR}_j - \mu_1 p_i + \mu_2 p_j, \quad i = 1, 2, j = 3 - i, \tag{3.1}$$

in which the parameter d_i indicates the potential market demand of product i, parameters τ_1 and τ_2 define the pharma-manufacturer i and its competitor's CSR effort elasticity coefficient of demand, respectively and should satisfy $\tau_1 > \tau_2$. Parameters μ_1 and μ_2 denote the price sensitivity of demand to own price of product i and its competitor's price, respectively and should satisfy $\mu_1 > \mu_2$.

In the investigated PSC, the pharma-retailer's profit includes revenue of selling two substitutable products minus cost of the purchased products from the pharma-manufacturers. The pharma-retailer decides on the selling prices of two substitutable products. According to the above assumptions and formulations, the profit function of pharma-retailer can be calculated as follows:

$$\begin{aligned}\pi_r(p_1,p_2) &= \sum_{i=1}^{2}(p_i-w_i)\,D_i(p_i,p_j,\mathrm{CSR}_i,\mathrm{CSR}_j)\\ &= (p_1-w_1)(d_1+\tau_1\mathrm{CSR}_1-\tau_2\mathrm{CSR}_2-\mu_1p_1+\mu_2p_2)\\ &\quad+(p_2-w_2)(d_2+\tau_1\mathrm{CSR}_2-\tau_2\mathrm{CSR}_1-\mu_1p_2+\mu_2p_1). \end{aligned}\tag{3.2}$$

Moreover, in the PSC under consideration, the profit function of pharma-manufacturer $i(i=1,2)$ consists of revenue received from the pharma-retailer for selling product i minus costs of production and CSR investment. The investment for CSR effort has a diminishing return to scale, *i.e.*, the next dollar invested by the pharma-manufacturer returns less CSR effort level than the last dollar invested. Put differently, it is harder (and it also costs more) to provide the next unit of CSR effort level than the last one. Considering such decreasing return of decisions (*i.e.*, CSR effort, promotional effort) through a quadratic function when such decisions (*i.e.*, CSR effort, promotional effort) enter linearly into a demand function is a standard assumption [50]. The pharma-manufacturers decide on the CSR investment. Accordingly, pharma-manufacturer i's profit function can be formulated as follows:

$$\pi_{m_i}(\mathrm{CSR}_i)=(w_i-e_i)\,D_i(p_i,p_j,\mathrm{CSR}_i,\mathrm{CSR}_j)-\frac{1}{2}\beta_i\mathrm{CSR}_i^2\quad i=1,2.\tag{3.3}$$

In the following sub-section, the investigated PSC is modeled in the decentralized model considering pharma-manufacturers–Stackelberg game, in which the pricing and CSR decisions are optimized individually.

3.1. Decentralized decision-making model

In the decentralized decision-making model, each SC member aims to maximize its own profit without considering other SC members' viewpoint [2]. In the decentralized PSC, two pharma-manufacturers act as Stackelberg game leaders and the pharma-retailer acts as a PSC follower. Moreover, two pharma-manufacturers follow Cournot behavior in which decisions on the CSR efforts are simultaneously determined. To solve the Stackelberg game and obtain the decision variables, backward induction method is used. Accordingly, the pharma-retailer firstly determines selling prices of two substitutable products. Then the pharma-manufacturers simultaneously decide on the CSR investment. The optimal retail prices of two substitutable products are achieved through the following proposition.

Proposition 3.1. *The pharma-retailer's profit function in the Stackelberg–Cournot game is concave w.r.t.* p_1 *and* p_2.

Proof. See Appendix A.

Thus, the optimal values of p_1 and p_2 are obtained by setting $\partial\pi_r/\partial p_i=0\,(i=1,2)$ as follows:

$$p_1=\frac{d_1}{2\mu_1}+\frac{w_1}{2}-\frac{\mu_2}{2\mu_1}w_2+\frac{\tau_1}{2\mu_1}\mathrm{CSR}_1-\frac{\tau_2}{2\mu_1}\mathrm{CSR}_2+\frac{\mu_2}{\mu_1}p_2,\tag{3.4}$$

$$p_2=\frac{d_2}{2\mu_1}+\frac{w_2}{2}-\frac{\mu_2}{2\mu_1}w_1+\frac{\tau_1}{2\mu_1}\mathrm{CSR}_2-\frac{\tau_2}{2\mu_1}\mathrm{CSR}_1+\frac{\mu_2}{\mu_1}p_1.\tag{3.5}$$

Solving equations (3.4) and (3.5) simultaneously gives:

$$p_1=\frac{w_1}{2}+\frac{\mu_1d_1+\mu_2d_2+\mathrm{CSR}_1(\mu_1\tau_1-\mu_2\tau_2)+\mathrm{CSR}_2(\mu_2\tau_1-\mu_1\tau_2)}{2(\mu_1^2-\mu_2^2)},\tag{3.6}$$

$$p_2=\frac{w_2}{2}+\frac{\mu_1d_2+\mu_2d_1+\mathrm{CSR}_1(\mu_2\tau_1-\mu_1\tau_2)+\mathrm{CSR}_2(\mu_1\tau_1-\mu_2\tau_2)}{2(\mu_1^2-\mu_2^2)}.\tag{3.7}$$

Therefore, by replacing equations (3.6) and (3.7) into the pharma-manufacturers profit function, the problem of each remanufacturer in Cournot behavior of pharma-manufacturers, PMP^{Ct} is modeled as follows:

$$\mathrm{RMP}^{Ct}: \max \pi_{m_i}\left(\mathrm{CSR}_i\right) = \left(w_i - e_i\right) D_i\left(p_i, p_j, \mathrm{CSR}_i, \mathrm{CSR}_j\right) - \frac{1}{2}\beta_i \mathrm{CSR}_i^2 \quad i = 1, 2, \tag{3.8}$$

$$\text{Subject to} \quad \left(p_1, p_2\right) \in \operatorname{argmax} \pi_r\left(p_1, p_2\right). \tag{3.8a}$$

The optimal values of pharma-manufacturers' CSR efforts can be obtained after proving the concavity of the pharma-manufacturers' profit functions which is proved through the following proposition. □

Proposition 3.2. *The profit function of pharma-manufacturer i in the Stackelberg–Cournot game is concave w.r.t.* CSR_i.

Proof. The second-order derivative of $\pi_{m_i}\left(\mathrm{CSR}_i\right)$ w.r.t. CSR in the Stackelberg–Cournot game can be calculated as $\partial^2 \pi_{m_i} / \partial \mathrm{CSR}_i^2 = -\beta_i < 0$. Thus, $\pi_{m_i}\left(\mathrm{CSR}_i\right)$ is concave w.r.t. CSR_i.

Hence, the optimal values of CSR_1 and CSR_2 are obtained by setting $\partial \pi_{m_i} / \partial \mathrm{CSR}_i = 0\,(i = 1, 2)$ as follows:

$$\mathrm{CSR}_1^{\mathrm{dec}} = \frac{\left(w_1 - e_1\right)\tau_1}{2\beta_1} \tag{3.9}$$

$$\mathrm{CSR}_2^{\mathrm{dec}} = \frac{\left(w_2 - e_2\right)\tau_1}{2\beta_2}. \tag{3.10}$$

Considering backward induction, the optimal values of retail prices of two substitutable products are determined as follows:

$$p_1^{\mathrm{dec}} = \frac{w_1}{2} + \frac{2\beta_1\beta_2\left(\mu_1 d_1 + \mu_2 d_2\right) + \tau_1\left[\beta_2\left(w_1 - e_1\right)\left(\mu_1\tau_1 - \mu_2\tau_2\right) + \beta_1\left(w_2 - e_2\right)\left(\mu_2\tau_1 - \mu_1\tau_2\right)\right]}{4\beta_1\beta_2\left(\mu_1^2 - \mu_2^2\right)} \tag{3.11}$$

$$p_2^{\mathrm{dec}} = \frac{w_2}{2} + \frac{2\beta_1\beta_2\left(\mu_1 d_2 + \mu_2 d_1\right) + \tau_1\left[\beta_2\left(w_1 - e_1\right)\left(\mu_2\tau_1 - \mu_1\tau_2\right) + \beta_1\left(w_2 - e_2\right)\left(\mu_1\tau_1 - \mu_2\tau_2\right)\right]}{4\beta_1\beta_2\left(\mu_1^2 - \mu_2^2\right)}. \tag{3.12}$$

In the decentralized model, the PSC decisions on the pricing and CSR efforts are optimized from the individual profit function of each PSC member in the Stackelberg–Cournot game. While, in the following sub-section, the investigated PSC is modeled in the centralized structure in which all PSC decisions are optimized from the whole PSC point of view. □

3.2. Centralized decision-making model

In the centralized structure, whole SC is considered as a unity in which all SC decisions are jointly optimized from the entire SC perspective [36]. In the centralized PSC, the CSR efforts and pricing decisions are optimized in such a way that the maximum profit of the entire PSC is achieved. The profit function of entire PSC is sum of the pharma-retailer's and two pharma-manufacturers' profits as follows:

$$\begin{aligned}
\pi_{\mathrm{SC}}\left(p_1, p_2, \mathrm{CSR}_1, \mathrm{CSR}_2\right) &= \pi_r + \pi_{m_1} + \pi_{m_2} \\
&= \left(p_1 - e_1\right) D_1 + \left(p_2 - e_2\right) D_2 - \frac{1}{2}\beta_1 \mathrm{CSR}_1^2 - \frac{1}{2}\beta_2 \mathrm{CSR}_2^2 \\
&= \left(p_1 - e_1\right)\left(d_1 + \tau_1 \mathrm{CSR}_1 - \tau_2 \mathrm{CSR}_2 - \mu_1 p_1 + \mu_2 p_2\right) \\
&\quad + \left(p_2 - e_2\right)\left(d_2 + \tau_1 \mathrm{CSR}_2 - \tau_2 \mathrm{CSR}_1 - \mu_1 p_2 + \mu_2 p_1\right) \\
&\quad - \frac{1}{2}\beta_1 \mathrm{CSR}_1^2 - \frac{1}{2}\beta_2 \mathrm{CSR}_2^2.
\end{aligned} \tag{3.13}$$

Through the following proposition, the concavity of the entire PSC profit function is proved and then the optimal values of p_1, p_2, CSR_1, and CSR_2 is calculated.

Proposition 3.3. *The entire PSC profit function in the centralized model is concave w.r.t.* p_1, p_2, CSR_1 *, and* CSR_2.

Proof. See Appendix B.

Due to the concavity of the whole PSC profit function, by setting $\frac{\partial \pi_{\mathrm{SC}}}{\partial \mathrm{CSR}_1} = 0$, $\frac{\partial \pi_{\mathrm{SC}}}{\partial \mathrm{CSR}_2} = 0$, $\frac{\partial \pi_{\mathrm{SC}}}{\partial p_1} = 0$, $\frac{\partial \pi_{\mathrm{SC}}}{\partial p_2}$, the optimal values of PSC decisions in the centralized structure are determined as follows:

$$\mathrm{CSR}_1^{\mathrm{cen}} = \frac{\tau_1 (p_1 - e_1) - \tau_2 (p_2 - e_2)}{\beta_1} \tag{3.14}$$

$$\mathrm{CSR}_2^{\mathrm{cen}} = \frac{\tau_1 (p_2 - e_2) - \tau_2 (p_1 - e_1)}{\beta_2} \tag{3.15}$$

$$p_1^{\mathrm{cen}} = \frac{\tau_1}{2\mu_1}\mathrm{CSR}_1 - \frac{\tau_2}{2\mu_1}\mathrm{CSR}_2 + \frac{\mu_2}{\mu_1}p_2 + \frac{d_1}{2\mu_1} - \frac{\mu_2}{2\mu_1}e_2 + \frac{1}{2}e_1 \tag{3.16}$$

$$p_2^{\mathrm{cen}} = \frac{\tau_1}{2\mu_1}\mathrm{CSR}_2 - \frac{\tau_2}{2\mu_1}\mathrm{CSR}_1 + \frac{\mu_2}{\mu_1}p_1 + \frac{d_2}{2\mu_1} - \frac{\mu_2}{2\mu_1}e_1 + \frac{1}{2}e_2. \tag{3.17}$$

Since the values of $p_r1, p_r2, \mathrm{CSR}_1$ and CSR_2 are circularly depending on each other, the following search algorithm is proposed to find the optimal values of $p_r1, p_r2, \mathrm{CSR}_1$ and CSR_2 in the centralized structure $(p_r1^{\mathrm{cen}}, p_r2^{\mathrm{cen}}, \mathrm{CSR}_1^{\mathrm{cen}}, \mathrm{CSR}_2^{\mathrm{cen}})$:

Entire PSC optimal search algorithm

Step 1: Set $p_r1 = w_1$ and $p_r2 = w_2$.
Step 2: Calculate CSR_1 and CSR_2 using equations (3.14) and (3.15), respectively.
Step 3: Calculate p_1 and p_2 using equations (3.16) and (3.17) and according to the calculated CSR_1 and CSR_2.
Step 4: If the difference between two successive values of p_1, p_2, CSR_1 and CSR_2 is negligible, then go to Step 5; otherwise, go to Step 2.
Step 5: The final iteration of p_1, p_2, CSR_1 and CSR_2 is optimal, resulting in maximum profit for the entire PSC.

Although the centralized decision-making model creates the best solution for the entire PSC system, it may not necessarily benefit all PSC members. Therefore, all PSC members will agree on the centralized structure if their profits improve compared to those of the decentralized structure. As a result, to encourage the PSC members to accept the centralized decision-making model, a coordination mechanism is developed which guarantees the profitability of all PSC members. □

3.3. Coordinated decision-making model

In this section, we develop a CSR cost-sharing contract as a coordination contract to coordinate decisions on the pricing and CSR efforts in the investigated PSC and ensure the improvement of all PSC members' profits. In the proposed CSR cost-sharing contract, the pharma-retailer shares the fractions of the CSR investments of two pharma-manufacturers, $\emptyset_1$ and $\emptyset_2$, and sets its selling prices consistent with those of the centralized structure. The pharma-manufacturers also set their CSR efforts consistent with those of the centralized model. The profit functions of the pharma-retailer and pharma-manufacturers in the coordinated structure are as follows:

$$\begin{aligned}\pi_r^{co}\left(p_1^{\mathrm{cen}}, p_2^{\mathrm{cen}}, \emptyset_1, \emptyset_2\right) &= \sum_{i=1}^{2}\left(p_i^{\mathrm{cen}} - w_i\right) D_i\left(p_i^{\mathrm{cen}}, p_j^{\mathrm{cen}}, \mathrm{CSR}_i^{\mathrm{cen}}, \mathrm{CSR}_j^{\mathrm{cen}}\right)\\ &= \left(p_1^{\mathrm{cen}} - w_1\right)\left(d_1 + \tau_1 \mathrm{CSR}_1^{\mathrm{cen}} - \tau_2 \mathrm{CSR}_2^{\mathrm{cen}} - \mu_1 p_1^{\mathrm{cen}}\right.\\ &\quad \left. + \mu_2 p_2^{\mathrm{cen}}\right) + \left(p_2^{\mathrm{cen}} - w_2\right)\left(d_2 + \tau_1 \mathrm{CSR}_2^{\mathrm{cen}} - \tau_2 \mathrm{CSR}_1^{\mathrm{cen}}\right.\\ &\quad \left. - \mu_1 p_2^{\mathrm{cen}} + \mu_2 p_1{}^{\mathrm{cen}}\right) - \emptyset_1\left(\frac{1}{2}\beta_1 \mathrm{CSR}_1^{\mathrm{cen}^2}\right) - \emptyset_2\left(\frac{1}{2}\beta_2 \mathrm{CSR}_2^{\mathrm{cen}^2}\right)\end{aligned} \tag{3.18}$$

$$\pi_{m_i}^{co}\left(\mathrm{CSR}_i^{\mathrm{cen}}, \emptyset_i\right) = \left(w_i - e_i\right) D_i\left(p_i^{\mathrm{cen}}, p_j^{\mathrm{cen}}, \mathrm{CSR}_i^{\mathrm{cen}}, \mathrm{CSR}_j^{\mathrm{cen}}\right) - \left(1-\emptyset_i\right)\frac{1}{2}\beta_i \mathrm{CSR}_i^{\mathrm{cen}^2}\ (i=1,2). \tag{3.19}$$

As above-mentioned, neither the pharma-retailer nor the pharma-manufacturers will accept the proposed CSR cost-sharing contract if their own profits are less than those of the decentralized model. Thus, the satisfaction conditions from the pharma-retailer's and pharma-manufacturers' perspectives are as follows:

$$\pi_r^{co}\left(p_1^{\mathrm{cen}}, p_2^{\mathrm{cen}}, \emptyset_1, \emptyset_2\right) \geq \pi_r^{\mathrm{dec}}\left(p_1^{\mathrm{dec}}, p_2^{\mathrm{dec}}\right) \tag{3.20}$$

$$\pi_{m_1}^{co}\left(\mathrm{CSR}_1^{\mathrm{cen}}, \emptyset_1\right) \geq \pi_{m_1}^{\mathrm{dec}}\left(\mathrm{CSR}_1^{\mathrm{dec}}\right) \tag{3.21}$$

$$\pi_{m_2}^{co}\left(\mathrm{CSR}_2^{\mathrm{cen}}, \emptyset_2\right) \geq \pi_{m_2}^{\mathrm{dec}}\left(\mathrm{CSR}_2^{\mathrm{dec}}\right). \tag{3.22}$$

Through equations (3.20)–(3.22) the at least expectations of pharma-retailer and pharma-manufacturers in the proposed CSR cost-sharing contract are guaranteed. Simplifying equations (3.20)–(3.22), the lower and upper bounds of the fractions of the CSR investments, $\emptyset_1$ and $\emptyset_2$, are calculated as follows:

$$\emptyset_1 \geq \frac{\left(w_1-e_1\right)\theta_1 - 0.5\beta_1\left(\mathrm{CSR}_1^{\mathrm{dec}^2} - \mathrm{CSR}_1^{\mathrm{cen}^2}\right)}{0.5\beta_1 \mathrm{CSR}_1^{\mathrm{cen}^2}} \tag{3.23}$$

$$\emptyset_2 \geq \frac{\left(w_2-e_2\right)\theta_2 - 0.5\beta_2\left(\mathrm{CSR}_2^{\mathrm{dec}^2} - \mathrm{CSR}_2^{\mathrm{cen}^2}\right)}{0.5\beta_2 \mathrm{CSR}_2^{\mathrm{cen}^2}} \tag{3.24}$$

$$\begin{aligned} 0.5\emptyset_1\beta_1\mathrm{CSR}_1^{\mathrm{cen}^2} + 0.5\emptyset_2\beta_2\mathrm{CSR}_2^{\mathrm{cen}^2} \leq{}& \left(p_1^{\mathrm{cen}} - w_1\right)\left(d_1 + \tau_1\mathrm{CSR}_1^{\mathrm{cen}} - \tau_2\mathrm{CSR}_2^{\mathrm{cen}} - \mu_1 p_1^{\mathrm{cen}} + \mu_2 p_2^{\mathrm{cen}}\right) \\ &+ \left(p_2^{\mathrm{cen}} - w_2\right)\left(d_2 + \tau_1\mathrm{CSR}_2^{\mathrm{cen}} - \tau_2\mathrm{CSR}_1^{\mathrm{cen}} - \mu_1 p_2^{\mathrm{cen}} + \mu_2 p_1^{\mathrm{cen}}\right) \\ &- \left(p_1^{\mathrm{dec}} - w_1\right)\left(d_1 + \tau_1\mathrm{CSR}_1^{\mathrm{dec}} - \tau_2\mathrm{CSR}_2^{\mathrm{dec}} - \mu_1 p_1^{\mathrm{dec}} + \mu_2 p_2^{\mathrm{dec}}\right) \\ &- \left(p_2^{\mathrm{dec}} - w_2\right)\left(d_2 + \tau_1\mathrm{CSR}_2^{\mathrm{dec}} - \tau_2\mathrm{CSR}_1^{\mathrm{dec}} - \mu_1 dec + \mu_2 p_1^{\mathrm{dec}}\right) \end{aligned} \tag{3.25}$$

in which,

$$\theta_1 = \tau_1\left(\mathrm{CSR}_1^{\mathrm{dec}} - \mathrm{CSR}_1^{\mathrm{cen}}\right) - \tau_2\left(\mathrm{CSR}_2^{\mathrm{dec}} - \mathrm{CSR}_2^{\mathrm{cen}}\right) - \mu_1\left(p_1^{\mathrm{dec}} - p_1^{\mathrm{cen}}\right) + \mu_2\left(p_2^{\mathrm{dec}} - p_2^{\mathrm{cen}}\right) \tag{3.26}$$

$$\theta_2 = \tau_1\left(\mathrm{CSR}_2^{\mathrm{dec}} - \mathrm{CSR}_2^{\mathrm{cen}}\right) - \tau_2\left(\mathrm{CSR}_1^{\mathrm{dec}} - \mathrm{CSR}_1^{\mathrm{cen}}\right) - \mu_1\left(p_2^{\mathrm{dec}} - p_2^{\mathrm{cen}}\right) + \mu_2\left(p_1^{\mathrm{dec}} - p_1^{\mathrm{cen}}\right). \tag{3.27}$$

Similar to Chaharsooghi and Heydari [2], a profit sharing strategy based on the bargaining power of all PSC members is proposed to calculate the exact values of the fractions of the CSR investments, $\emptyset_1$ and $\emptyset_2$. The extra profit which is obtained in the proposed coordination model is as follows:

$$\Delta = \pi_{\mathrm{SC}}\left(p_r 1^{\mathrm{cen}}, p_r 2^{\mathrm{cen}}, \mathrm{CSR}_1^{\mathrm{cen}}, \mathrm{CSR}_2^{\mathrm{cen}}\right) - \pi_{\mathrm{SC}}\left(p_r 1^{\mathrm{dec}}, p_r 2^{\mathrm{dec}}, \mathrm{CSR}_1^{\mathrm{dec}}, \mathrm{CSR}_2^{\mathrm{dec}}\right). \tag{3.28}$$

The bargaining powers of pharma-retailer and pharma-manufacturers are indicated by α_r, α_1, and α_2. Therefore, based on the surplus profit and the bargaining powers of pharma-retailer and pharma-manufacturers, the share of pharma-retailer from the proposed coordination model is calculated as follows:

$$\frac{\alpha_r}{\alpha_r + \alpha_1 + \alpha_2}\Delta. \tag{3.29}$$

Hence, the profit function of the pharma-retailer in the proposed CSR cost-sharing contract considering the established profit sharing mechanism is as follows:

$$\begin{aligned}\pi_r^{co}\left(p_1^{\text{cen}}, p_2^{\text{cen}}, \emptyset_1, \emptyset_2\right) = \pi_r^{\text{dec}}\left(p_1^{\text{dec}}, p_2^{\text{dec}}\right) + \frac{\alpha_r}{\alpha_r+\alpha_1+\alpha_2}\Delta \\ = \left(p_1^{\text{cen}} - w_1\right)\left(d_1 + \tau_1 \text{CSR}_1^{\text{cen}} - \tau_2 \text{CSR}_2^{\text{cen}} - \mu_1 p_1^{\text{cen}}\right. \\ \left. + \mu_2 p_2^{\text{cen}}\right) + \left(p_2^{\text{cen}} - w_2\right)\left(d_2 + \tau_1 \text{CSR}_2^{\text{cen}} - \tau_2 \text{CSR}_1^{\text{cen}}\right. \\ \left. - \mu_1 p_2^{\text{cen}} + \mu_2 p_1^{\text{cen}}\right) - \emptyset_1\left(\frac{1}{2}\beta_1 \text{CSR}_1^{\text{cen}^2}\right) \\ - \emptyset_2\left(\frac{1}{2}\beta_2 \text{CSR}_2^{\text{cen}^2}\right) + \frac{\alpha_r}{\alpha_r+\alpha_1+\alpha_2}\Delta. \end{aligned} \tag{3.30}$$

Similarly, in the proposed CSR cost-sharing contract and profit sharing scheme, the pharma-manufacturers' profit functions are as follows:

$$\pi_{m_1}^{co}\left(\text{CSR}_1^{\text{cen}}, \emptyset_1\right) = \pi_{m_1}^{\text{dec}}\left(\text{CSR}_1^{\text{dec}}\right) + \frac{\alpha_1}{\alpha_r+\alpha_1+\alpha_2}\Delta$$

$$= \left(w_1 - e_1\right)\left(d_1 + \tau_1 \text{CSR}_1^{\text{dec}} - \tau_2 \text{CSR}_2^{\text{dec}} - \mu_1 p_1^{\text{dec}} + \mu_2 p_2^{\text{dec}}\right) \tag{3.31}$$

$$- \left(1 - \emptyset_1\right)\frac{1}{2}\beta_1 \text{CSR}_1^{\text{dec}^2} + \frac{\alpha_1}{\alpha_r+\alpha_1+\alpha_2}\Delta \tag{3.32}$$

$$\begin{aligned}\pi_{m_2}^{co}\left(\text{CSR}_2^{\text{cen}}, \emptyset_2\right) = \pi_{m_2}^{\text{dec}}\left(\text{CSR}_2^{\text{dec}}\right) + \frac{\alpha_2}{\alpha_r+\alpha_1+\alpha_2}\Delta \\ = \left(w_2 - e_2\right)\left(d_2 + \tau_1 \text{CSR}_2^{\text{dec}} - \tau_2 \text{CSR}_1^{\text{dec}} - \mu_1 p_2^{\text{dec}} + \mu_2 p_1^{\text{dec}}\right) \\ - \left(1 - \emptyset_2\right)\frac{1}{2}\beta_2 \text{CSR}_2^2 + \frac{\alpha_2}{\alpha_r+\alpha_1+\alpha_2}\Delta. \end{aligned} \tag{3.33}$$

Simplifying equations (3.32) and (3.33), the exact values of the fractions of the CSR investments, $\emptyset_1$ and $\emptyset_2$, are determined as follows:

$$\emptyset_1 = \frac{\left(w_1 - e_1\right)\theta_1 - 0.5\beta_1\left(\text{CSR}_1^{\text{dec}^2} - \text{CSR}_1^{\text{cen}^2}\right) + \frac{\alpha_2}{\alpha_r+\alpha_1+\alpha_2}\Delta}{0.5\beta_1 \text{CSR}_1^{\text{cen}^2}} \tag{3.34}$$

$$\emptyset_2 = \frac{\left(w_2 - e_2\right)\theta_2 - 0.5\beta_2\left(\text{CSR}_2^{\text{dec}^2} - \text{CSR}_2^{\text{cen}^2}\right) + \frac{\alpha_2}{\alpha_r+\alpha_1+\alpha_2}\Delta}{0.5\beta_2 \text{CSR}_2^{\text{cen}^2}}. \tag{3.35}$$

4. Numerical example and sensitivity analysis

In this section, to evaluate the performance of the proposed models, a set of numerical examples is provided which is shown in Table 2.

It is noteworthy that in practice, bargaining power of SC members can be measured based on some indicators such as level of monopoly/oligopoly, market share, and brand popularity [1]. We consider α_r, α_1, and α_2 as the bargaining power of pharma-retailer, pharma-manufacturer 1, and pharma-manufacturer 2, respectively, where $0 < \alpha_r, \alpha_1, \alpha_2 < 1$. In the investigated model, pharma-manufacturers have dominant powers relative to the pharma-retailer and thus they act as Stackelberg leaders in the market and pharma-retailer is their follower. Thus, due to the pharma-manufacturers–Stackelberg game played among PSC actors, the bargaining powers of PSC members relate to investment in CSR effort and are defined as $\alpha_1 = 0.4, \alpha_2 = 0.4, \alpha_r = 0.2$, for pharma-manufacturer 1, pharma-manufacturer 2, and the pharma-retailer, respectively.

Results of running the test problems in three decision-making models are indicated in Table 3. According to Table 3, although, the centralized model increases the profits of entire PSC and the pharma-retailer compared

Table 2. Test problems.

Test problem	d_1, d_2	τ_1, τ_2	μ_1, μ_2	w_1, w_2	e_1, e_2	β_1, β_2	$\alpha_1, \alpha_2, \alpha_r$
TP#1	$300, 200$	$4, 2$	$3, 2$	$120, 110$	$80, 70$	$15, 10$	$0.4, 0.4, 0.2$
TP#2	$1500, 1100$	$9, 6$	$10, 7$	$300, 280$	$260, 240$	$16, 10$	$0.45, 0.45, 0.1$
TP#3	$1700, 1400$	$8, 2$	$23, 18$	$190, 180$	$80, 70$	$10, 8$	$0.35, 0.35, 0.3$

Table 3. Results of running the proposed models in three decision-making structures.

Test problem	Decentralized model	Centralized model	Coordinated model
TP#1			
CSR_1	5.33	14.22	14.22
CSR_2	8.00	20.64	20.64
p_1	195.86	185.50	185.50
p_2	182.46	174.35	174.35
$\emptyset_1$	–	–	71.00%
$\emptyset_2$	–	–	53.20%
$\partial\pi_r$	11 030.28	13 629.90	11 419.68
$\partial\pi_{m_1}$	3093.33	2795.32	3872.13
$\partial\pi_{m_2}$	2306.66	1952.06	3085.46
π_{SC}	16 430.28	18 377.29	18 377.29
TP#2			
CSR_1	11.25	16.19	18.18
CSR_2	18	37.09	18.05
p_1	378.37	361.26	328.54
p_2	359.58	348.71	344.35
$\emptyset_1$	–	–	87.10%
$\emptyset_2$	–	–	25.52%
π_r	37 438.76	41 407.88	37 825.68
π_{m_1}	8052.5	7966.86	9793.63
π_{m_2}	8269.99	8255.69	10 011.13
π_{SC}	53 761.26	57 630.44	57 630.44
TP#3			
CSR_1	44.00	115.83	115.83
CSR_2	55.00	151.97	151.97
p_1	280.85	274.96	274.96
p_2	273.54	270.71	270.71
$\emptyset_1$	–	–	44.65%
$\emptyset_2$	–	–	42.22%
π_r	85 155.96	174 464.10	105 503.67
π_{m_1}	34 979.99	28 764.96	58 719.00
π_{m_2}	44 660.00	29 392.61	68 399.00
π_{SC}	164 795.96	232 621.68	232 621.68

to those of the decentralized model in all test problems, the pharma-manufacturers incur losses. While, in the proposed CSR cost-sharing contract as a coordination model, all PSC members achieve more profit relative to the decentralized structure. Moreover, in all test problems, the proposed coordination model enhances the entire PSC profit up to that of the centralized structure and thus the proposed CSR cost-sharing contract is able to achieve channel coordination in the investigated PSC. In addition, in the proposed coordination scheme not only the CSR efforts of pharma-manufacturers increase but also the retail prices of two substitutable products

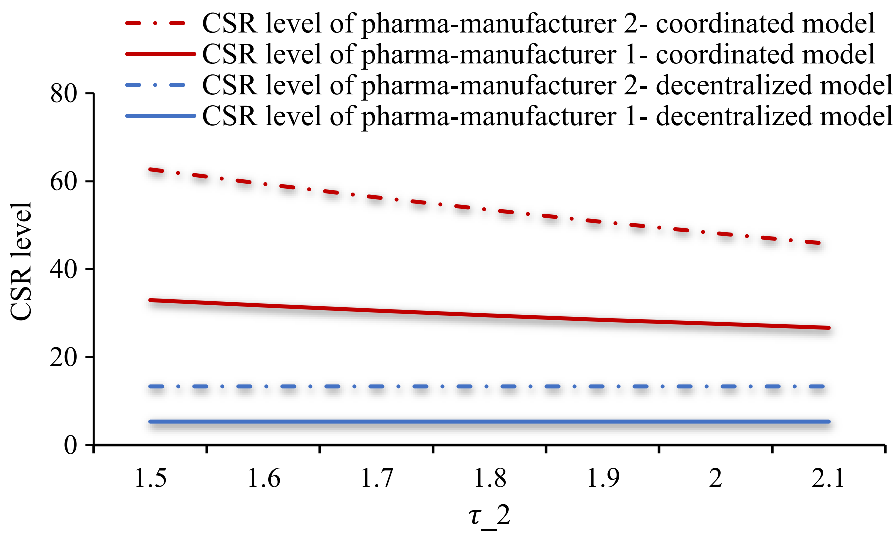


FIGURE 2. Level of CSR effort over τ_2 in decision-making structures.

decrease, indicating that the market demand will be increased in the coordination model compared to the decentralized model.

In addition, a set of sensitivity analysis is conducted to investigate the impact of parameters $\tau_2, \emptyset_1$, and $\emptyset_2$ on the CSR investment level, retail prices, and whole PSC profit and its members' profit. Test problem 1 is used to analyze the impact of competition level between two pharma-manufacturers, τ_2, on the proposed models. Figure 2 shows the changes of level of CSR effort invested by two pharma-manufacturers over increasing competition level between pharma-manufacturers, τ_2 in the decentralized and coordinated models. From Figure 2, as τ_2 increases, the CSR effort has not any significant changes in the decentralized structure. While, by increasing competition level between pharma-manufacturers, the level of CSR effort decreases in the proposed CSR cost-sharing contract. However, the proposed coordination scheme can create higher CSR level for the pharma-manufacturers compared to the decentralized structure. This result implies that the proposed coordination model is of high applicability and efficiency in the investigated PSC.

Figures 3 and 4 indicate how the prices of two substitutable products change over changing the competition level between two pharma-manufacturers on the CSR effort, τ_2, in both decentralized and coordinated structures. As can be seen in Figure 3, by increasing τ_2, the retail price of product 1 (*i.e.*, product produced by pharma-manufacturer 1) decreases in both decentralized and coordinated models. However, the proposed coordination model significantly decreases the retail price of product 1, resulting in more demand share for the pharma-manufacturer 1 compared to the decentralized structure. In addition, as competition level between two pharma-manufacturers on the CSR effort increases, the difference between retail prices of product 1 in the coordinated and decentralized models increases which creates the proposed model more efficient.

According to Figure 4, as τ_2 increases, the difference between retail prices of product 2 in the coordinated and decentralized structures grows demonstrating the applicability of the proposed coordination model in the investigated PSC. As a result, in the intense level of competition between manufacturers on the CSR effort, using the proposed CSR cost-sharing contract is of high importance.

The changes of profits of whole PSC system and its members over changing τ_2 in the decentralized, centralized, and coordinated models are illustrated in Figures 5–8. As Figure 5 shows, as competition level between pharma-manufacturers on the CSR effort increases, the pharma-retailer's profit decreases in all decision-making structures. However, the profits of pharma-retailer significantly decreases in the centralized model. Although,

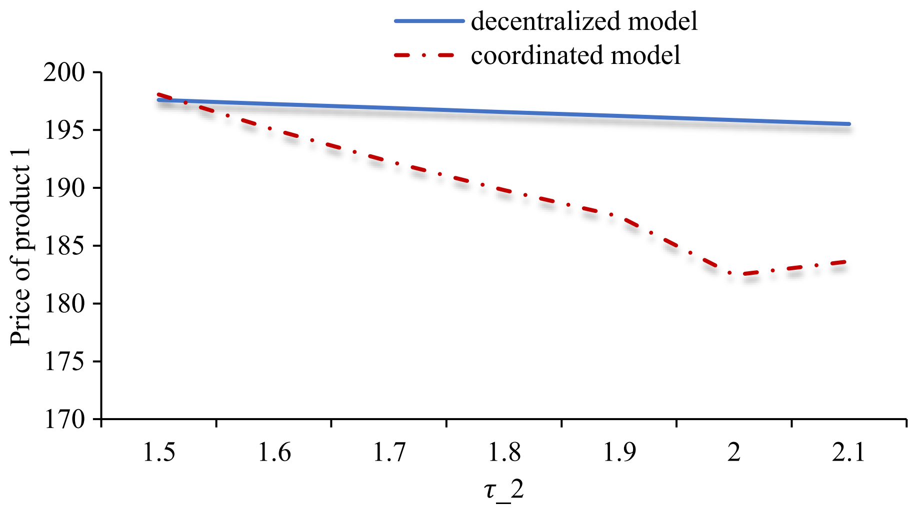


FIGURE 3. Retail price of product 1 over τ_2 in decision-making structures.

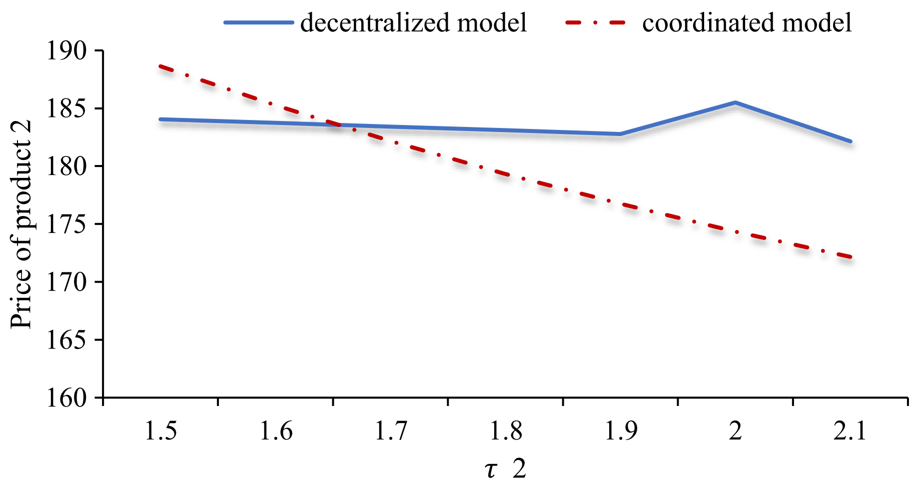


FIGURE 4. Retail price of product 2 over τ_2 in decision-making structures.

the centralized model creates maximum profit for the pharma-retailer compared to other models, two pharma-manufacturers incur losses in the centralized model as shown in Figures 6 and 7. As Figure 5 depicts, the proposed CSR cost-sharing contract as a coordination model results in more profit for the pharma-retailer relative to the decentralized model which demonstrates that the proposed CSR cost-sharing contract is flexible enough to convince the pharma-retailer to accept the coordination plan.

Figure 8 depicts the whole PSC profit as competition level between pharma-manufacturers on the CSR effort, τ_2, increases in the decentralized, centralized, and coordinated models. As Figure 8 shows, by increasing τ_2, the profit of entire PSC decreases in all decision-making structures. However, as τ_2 increases, the proposed CSR cost-sharing contract creates more profit for the entire PSC in comparison with the decentralized model. Moreover, the proposed CSR cost-sharing contract improves the profit up to that of the centralized model for

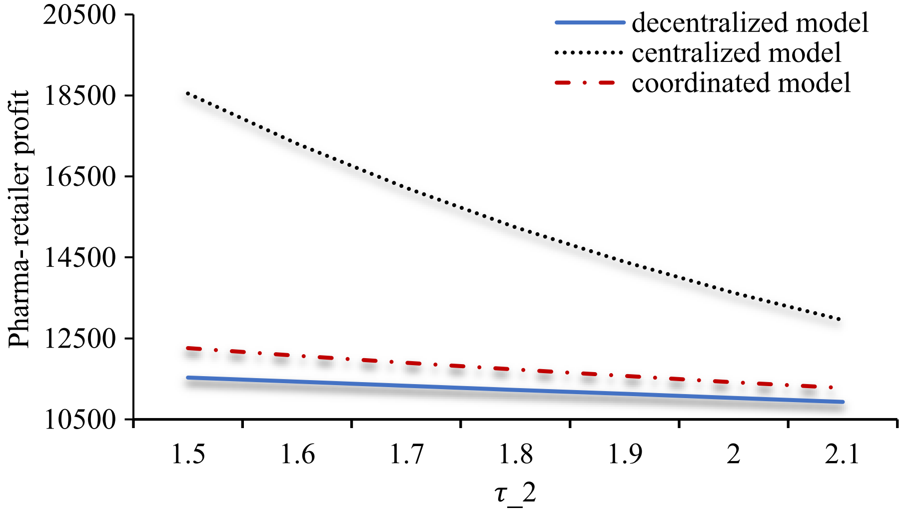


FIGURE 5. Pharma-retailer profit over τ_2 in decision-making structures.

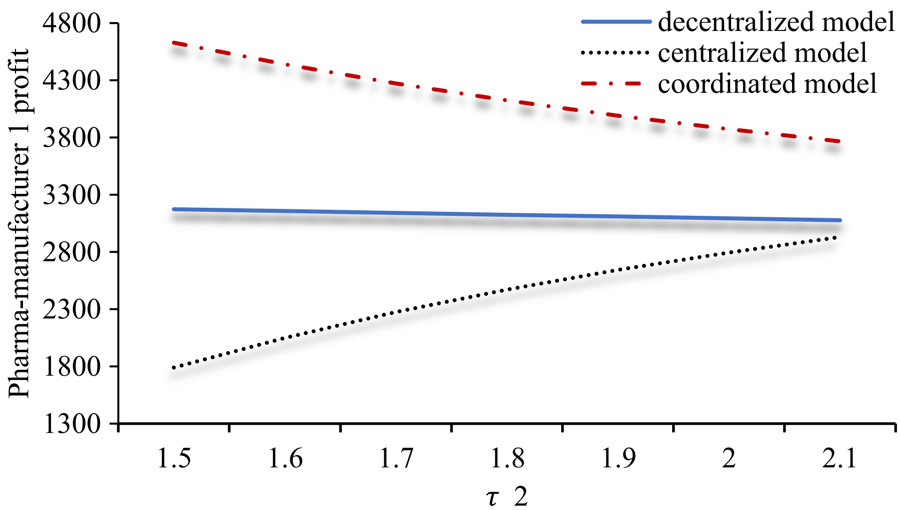


FIGURE 6. Pharma-manufacturer 1 profit over τ_2 in decision-making structures.

the whole PSC, indicating the proposed coordination model is capable of achieving channel coordination in the investigated PSC.

Moreover, test problem 3 is used to investigate the effect of parameters $\emptyset_1$ and $\emptyset_2$ on the PSC members' profit in the proposed coordination model. Figure 9 indicates the changes of PSC members' profit over different combination of coordination parameters, *i.e.*, $\emptyset_1$ and $\emptyset_2$. According to Figure 9 and Table 3, the combination of $(\emptyset_1 = 7.26\%, \emptyset_2 = 10.22\%)$ creates profits of 33 638.3 and 38 835.9 for the pharma-manufacturers in the proposed coordination plan which is not beneficial to them since their profits decrease compared to those of the decentralized model, *i.e.*, (34 979.99, 44 660.00). However, this combination of coordination parameters improves the pharma-retailer's profit compared to that of the decentralized model. In addition, combination of $(\emptyset_1 = 57.26\%, \emptyset_2 = 60.22\%)$ incurs the pharma-retailer losses in the proposed CSR cost-sharing contract as it

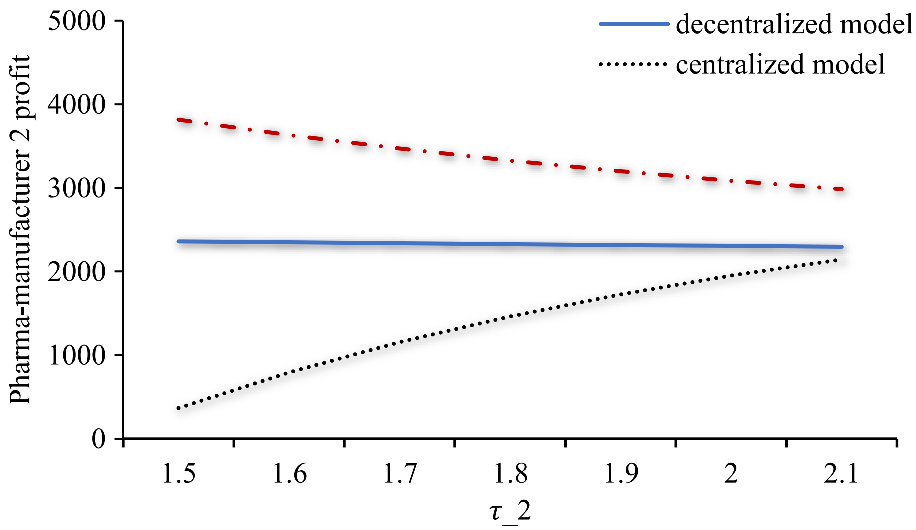


FIGURE 7. Pharma-manufacturer 2 profit over τ_2 in decision-making structures.

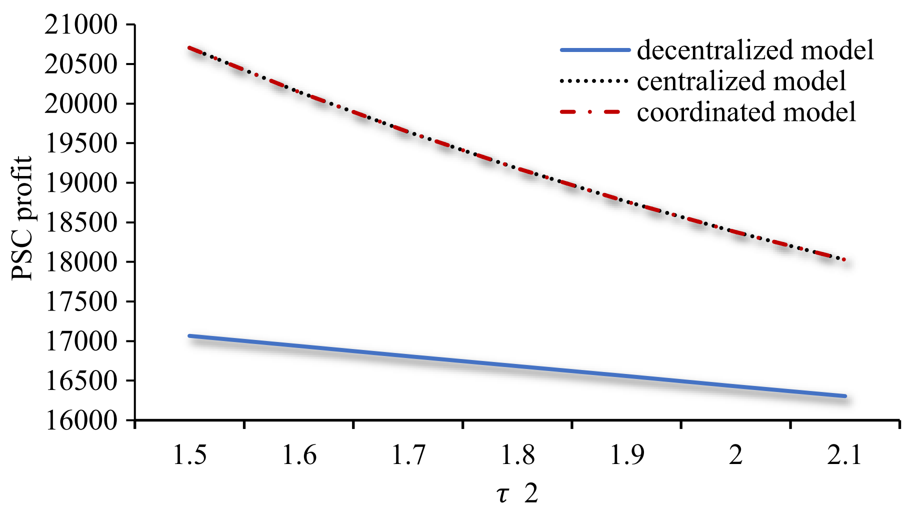
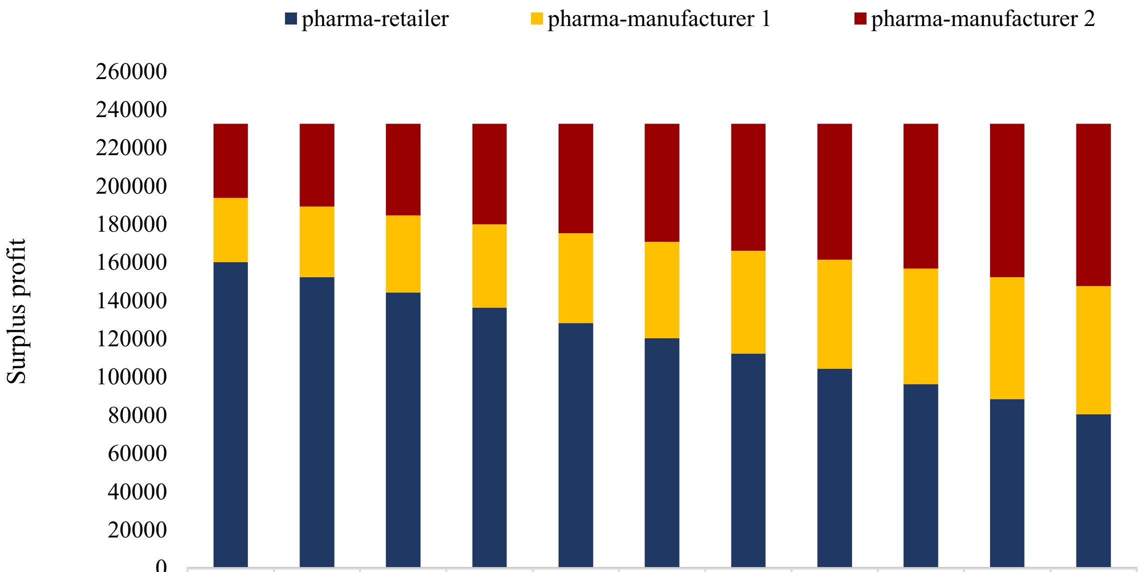


FIGURE 8. Whole PSC profit over τ_2 in decision-making structures.

creates profit of 80 413.5 for him which is lower than that of the decentralized model, *i.e.*, 85 155.96. Other combinations of $(\emptyset_1, \emptyset_2)$ create more profits for all PSC members, *i.e.*, two pharma-manufacturers and pharma-retailer relative to the decentralized model, thus providing a win-win situation for all PSC members.

5. MANAGERIAL INSIGHTS

– The proposed CSR cost-sharing contract is able to motivate pharma-manufacturers to invest more in CSR effort compared to the decentralized model. On the other hand, the proposed CSR cost-sharing contract can encourage pharma-retailer to decrease retail prices of two substitutable products relative to the decentralized structure. As a result, the proposed coordination model can benefit both customers through decreasing selling



	(7.26 %,10. 22%)	(12.26 %,15. 22%)	(17.26 %,20. 22%)	(22.26 %,25. 22%)	(27.26 %,30. 22%)	(32.26 %,35. 22%)	(37.26 %,40. 22%)	(42.26 %,45. 22%)	(47.26 %,50. 22%)	(52.26 %,55. 22%)	(57.26 %,60. 22%)
pharma-manufacturer 2	38835.9	43455.1	48074.4	52693.6	57312.8	61932.1	66551.3	71170.5	75789.8	80409	85028.3
pharma-manufacturer 1	33638.3	36992.5	40346.7	43700.8	47055	50409.1	53763.3	57117.4	60471.6	63825.7	67179.9
pharma-retailer	160147	152174	144201	136227	128254	120280	112307	104334	96360.3	88386.9	80413.5

Ø_1, Ø_2

FIGURE 9. Profit sharing over $\emptyset_1$ and $\emptyset_2$ in the CSR cost-sharing contract.

prices of substitutable products and supply chain systems through increasing CSR effort which results in more market share for SC systems.

- Considering the impact of CSR effort invested by manufacturers on the retail prices of substitutable products of retailer and the effect of retailer's prices on the profits of manufacturers, SC managers can achieve more benefit from a CSR cost-sharing contract as it is capable of coordinating the chain members' decisions on the retail prices and CSR effort simultaneously.
- The proposed CSR cost-sharing contract can increase profits of all PSC members (*i.e.*, pharma-manufacturers and pharma-retailer) compared to the decentralized model in addition to improve the whole PSC profit up to that of the centralized structure; thus providing a win-win situation for all PSC participants and achieving channel coordination in the investigated PSC.
- Regarding competitive situation between pharma-manufacturers on the CSR investment, the proposed CSR cost-sharing contract can make higher CSR level for the pharma-manufacturers relative to the decentralized model. It can be concluded that under intense competition between manufacturers in the business market, implementing the proposed CSR cost-sharing contract is of high applicability and efficiency. In addition, the proposed CSR cost-sharing contract can significantly decrease retail prices of substitutable products compared to the decentralized model. Moreover, as competition level between two pharma-manufacturers on the CSR effort grows, the difference between retail prices of products in the coordinated and decentralized structures increases which creates the proposed CSR cost-sharing contract more efficient. As a result, under

the proposed CSR cost-sharing contract, SC managers can achieve more market share through increasing their CSR efforts and decreasing retail prices of substitutable products.

6. Conclusion

This paper addresses corporate social responsibility (CSR) effort under competitive situation and supply chain coordination model for a two-echelon pharmaceutical supply chain (PSC) with two substitutable products. The PSC under consideration consists of two pharma-manufacturers, competitively investing in the CSR effort to produce a new herbal medicine, and one pharma-retailer, selling the substitutable products of pharma-manufacturers to consumers. The pharma-retailer decides on the retail prices of two products. Thus, the market demand is dependent on both CSR efforts of the pharma-manufacturers and retail prices of the pharma-retailer. The investigated PSC is modeled in three decision-making structures, *i.e.*, (1) decentralized, (2) centralized, and (3) coordinated models. In the decentralized model considering the pharma-manufacturers–Stackelberg game structure, the pricing and CSR decisions are individually determined by each PSC member such that each PSC member's profit is optimized. Although in the centralized model as a benchmark, the maximum profit of whole PSC system is obtained, it is not necessarily beneficial for all PSC members as it may decrease the profits of some PSC members. Thus, a CSR cost-sharing contract as a coordination model is proposed to improve all PSC members' profits and create profit up to that of the centralized model for whole PSC system. Moreover, in the proposed coordination scheme, the fractions of the CSR investments of two pharma-manufacturers shared by the pharma-retailer are determined in a way that the proposed coordination plan is acceptable for all PSC members, thus providing a win-win situation for all PSC participants. Our results demonstrate that the proposed CSR cost-sharing contract is able to simultaneously coordinate the CSR and pricing decisions under competitive situation. Moreover, the proposed CSR cost-sharing contract is able to achieve channel coordination under various combinations of fractions of the CSR investments shared by the pharma-retailer. In addition, under intense competition between two pharma-manufacturers on the CSR effort, the proposed coordination model creates more profit for the entire PSC system and its members compared to the decentralized model. Moreover, in competitive environment, the proposed CSR cost-sharing contract is capable of increasing market demand of the PSC system through significantly decreasing retail prices of two substitutable products along with increasing the pharma-manufacturers' level of the CSR efforts.

For future research study, this study can be extended in several directions. In this study, deterministic price-CSR dependent demand is assumed. This model can be extended by incorporating uncertainty into market demand. Moreover, this paper investigates competitive situation only between manufacturers. However, in practice, retailers usually compete on providing selling prices. Therefore, this study can be developed by considering simultaneous competitive situations in both manufacturers and retailers sides. In this study, it is considered that only manufacturers invest in CSR efforts. However, in practice, retailer can also corporate in CSR effort. As another future research, this model could be extended by investigating CSR efforts of both manufacturers and retailer. Moreover, this study considers the effect of CSR efforts made by competing manufacturers in the market demand. One can extend the model, investigating CSR competition between manufacturers in the form of consumer surplus. In this study, CSR investment cost and production cost are considered to be known to both manufacturers and retailer. However, in practice, manufacturers usually have private information about their CSR investment cost and production cost and such costs may not be known to other channel members. As another future research, it will be challenging to investigate this model under asymmetric CSR investment information or asymmetric production cost information. Finally, this study proposes CSR cost-sharing contract to coordinate manufacturers-retailer SC. This model can be extended by investigating other SC coordination schemes such as two-part tariff, revenue-sharing, and collaborative models.

Appendix A. Proof of Proposition 3.1

To prove the concavity of pharma-retailer's profit function w.r.t. p_1 and p_2, the Hessian matrix of $\pi_r\left(p_1, p_2\right)$ w.r.t. p_1 and p_2 is calculated as follows. If the Hessian matrix is negative definite, then $\pi_r\left(p_1, p_2\right)$ is concave w.r.t. p_1 and p_2.

$$H\left(\pi_r\right)=\begin{bmatrix}\frac{\partial^2\pi_r}{\partial p_1^2} & \frac{\partial^2\pi_r}{\partial p_1\partial p_2}\\ \frac{\partial^2\pi_r}{\partial p_2\partial p_1} & \frac{\partial^2\pi_r}{\partial p_2^2}\end{bmatrix}. \tag{A.1}$$

The second-order partial derivatives of the profit of pharma-retailer w.r.t. p_1 and p_2 can be calculated as:

$$H_{11}=\frac{\partial^2\pi_r}{\partial p_1^2}=\frac{\partial^2\pi_r}{\partial p_2^2}=-2\mu_1<0, \tag{A.2}$$

$$\frac{\partial^2\pi_r}{\partial p_1\partial p_2}=\frac{\partial^2\pi_r}{\partial p_1\partial p_2}=2\mu_2>0, \tag{A.3}$$

The second principle minor is always positive, because of the assumption $\mu_1>\mu_2$

$$H_{22}=4\left(\mu_1^2-\mu_2^2\right)>0, \tag{A.4}$$

Thus, the hessian matrix of $H\left(\pi_r\right)$ is negative definite. So, $\pi_r\left(p_1,p_2\right)$ is concave w.r.t. p_1 and p_2.

Appendix B. Proof of Proposition 3.3

To prove the concavity of the entire PSC profit function with respect to p_1, p_2, CSR_1, and CSR_2, the Hessian matrix of the entire PSC profit function, $\pi_{\mathrm{SC}}\left(p_1,p_2,\mathrm{CSR}_1,\mathrm{CSR}_2\right)$ w.r.t. p_1, p_2, CSR_1, and CSR_2 should be calculated. If the Hessian matrix is negative definite, then p_1, p_2, CSR_1, and CSR_2 is concave w.r.t. p_1, p_2, CSR_1, and CSR_2. The associated Hessian matrix of $\pi_{\mathrm{SC}}\left(p_1,p_2,\mathrm{CSR}_1,\mathrm{CSR}_2\right)$ is as follows:

$$H\left(\pi_s c(p_1,p_2,\mathrm{CSR}_1,\mathrm{CSR}_2)\right)=\begin{bmatrix}\frac{\partial^2\pi SC}{\partial \mathrm{CSR}_1^2} & \frac{\partial^2\pi SC}{\partial \mathrm{CSR}_1\partial \mathrm{CSR}_2} & \frac{\partial^2\pi SC}{\partial \mathrm{CSR}_1\partial p} & \frac{\partial^2\pi SC}{\partial \mathrm{CSR}_1\partial p_2}\\ \frac{\partial^2\pi SC}{\partial p_1\partial \mathrm{CSR}_1} & \frac{\partial^2\pi SC}{\partial p_1\partial \mathrm{CSR}_2} & \frac{\partial^2\pi SC}{\partial p_1} & \frac{\partial^2\pi SC}{\partial p_1\partial p_2}\\ \frac{\partial^2\pi SC}{\partial p_2\partial \mathrm{CSR}_1} & \frac{\partial^2\pi SC}{\partial p_2\partial \mathrm{CSR}_2} & \frac{\partial^2\pi SC}{\partial p_2\partial p_1} & \frac{\partial^2\pi SC}{\partial p_2^2}\end{bmatrix} \tag{B.1}$$

in which,

$$H_{11}=\frac{\partial^2\pi_{\mathrm{SC}}}{\partial \mathrm{CSR}_1^2}=-\beta_1<0 \tag{B.2}$$

$$H_{22}=\frac{\partial^2\pi_{\mathrm{SC}}}{\partial \mathrm{CSR}_1^2}\times\frac{\partial^2\pi_{\mathrm{SC}}}{\partial \mathrm{CSR}_2^2}-\left(\frac{\partial^2\pi_{\mathrm{SC}}}{\partial \mathrm{CSR}_1\partial \mathrm{CSR}_2}\right)^2=\beta_1\beta_2>0 \tag{B.3}$$

The third principle minor is negative if the following condition is satisfied:

$$\beta_2\tau_1^2<\beta_1\left(2\mu_1\beta_2+\tau_2\right) \tag{B.4}$$

The forth principle minor is positive if the following condition is satisfied:

$$2\mu_1\beta_1\left(\tau_1^2-\tau_2^2\right)+4\beta_1\beta_2\left(\mu_1^2-\mu_2^2\right)+4\beta_2\mu_2\tau_1\tau_2>2\mu_1\beta_2\left(\tau_1^2+\tau_2^2\right) \tag{B.5}$$

Acknowledgements. The authors sincerely thank the editor, associate editor and reviewers for their kind and constructive comments and suggestions, which significantly improved this paper. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] Z. Basiri and J. Heydari, A mathematical model for green supply chain coordination with substitutable products. *J. Cleaner Prod.* **145** (2017) 232–249.

[2] S.K. Chaharsooghi and J. Heydari, Supply chain coordination for the joint determination of order quantity and reorder point using credit option. *Eur. J. Oper. Res.* **204** (2010) 86–95.

[3] S.K. Chaharsooghi, J. Heydari and I.N. Kamalabadi, Simultaneous coordination of order quantity and reorder point in a two-stage supply chain. *Comput. Oper. Res.* **38** (2011) 1667–1677.

[4] K. Chen, L. Yang and Y. Liu, An analysis of supply chain decisions with asymmetrical retailers: effects of disruptions and static service cost on coordination mechanism. *RAIRO: OR* **46** (2012) 159–187.

[5] J.M. Cruz and T. Wakolbinger, Multiperiod effects of corporate social responsibility on supply chain networks, transaction costs, emissions, and risk. *Int. J. Prod. Econ.* **116** (2008) 61–74.

[6] H. Droppert and S. Bennett, Corporate social responsibility in global health: an exploratory study of multinational pharmaceutical firms. *Globalization Health* **11** (2015) 15.

[7] P. Dutta, D. Das, F. Schultmann and M. Fröhling, Design and planning of a closed-loop supply chain with three way recovery and buy-back offer. *J. Cleaner Prod.* **135** (2016) 604–619.

[8] S. Ebrahimi, S.M. Hosseini-Motlagh and M. Nematollahi, Proposing a delay in payment contract for coordinating a two-echelon periodic review supply chain with stochastic promotional effort dependent demand. *Int. J. Mach. Learn. Cybern.* **10** (2019) 1037–1050.

[9] T. Farrington, R. Curran, K. Gori, K.D. O'Gorman and C.J. Queenan, Corporate social responsibility: reviewed, rated, revised. *Int. J. Contemp. Hospitality Manage.* **29** (2017) 30–47.

[10] C.J. Fombrun, The leadership challenge: building resilient corporate reputations. *Handb. Responsible Leadership Governance Global Bus.* **54** (2005) 68.

[11] J. Gao, K. Iyer and H. Topaloglu, Price competition under linear demand and finite inventories: contraction and approximate equilibria. *Oper. Res. Lett.* **45** (2017) 382–387.

[12] K. Govindan and M.N. Popiuc, Reverse supply chain coordination by revenue sharing contract: a case for the personal computers industry. *Eur. J. Oper. Res.* **233** (2014) 326–336.

[13] S.M. Hosseini-Motlagh and S. Ebrahimi, Coordination of a green supply chain with one manufacturer and two duopolistic retailers through an environmental and social cost-sharing contract. *J. Ind. Syst. Eng.* **11** (2018) 108–126.

[14] S.M. Hosseini-Motlagh, M. Nematollahi and M. Nouri, Coordination of green quality and green warranty decisions in a two-echelon competitive supply chain with substitutable products. *J. Cleaner Prod.* **196** (2018) 961–984.

[15] S.M. Hosseini-Motlagh, M. Nematollahi, M. Johari and B.R. Sarker, A collaborative model for coordination of monopolistic manufacturer's promotional efforts and competing duopolistic retailers' trade credits. *Int. J. Prod. Econ.* **204** (2018) 108–122.

[16] S.M. Hosseini-Motlagh, P. Pazari and M. Nouri, Coordination of promotional effort, corporate social responsibility and periodic review replenishment decisions in a two-echelon socially responsible supply chain. *J. Ind. Syst. Eng.* **11** (2018) 60–83.

[17] S.M. Hosseini-Motlagh, K. Govindan, M. Nematollahi and A. Jokar, An adjustable bi-level wholesale price contract for coordinating a supply chain under scenario-based stochastic demand. *Int. J. Prod. Econ.* **214** (2019) 175–195.

[18] S.M. Hosseini-Motlagh, M. Nematollahi, M. Johari and T.M. Choi, Reverse supply chain systems coordination across multiple links with duopolistic third party collectors. To appear in: *IEEE Transactions on Systems, Man, and Cybernetics: Systems.* DOI: 10.1109/TSMC.2019.2911644 (2019).

[19] C.F. Hsueh, Improving corporate social responsibility in a supply chain through a new revenue sharing contract. *Int. J. Prod. Econ.* **151** (2014) 214–222.

[20] Y.S. Huang, S.H. Lin and C.C. Fang, Pricing and coordination with consideration of piracy for digital goods in supply chains. *J. Bus. Res.* **77** (2017) 30–40.

[21] H. Jafari, S.R. Hejazi and M. Rasti, Pricing decisions in dual-channel supply chain with one manufacturer and multiple retailers: a game-theoretic approach. *RAIRO: OR* **51** (2017) 1269–1287.

[22] M. Jazinaninejad, S.M. Seyedhosseini, S.M. Hosseini-Motlagh and M. Nematollahi, Coordinated decision-making on manufacturer's EPQ-based and buyer's period review inventory policies with stochastic price-sensitive demand: a credit option approach. *RAIRO: OR* **53** (2019) 1129–1154.

[23] M. Johari and S. Hosseini-Motlagh, Coordination of cooperative promotion efforts with competing retailers in a manufacturer-retailer supply chain. *Uncertain Supply Chain Manage.* **6** (2018) 25–48.

[24] M. Johari and S.M. Hosseini-Motlagh, Coordination of social welfare, collecting, recycling and pricing decisions in a competitive sustainable closed-loop supply chain: a case for lead-acid battery. To appear in: *Ann. Oper. Res.* DOI: 10.1007/s10479-019-03292-1 (2019).

[25] M. Johari, S.M. Hosseini-Motlagh and M.R. Nematollahi, Coordinating pricing and periodic review replenishment decisions in a two-echelon supply chain using quantity discount contract. *J. Ind. Eng. Manage. Stud.* **3** (2016) 58–87.

[26] M. Johari, S.M. Hosseini-Motlagh and M. Nematollahi, Simultaneous coordination of review period and order-up-to-level in a manufacturer-retailer chain. Special issue on production and inventory *J. Ind. Syst. Eng.* **10** (2017) 1–17.

[27] M. Johari, S.M. Hosseini-Motlagh, M. Nematollahi, M. Goh and J. Ignatius, Bi-level credit period coordination for periodic review inventory system with price-credit dependent demand under time value of money. *Transp. Res. Part E: Logistics Transp. Rev.* **114** (2018) 270–291.

[28] W. Li and J. Chen, Pricing and quality competition in a brand-differentiated supply chain. *Int. J. Prod. Econ.* **202** (2018) 97–108.

[29] N.M. Modak, S. Panda, S.S. Sana and M. Basu, Corporate social responsibility, coordination and profit distribution in a dual-channel supply chain. *Pac. Sci. Rev.* **16** (2014) 235–249.

[30] N.M. Modak, S. Panda, R. Mishra and S.S. Sana, A three-layer supply chain coordination in socially responsible distribution system. *Tékhne* **14** (2016) 75–87.

[31] N.M. Modak, S. Panda, S.S. Sana, Pricing policy and coordination for a two-layer supply chain of duopolistic retailers and socially responsible manufacturer. *Int. J. Logistics Res. App.* **19** (2016) 487–508.

[32] N.M. Modak, S. Panda and S.S. Sana, Three-echelon supply chain coordination considering duopolistic retailers with perfect quality products. *Int. J. Prod. Econ.* **182** (2016) 564–578.

[33] N.M. Modak, N. Kazemi and L.E. Cárdenas-Barrón, Investigating structure of a two-echelon closed-loop supply chain using social work donation as a Corporate Social Responsibility practice. *Int. J. Prod. Econ.* **207** (2019) 19–33.

[34] M. Nematollahi, S.M. Hosseini-Motlagh and J. Heydari, Coordination of social responsibility and order quantity in a two-echelon supply chain: a collaborative decision-making perspective. *Int. J. Prod. Econ.* **184** (2017) 107–121.

[35] M. Nematollahi, S. M. Hosseini-Motlagh and J. Heydari, Economic and social collaborative decision-making on visit interval and service level in a two-echelon pharmaceutical supply chain. *J. Cleaner Prod.* **142** (2017) 3956–3969.

[36] M. Nematollahi, S.M. Hosseini-Motlagh, J. Ignatius, M. Goh and M.S. Nia, Coordinating a socially responsible pharmaceutical supply chain under periodic review replenishment policies. *J. Cleaner Prod.* **172** (2018) 2876–2891.

[37] D. Ni and K.W. Li, A game-theoretic analysis of social responsibility conduct in two-echelon supply chains. *Int. J. Prod. Econ.* **138** (2012) 303–313.

[38] M. Nouri, S.M. Hosseini-Motlagh and M. Nematollahi, Proposing a discount policy for two-level supply chain coordination with periodic review replenishment and promotional efforts decisions. To appear in: *Oper. Res. Int. J.* DOI: 10.1007/s12351-018-0434-x (2018).

[39] M. Nouri, S.M. Hosseini-Motlagh, M. Nematollahi and B.R. Sarker, Coordinating manufacturer's innovation and retailer's promotion and replenishment using a compensation-based wholesale price contract. *Int. J. Prod. Econ.* **198** (2018) 11–24.

[40] S. Panda, Coordination of a socially responsible supply chain using revenue sharing contract. *Transp. Res. Part E: Logistics Transp. Rev.* **67** (2014) 92–104.

[41] S. Panda and N.M. Modak, Exploring the effects of social responsibility on coordination and profit division in a supply chain. *J. Cleaner Prod.* **139** (2016) 25–40.

[42] S. Panda, N.M. Modak, M. Basu and S.K. Goyal, Channel coordination and profit distribution in a social responsible three-layer supply chain. *Int. J. Prod. Econ.* **168** (2015) 224–233.

[43] S. Panda, N.M. Modak and D. Pradhan, Corporate social responsibility, channel coordination and profit division in a two-echelon supply chain. *Int. J. Manage. Sci. Eng. Manage.* **11** (2016) 22–33.

[44] S. Panda, N.M. Modak and L.E. Cárdenas-Barrón, Coordinating a socially responsible closed-loop supply chain with product recycling. *Int. J. Prod. Econ.* **188** (2017) 11–21.

[45] A. Raj, I. Biswas and S.K. Srivastava, Designing supply contracts for the sustainable supply chain using game theory. *J. Cleaner Prod.* **185** (2018) 275–284.

[46] S. Sen and C.B. Bhattacharya, Does doing good always lead to doing better? Consumer reactions to corporate social responsibility. *J. Marketing Res.* **38** (2001) 225–243.

[47] S.M. Seyedhosseini, S.M. Hosseini-Motlagh, M. Johari and M. Jazinaninejad, Social price-sensitivity of demand for competitive supply chain coordination. *Comput. Ind. Eng.* **135** (2019) 1103–1126.

[48] M. Sinayi and M. Rasti-Barzoki, A game theoretic approach for pricing, greening, and social welfare policies in a supply chain with government intervention. *J. Cleaner Prod.* **196** (2018) 1443–1458.

[49] J. Witkowska, Corporate Social Responsibility (CSR) of Innovative Pharmaceutical Corporations. The Case of BIOGEN. *Comp. Econ. Res. Cent. Eastern Eur.* **21** (2018) 45–62.

[50] D.D. Wu, Bargaining in supply chain with price and promotional effort dependent demand. *Math. Comput. Model.* **58** (2013) 1659–1669.

[51] S. Yang, C.V. Shi, Y. Zhang and J. Zhu, Price competition for retailers with profit and revenue targets. *Int. J. Prod. Econ.* **154** (2014) 233–242.

[52] P. Zhang, Y. He and C.V. Shi, Transshipment and coordination in a two-echelon supply chain. *RAIRO: OR* **51** (2017) 729–747.

[53] J. Zhao, W. Liu and J. Wei, Competition under manufacturer service and price in fuzzy environments. *Knowl.-Based Syst.* **50** (2013) 121–133.