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A game theoretic approach for pricing and determining quality level through coordination contracts in a dual-channel supply chain including manufacturer and packaging company

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ABSTRACT

In this study, a dual-channel supply chain (SC) comprising one manufacturer and one packaging company is considered under price and quality dependent demand. The manufacturer and packaging company compete on offered selling price and quality decisions. For the first time, this study investigates how the packaging company can influence the quality of products through packaging products. We also analyze how different game structures affect the optimal pricing and quality decisions as well as SC members' profit. In doing so, we model the investigated SC under three scenarios: (1) non-cooperative game, (2) cooperative game through revenue-sharing contract, and (3) cooperative game through profit-sharing contract. The results show that the competitive game of manufacturer and packaging company is highly beneficial for price-seeking customers. Moreover, from quality-seeking customers' perspective, the cooperation of manufacturer and packaging company under profit-sharing contract is more preferable. Furthermore, when the customers' demand is highly sensitive to the products quality, the cooperation of manufacturer and packaging company through profit-sharing contract is more beneficial for them.

1. Introduction

In today's business market, to gain competitive advantage, firms adopt strategies to positively influence customers' purchasing behavior and satisfy customers' expectation. Investment in quality improvement can be considered as an effective strategy attracting the attention of customers to purchase products (Li and Chen, 2018). Therefore, some manufacturing companies incorporate packaging activities into their production process to increase products quality. For example, Amcor packaging company has started packaging for the first time from 1971 in Australia and now it is a global leader in development and production of high-quality and responsible packaging for a variety of food, pharmaceutical, home and personal-care, medical-device, and other products (https://www.amcor.com/). Likewise, Bemis Company is a global supplier packaging many products such as chees, dairy, bulk, and foods. Bemis aims to satisfy consumers by making their lives easier through packaging products.

Products packaging is defined as a degree of products quality (Singh, 2007). The quality of packaging includes several efforts such as prevention of transport pollution and damage that occurring in transportation. Therefore, the packaging activity can change customers' behavior, especially quality-seeking customers to choose packaged products.

Moreover, in the competitive market, manufacturer can positively affect purchasing behavior of customers by adopting direct sales channel besides its retailer channel (Huang et al., 2012). In such a case, the manufacturer and retailer compete on selling prices offered to the customers. Therefore, competition between the manufacturer and the retailer cannot be ignored. On the other hand, in traditional business market, the manufacturer and the retailer individually make decisions such that their costs are minimized (Beloff et al., 2005) regardless of the other chain members' cost which may cause conflicts within supply chain and consequently decrease channel performance (Whang, 1995). Thus, competitive situation and such individual decisions make supply chain complex. To cope with these challenges, implementing appropriate coordination contracts between supply chain members is of high importance (Giannoccaro and Pontrandolfo, 2004).

Nowadays, competition among manufacturers has grown to gain more market share. Such competition could cause concern for manufacturers about how to get more profit with the minimum cost? How can achieve more market share and gain competitive edge compared to the

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other manufacturers? What effect does the competition or cooperation among manufacturers have on their sales, demand and profits? What effect does the products quality of the manufacturer and packaging company have on their profit and market share?

The above discussions highlight the importance of quality strategies as well as competition within supply chains. This paper aims to investigate products quality by considering packaging company in a dual-channel supply chain. Specifically, this study examines interactions between a manufacturer and a packaging company in a dual-channel supply chain on pricing and quality decisions under cooperative and non-cooperative scenarios considering coordination contracts. The main contributions of this paper are as follows:

- Quality improvement is proposed through products packaging in a supply chain.
- Pricing and quality decisions are analyzed under price and quality dependent demand.
- Channel selection is analyzed under competition and cooperation models.
- Coordination contracts are used to analyze the performance of whole system.

The rest of the research is as follows. Section 2 presents literature review. In Section 3, problem under study is defined in details. The mathematical models are formulated in Section 4. Section 5 provides parametric analysis. Numerical results are carried out in Section 6. In Section 7, managerial insights are discussed. Finally, in Section 8, concluding remarks and future research directions are provided.

2. Literature review

In this section, we present a review of the related literature on two research fields, i.e., pricing policy in dual-channel supply chain and quality strategy for packaging products in supply chain.

2.1. Pricing policy in dual-channel supply chain

In the past years, dual-channel structure has been extensively investigated in the supply chain management literature. Tsay and Agrawal (2004) develop a comprehensive review of the quantitative methods used in dual-channel supply chains. Kurata et al. (2007) evaluate pricing policy in multiple distribution channels under competition between the national brand and the store brand. Mukhopadhyay et al. (2008) study mixed channels where value added pricing of a retailer and wholesale price of a producer are optimized. Cai et al. (2009) investigate pricing policies in dual-channel supply chains considering competition. Yao et al. (2009) explore inventory decisions in a dual-channel supply chain in which a manufacturer sells products through both online and direct sales channels under different strategies. Xie et al. (2018) also discuss pricing policies considering coordination contracts in the dual-channel supply chain. However, they do not incorporate the packaging company into the dual-channel supply chain.

Hua et al. (2010) investigate the effect of channel structure on pricing and delivery time decisions. They examine the impact of channel structure and coordination model on dual-channel and single-channel supply chains. Chen et al. (2012) consider pricing strategy in a dual-channel supply chain through coordination contracts and show that coordination contracts can achieve a win-win situation in the dual-channel supply chain. All above reviewed papers only consider pricing strategy in dual-channel supply chains and quality strategy has not been investigated in these studies. Moreover, these studies analyze interactions between retailer and manufacturer. Different from the previous studies, we consider dual-channel supply chain including one packaging company who invests in quality improvement activities and one manufacturer who partially sells its products through direct sales channel. Although there exist studies in the dual-channel supply chain considering different approaches such as consumer surplus (Hendershott and Zhang, 2006), recycling effort (Jafari et al., 2017), and multi-channel supply chain with product brand differentiation (Yan, 2011), they do not investigate quality strategies made by the packaging company under competitive and cooperative models using coordination contracts.

2.2. Quality strategy for packaging products in supply chain

Recently, manufacturers have taken important steps towards customer orientation in order to increase their market demand. One of these steps is the increase of product quality which has been attracted by manufacturers (Taleizadeh et al., 2018). For example Mazeroon industrial group consists of four companies packaging many products such as foods, meat, fish, and poultry with anti-bacterial packaging. The quality of Mazeroon products is related to the packaging. Moreover, in recent years, customers are quality concerned (Li and Chen, 2018).

Quality can be considered from several perspectives such as remanufactured and repaired products (Christy et al., 2017; Maiti and Giri, 2015; Vorasayan and Ryan, 2006). In addition, quality can be due to the standard requirement of the product. For example, Chen et al. (2017) consider two products with different quality in a dual-channel supply chain. As noted by Danaher et al. (2003); Dukes et al. (2014); Gao et al. (2015), a quality of a single product is characterized by different features under different distribution channels. Products packaging also represents another aspect of quality. For instance, packaging of products such as dairy products, i.e., milk can reduce the pollution and increase the quality, durability, and customer satisfaction (Hayes and Zimmerman, 2006).

During and after World War II, the issue of food packaging was taken into account for several reasons such as the freshness of the product, quality and attractiveness as well as the ease of storage and distribution (Zabaniotou and Kassidi, 2003). Products packaging guarantees the quality, safety, and health of the products (Fresner and Engelhardt, 2004). However, as noted by Mathlouthi (2013), planning for the packaging of products so as to save quality, energy, and raw materials is very complex and may cause conflicts throughout packaging.

Moreover, products packaging is investigated by considering environmental, recycling, and renewable issues. Zabaniotou and Kassidi (2003) compare two types of packaging in terms of environmental issue. Nilsson et al. (2004) investigate label on the packaging of products, product characteristics, and the quality of packaging. In the current research, for the first time, products quality through packaging of the product is studied. To be more precise, decisions of one manufacturer and one packaging company on price and quality level of product are investigated. It is worth mentioning that selling products without proper packaging can cause product quality reduction and damaged product (Wang and Li, 2012).

Although Shi et al. (2013) and Chen et al. (2017) investigate pricing and quality decisions in dual sales channels, they neither address quality decision in a manufacturer-packaging company chain nor analyze different competitive and cooperative scenarios in a dual-channel supply chain. Zhao et al. (2017) establish environmental issue by considering packaging company besides online and traditional retailers. Hosseini-Motlagh et al. (2018) investigate coordination of green quality and warranty decisions for substitutable products in a competitive supply chain. They concluded that coordinating the manufacturer's green quality and competing retailers' warranty periods not only increases the economic profitability of all SC members compared to the decentralized model but also increases the green quality of the new released product. However, they do not examine quality improvement of packaging company. Table 1 provides summary of the reviewed literature on the pricing and quality decisions in supply chain.

This study investigates a dual-channel supply chain (SC) consisting of a manufacturer and a packaging company. The packaging company invests in product quality improvement activities. The effects of channel structure on the pricing and quality decisions of packaging company and manufacturer are analyzed under competitive and cooperative scenarios. First scenario investigates competition game between the packaging company and manufacturer. Second and third scenarios examine cooperative game through revenue-sharing contract and profit-sharing contract, respectively.

3. Model description

In this study, a dual-channel supply chain (SC) including one manufacturer and one packaging company is considered. The manufacturer produces its products with regard to customers demand and then sells part of its products to market directly, first product, and sells rest of them to the packaging company. The packaging company improves the quality of products through appropriate packaging which complies with transportation standards and sells high quality products to market, second product. First and second products are different in terms of packaging quality. We examine three different scenarios between the manufacturer and the packaging company. The timeline of the SC members' decisions is shown in Fig. 1.

In the first scenario, the manufacturer partially sells its products to its customers without packaging and sells rest of them to the packaging company to improve the quality level of products such that it satisfies customers' expectations. After receiving the products, the packaging company increases the products quality through packaging effort to reach a specific standard level of quality and then the packaged products are sold at a higher quality and price. In fact, the quality considered for the products is the perceived quality by the customers, which customer perception of quality is different for the two products. For example, Wipak Company as packaging company focuses on developing innovative, efficient, and ecologically-sustainable packs for customers. Wipak Company packages chees and dairy products and customer perception of products quality is different. Thus, in this setting, the packaging company and the manufacturer compete each other to sell its products to customers. In the second scenario, the packaging company and the manufacturer cooperate each other under a revenue-sharing contract in which the manufacturer receives a fraction of packaging company's revenue in addition to receiving payment of selling products the packaging company. Under the third scenario, a profit-sharing contract is proposed between the manufacturer and the packaging company. Under all scenarios, each SC member decides on the selling price and quality level of products. We aim to find the optimal values of selling price of two products, which are sold by the manufacturer and the packaging company to the customers, quality levels, SC members' profit, and demand under both competitive and cooperative situations. Fig. 2 illustrates the investigated SC under three scenarios.

Table 1
Comparative review of pricing and quality decisions in supply chain.

Author (s)	Game theory	Contracts		Dual-channel SC	Quality decision
		Profit-sharing	Revenue-sharing		
Hendershott and Zhang (2006)	✓			✓	
Jaber and Osman (2006)		✓			
Mukhopadhyay et al. (2008)	✓				
Cai (2010)	✓			✓	
Yan (2011)	✓	✓		✓	
Chen et al. (2012)	✓			✓	
Christy et al. (2017)	✓				✓
Jafari et al. (2017)	✓			✓	
Heydari and Ghasemi (2018)			✓		✓
Li and Chen (2018)	✓			✓	
Xie et al. (2018)	✓		✓	✓	
Current research	✓	✓	✓	✓	✓

The notations used throughout this paper are provided in the following two sub-sections, respectively.

3.1. Notations

The following notations are used to model the investigated supply chain.

Indices

i	Quality level $i \in \{L(Low), \ H(High)\}$
j	Product $j \in \{1, 2\}$
k	Scenario $k \in \{1, 2, 3\}$
Parameters	
α_j	The number of customers who choose product j
β_j	Self-price elasticity of demand for product j
γ_j	Cross-price elasticity of demand for product j
c_j	Unit operating cost of product j ($/unit)
ϕ	Fraction of packaging company's revenue shared with manufacturer $(0 < \varphi < 1)$
θ	Fraction of packaging company's profit shared with manufacturer $(0 < \theta < 1)$
μ	Coefficient of quality cost
Decision variables	
q_i^k	Quality i under scenario k
w_1^k	Unit wholesale price paid by the packaging company to the manufacturer under scenario k ($/unit)
p_1^k	Unit selling price of the manufacturer's product under scenario k ($/unit)
p_2^k	Unit selling price of the packaging company's product under scenario k ($/unit)
Demand and profit functions	
D_j^k	Demand of product j under scenario k
π_{Cj}^k	Profit function of company j under scenario k

3.2. Assumptions

The following assumptions are considered to model the investigated supply chain.

1) Demand of products is assumed as a linear function of price and quality similar to Edirisinghe et al. (2011); Pan et al. (2010); Wang et al. (2016).
2) Both manufacturer and packaging company can respond to a high level of demand from their customers similar to Ferrer and Ketzenberg (2004) and Savaskan and Van Wassenhove (2006).
3) Similar to Chen et al. (2013), Dan et al. (2012), and Lu et al. (2011), self-price elasticity of demand is considered more than cross-price elasticity of demand $(\beta_1 > \gamma_1, \beta_2 > \gamma_2)$.
4) It is assumed that the operating cost of the manufacturer is greater than that of the packaging company $(c_1 > c_2)$.
5) It is assumed that the product quality of the manufacturer is less than that of the packaging company $(q_L < q_H)$.
6) It is assumed that the selling price of the manufacturer is less than that of the packaging company $(p_1 < p_2)$.
7) Similar to Chaab and Rasti-Barzoki (2016) and Jafari et al. (2017), it is assumd that the wholesale price paid to the manufacturer by the packaging company is less than the selling price of the first product sold to the market under all three scenarios $(w_1 \le p_1)$.
8) It is considered that the coefficient of quality cost, μ takes value 1 similar to De Giovanni (2011) Johari and Hosseini-Motlagh (2018), and Zhang et al. (2013).

4. Model formulation

This section formulates demand and profit functions of SC members under three scenarios: (1) non-cooperative game, (2) cooperative game through revenue-sharing contract, and (3) cooperative game through profit-sharing contract.

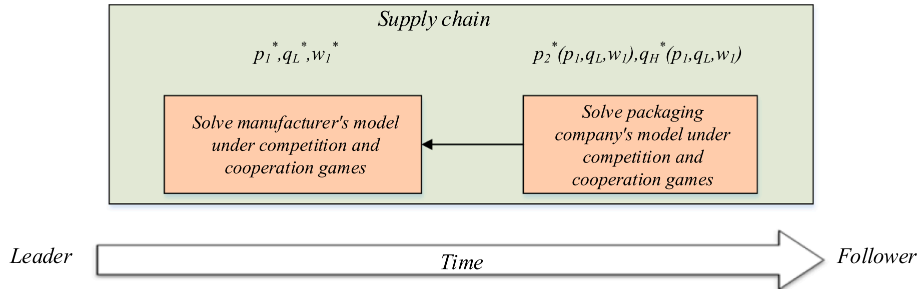

Fig. 1. Supply chain decisions timeline.

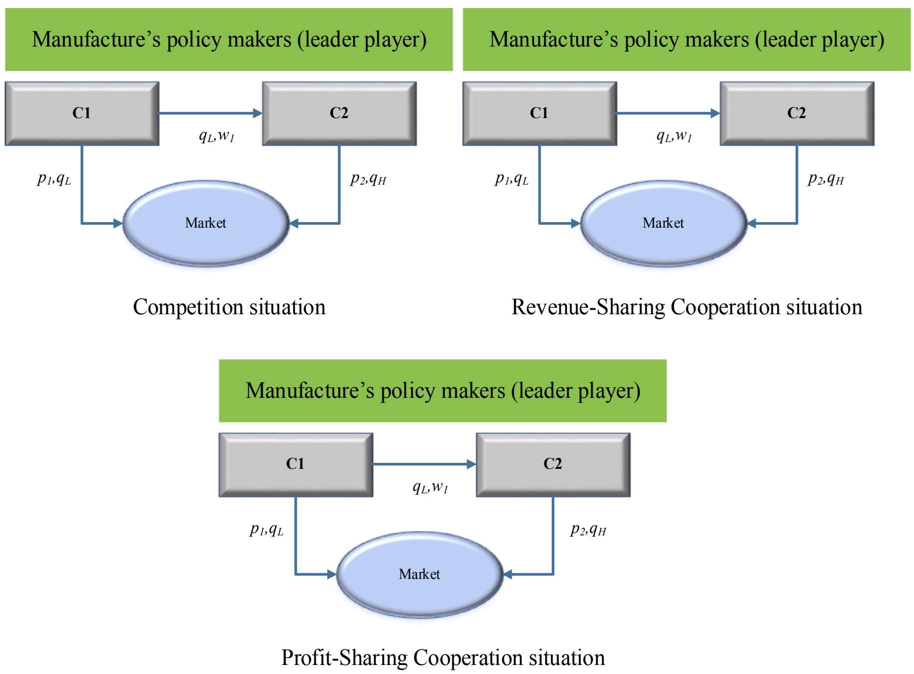

Fig. 2. Supply chain structure under three scenarios.

4.1. Scenario 1: non-cooperative game

Under this scenario, a non-cooperative game is played between the manufacturer (C1) and the packaging company (C2). In this setting, the manufacturer partially sells its products to end customers at price of p_1 and quality of q_L and sells rest of them to the packaging company at price and quality of w_1 and q_L, respectively. After receiving products, the packaging company enhances the quality of products through packaging and then sells them to the market at price and quality of p_2 and q_H, respectively. Eqs. (1) and (2) formulate the market demand of manufacturer and packaging company, respectively, which are simultaneously dependent on the price and quality of the products. In addition, Eqs. (3) and (4) calculate the profit functions of the manufacturer and the packaging company, respectively.

$$D_1{}^1 = \alpha_1 - \beta_1 p_1 + \beta_2 p_2 + \gamma_1 q_L - \gamma_2 q_H \tag{1}$$

$$D_2{}^1 = \alpha_2 - \beta_1 p_2 + \beta_2 p_1 + \gamma_1 q_H - \gamma_2 q_L \tag{2}$$

$$\pi_{C1}{}^1 = (p_1 - c_1)D_1 + (w_1 - c_1)D_2 - \frac{q_L{}^2}{2} \tag{3}$$

$$\pi_{C2}{}^1 = (p_2 - w_1 - c_2)D_2 - \frac{(q_H - q_L)^2}{2} \tag{4}$$

From Eq. (3), term $D_2(w_1 - c_1)$ indicates revenue received from the packaging company through selling products. Similar to Chen et al. (2017) and Wang et al. (2017), from Eqs. (3) and (4), terms $\frac{q_L^2}{2}$ and $\frac{(q_H-q_L)^2}{2}$ are considered as quality improvement cost invested by the manufacturer and packaging company, respectively. In this scenario, Stackelberg game is followed by SC members in which the manufacturer is leader and the packaging company is its follower. In order to obtain Stackelberg equilibrium, backward induction is applied. To this end, firstly, the follower's problem should be solved and then the leader's problem is solved. The aim of the manufacturer and the packaging company is to determine decisions on the pricing and quality of their products such that their profits are maximized. The problem of manufacturer and packaging company is formulated as follows:

$$\begin{cases} \max\limits_{(p_1^1, q_L^1, w_1^1)} \ \pi_{C1}^1\left(p_1^1, q_L^1, w_1^1, p_2\left(p_1^1, q_L^1, w_1^1\right), q_H\left(p_1^1, q_L^1, w_1^1\right)\right) \\ S.t. \\ p_1^1, q_L^1, w_1^1 > 0 \end{cases} \tag{5}$$

$$\begin{cases} \max\limits_{(p_2^1, q_H^1)} \ \pi_{C2}^1\left(p_2^1, q_H^1\right) \\ S.t. \\ p_2^1, q_H^1 > 0 \end{cases} \tag{6}$$

Proposition 1. *The profit function of the packaging company under the non-cooperative game is concave with respect to* $p_2{}^1$ *and* $q_H{}^1$.

Proof. See Appendix.

Theorem 1. *Due to the concavity of the packaging company's profit function, the optimal values of pricing and quality of the second product under the non-cooperative game are obtained as follows:*

$$p_2{}^1 = \frac{\alpha_2 + p_1\beta_2 + (c_2 + w_1)(\beta_1 - \gamma_1^2) + q_L(\gamma_1 - \gamma_2)}{2\beta_1 - \gamma_1^2} \tag{7}$$

$$q_H{}^1 = \frac{(\alpha_2 - (c_2 + w_1)\beta_1 + p_1\beta_2)\gamma_1 + q_L(2\beta_1 - \gamma_1\gamma_2)}{2\beta_1 - \gamma_1^2} \tag{8}$$

Proposition 2. *The profit function of the manufacturer under the non-cooperative game is concave with respect to* $p_1{}^1$, $q_L{}^1$, *and* $w_1{}^1$.

Proof. See Appendix.

Theorem 2. *Regarding Proposition 2, the optimal values of manufacturer's selling price, wholesale price, and quality of products under the non-cooperative game are obtained as follows:*

$$p_1^1 = \frac{\left(\alpha_1\beta_1^2(4\beta_1 - 3\gamma_1^2 + 2\gamma_1\gamma_2 - \gamma_2^2) + \beta_1(c_2\beta_1(-(\beta_1 + 2\beta_2)\gamma_1^2 + (3\beta_1 + 2\beta_2)\gamma_1\gamma_2 - (\beta_1 + \beta_2)\gamma_2^2) - 3\gamma_1\gamma_2 + \gamma_2^2\right)}{\omega_1} \tag{9}$$

$$q_L{}^1 = \frac{-((\beta_1(\gamma_1 - \gamma_2)(\alpha_2(-2\beta_1^2 + \beta_1(-4\beta_2 + \gamma_1\gamma_2) + \beta_2(-2\beta_2 + \gamma_1^2 + 2\gamma_1\gamma_2))}{\omega_1} \tag{10}$$

$$\begin{aligned} w_1{}^1 = {} & 4\alpha_2\beta_1^3 + 4c_1\beta_1^4 - 4c_2\beta_1^4 + 4\alpha_1\beta_1^2\beta_2 - 4c_1\beta_1^2\beta_2^2 + 4c_2\beta_1^2\beta_2^2 + 2\alpha_1\beta_1^2\gamma_1^2 \\ & -4\alpha_2\beta_1^2\gamma_1^2 - 8c_1\beta_1^3\gamma_1^2 \\ & +4c_2\beta_1^3\gamma_1^2 - 3\alpha_1\beta_1\beta_2\gamma_1^2 - \alpha_2\beta_1\beta_2\gamma_1^2 - 6c_1\beta_1^2\beta_2\gamma_1^2 + 3c_2\beta_1^2\beta_2\gamma_1^2 - \alpha_2\beta_2^2\gamma_1^2 \\ & -c_1\beta_1\beta_2^2\gamma_1^2 - 2c_2\beta_1\beta_2^2\gamma_1^2 - c_1\beta_2^3\gamma_1^2 - \alpha_1\beta_1\gamma_1^4 + \alpha_2\beta_1\gamma_1^4 + 2c_1\beta_1^2\gamma_1^4 - c_2\beta_1^2\gamma_1^4 \\ & +\alpha_1\beta_2\gamma_1^4 + c_1\beta_1\beta_2\gamma_1^4 - c_2\beta_1\beta_2\gamma_1^4 + c_2\beta_2^2\gamma_1^4 + \gamma_1(\beta_1(2\beta_1A_1\gamma_1\gamma_2^3)/A_3 \end{aligned} \tag{11}$$

The values of A_i and ω_i are indicated in Appendix.

Through backward induction, the optimal values of packaging company's price and quality of products under the non-cooperative game are achieved as follows:

$$\begin{aligned} p_2^1 = {} & (2c_2\beta_1^4 + 4\alpha_1\beta_1^2\beta_2 - 2c_2\beta_1^2\beta_2^2 + 3\alpha_1\beta_1^2\gamma_1^2 - 5c_2\beta_1^3\gamma_1^2 - \alpha_1\beta_1\beta_2\gamma_1^2 - 3c_2\beta_1^2\beta_2\gamma_1^2 + c_2\beta_1\beta_2^2\gamma_1^2 \\ & -\alpha_1\beta_1\gamma_1^4 + c_2\beta_1^2\gamma_1^4 + \alpha_1\beta_2\gamma_1^4 + c_2\beta_1\beta_2\gamma_1^4 + \beta_1\gamma_1(-\alpha_1(5\beta_1 + 4\beta_2) + c_2(\beta_1(6\beta_1 + 7\beta_2) - (\beta_1 c_2(\beta_1 + \beta_2)(3\beta_1 + \gamma_1^2) - \alpha_1(3\beta_1 + 2\beta_2 + \gamma_1^2))\gamma_2^2 + A_4 + \beta_1(-\alpha_1 \\ & +\beta_2)\gamma_1^2))\gamma_2 - \beta_1(\\ & +\beta_1\left(-2\beta_2^2 - 2\beta_2(\gamma_1 - \gamma_2)^2 + \gamma_1\left(\gamma_1^3 - \gamma_1^2\gamma_2 - 2\gamma_1\gamma_2^2 + \gamma_2^3\right)\right)\Big)\Big)/A_3 \end{aligned} \tag{12}$$

$$\begin{aligned} q_H^1 = {} & (4\beta_1^2(\alpha_1 + \alpha_2 - (2c_1 + c_2)(\beta_1 - \beta_2))(\beta_1 + \beta_2)\gamma_1 + (\alpha_1\beta_1(-\beta_1 + \beta_2) + \alpha_2(-\beta_1^2 - 2\beta_1\beta_2 + \beta_2^2) \\ & +(\beta_1 + \beta_2)(c_2\beta_1^2 + A_5 + \beta_1(\alpha_1(2\beta_1 + \beta_2) + 2c_1(-\beta_1^2 + \beta_2^2) + \beta_2(\alpha_2 + c_2(\beta_1 + \beta_2)))\gamma_1\gamma_2^2)/A_3 \end{aligned} \tag{13}$$

The values of A_i are indicated in Appendix.

4.2. Scenario 2: cooperative game through revenue-sharing contract

In this scenario, a cooperative game is played between the manufacturer (C1) and the packaging company (C2) in which the packaging company cooperates with the manufacturer for having a long-term supply of customer demand and pays a fraction of its revenue to the manufacturer. Similar to the first scenario, the manufacturer sells part of its products directly to end customers at price and quality of p_1 and q_L and sells rest of them to the packaging company at price of w_1 with the same quality in order to improve quality of products. The packaging company seeks to increase the quality of the products by packaging them and then sells the packed products to the market at price and quality of p_2 and q_H. Under the cooperative game through the revenue-sharing contract, the manufacturer receives a fraction of packaging company's revenue, ϕ. In fact, the goal of manufacturer is to satisfy the packaging company for long-term cooperation with the packaging company. Eqs. (14) and (15) formulate the demand functions of the manufacturer and the packaging company under the cooperative game through the revenue-sharing contract, respectively. Moreover, Eqs. (16) and (17) calculate the profit functions of the manufacturer and the packaging company under cooperation of two SC members through the revenue-sharing contract, respectively.

$$D_1{}^2 = \alpha_1 - \beta_1 p_1 + \beta_2 p_2 + \gamma_1 q_L - \gamma_2 q_H \tag{14}$$

$$D_2{}^2 = \alpha_2 - \beta_1 p_2 + \beta_2 p_1 + \gamma_1 q_H - \gamma_2 q_L \tag{15}$$

$$\pi_{C1}{}^2 = (p_1 - c_1)D_1 + (w_1 - c_1)D_2 + \phi p_2 D_2 - \frac{q_L{}^2}{2} \tag{16}$$

$$\pi_{C2}{}^2 = ((1 - \phi)p_2 - w_1 - c_2)D_2 - \frac{(q_H - q_L)^2}{2} \tag{17}$$

Similar to the previous scenario, Stackelberg game is adopted between SC members in which the manufacturer is a Stackelberg game leader and the packaging company is follower. At first, the packaging company obtains its price and quality decisions such that its profit function, Eq. (20), is maximized. Afterward, considering the packaging company's response, the manufacturer as a leader determines the optimal values of selling price, wholesale price, and quality of products in such a way that its profit function is maximized, Eq. (19). The problems of both SC members under the cooperative game through the revenue-sharing contract are formulated as follows:

$$\begin{cases} \max \pi_{C1}(p_1, q_L, w_1, p_2(p_1, q_L, w_1), q_H(p_1, q_L, w_1)) \\ (p_1, q_L, w_1) \\ \quad S.t. \\ p_1, q_L, w_1 > 0 \end{cases} \tag{18}$$

$$\begin{cases} \max\ \pi_{C2}(p_2, q_H) \\ (p_2, q_H) \\ S.t. \\ p_2, q_H > 0 \end{cases} \tag{19}$$

In order to obtain the packaging company's optimal decisions on the price, ${p_2}^2$ and quality, ${q_H}^2$, firstly the concavity of the packaging company's profit function is proved through the following proposition.

Proposition 3. *The profit function of the packaging company under the cooperative game through the revenue-sharing contract is concave with respect to ${p_2}^2$ and ${q_H}^2$.*

Proof. See Appendix.

Theorem 3. *Thus, the optimal price and quality of the products sold by the packaging company are determined as follows:*

$$ {p_2}^2 = \frac{-(1-\phi)\alpha_2 - c_2\beta_1 - w_1\beta_1 - (1-\phi)p_1\beta_2 - (1-\phi)\gamma_1(q_L - c_2\gamma_1 - w_1\gamma_1) + (1-\phi)q_L\gamma_2}{(1-\phi)^2\gamma_1^2 - 2(1-\phi)\beta_1} \tag{20} $$

$$ {q_H}^2 = \frac{-2q_L\beta_1 - \alpha_2\gamma_1 + \phi\alpha_2\gamma_1 + c_2\beta_1\gamma_1 + w_1\beta_1\gamma_1 - p_1\beta_2\gamma_1 + \phi p_1\beta_2\gamma_1 + q_L\gamma_1\gamma_2 - \phi q_L\gamma_1\gamma_2}{\gamma_1^2 - 2\beta_1 + \phi\gamma_1^2} \tag{21} $$

The values of A_i and ω_i are indicated in Appendix.

Proposition 4. *The profit function of the manufacturer under the cooperative game through the revenue-sharing contract is concave with respect to p_1^2, w_1^2, and q_L^2.*

Proof. See Appendix.

Theorem 4. *Regarding Proposition 4, the optimal values of p_1^2, w_1^2, and q_L^2 under the cooperative game through the revenue-sharing contract are obtained as follows:*

$$ {p_1}^2 = \frac{(\alpha_1\beta_1^2(2(-2+\phi)\beta_1 + (3-2\phi)\gamma_1^2 - 2\gamma_1\gamma_2 + \gamma_2^2) + A_{10} - 2\beta_2)\gamma_1\gamma_2 + (\beta_1+\beta_2)\gamma_2^2)}{\omega_1} \tag{22} $$

$$ {q_L}^2 = \frac{A_9 - 2(-2+\phi)\beta_2 + (-1+\phi)\gamma_1\gamma_2) + \alpha_1(-2(-2+\phi)\beta_1^2 4\beta_2 + \gamma_1\gamma_2) + \beta_2(-2\beta_2 + \gamma_1^2 + 2\gamma_1\gamma_2))}{\omega_1} \tag{23} $$

$$ \begin{aligned} {w_1}^2 = -((&-4c_2\beta_1^4 + 4\alpha_1\beta_1^2\beta_2 - A_{13} - \beta_1\gamma_1((-1+\phi)\alpha_1(2(-1+\phi)\beta_1 + (-2+4\phi)\beta_2 - (-1 \\ &+\phi)\phi\gamma_1^2) + c_2(4(1+\phi)\beta_1^2 - A_{11} - 2(-1+\phi)\beta_1^2(2\gamma_1^2 - 2\gamma_1\gamma_2 + \gamma_2^2) + \beta_1(-2\phi\beta_2^2 \\ &+\beta_2((1-2\phi)\gamma_1^2 + (-3+5\phi)\gamma_1\gamma_2 + (1-2\phi)\gamma_2^2) + A_{12} - (-1+\phi)\gamma_1((1+\phi)\gamma_1^3 \\ &-2\gamma_1^2\gamma_2 + (-3+\phi)\gamma_1\gamma_2^2 + 2\gamma_2^3))))/\omega_1 \end{aligned} \tag{24} $$

The values of A_i and ω_i are indicated in Appendix.

Using backward induction, the optimal values of packaging company's decision variables under the cooperative game through the revenue-sharing contract are obtained as follows:

$$ \begin{aligned} {p_2}^2 = ((&-2c_2\beta_1^4 - 4\alpha_1\beta_1^2\beta_2 + 2\phi\alpha_1\beta_1^2\beta_2 + 2c_2\beta_1^2\beta_2^2 - 3\alpha_1\beta_1^2\gamma_1^2 + 2\phi\alpha_1\beta_1^2\gamma_1^2 + 5c_2\beta_1^3\gamma_1^2 - 2\phi c_2\beta_1^3\gamma_1^2 \\ &+A_{15} + (-1+\phi)\beta_1(-\alpha_1 + c_2(\beta_1+\beta_2))\gamma_1\gamma_2^3 + c_1(\beta_1(-2(\beta_1 - (-1+\phi)\beta_2)(\beta_1^2 \\ &-\beta_2^2) + (-4(-2+\phi)\beta_1^2 + (7-3\phi)\beta_1\beta_2 - (-1+\phi)\beta_2^2)\gamma_1^2 + (-1+\phi)(2\beta_1 + (1 \\ &+\phi)\beta_2)\gamma_1^4) - A_{16}/\omega_1 \end{aligned} \tag{25} $$

$$ \begin{aligned} {q_H}^2 = \alpha_1\beta_1(&2(-2+\phi)\beta_1(\beta_1+\beta_2)\gamma_1 - (-1+\phi)(\beta_1 + (-1+\phi)\beta_2)\gamma_1^3 + (-2(-2+\phi)\beta_1(\beta_1+\beta_2) \\ &+(-1+\phi)((-2+\phi)\beta_1 - \beta_2)\gamma_1^2)\gamma_2 + (-1+\phi)(2\beta_1+\beta_2)\gamma_1\gamma_2^2) \\ &+\alpha_2\left(-(-1+\phi)^2\beta_2^2\gamma_1^3 + \beta_1^2\left(2\left(-2+\phi\right)\beta_2 - \left(-1+\phi\right)\gamma_1^2\right)\left(\gamma_1 - \gamma_2\right) + 2\beta_1^3\left(\left(-2\right.\right.\right. \\ &\left.\left.\left.+\phi)\gamma_1 + \gamma_2\right) + (-1+\phi)\beta_1\beta_2(-2\beta_2\gamma_2 + \gamma_1(-2\gamma_1^2 + \phi\gamma_1\gamma_2 + \gamma_2^2))\right) - A_{17}/\omega_1 \end{aligned} \tag{26} $$

4.3. Scenario 3: cooperative game through profit-sharing contract

Under this scenario, a cooperative game is played between both SC members in which the manufacturer (C1) cooperate with the packaging company (C2) through a profit-sharing contract. Under such a case, the manufacturer takes a fraction of the packaging company's profit, θ. In addition, similar to the two previous scenarios, the manufacturer sells part of its products at price and quality of p_1 and q_L to end customers and sells rest of them to the packaging company at price of w_1 with the same quality. After enhancement of products quality through packaging, the packaging company sells products to the market at price and quality of p_2 and q_H. Demand functions along with the profit functions of the manufacturer and the packaging company are formulated through Eqs. (27)–(30), respectively.

The concavity of the manufacturer's and the packaging company's profit function under the cooperative game through the profit-sharing contract is provided in Appendix.

$$D_1{}^3 = \alpha_1 - \beta_1 p_1 + \beta_2 p_2 + \gamma_1 q_L - \gamma_2 q_H \tag{27}$$

$$D_2{}^3 = \alpha_2 - \beta_1 p_2 + \beta_2 p_1 + \gamma_1 q_H - \gamma_2 q_L \tag{28}$$

$$\pi_{C1}{}^3 = (p_1 - c_1)D_1 + (w_1 - c_1)D_2 + \theta\left((p_2 - w_1 - c_2)D_2 - \frac{(q_H - q_L)^2}{2}\right) - \frac{q_L{}^2}{2} \tag{29}$$

$$\pi_{C2}{}^3 = (1-\theta)\left((p_2 - w_1 - c_2)D_2 - \frac{(q_H - q_L)^2}{2}\right) \tag{30}$$

Under this scenario, similar to the previous scenarios, Stackelberg game is played between SC actors where the manufacturer is a Stackelberg game leader and the packaging company is its follower. Firstly, the packaging company maximizes its profit function and then regarding the packaging company's decisions, the manufacturer maximizes its profit function. Similar to the pervious explanations about determining the optimal decisions, summary of the optimal decisions on the pricing and quality of SC members under the cooperative game through the profit-sharing contract are achieved as follows:

From Eq. (36), the first derivative of p_1 with respect to parameter α_2 is derived as the following:

$$\frac{dp_1}{d\alpha_2} = \frac{\beta_1\left((1-\phi)\beta_2\gamma_1^2 + \beta_1 A_{23}\right)}{A_{24}} \tag{36}$$

If conditions (37) and (38) are established, then $\frac{dp_1}{d\alpha_2} > 0$.

$$0 < \phi < \frac{-4\beta_1\beta_2 - \beta_1\gamma_1^2 + \beta_2\gamma_1^2 + 3\beta_1\gamma_1\gamma_2 - \beta_1\gamma_2^2}{-2\beta_1\beta_2 + \beta_2\gamma_1^2 + \beta_1\gamma_1\gamma_2} \tag{37}$$

$$\beta_2 > \frac{\gamma_1^2 - 3\gamma_1\gamma_2 + \gamma_2^2}{-4 + \gamma_1} \tag{38}$$

According to Eq. (36), parameter $\boldsymbol{\alpha_2}$ has a direct effect on $\boldsymbol{p_2}$. If Eqs. (37) and (38) are satisfied, by increasing the number of customers for the second product, selling price of the manufacturer's product increases. This result implies that the managers of SC and manufacturers are able to offer a higher price to customers by increasing the number of customers through advertising efforts.

5.2. *The operating cost of the first product parameter*

This sub-section evaluates how the operating cost of the first product,

$$\begin{aligned} p_1{}^3 = {} & (\alpha_1\beta_1^2(2(-2+\theta)\beta_1 - (-3+\theta)\gamma_1^2 - 2\gamma_1\gamma_2 + \gamma_2^2) + \beta_1(c_2\beta_1((\beta_1 + 2\beta_2)\gamma_1^2 - (3\beta_1 + 2\beta_2)\gamma_1\gamma_2 \\ & + (\beta_1+\beta_2)\gamma_2^2) + \alpha_2(-\beta_2\gamma_1^2 + \beta_1(4\beta_2 + \gamma_1^2 - 3\gamma_1\gamma_2 + \gamma_2^2))) + c_1(4\beta_1^4 - \beta_2^2\gamma_1^4 \\ & + \beta_1^3(-8\gamma_1^2 + 13\gamma_1\gamma_2 - 6\gamma_2^2) - \beta_1^2(4\beta_2^2 + \beta_2(9\gamma_1^2 - 15\gamma_1\gamma_2 + 8\gamma_2^2) + \gamma_1(-2\gamma_1^3 \\ & + 2\gamma_1^2\gamma_2 + 3\gamma_1\gamma_2^2 - 2\gamma_2^3)) + \beta_1\beta_2(\beta_2(\gamma_1^2 + 4\gamma_1\gamma_2 - 2\gamma_2^2) + 2\gamma_1(\gamma_1^3 - \gamma_1\gamma_2^2 \\ & + \gamma_2^3))))/A_3 \end{aligned} \tag{31}$$

$$\begin{aligned} q_L{}^3 = {} & -((\beta_1(\gamma_1 - \gamma_2)(\alpha_2(-2\beta_1^2 + \beta_1(-4\beta_2 + \gamma_1\gamma_2) + \beta_2(-2\beta_2 + \gamma_1^2 + 2\gamma_1\gamma_2)) + \alpha_1(-4\beta_1^2 + \beta_2\gamma_1^2 \\ & + \beta_1(-4\beta_2 + \gamma_1(2\gamma_1 + \gamma_2))) + (\beta_1+\beta_2)(2c_1(\beta_1 - \beta_2)(3\beta_1 + \beta_2 - \gamma_1(\gamma_1 + \gamma_2)) \\ & + c_2(2\beta_1^2 + \beta_2\gamma_1^2 - \beta_1(2\beta_2 + \gamma_1\gamma_2))))))/A_3 \end{aligned} \tag{32}$$

$$\begin{aligned} w_1{}^3 = {} & A_{18} + \beta_1(c_2(2\beta_1 + \beta_2)(\beta_1 + \beta_2 + \gamma_1^2) + \alpha_1(2\beta_1 + \beta_2 + \gamma_1^2))\gamma_2^2 - \beta_1(\alpha_1 + c_2(\beta_1 + \beta_2))\gamma_1\gamma_2^3 \\ & + \alpha_2(4\beta_1^3 + \beta_2\gamma_1^2(-\beta_2 + \gamma_1\gamma_2) - A_{19} + \beta_1^2((-4+8\theta)\beta_2^2 + \beta_2((-6+8\theta)\gamma_1^2 + (17 \\ & - 16\theta)\gamma_1\gamma_2 + 8(-1+\theta)\gamma_2^2) + \gamma_1(-2(-1+\theta)\gamma_1^3 + (-1+2\theta)\gamma_1^2\gamma_2 + (-2 \\ & + 3\theta)\gamma_1\gamma_2^2 - 2(-1+\theta)\gamma_2^3))))/A_3 \end{aligned} \tag{33}$$

$$\begin{aligned} p_2{}^3 = {} & A_{20} - \beta_1(c_2(\beta_1+\beta_2)(3\beta_1 + \gamma_1^2) - \alpha_1(3\beta_1 + 2\beta_2 + \gamma_1^2)\gamma_2^2 + \beta_1(-\alpha_1 + c_2(\beta_1 + \beta_2)\gamma_1\gamma_2^3 \\ & + c_1\left(\beta_1\left(2\left(\beta_1 - \beta_2\right)(\beta_1+\beta_2)^2 - \left(8\beta_1^2 + 7\beta_1\beta_2 + \beta_2^2\right)\gamma_1^2 + \left(2\beta_1 + \beta_2\right)\gamma_1^4\right) \right. \\ & + \gamma_1 A_{21}/A_3 \end{aligned} \tag{34}$$

$$\begin{aligned} q_H{}^3 = {} & (4\beta_1^2(\alpha_1 + \alpha_2 - (2c_1 + c_2)(\beta_1 - \beta_2))(\beta_1+\beta_2)\gamma_1 + (\alpha_1\beta_1(-\beta_1 + \beta_2) + \alpha_2(-\beta_1^2 - 2\beta_1\beta_2 + \beta_2^2) \\ & + (\beta_1+\beta_2)(c_2\beta_1^2 + c_1(2\beta_1^2 - 3\beta_1\beta_2 + \beta_2^2)))\gamma_1^3 - A_{22}/A_3 \end{aligned} \tag{35}$$

The values of A_i are indicated in Appendix.

5. Parametric analysis

In this section, the effect of some parameters on the decision variables is investigated.

5.1. *The number of customers choosing the second product parameter*

In this sub-section, we analyze how the number of customers for the second product, α_2 could affect the selling price of the first product, p_1.

c_1 could affect the demand of the first product under the third scenario, $D_1{}^3$.

Eq. (39) formulates the first order derivative of the demand of first product under the third scenario, $D_1{}^3$, with respect to the operating cost of the first product, c_1.

$$\frac{dD_1{}^3}{dc_1} = \frac{(\beta_1^2 - \beta_2^2)A_{25}}{A_{26}} \tag{39}$$

From Eq. (39), we have $\frac{dD_1{}^3}{dc_1} < 0$, if the following conditions, Eqs. (40) and (41) hold.

Table 2
Data of parameters.

Parameter	α_1	α_2	β_1	β_2	γ_1	γ_2	c_1	c_2	θ	ϕ
Value	140	120	0.05	0.02	0.02	0.01	60	40	0.3	0.3

Table 3
Optimal values under three scenarios.

Variables	Value		
	First scenario	Second scenario	Third scenario
p_1	2253.32	2293.94	2293.32
p_2	2785.33	2658.72	2763.33
w_1	2128.87	1332.32	2110.8
q_L	74.42	76.51	74.44
q_H	95.256	91.17	92.25
D_1	80.91	79.86	81.91
D_2o	31.72	34.91	29.72
π_{M1}	241642	247745	241657
π_{M2}	17550.23	16957.26	17510.25

$$\phi > \frac{4\beta_1^2 - \beta_1\left(2\beta_2 + \gamma_1(2\gamma_1 + \gamma_2)\right) + \beta_2\left(-2\beta_2 + \gamma_1(\gamma_1 + 2\gamma_2)\right)}{2\beta_1^2 - \beta_1\gamma_1(2\gamma_1 + \gamma_2) + \beta_2\left(-2\beta_2 + \gamma_1(\gamma_1 + 2\gamma_2)\right)} \tag{40}$$

$$\frac{\beta_2(-\beta_1 + 2\beta_2)}{4\beta_1 - 2\beta_2} - \frac{1}{2}A_{27} > \gamma_1 \;\&\; \gamma_1 > \frac{1}{2}\left(\frac{(\beta_1 - 2\beta_2)\beta_2}{-2\beta_1 + \beta_2} + A_{27}\right) \tag{41}$$

As a result, parameter c_1 has a negative effect on ${D_1}^3$ which means that as c_1 decreases, ${D_1}^3$ increases. It can be concluded that the managers of SC and manufacturers can achieve more market share by decreasing their operation costs through controlling their production lines.

5.3. The operating cost of the second product parameter

In this sub-section, we investigate how the operating cost of the second product could affect the demand of the second product under the second scenario (i.e., cooperative game through the revenue-sharing contract).

Eq. (42) calculates the first order derivative of the demand of second

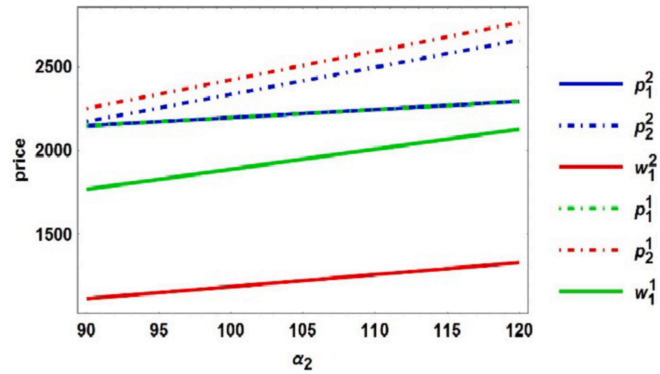

Fig. 4. The effect of α_2 on prices under first and second scenarios.

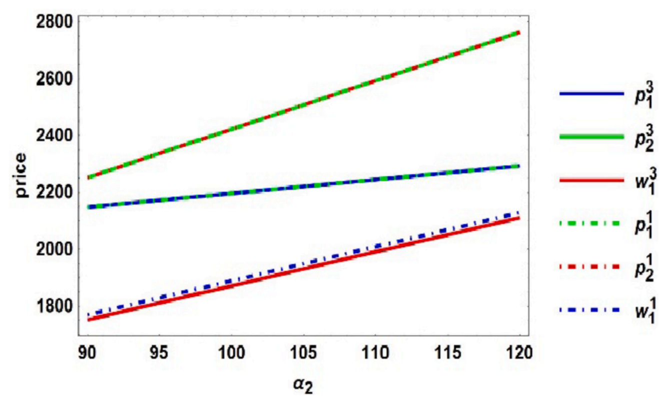

Fig. 5. The effect of α_2 on prices under first and third scenarios.

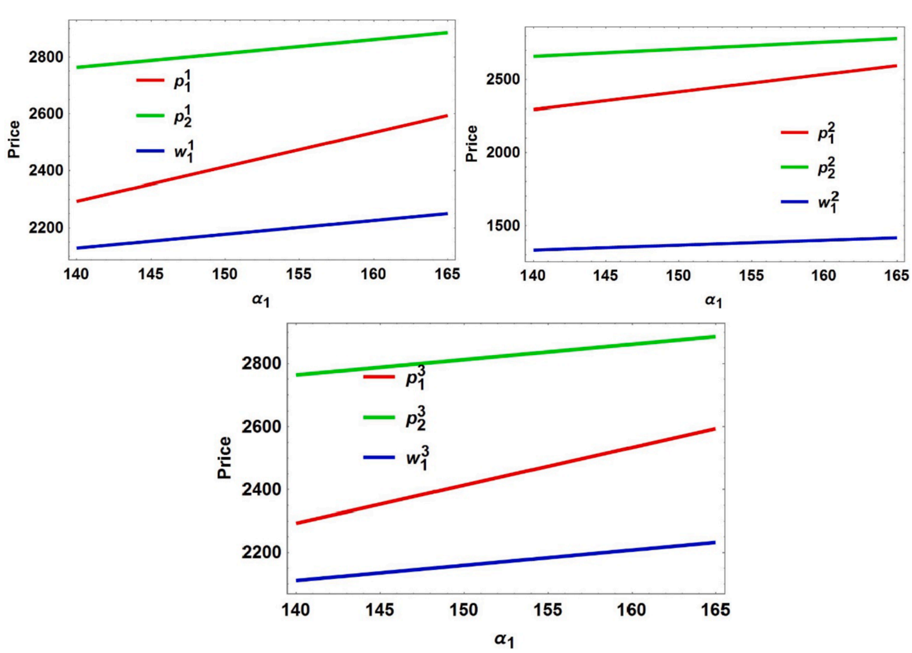

Fig. 3. The effect of α_1 on prices under three scenarios.

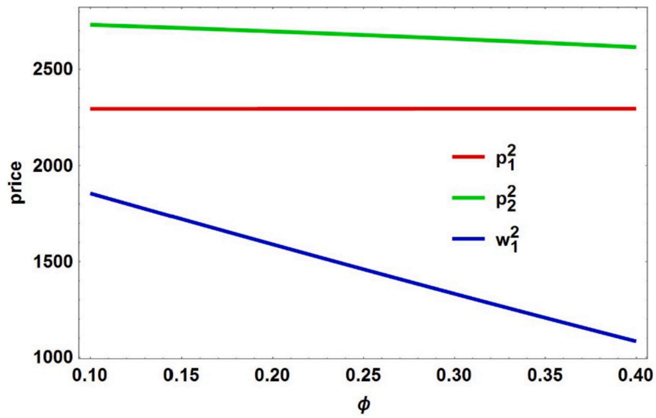

Fig. 6. The effect of φ on prices in the second scenario.

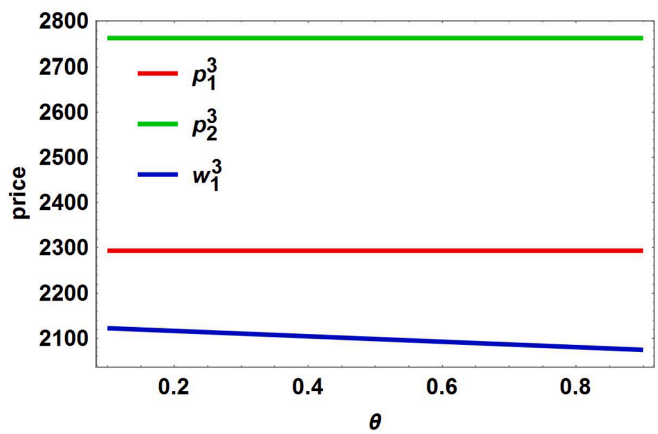

Fig. 7. The effect of θ on prices under third scenario.

product under the second scenario,$D_2{}^2$ with respect to the operating cost of the second product, c_2.

$$\frac{dD_2{}^2}{dc_2} = \frac{\beta_1^2(\beta_1+\beta_2)\left(2\beta_1^2-\beta_1\left(2\beta_2+(\gamma_1-\gamma_2)^2\right)-\beta_2\left(\gamma_1-\gamma_2\right)^2\right)}{A_{24}} \tag{42}$$

By satisfying condition (43), we have $\frac{dD_2{}^2}{dc_2} < 0$. As a result, as the operating cost of second product, c_2 decreases, the market demand of second product, $D_2{}^2$ increases. It can be concluded that the packaging companies are able to attain more market demand by decreasing their operating costs under the cooperative game with the manufacturers.

$$\beta_2 > \frac{2\beta_1^2-\beta_1\gamma_1^2+2\beta_1\gamma_1\gamma_2-\beta_1\gamma_2^2}{2\beta_1+\gamma_1^2-2\gamma_1\gamma_2+\gamma_2^2} \tag{43}$$

That values of A_i are provided in the appendix.

6. Numerical results

In this section, numerical example is provided in order to analyze the performance of the proposed models. The data of the parameters are indicated in Table 2.

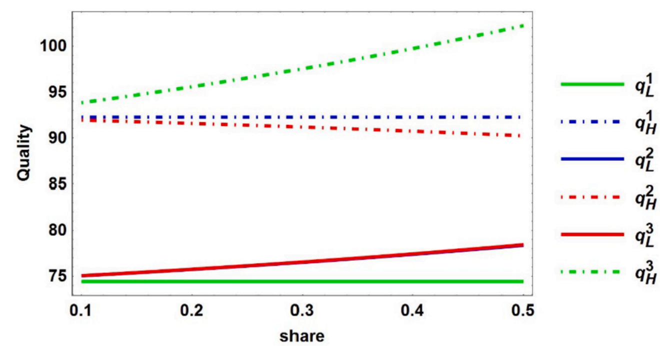

Fig. 9. The effect of θ, φ on the quality of two products under three scenarios.

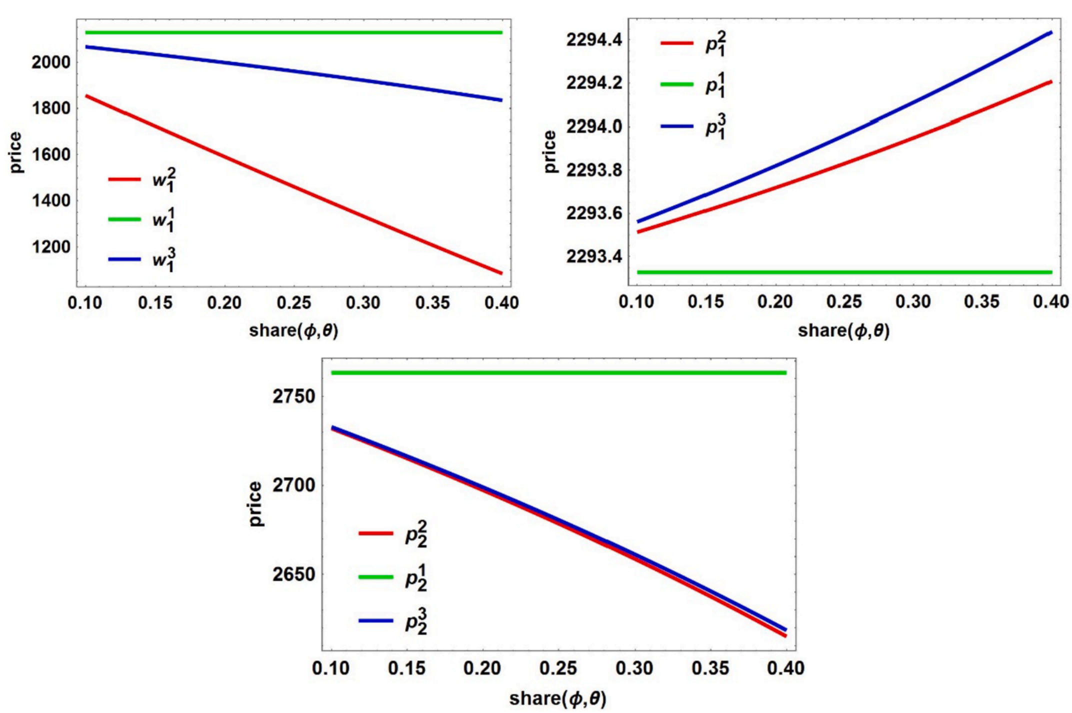

Fig. 8. The effect of (φ, θ) on prices under three scenarios.

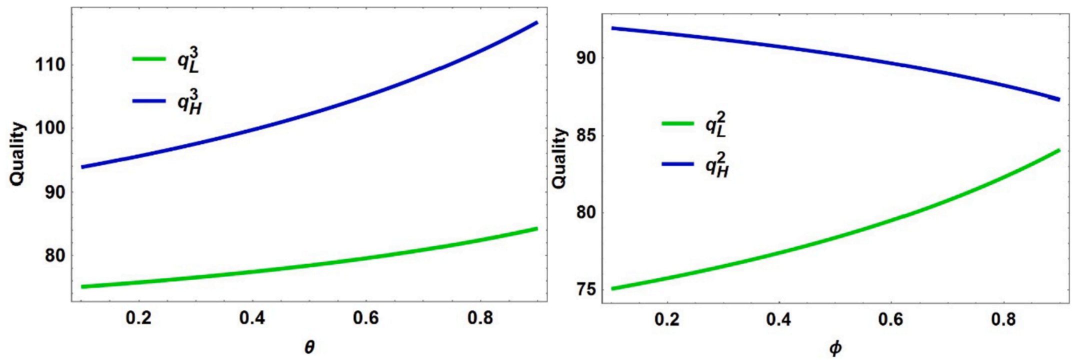

Fig. 10. The effect of θ, φ on the quality of two products under second and third scenarios.

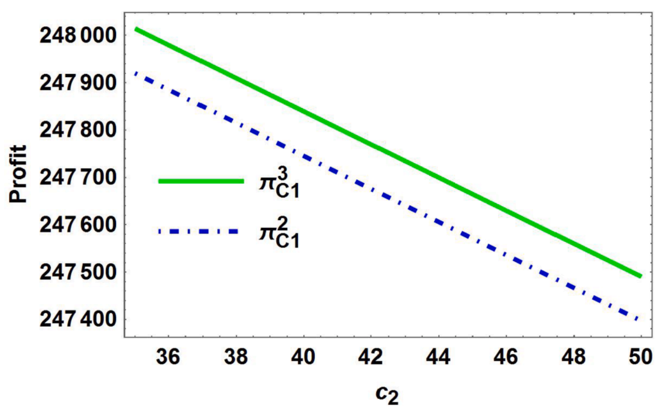

Fig. 11. The effect of c_2 on manufacturer's profit under second and third scenarios.

The optimal values of decision variables, demand functions, and profit functions of SC members under the three scenarios are shown in Table 3. All the results obtained in Table 3 are obtained under the condition of the problem and according to assumptions. For example, the price of a second product of the first product in all three scenarios is lower. From Table 3, the manufacturer receives the maximum profit under the second scenario, while the packaging company receives the maximum profit under the first scenario.

Moreover, a set of sensitivity analysis is conducted on the important parameters to investigate the performance of the proposed models. The effect of manufacturer's and packaging company's market size, α_1 and α_2 on the prices under three scenarios is shown in Figs. 3 and 4. As shown in Fig. 3, as the number of customers choosing the manufacturer's product, α_1 increases, selling prices of the manufacturer and the packaging company and wholesale price increase in all scenarios. In addition, as can be seen in Fig. 3, the price of second product (i.e., packaging company's product) is higher than that of the first product (i.e., manufacturer's product). Moreover, the highest price of packaging company, p_1 and the lowest wholesale price, w_1 are obtained under the first scenario. It can be concluded that under competitive situation (i.e., first scenario), the manufacturer can sell its product directly in the market with higher price. In addition, from the customers' perspective, second scenario is preferable as it results in the lowest selling prices. Furthermore, under second scenario, the selling price offered by the packaging company, p_2 approaches the manufacturer's selling price, p_1.

Figs. 4 and 5 show increase in the selling prices and wholesale price over increasing the number of customers purchasing the packaged products. By increasing market size of packaging company, under the competitive scenario (i.e., first scenario), selling price offered by the packaging company is equal to that of the cooperative game through profit-sharing and surpasses that of the cooperative game through revenue-sharing. As shown in Fig. 4, the wholesale price is in the lowest value under cooperative game through revenue-sharing. This result implies that by investing in promotional efforts such as advertising, the packaging company can influence the purchasing behaviors of customers to purchase packaged products. Furthermore, the packaging company can purchase products at lower wholesale price from the

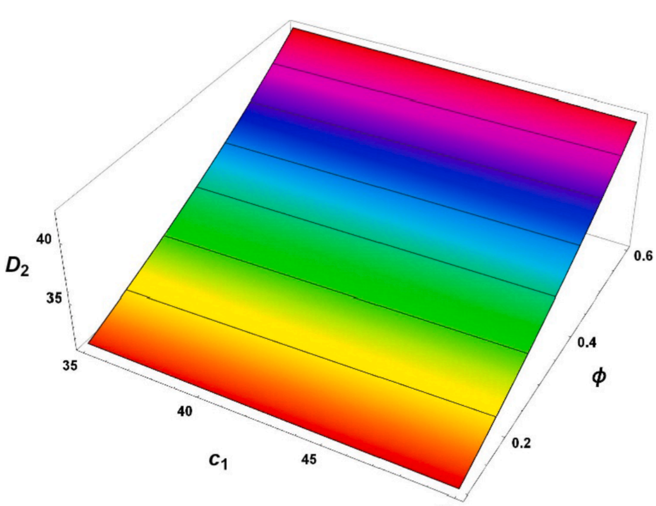

Fig. 12. The effect of φ and c_2 on the demand for the second product under the second scenario.

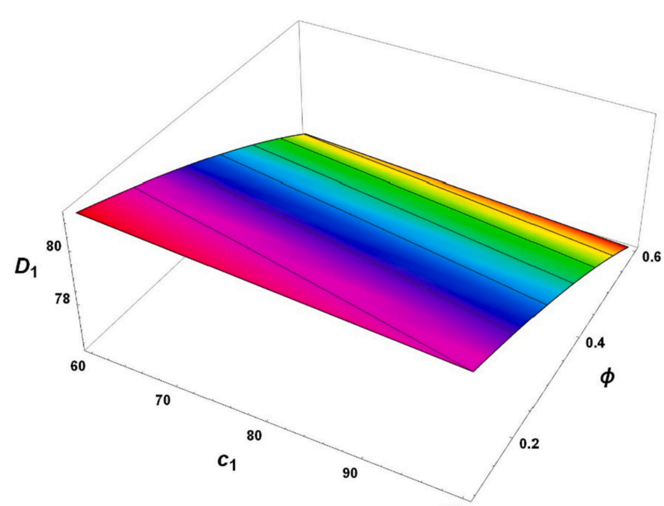

Fig. 13. The effect of φ and c_1 on the demand for the first product under the second scenario.

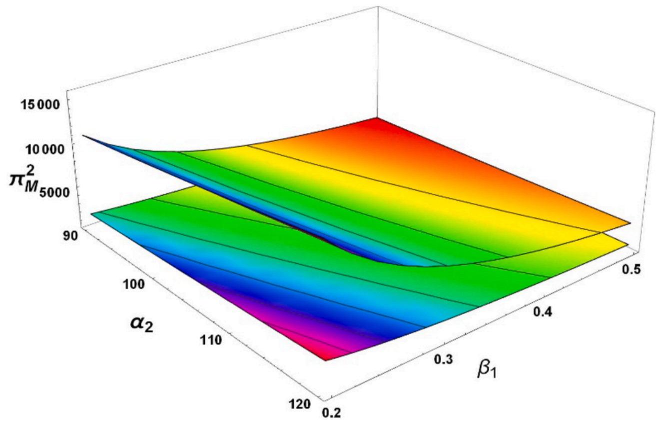

Fig. 14. The effect of α_2 and β_1 on the profit of two members under the second scenario.

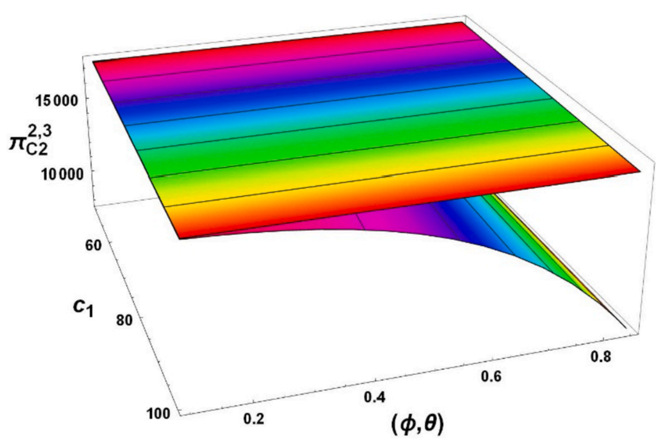

Fig. 15. The effect of θ, φ, and c_1 on the packaging company's profit.

manufacturer under the revenue-sharing contract.

Figs. 6 and Fig. 7 illustrate the changes in the prices over increasing the manufacturer's share of the packaging company's revenue and the manufacturer's share of the packaging company's profit, respectively. According to Figs. 6 and 7, by increasing the manufacturer's share of revenue and profit of the packaging company, w_1 and p_2 decrease. This result implies that the manufacturer can receive more share of the packaging company's revenue and profit under cooperation with the packaging company. Whereas, the manufacturer should decrease the wholesale price which in turn the packaging company can decrease its selling price.

Fig. 8 depicts the effect of the manufacturer's share from the packaging company's revenue and profit on the prices under two cooperative scenarios. From Fig. 8, as manufacturer's share increases, selling price of the manufacturer, p_1 reaches the maximum value under the third scenario, which benefits the manufacturer relative to the other scenarios, and has the lowest amount under the competitive scenario. Moreover, selling price of the packaging company, p_2 is much higher than the other scenarios under the competitive scenario and has the minimum value under the cooperative revenue-sharing scenario. In addition, wholesale price, w_1 has the same trend with the selling price of the packaging company, p_2. As a result, under increase of manufacturer's share from the packaging company's revenue and profit, cooperation model through the revenue-sharing contract (i.e., second scenario) is preferred by the packaging company and from the manufacturer's perspective, the cooperation model through the profit-sharing contract (i.e., third scenario) is more preferable.

Figs. 9 and 10 show the changes in the products quality over increasing the manufacturer's share of the packaging company's

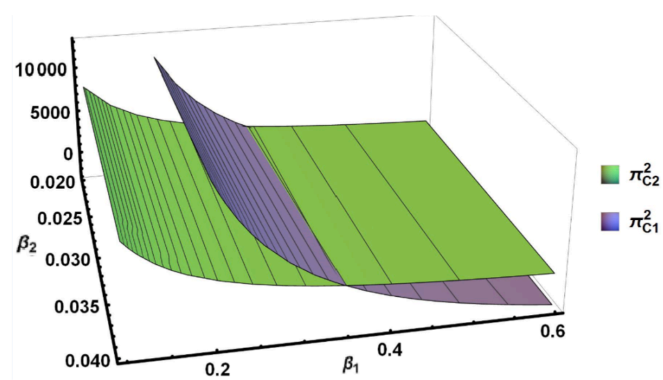

Fig. 17. The effect of β_1 and β_2 on the profit of two SC members.

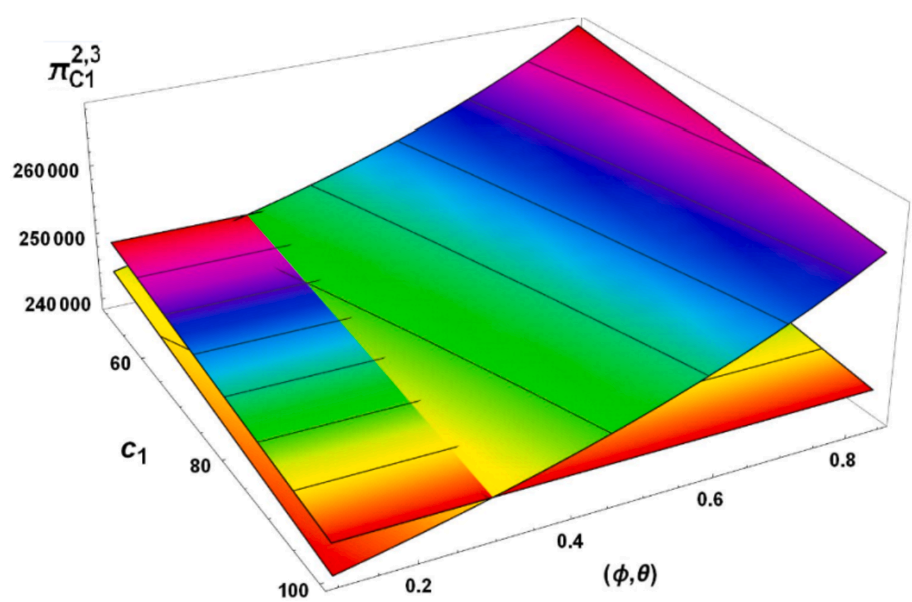

Fig. 16. The effect of θ, φ, and c_1 on the manufacturer's profit.

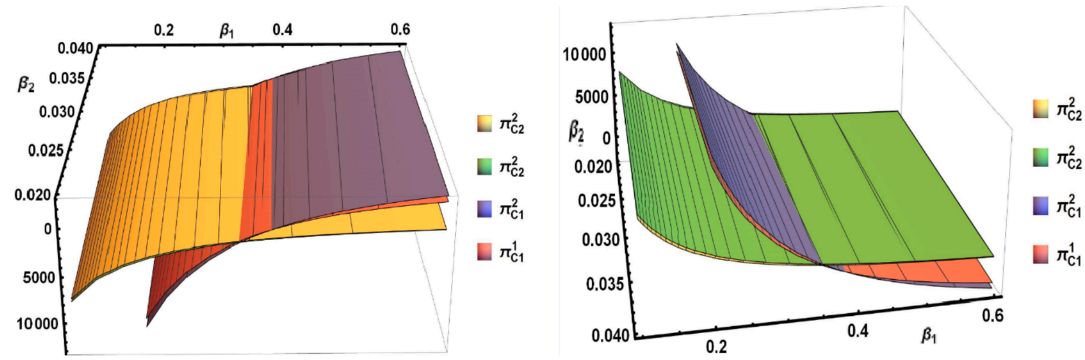

Fig. 18. The effect of β_1 and β_2 on the profit of two SC members under first and second scenarios.

revenue and profit (φ, θ) under three scenarios. From Fig. 9, as manufacturer's share of revenue increases, the products quality of packaging company, q_H has a declining trend. Whereas, as manufacturer's share of profit increases, the products quality of packaging company, q_H has an increasing trend. Moreover, under both increase of manufacturer's share of revenue and profit, products quality of manufacturer, q_L increases. As can be seen in Fig. 9, products quality of packaging company, q_H reaches its maximum amount under the cooperative game through profit-shring scenario (i.e., third scenario). It can be concluded that cooperation between the manufacturer and packaging company under profit-sharing contract is highly beneficial from the supply chain perspective as it improves the products quality and benefits both SC members and customers.

Fig. 10 compares the quality of two products over increasing the manufacturer's share of the packaging company's revenue and profit (φ, θ) under second and third scenarios. From Fig. 10, considering second scenario, as manufacturer's share of revenue increases, the products quality of the manufacturer increases and the products quality of the packaging company goes down. As a result, by increasing the manufacturer's share of revenue under cooperation model through revenue-sharing, the manufacturer should improve its product quality to maximize its profit while the packaging company's products quality goes down. Moreover, regarding third scenario, by increasing the manufacturer's share of the packaging company's profit, the products quality of both SC members improves. It can be concluded that under cooperation of the manufacturer and the packaging company through the profit-sharing contract, both SC actors should enhance their products quality.

Fig. 11 illustrates the changes in the manufacturer's profit over increasing the packaging company's cost c_2, under second and third scenarios. As shown in Fig. 11, as cost of packaging company increases, the manufacturer obtains more profit under cooperation game through profit-sharing scenario (i.e., third scenario) compared to the cooperation game through revenue-sharing scenario (i.e., second scenario). Accordingly, when the packaging company faces high operating cost, the cooperative game under profit-sharing contract is more beneficial for the manufacturer.

Fig. 12 shows the changes in the packaging company's demand by simultaneously increasing the manufacturer's share of revenue, φ, and packaging company's operating cost, c_2, under the second scenario. As can be seen in Fig. 12, as φ increases, the demand of packaging company increases. While, by increasing c_2, packaging company's demand has no significant changes. As a result, under cooperative model, by sharing more revenue with the manufacturer, the packaging company can gain more market demand.

In addition, Fig. 13 depicts the manufacturer's demand by simultaneously changing the manufacturer's share of revenue, φ, and manufacturer's operating cost, c_1. From Fig. 13, the manufacturer's demand reaches its highest amount as φ reaches its maximum value as well as c_1 reaches its highest value. Moreover, the manufacturer's demand is at its maximum amount when the manufacturer's share and production cost are in the lowest values.

As shown in Fig. 14, with simultaneous increase in α_2, and decrease in β_1, both the profit of the manufacturer and the packaging company reaches the lowest value. By increasing α_2, and decreasing β_1, the manufacturer's profit grow more than the packaging company's profit under the second scenario. As a result, the manufacturer can increase its profitability by decreasing its customers' price sensitivity.

Figs. 15 and 16 show the changes in the packaging company's and manufacturer's profit over changing the manufacturer's share of revenue and profit of packaging company and manufacturer's operating cost under second and third scenarios, respectively. According to Fig. 15, the packaging company obtains less profit under the second scenario compared to the third scenario since under the third scenario, the packaging company's profit is shared with the manufacturer while under the second scenario the packaging company's revenue is shared with the manufacturer. As a result, from the packaging company's point of view, cooperative model through the profit-sharing contract is more preferable.

In Fig. 16, as the manufacturer's share increases, its profit is higher under the second scenario relative to the third scenario. Therefore, under high value of manufacturer's share, it is beneficial for the manufacturer to choose a revenue-sharing contract under cooperative model, and from the packaging company's perspective, profit-sharing contract is more preferable. When manufacturer's share is less than 0.3, the preferences of two members will be vice versa.

The effect of self-price sensitivities of demand, β_1 and β_2 on the profits of the manufacturer and packaging company under the first and second scenarios is investigated through Figs. 17 and 18. As shown in Fig. 17, by increasing β_1 and β_2, the manufacturer's profit is higher than the profit of the packaging company. When β_1 is greater than 0.5, the packaging company's profit is more than the manufacturer's profit. From Fig. 18, when $0.35 < \beta_1$, the highest profit of the packaging company is obtained under the first scenario and when $0.4 < \beta_1$, the lowest profit of the manufacturer is achieved under the second scenario. When $0.35 > \beta_1$, the manufacturer's profit reaches its maximum value and the packaging company's profit reaches its minimum amount under the second scenario. In addition when $0.35 < \beta_1 < 0.4$, the lowest profit of the manufacturer is obtained under the first scenario.

7. Managerial insights

This paper examines pricing policies and products quality level of two companies including a packaging company and a manufacturer in a dual-channel supply chain. Moreover, we analyze one competition and two cooperation scenarios between two companies and determine their optimal strategies. This study suggests following managerial insights.

- Analyzing three scenarios demonstrates that under the competition of manufacturer and packaging company, the lowest amount of wholesale price, the maximum amount of packaging company's selling price, and the lowest amount of manufacturer's selling price are obtained compared to the cooperation model. It is of high beneficial for the packaging company to adopt competitive behavior. However, from the customers' perspective, the cooperation of the manufacturer and the packaging company under revenue-sharing contract is more preferable as the selling prices offered to customers are at the minimum amounts. Therefore, to keep market demand, the packaging company should make trade-off between purchasing products at lower price (i.e., second scenario) and selling products at the maximum price (i.e., first scenario). Whereas, to gain more market share, the manufacturer should make trade-off between adopting cooperative model (i.e., third scenario) which creates the maximum products' selling price and competitive model (i.e., first scenario) which benefits customers by providing the lowest selling price.

- Investigating the effect of competition and cooperation models on the products quality reveals that the packaging company can improve quality level of products under cooperative models (i.e., second and third scenarios). While, the quality level of manufacturer's products can be enhanced only under third scenario. As a result, under intense sensitivity of customers to the products quality, managers of supply chain should adopt cooperative model through profit-sharing contract to increase more market share.
- Comparing two cooperative scenarios regarding different contracts indicates that the packaging company can obtain more profit by sharing a fraction of its profit compared to sharing a fraction of its revenue. On the other hand, when the manufacturer's share of the packaging company' revenue is more than 0.3, it is beneficial to participate in the revenue-sharing contract. Whereas, if the manufacturer's share of the packaging company' profit is less than 0.3, the manufacturer prefers to cooperate with the packaging company under profit-sharing contract.

8. Conclusions

In this paper, pricing and quality decisions are investigated in a dual-channel SC including one manufacturer and one packaging company. Besides producing, the manufacturer initiates a sales channel for directly selling part of its products and sells rest of them to the packaging company. After receiving products, the packaging company increases the quality of products through packaging. In this setting, the manufacturer and packaging company compete with each other on the selling prices and quality of the products. In the investigated SC, we model interactions between the manufacturer and packaging company under three scenarios including one non-cooperative and two cooperative game structures. Moreover, under cooperative scenarios, we examine the effect of two different contracts (i.e., revenue-sharing and profit-sharing) on the optimal solutions and profits of SC members. Moreover, the proposed models are analytically tested through numerical example. Our results indicate that from price-sensitive customers' perspective, competition game (i.e., non-cooperative game between the manufacturer and packaging company) is more beneficial as it creates the lowest amount of selling price. Whereas, adopting third scenario (i.e., cooperative game under the profit-sharing contract) by SC members is highly beneficial for the quality-sensitive customers. On the other hand, the manufacturer should make trade-off between second and third scenarios. Under third scenario, the manufacturer can achieve the maximum amount of selling price. Whereas, the manufacturer can achieve the maximum profit under second scenario. In addition, from the packaging company's perspective, second scenario is more preferable compared to third scenario as he can achieve more profit.

As future research, this paper can be extended in many directions. In this study, interaction between one manufacturer and one packaging company is considered in a dual-channel SC. One can extend the model, considering a retailer in addition to the manufacturer and packaging company. Moreover, analyzing government role in improving environmental index will be an interesting topic for future research. As another future research, this model can be extended under environmental considerations. Finally, it will be challenging to examine this model under stochastic nonlinear demand function.

Appendix

$$\begin{aligned}\omega_1 = \Big(4\big(-2+\phi\big)\beta_1^4 + (-1+\phi)^2\beta_2^2\gamma_1^4 + 2\beta_1^3\Big(\big(5-3\phi\big)\gamma_1^2 + 2\big(-3+\phi\big)\gamma_1\gamma_2 - \big(-3 \\ +\phi)\gamma_2^2\Big) - 2(-1+\phi)\beta_1\beta_2(-\gamma_1^2(\beta_2+\gamma_1^2) + \gamma_1(-2\beta_2+\phi\gamma_1^2)\gamma_2 + (\beta_2 \\ +\gamma_1^2)\gamma_2^2 - \gamma_1\gamma_2^3) + \beta_1^2(-4(-2+\phi)\beta_2^2 - 4(-2+\phi)\beta_2(\gamma_1-\gamma_2)^2 + \big(-1 \\ +\phi)\gamma_1(2\gamma_1^3 - 2\gamma_1^2\gamma_2 + (-3+\phi)\gamma_1\gamma_2^2 + 2\gamma_2^3))\end{aligned} \tag{A.1}$$

$$\omega_2 = (-1+\phi)\gamma_1^2 \tag{A.2}$$

$$\omega_3 = (-1+\phi)\beta_2 \tag{A.3}$$

$$\omega_4 = \alpha_1\beta_1^2 \tag{A.4}$$

$$\omega_5 = c_2\beta_1 \tag{A.5}$$

$$\omega_6 = (-1+\phi)(2\beta_1 + (-1+\phi)\gamma_1^2) \tag{A.6}$$

$$\begin{aligned}A_1 = (-\alpha_1 + 2\alpha_2 + (5c_1-2c_2)\beta_1) + (-2\alpha_1 + 3\alpha_2 + (17c_1-5c_2)\beta_1)\beta_2 + (5c_1-2c_2)\beta_2^2) \\ +(-\beta_1(\alpha_2 + (c_1-c_2)\beta_1) + (\alpha_2 - (2c_1+c_2)\beta_1)\beta_2 + c_1\beta_2^2)\gamma_1^2)\gamma_2 \\ +\beta_1(-(\beta_1+\beta_2)(-c_2(2\beta_1+\beta_2) + 2c_1(3\beta_1+\beta_2)) + (2(-c_1+c_2)\beta_1 \\ +(-3c_1+c_2)\beta_2)\gamma_1^2 + \alpha_1(2\beta_1+\beta_2+\gamma_1^2) - \alpha_2(2\beta_1+\beta_2+2\gamma_1^2))\gamma_2^2 \\ +\beta_1(-\alpha_1+\alpha_2+(2c_1-c_2)(\beta_1+\beta_2))\end{aligned} \tag{A.7}$$

$$A_2 = -\omega_2(\gamma_1-\gamma_2)+2\beta_1^3((-2+\phi)\gamma_1+\gamma_2)+(-1+\phi)\beta_1\beta_2(-2\beta_2\gamma_2+\gamma_1(-2\gamma_1^2+\phi\gamma_1\gamma_2 +\gamma_2^2)))-(\beta_1+\beta_2)(c_1(\beta_1-\beta_2)(-\omega_3\omega_2\gamma_1 +2\beta_1^2(2(-2+\phi)\gamma_1-(-3+\phi)\gamma_2)+c_2\beta_1(\omega_2\beta_2-(-1+\phi)\gamma_2^2 +2\beta_1^2((-2+\phi)\gamma_1+\gamma_2)+\beta_1(\omega_2(-\gamma_1+\gamma_2)-2\beta_2((-2+\phi)\gamma_1 +\gamma_2)))))/\omega_1 \tag{A.8}$$

$$A_3 = (8\beta_1^4-\beta_2^2\gamma_1^4-2\beta_1^3(5\gamma_1^2-6\gamma_1\gamma_2+3\gamma_2^2)-\beta_1^2(8\beta_2^2+8\beta_2(\gamma_1-\gamma_2)^2+\gamma_1\Big(-2\gamma_1^3 +2\gamma_1^2\gamma_2+3\gamma_1\gamma_2^2-2\gamma_2^3))+2\beta_1\beta_2(\beta_2(\gamma_1^2+2\gamma_1\gamma_2-\gamma_2^2)+\gamma_1(\gamma_1^3-\gamma_1\gamma_2^2 +\gamma_2^3))) \tag{A.9}$$

$$A_4 = +c_2\Big(\beta_1+\beta_2\Big)\Big)\gamma_1\gamma_2^3+c_1\Big(\beta_1\Big(2\Big(\beta_1-\beta_2\Big)(\beta_1+\beta_2)^2-\Big(8\beta_1^2+7\beta_1\beta_2+\beta_2^2\Big)\gamma_1^2+\Big(2\beta_1 +\beta_2)\gamma_1^4)+\gamma_1(\beta_1(11\beta_1^2+17\beta_1\beta_2+4\beta_2^2)+(-\beta_1^2-2\beta_1\beta_2+\beta_2^2)\gamma_1^2)\gamma_2 -\beta_1(2(\beta_1+\beta_2)(3\beta_1+\beta_2)+(2\beta_1+3\beta_2)\gamma_1^2)\gamma_2^2+2\beta_1(\beta_1+\beta_2)\gamma_1\gamma_2^3) +\alpha_2(6\beta_1^3+\beta_2\gamma_1^3\gamma_2+\beta_1^2(-5\gamma_1^2+6\gamma_1\gamma_2-3\gamma_2^2) \tag{A.10}$$

$$A_5 = c_1(2\beta_1^2-3\beta_1\beta_2+\beta_2^2)))\gamma_1^3-\beta_1(2(\beta_1+\beta_2)(2\alpha_1\beta_1+\alpha_2(\beta_1+\beta_2)-(\beta_1-\beta_2)((3c_1 +c_2)\beta_1+c_1\beta_2))+(-\beta_1(-2\alpha_1+\alpha_2+(c_1-c_2)\beta_1)+(\alpha_1+2c_2\beta_1)\beta_2 +(c_1+c_2)\beta_2^2)\gamma_1^2)\gamma_2 \tag{A.11}$$

$$A_6 = \beta_2((-1+\phi)\alpha_2+(-1+\phi)p_1\beta_2-(c_2+w_1)(\beta_1+(-1+\phi)\gamma_1^2)-\phi q_L\gamma_2+q_L((-1 +\phi)\gamma_1+\gamma_2)) \tag{A.12}$$

$$A_7 = \phi\beta_1((-1+\phi)\alpha_2+(c_2+w_1)\beta_1+(-1+\phi)(p_1\beta_2+q_L(\gamma_1-\gamma_2)))(-(-1+\phi)\alpha_2 -(-1+\phi)p_1\beta_2+(c_2+w_1)(\beta_1+(-1+\phi)\gamma_1^2)+\phi q_L\gamma_2-q_L((-1 +\phi)\gamma_1+\gamma_2)) \tag{A.13}$$

$$A_8 = \gamma_2(((-1+\phi)\alpha_2+(c_2+w_1)\beta_1+(-1+\phi)p_1\beta_2)\gamma_1+q_L(-2\beta_1-(-1+\phi)\gamma_1\gamma_2)) \tag{A.14}$$

$$A_9 = -((\beta_1(\gamma_1-\gamma_2)(\alpha_2(-2\beta_1^2+\beta_1(-((\beta_1(\gamma_1-\gamma_2)(\alpha_2(2\beta_1^2 +(-1+\phi)\beta_2(-2\beta_2+\gamma_1^2+2\gamma_1\gamma_2)) \tag{A.15}$$

$$A_{10} = \beta_1(c_2\beta_1((\beta_1-(-2+\phi)\beta_2)\gamma_1^2+((-3+\phi)\beta_1 \tag{A.16}$$

$$A_{11} = (-1+\phi)\beta_2(2\beta_2+(1-3\phi)\gamma_1^2)-(1+\phi)\beta_1((-5+\phi)\beta_2-(-1+\phi)\gamma_1^2)))\gamma_2 +\beta_1((-1+\phi)\alpha_1(2(-1+\phi)\beta_1+(-1+2\phi)\beta_2+(-1+\phi)\gamma_1^2)+c_2((\beta_1 +\beta_2)(2(1+\phi)\beta_1-(-1+\phi)\beta_2)-(-1+\phi)(2\beta_1+(1+\phi)\beta_2)\gamma_1^2))\gamma_2^2 +(-1+\phi)\beta_1(-(-1+\phi)\alpha_1+(1+\phi)c_2(\beta_1+\beta_2))\gamma_1\gamma_2^3+(-1 +\phi)\alpha_2(4(-1+\phi)\beta_1^3+(-1+\phi)\beta_2\gamma_1^2(-\beta_2-(-1+\phi)\gamma_1\gamma_2) \tag{A.17}$$

$$A_{12} = (-1+\phi)\gamma_1(\gamma_1^3-\gamma_1^2\gamma_2+(-2+\phi)\gamma_1\gamma_2^2+\gamma_2^3)))-(-1+\phi)c_1(4\beta_1^4+(-1 +\phi)\beta_2^2\gamma_1^2(\beta_2+(-1+\phi)\gamma_1\gamma_2)-2\beta_1^3(\phi\beta_2-2(-2+\phi)\gamma_1^2+(-5 +\phi)\gamma_1\gamma_2-(-3+\phi)\gamma_2^2)+\beta_1^2(-4\beta_2^2+\beta_2(2(-3+\phi)\gamma_1^2+(17-9\phi)\gamma_1\gamma_2 +4(-2+\phi)\gamma_2^2)+(-1+\phi)\gamma_1(-2\gamma_1^3+(1+\phi)\gamma_1^2\gamma_2+2\gamma_1\gamma_2^2-2\gamma_2^3)) +\beta_1\beta_2(2\phi\beta_2^2+(-1+\phi)\beta_2(\gamma_1^2-5\gamma_1\gamma_2+2\gamma_2^2) \tag{A.18}$$

$$A_{13} = 6\phi\alpha_1\beta_1^2\beta_2+2\phi^2\alpha_1\beta_1^2\beta_2+4c_2\beta_1^2\beta_2^2+2\alpha_1\beta_1^2\gamma_1^2-4\phi\alpha_1\beta_1^2\gamma_1^2+2\phi^2\alpha_1\beta_1^2\gamma_1^2 +4c_2\beta_1^3\gamma_1^2+2\phi c_2\beta_1^3\gamma_1^2-2\phi^2c_2\beta_1^3\gamma_1^2-3\alpha_1\beta_1\beta_2\gamma_1^2+5\phi\alpha_1\beta_1\beta_2\gamma_1^2 -2\phi^2\alpha_1\beta_1\beta_2\gamma_1^2+3c_2\beta_1^2\beta_2\gamma_1^2+\phi c_2\beta_1^2\beta_2\gamma_1^2-2c_2\beta_1\beta_2^2\gamma_1^2+\phi c_2\beta_1\beta_2^2\gamma_1^2 +\phi^2c_2\beta_1\beta_2^2\gamma_1^2-\alpha_1\beta_1\gamma_1^4+2\phi\alpha_1\beta_1\gamma_1^4-\phi^2\alpha_1\beta_1\gamma_1^4-c_2\beta_1^2\gamma_1^4+\phi^2c_2\beta_1^2\gamma_1^4 +\alpha_1\beta_2\gamma_1^4-3\phi\alpha_1\beta_2\gamma_1^4+3\phi^2\alpha_1\beta_2\gamma_1^4-\phi^3\alpha_1\beta_2\gamma_1^4-c_2\beta_1\beta_2\gamma_1^4 +\phi^2c_2\beta_1\beta_2\gamma_1^4+c_2\beta_2^2\gamma_1^4-2\phi c_2\beta_2^2\gamma_1^4+\phi^2c_2\beta_2^2\gamma_1^4 \tag{A.19}$$

$$A_{14} = (-1+\phi)\beta_2^2)\gamma_1^2\gamma_2+\beta_1(-2(\beta_1+\beta_2)((-3+\phi)\beta_1+(-1+\phi)\beta_2)+(-1+\phi)(-2\beta_1 +(-3+\phi)\beta_2)\gamma_1^2)\gamma_2^2+2(-1+\phi)\beta_1(\beta_1+\beta_2)\gamma_1\gamma_2^3)+\alpha_2((-6+4\phi)\beta_1^3 -(-1+\phi)^2\beta_2\gamma_1^3\gamma_2+\beta_1^2((5-4\phi)\gamma_1^2+2(-3+2\phi)\gamma_1\gamma_2+(3-2\phi)\gamma_2^2) +\Big(-1+\phi\Big)\beta_1\Big(-2\beta_2^2-2\beta_2(\gamma_1-\gamma_2)^2 \tag{A.20}$$

$$A_{15} = \alpha_1\beta_1\beta_2\gamma_1^2 - \phi\alpha_1\beta_1\beta_2\gamma_1^2 + 3c_2\beta_1^2\beta_2\gamma_1^2 - c_2\beta_1\beta_2^2\gamma_1^2 + \phi c_2\beta_1\beta_2^2\gamma_1^2 + \alpha_1\beta_1\gamma_1^4 - \phi\alpha_1\beta_1\gamma_1^4 - c_2\beta_1^2\gamma_1^4 + \phi c_2\beta_1^2\gamma_1^4 - \alpha_1\beta_2\gamma_1^4 + 2\phi\alpha_1\beta_2\gamma_1^4 - \phi^2\alpha_1\beta_2\gamma_1^4 - c_2\beta_1\beta_2\gamma_1^4 + \phi c_2\beta_1\beta_2\gamma_1^4 + \beta_1\gamma_1(c_2(\beta_1(-6\beta_1 + (-7+\phi)\beta_2) - (-1+\phi)(\beta_1+\beta_2)\gamma_1^2) + \alpha_1((5-3\phi)\beta_1 + (-1+\phi)(-4\beta_2 + \phi\gamma_1^2)))\gamma_2 + \beta_1(c_2(\beta_1+\beta_2)(3\beta_1 - (-1+\phi)\gamma_1^2) + \alpha_1((-3+2\phi)\beta_1 + (-1+\phi)(2\beta_2+\gamma_1^2)))\gamma_2^2 \tag{A.21}$$

$$A_{16} = \gamma_1(\beta_1((11-3\phi)\beta_1^2 + (17-9\phi)\beta_1\beta_2 - 4(-1+\phi)\beta_2^2) + (-1+\phi)((1+\phi)\beta_1^2 + 2\beta_1\beta_2 + A_{14} + \gamma_1(\gamma_1^3 - \gamma_1^2\gamma_2 + (-2+\phi)\gamma_1\gamma_2^2 + \gamma_2^3)))) \tag{A.22}$$

$$A_{17} = \left(\beta_1+\beta_2\right)\left(c_1\left(\beta_1-\beta_2\right)\left(-(-1+\phi)^2\beta_2\gamma_1^3 + 2\beta_1^2\left(2\left(-2+\phi\right)\gamma_1 - \left(-3+\phi\right)\gamma_2\right) + \left(-1+\phi\right)\beta_1(-2\gamma_1^3 - 2\beta_2\gamma_2 + (-1+\phi)\gamma_1^2\gamma_2 + 2\gamma_1\gamma_2^2)\right) + c_2\beta_1((-1+\phi)\beta_2\gamma_1(\gamma_1-\gamma_2)\gamma_2 + 2\beta_1^2((-2+\phi)\gamma_1+\gamma_2) + \beta_1((-1+\phi)\gamma_1^2(-\gamma_1+\gamma_2) - 2\beta_2((-2+\phi)\gamma_1+\gamma_2)))\right) \tag{A.23}$$

$$A_{18} = -4c_2\beta_1^4 + 4\alpha_1\beta_1^2\beta_2 + 4c_2\beta_1^2\beta_2^2 + 2\alpha_1\beta_1^2\gamma_1^2 + 4c_2\beta_1^3\gamma_1^2 - 3\alpha_1\beta_1\beta_2\gamma_1^2 + 3c_2\beta_1^2\beta_2\gamma_1^2 - 2c_2\beta_1\beta_2^2\gamma_1^2 - \alpha_1\beta_1\gamma_1^4 - c_2\beta_1^2\gamma_1^4 + \alpha_1\beta_2\gamma_1^4 - c_2\beta_1\beta_2\gamma_1^4 + c_2\beta_2^2\gamma_1^4 - \beta_1\gamma_1(2\alpha_1(\beta_1+\beta_2) + c_2(4\beta_1^2 + 5\beta_1\beta_2 + 2\beta_2^2 + (-\beta_1+\beta_2)\gamma_1^2))\gamma_2 \tag{A.24}$$

$$A_{19} = 2\beta_1^2(2\gamma_1^2 - 2\gamma_1\gamma_2 + \gamma_2^2) + \beta_1(-\beta_2(\gamma_1^2 - 3\gamma_1\gamma_2 + \gamma_2^2) + \gamma_1(\gamma_1^3 - \gamma_1^2\gamma_2 - 2\gamma_1\gamma_2^2 + \gamma_2^3))) + c_1((4-8\theta)\beta_1^4 + 2\beta_1^3((-4+5\theta)\gamma_1^2 + (5-6\theta)\gamma_1\gamma_2 + 3(-1+\theta)\gamma_2^2) + \beta_2^2\gamma_1^2(-\beta_2 + \gamma_1(\theta\gamma_1+\gamma_2)) + \beta_1\beta_2(\beta_2(-(1+2\theta)\gamma_1^2 + (5-4\theta)\gamma_1\gamma_2 + 2(-1+\theta)\gamma_2^2) + \gamma_1((1-2\theta)\gamma_1^3 - 2\gamma_1^2\gamma_2 + (-3+2\theta)\gamma_1\gamma_2^2 - 2(-1+\theta)\gamma_2^3)) \tag{A.25}$$

$$A_{20} = (2c_2\beta_1^4 + 4\alpha_1\beta_1^2\beta_2 - 2c_2\beta_1^2\beta_2^2 + 3\alpha_1\beta_1^2\gamma_1^2 - 5c_2\beta_1^3\gamma_1^2 - \alpha_1\beta_1\beta_2\gamma_1^2 - 3c_2\beta_1^2\beta_2\gamma_1^2 + c_2\beta_1\beta_2^2\gamma_1^2 - \alpha_1\beta_1\gamma_1^4 + c_2\beta_1^2\gamma_1^4 + \alpha_1\beta_2\gamma_1^4 + c_2\beta_1\beta_2\gamma_1^4 + \beta_1\gamma_1(-\alpha_1(5\beta_1 + 4\beta_2) + c_2\beta_1(6\beta_1 + 7\beta_2) - (\beta_1+\beta_2)\gamma_1^2))\gamma_2 \tag{A.26}$$

$$A_{21} = (\beta_1(11\beta_1^2 + 17\beta_1\beta_2 + 4\beta_2^2) + (-\beta_1^2 - 2\beta_1\beta_2 + \beta_2^2)\gamma_1^2)\gamma_2 - \beta_1(2(\beta_1+\beta_2)(3\beta_1+\beta_2) + (2\beta_1+3\beta_2)\gamma_1^2)\gamma_2^2 + 2\beta_1(\beta_1+\beta_2)\gamma_1\gamma_2^3) + \alpha_2(6\beta_1^3 + \beta_2\gamma_1^3\gamma_2 + \beta_1^2(-5\gamma_1^2 + 6\gamma_1\gamma_2 - 3\gamma_2^2\Big) + \beta_1\Big(-2\beta_2^2 - 2\beta_2(\gamma_1-\gamma_2)^2 + \gamma_1\Big(\gamma_1^3 - \gamma_1^2\gamma_2 - 2\gamma_1\gamma_2^2 + \gamma_2^3))) \tag{A.27}$$

$$A_{22} = \beta_1(2(\beta_1+\beta_2)(2\alpha_1\beta_1 + \alpha_2(\beta_1+\beta_2) - (\beta_1-\beta_2)((3c_1+c_2)\beta_1 + c_1\beta_2)) + (-\beta_1(-2\alpha_1 + \alpha_2 + (c_1-c_2)\beta_1) + (\alpha_1 + 2c_2\beta_1)\beta_2 + (c_1+c_2)\beta_2^2)\gamma_1^2)\gamma_2 + \beta_1(\alpha_1(2\beta_1+\beta_2) + 2c_1(-\beta_1^2+\beta_2^2) + \beta_2(\alpha_2 + c_2(\beta_1+\beta_2)))\gamma_1\gamma_2^2) \tag{A.28}$$

$$A_{23} = 2(-2+\phi)\beta_2 - \gamma_1^2 - (-3+\phi)\gamma_1\gamma_2 - \gamma_2^2 \tag{A.29}$$

$$A_{24} = 4(-2+\phi)\beta_1^4 + (-1+\phi)^2\beta_2^2\gamma_1^4 - 2\beta_1^3\Big(\Big(-5+3\phi\Big)\gamma_1^2 - 2\Big(-3+\phi\Big)\gamma_1\gamma_2 + \Big(-3+\phi)\gamma_2^2) + 2(-1+\phi)\beta_1\beta_2(\gamma_1^2(\beta_2+\gamma_1^2) + \gamma_1(2\beta_2 - \phi\gamma_1^2)\gamma_2 - (\beta_2+\gamma_1^2)\gamma_2^2 + \gamma_1\gamma_2^3) + \beta_1^2(-4(-2+\phi)\beta_2^2 - 4(-2+\phi)\beta_2(\gamma_1-\gamma_2)^2 + \Big(-1+\phi)\gamma_1(2\gamma_1^3 - 2\gamma_1^2\gamma_2 + (-3+\phi)\gamma_1\gamma_2^2 + 2\gamma_2^3)) \tag{A.30}$$

$$A_{25} = 2(-2+\phi)\beta_1^3 + \phi\beta_2^2\gamma_1^2 + \beta_1^2(2\beta_2 + \gamma_1((2-\phi)\gamma_1 + \gamma_2)) - \beta_1\beta_2(2(-1+\phi)\beta_2 + \gamma_1(\gamma_1 + 2\gamma_2)) \tag{A.31}$$

$$A_{26} = 2\beta_1^4((5-2\phi)\gamma_1^2 + 2(-3+\phi)\gamma_1\gamma_2 - (-3+\phi)\gamma_2^2) + \beta_2^2\gamma_1^2((1+\phi)\gamma_1^2 - 2\phi\gamma_1\gamma_2 + \phi\gamma_2^2) + \beta_1^2(-4(-2+\phi)\beta_2^2 - 4(-2+\phi)\beta_2(\gamma_1-\gamma_2)^2 + \gamma_1\Big(\Big(-2+\phi\Big)\gamma_1^3 - 2(-1+\phi)\gamma_1^2\gamma_2 + (3+\phi)\gamma_1\gamma_2^2 - 2\gamma_2^3)) - 2\beta_1\beta_2(\beta_2(\gamma_1^2 - 2(-1+\phi)\gamma_1\gamma_2 + (-1+\phi)\gamma_2^2) + \gamma_1((1-\phi)\gamma_1^3 + 2\phi\gamma_1^2\gamma_2 - (1+\phi)\gamma_1\gamma_2^2 + \gamma_2^3)) \tag{A.32}$$

$$A_{27} = \sqrt{\frac{32\beta_1^3 + \beta_1^2(-32+\beta_2)\beta_2 - 4\beta_1\beta_2^2(2+\beta_2) + 4\beta_2^3(2+\beta_2)}{(-2\beta_1+\beta_2)^2}} \tag{A.33}$$

Proof of Proposition 1

To prove the concavity of the packaging company profit function w.r.t. ${p_2}^1$ and ${q_H}^1$, the Hessian matrix of the packaging company profit function is calculated as follows. If the Hessian matrix is negative definite, then the profit function of packaging company is convace w.r.t. ${p_2}^1$ and ${q_H}^1$.

$$\begin{pmatrix} -2\beta_1 & \gamma_1 \\ \gamma_1 & -1 \end{pmatrix} \tag{A.34}$$

The first principal minor is always negative and the second principal minor is positive when:

$$2\beta_1 > \gamma_1^2 \tag{A.35}$$

Thus, the profit function of the packaging company is concave w.r.t. ${p_2}^1$ and ${q_H}^1$.·

Proof of Proposition 2

The Hessian matrix of the manufacturer profit function is calculated as follows:

$$\begin{pmatrix} \frac{2\left(-2\beta_1^2+\beta_1\gamma_1^2+\beta_2(\beta_2-\gamma_1\gamma_2)\right)}{2\beta_1-\gamma_1^2} & \frac{(\gamma_1-\gamma_2)\left(2\beta_1+\beta_2-\gamma_1(\gamma_1+\gamma_2)\right)}{2\beta_1-\gamma_1^2} & \beta_2+\frac{\beta_1\gamma_1\gamma_2}{2\beta_1-\gamma_1^2} \\ \frac{(\gamma_1-\gamma_2)\left(2\beta_1+\beta_2-\gamma_1(\gamma_1+\gamma_2)\right)}{2\beta_1-\gamma_1^2} & -1 & \frac{\beta_1(\gamma_1-\gamma_2)}{2\beta_1-\gamma_1^2} \\ \beta_2+\frac{\beta_1\gamma_1\gamma_2}{2\beta_1-\gamma_1^2} & \frac{\beta_1(\gamma_1-\gamma_2)}{2\beta_1-\gamma_1^2} & \frac{2\beta_1^2}{-2\beta_1+\gamma_1^2} \end{pmatrix} \tag{A.36}$$

The first principal minor is negative, the second principal minor is positive, and the third principal minor is negative under the following conditions:

$$\sqrt{\beta_1(2\beta_1-\gamma_1^2)} \geq \beta_2 \;\; \& \;\; \sqrt{\frac{\beta_1\left(-2\beta_1+\gamma_1^2\right)}{-1+\gamma_1}} > \beta_2 \tag{A.37}$$

Therefore, the profit function of the manufacturer is concave w.r.t. ${p_1}^1$, ${q_L}^1$, and ${w_1}^1$.·

Proof of Proposition 3

The Hessian matrix of the packaging company profit function is calculated as follows:

$$\begin{pmatrix} 2(-1+\phi)\beta_1 & -(-1+\phi)\gamma_1 \\ -(-1+\phi)\gamma_1 & -1 \end{pmatrix} \tag{A.38}$$

The first principal minor is negative and the second principal minor is positive under the following conditions:

$$\beta_1 \leq \frac{\gamma_1^2}{2} \;\; \&\& \; 0 < \phi < 1 \tag{A.39}$$

Therefore, the profit function of the packaging company is concave with respect to ${p_2}^2$ and ${q_H}^2$.·

Proof of Proposition 4

The Hessian matrix of the manufacturer profit function is calculated as follows:

$$\begin{pmatrix} 2\left(\beta_1\left(-1+\frac{\phi\beta_2^2}{\left(2\beta_1+(-1+\phi)\gamma_1^2\right)^2}\right)+\frac{\beta_2(\beta_2+(-1+\phi)\gamma_1\gamma_2)}{2\beta_1+(-1+\phi)\gamma_1^2}\right) & \frac{(\gamma_1-\gamma_2)\left(4\beta_1^2+(-1+\phi)\gamma_1^2(\beta_2+(-1+\phi)\gamma_1(\gamma_1+\gamma_2))\right)}{\left(2\beta_1+(-1+\phi)\gamma_1^2\right)^2} & \frac{-(-1+\phi)^2\beta_2\gamma_1^4+(-1+\phi)\beta_1\gamma_1^2}{(-1+\phi)\left(2\beta_1+(-1+\phi)\gamma_1^2\right)^2} \\ \frac{(\gamma_1-\gamma_2)\left(4\beta_1^2+(-1+\phi)\gamma_1^2(\beta_2+(-1+\phi)\gamma_1(\gamma_1+\gamma_2))\right))}{\left(2\beta_1+(-1+\phi)\gamma_1^2\right)^2} & -1+\frac{2\phi\beta_1(\gamma_1-\gamma_2)^2}{\left(2\beta_1+(-1+\phi)\gamma_1^2\right)^2} & \frac{\beta_1(2\beta_1-\gamma_1^2)(\gamma_1-\gamma_2)}{\left(2\beta_1+(-1+\phi)\gamma_1^2\right)^2} \\ \frac{-(-1+\phi)^2\beta_2\gamma_1^4+(-1+\phi)\beta_1\gamma_1^2(-4\beta_2+(-1+\phi)\gamma_1\gamma_2)}{(-1+\phi)\left(2\beta_1+(-1+\phi)\gamma_1^2\right)^2} & \frac{\beta_1(2\beta_1-\gamma_1^2)(\gamma_1-\gamma_2)}{\left(2\beta_1+(-1+\phi)\gamma_1^2\right)^2} & \frac{2\beta_1^2\left((-2+\phi)\beta_1-(-1+\phi)\gamma_1^2\right)}{(-1+\phi)^2\left(2\beta_1+(-1+\phi)\gamma_1^2\right)^2} \end{pmatrix} \tag{A.40}$$

The first principal minor is negative, the second principal minor is positive, and the third principal minor is negative under the following conditions:

$$\beta_2 \leq \left(2\beta_1+(-1+\phi)\gamma_1^2\right)\sqrt{\frac{\beta_1}{(2+\phi)\beta_1+(-1+\phi)\gamma_1^2}} \tag{A.41}$$

$$2+\sqrt{\frac{2\beta_1(1-4\gamma_1)\gamma_1^2+\gamma_1^4+\beta_1^2(1+2\gamma_1)^2}{\gamma_1^6}} \geq 2\phi+\frac{1}{\gamma_1}+\frac{\beta_1(1+2\gamma_1)}{\gamma_1^3} \tag{A.42}$$

$$\beta_2 \leq \sqrt{\frac{\beta_1\left(2\beta_1+(-1+\phi)\gamma_1^2\right)^2}{(2+\phi)\beta_1+(-1+\phi)\gamma_1^2}} \tag{A.43}$$

Therefore, the profit function of the manufacturer is concave w.r.t. $p_1{}^2$, $q_L{}^2$, and $w_1{}^2$.·

Proof of concavity of the manufacturer's and the packaging company's profit function under scenario 3

The Hessian matrix of the packaging company profit function is calculated as follows:

$$\begin{pmatrix} 2(-1+\theta)\beta_1 & -(-1+\theta)\gamma_1 \\ -(-1+\theta)\gamma_1 & -1+\theta \end{pmatrix} \tag{A.44}$$

The first principal minor is negative and the second principal minor is positive under the following condition:

$$\beta_1 \le \frac{\gamma_1^2}{2} \tag{A.45}$$

Therefore, the profit function of the packaging company is concave w.r.t. $p_2{}^3$ and $q_H{}^3$.·

The Hessian matrix of the manufacturer profit function is calculated as follows:

$$\begin{pmatrix} \frac{-4\beta_1^2+2\beta_1\gamma_1^2+\beta_2((2+\phi)\beta_2-2\gamma_1\gamma_2)}{2\beta_1-\gamma_1^2} & \frac{(\gamma_1-\gamma_2)(2\beta_1+(1+\phi)\beta_2-\gamma_1(\gamma_1+\gamma_2))}{2\beta_1-\gamma_1^2} & \frac{-\beta_2((-2+\phi)\beta_1+\gamma_1^2)+\beta_1\gamma_1\gamma_2}{2\beta_1-\gamma_1^2} \\ \frac{(\gamma_1-\gamma_2)(2\beta_1+(1+\phi)\beta_2-\gamma_1(\gamma_1+\gamma_2))}{2\beta_1-\gamma_1^2} & \frac{-2\beta_1+(1+\phi)\gamma_1^2-2\phi\gamma_1\gamma_2+\phi\gamma_2^2}{2\beta_1-\gamma_1^2} & -\frac{(-1+\phi)\beta_1(\gamma_1-\gamma_2)}{2\beta_1-\gamma_1^2} \\ \frac{-\beta_2((-2+\phi)\beta_1+\gamma_1^2)+\beta_1\gamma_1\gamma_2}{2\beta_1-\gamma_1^2} & -\frac{(-1+\phi)\beta_1(\gamma_1-\gamma_2)}{2\beta_1-\gamma_1^2} & \frac{(-2+\phi)\beta_1^2}{2\beta_1-\gamma_1^2} \end{pmatrix} \tag{A.46}$$

The first principal minor is negative, the second principal minor is positive, and the third principal minor is negative under the following conditions:

$$\gamma_1 < \beta_1 < \frac{\gamma_1^2}{2} \ \& \ 2+\phi > \frac{4\beta_1^2-2\beta_1\gamma_1^2+2\beta_2\gamma_1\gamma_2}{\beta_2^2} \tag{A.47}$$

Therefore, the profit function of the manufacturer is concave w.r.t. $p_1{}^3$, $q_L{}^3$, and $w_1{}^3$.

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