Balancing price and green quality in presence of consumer environmental awareness a green supply chain coordination approach

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Published in:
International Journal of Production Research

DOI:
10.1080/00207543.2020.1771457

Publication date:
2021

Document version:
Accepted manuscript

To cite this paper:

Heydari, J., Govindan, K., & Basiri, Z. (2021). Balancing price and green quality in presence of consumer environmental awareness: a green supply chain coordination approach. *International Journal of Production Research*, *59*(7), 1957-1975.

Balancing price and green quality in presence of consumer environmental awareness: A green supply chain coordination approach

Abstract:

This study analyzes the green channel coordination problem in a two-echelon supply chain where demand is a function of the selling price and the product's green quality. The retailer decides on the selling price while the manufacturer regulates the green quality of the product. To initiate the channel coordination and to establish a win-win outcome for both parties, a hybrid of "greening cost sharing" and "revenue sharing" contract (HGRS) is developed. This study contributes to the literature by providing an analytical approach to address the channel coordination and pricing issues in a green supply chain under the consumer environmental awareness while the manufacturer has the ability of enhancing, with investments, the product's green quality. Our study reveals that: (a) the proposed HGRS contract is capable of achieving channel coordination while both supply chain members gain more profit than in decentralized decision making, (b) the new suggested contract enhances the product's green quality, reduces the selling price, and stimulates the market demand, and (c) HGRS contract results in more satisfied customers (by offering low prices) as well as more sustainable operations (by increasing greenness level) at the same time.

Key words: Supply chain coordination; green supply chain; revenue sharing; consumer environmental awareness; environmental quality

1. Introduction

With the global economy's rapid development, the environment is changing fast. Challenges that exist between environmental and economic objectives make it difficult to achieve environmental goals. In modern business environments, many economic complexities underscore global supply chains (SCs), and environmentally aware customers pressure supply chains to be more green (Du et al., 2015; Kuiti et al. 2019). As a result, supply chains that can minimize environmental damage have become more competitive over the last decade (Kumar et al., 2012). Some samples of these environmental efforts around the world are the development of closed-loop supply chains, reverse supply chains, considering life cycle of products, producing green products, and reducing the amount of greenhouse gases (carbon dioxide, sulfur dioxide, nitrogen dioxide, etc.) emissions throughout the chain (Jaber et al., 2013).

Before the industrial revolution, the emission concentration of greenhouse gases in the atmosphere was approximately constant (250-300 ppm) over the 10000 years, while from the beginning of industrial revolution, the concentration of CO_2 increased to the amount of 400 ppm and concentration of CH_4 has doubled (Gupta & Palsule-Desai, 2011). Recent research shows that 30-40% and 50-60% of carbon pollutions are emitted during manufacturing and transportation steps, respectively (Zheng et al., 2015). Some regulations like European Union Emissions Trading System hope to reduce CO2 emissions, significantly (Jaber et al., 2013). These figures imply an urgent need for green operations in both production and consumption.

Green practices are a major concern around the world, in both developed and developing economies. In Asian emerging economies (AEE), green supply chain management (GSCM) practices have led to better performance in three aspects: economic, environmental, and operational (Geng et al., 2017). Chinese enterprises have increased their environmental awareness due to regulatory demands, drivers, and to competitive and marketing pressures (Zhu et al., 2005). By surveying 396 Chinese manufacturing enterprises, Zhu et al. (2012) proved the significant impact of coordination between internal (e.g. eco-design, management practices, financial policies) and external (e.g. green purchasing, customer cooperation, investment recovery) practices of green supply chain management on performance improvements. About one-third of world resources are extracted to respond the consumption from the five BRICS countries (Brazil, Russia, India, China, and South Africa). During 1995-2008, per-capita footprints in BRICS countries increased in a faster manner than the whole world average (Wu et al., 2017). European Union Emissions Trading System (EU ETS) is the first emission trading scheme which is launched in 2005 to control the industrial emission in industries of 31 countries, including all 28 EU countries which implies the severe intention of developed countries toward green practices (Jaber et al., 2013). Meanwhile, surveys in developed countries indicate that about half of respondents prefer to purchase green product, and about half of them even like to pay higher prices for the green version of a product (Ranjan & Jha, 2019) which means a high customer-side pressure for being greener.

It is possible for a supply chain to enhance its greenness level in several ways. For example, the Adidas Company successfully reduced its harmful materials and wastes from used substances in both production and packaging processes (Ghosh & Shah, 2012). In another instance, in India, Coca-Cola collaborated with vendors to recycle bottle wastes (Ghosh & Shah, 2015). Due to an increase in consumer environmental awareness (CEA), customers will pay more for products with higher green quality (Chitra, 2007). The BBMG Conscious Consumer Report states that 67% of American citizens support the idea of purchasing green products, and 51% are willing to pay more for these products (Bemporad & Baranowski, 2007). The U.S. Environmental Protection Agency (EPA) provides online carbon footprint calculators for consumers and encourages them to buy green products (Teisl et al., 2002). A survey shows that 50% of firms decided to redesign their supply chain to be more sustainable, and almost 80% of them intend to arrange their policies according to new environmental rules (Chaabane et al., 2011). Ideally, all of a supply chain's environmental activities should be in equilibrium with economic objectives (Ghosh & Shah, 2012; Jaber et al., 2013). In this condition, this study seeks to develop decision models to attain both profit-oriented as well as environmental objectives for supply chains.

This paper investigates coordination between the supply chain members while both environmental and economic decisions are considered. This research expands the extent of supply chain coordination to include environmental concerns. Coordinated inventory and production decision making by supply chain members is an important path to attain a competitive advantage in modern business environments (Jaber et al., 2014). The primary goal of a coordination model is to improve the supply chain members' ability to optimize the whole supply chain profit instead of optimizing their own profit. Strategies to achieve an effective and efficient coordination in a seller-buyer channel should be accompanied by appropriate contracts to ensure more profitability for all channel members.

In this research, it is pursued to answer three research questions: (1) How can the channel members' decisions on both green quality and selling price be optimized in the presence of environmentally aware customers? (2) How do the factors of consumer environmental awareness and the green quality of product serve as adjustable decision variables that influence channel coordination? (3) How can the right balance of green quality and selling price be achieved in a manner that optimizes the whole channel profit and to allow both members to benefit?

To answer the research questions, a two-echelon (single manufacturer/single retailer) supply chain is modelled where the demand is dependent to both selling price and green quality of product. The retailer decides on the selling price while the manufacturer regulates the product's green quality. Each member's profit function and the total supply chain are extracted and optimized under three scenarios: (1) decentralized decision model where each supply chain member make decisions unaccompanied according to own profit function, (2) centralized scenario where a central decision maker aims to optimize the whole supply chain profit, and (3) coordinated scenario where a contract is designated to convince members to globally optimize decision variables. To ensure global optimal decisions and guaranteed profit of both members, a hybrid of greening cost and revenue sharing contract (HGRS) is applied. A conventional revenue sharing contract can coordinate the investigated SC, but it cannot necessarily result in a win-win situation for both parties if there are two or more conflicting decisions. Indeed, the conventional revenue sharing contracts only have two controlling parameters; one of them can just coordinate one decision variable, and another can be used for sharing the risks/benefits. If there are two conflicting decisions, then both controlling parameters of the conventional revenue sharing contracts are used to coordinate two conflicting decisions, and no controlling parameter remains to share the risks/benefits. There are some examples of such situations in the literature of SC coordination for various contracts (e.g. Yoo et al., 2015; Ji et al., 2020). In the investigated model of this study, two decision variables exist (selling price and product environmental quality), and a win-win construct is still possible. Since a conventional revenue sharing contract is ineffective in our case, we develop a hybrid contract of greening cost sharing and revenue sharing between two channel members. Our findings show that the proposed model is capable of coordinating both pricing and green quality decisions simultaneously while no channel member ends up worse off. In addition, our model reveals that coordinated decision-making leads to a lower selling price and higher green quality for products. Meanwhile, both the SC members gain more profit under the proposed contract compared to their profit under the decentralized decision-making. This finding confirms that the proposed contract is able to achieve a Pareto-improving coordination scheme.

We are motivated to conduct this study because previous studies in this context have rarely considered the issue of green quality enhancement accompanied with consumer environmental awareness and complete channel coordination. The investigated real-life examples show that a product's green quality should be treated as a decision variable to be optimized by supply chain members, and it appears that this finding less explored in prior channel coordination research, especially in conjunction with pricing schemes where there are two conflicting decisions in the SC. While some recent papers (e.g. Guo et al., 2020) consider green quality as a decision variable, none of them investigate the mutually effects of green quality enhancement and pricing schemes in presence of CEA as conflicting decisions. With respect to previous models, the proposed model contributes to an analysis of the channel coordination issue in the presence of consumer environmental awareness; it treats green quality as a decision variable under an upstream authority. In the proposed model, the product's green quality influences the market demand; a green quality cost sharing contract, along with a revenue sharing contract, is designated to encourage the manufacturer to enhance the greening level and, at the same time, to convince the retailer to reduce the selling price in order to stimulate demand.

The current study is structured as follows. In Section 2 the previous literature is reviewed. Section 3 the symbols and notations are introduced and also it describes the basic models. Section 4 formulates mathematical models and discusses obtained solutions. Section 5 studies some numerical investigations and sensitivity analysis, and Section 6 represents our findings and also provides further research opportunities.

2. Literature Review

The current research deals with the problem of channel coordination in a green supply chain by an in-depth analysis of contracts. There is limited but growing literature in the fields of channel coordination and green supply chain management (e.g. Govindan & Hasanagic, 2018; Swami & Shah, 2013). In this section, we review the literature briefly to position the present study in the body of literature and to illustrate the current study's contribution to the previous models.

Consumer environmental awareness (CEA) and customers' tendency to buy green products are key factors influencing the green policies of contemporary supply chains (Zhu & Sarkis, 2007; Chelly et al. 2020). Liu et al. (2012) assumed a supply chain with two types of substitutable (i.e. traditional and green types) products where the demand is CEA-dependent. Using game theory approach, they optimize decisions appropriately and reach equilibrium. When the demand depends on price, environmental quality, and consumer environmental awareness, a two-part tariff was proposed to coordinate the channel (Ghosh & Shah, 2012); however, they found that a two-part tariff could not guarantee more profit to the manufacturer. Hence, from a practical point of view, the two-part tariff could not be implemented because the manufacturer refuses to participate in the plan. Zhang & Liu (2013) considered a supply chain by a Stackelberg model and proposed a revenue-sharing mechanism. They found that a revenue sharing mechanism divides the profit fairly for cooperating members and, as a result, suitable channel coordination can be achieved. In a two-echelon serially-connected supply chain that faces a deterministic demand, Xia & He (2014) showed that it is effective to encourage the manufacturer to decrease carbon emissions by sharing the cost of carbon reduction activities. They introduced a new side payment mechanism to attain a Pareto optimal solution (Xia & He, 2014). De Giovanni (2014) proposed a revenue sharing contract in a closed-loop supply chain with green sales efforts to coordinate the whole channel. In another study, a cost sharing contract was applied to encourage the producer to enhance the product's green level (Ghosh & Shah, 2015); although they found equilibrium levels of product greening under cost sharing, their solution was not compared to a centralized solution and, therefore, the channel coordination did not achieve. In a two-echelon supply chain with two substitutable products (again, traditional and green), a return policy was proposed to coordinate order quantity (Zhang et al., 2015). In that study, demand is assumed dependent to price and green level of product under the effect of a stochastic CEA. However, in contrast to the current study, Zhang et al. (2015) did not treat green level and market price of products as decision variables. Indeed, in their model, both the market price and green level of products are fixed and predetermined. In another study, Saha et al. (2019) investigated the effect of government subsidy policies when demand is sensitive to green marketing effort, price, and greening level. They investigated the supply chain under both revenue sharing contract and green-marketing effort sharing contract and they found that under a consumers' subsidy policy both contracts fail to improve the supply chain's performance. On the other hand, they found that a manufacturer subsidy policy motivates members to cooperate.

Emission reduction and carbon policies are among other major concerns of researchers in the field of green/sustainable supply chain management. In presence of cap and trade policy, a coopetition model between two competitor manufacturers with different emission reduction efficiencies was investigated by Luo et al. (2016) and it is found that, in the case of a price and emission sensitive demand, co-opetition results in a more profit and carbon emission reduction versus the pure competition. Toptal et al, (2014), by extending economic order quantity, optimized joint inventory and carbon reduction investment decisions under three governmental carbon regulations. They assumed a deterministic market demand which is not dependent to price or carbon reduction investment. In a two-stage supply chain model with deterministic and constant demand function, Zanoni et al. (2014) investigated joint economic lot size problem to coordinate inventory decisions under vendor-managed inventory system along with a consignment stock agreement under an emission tax and penalty regime. They found that consignment stock agreement may help to reduce emissions. Under two conventional carbon emission regulations (i.e. emission constraint and cap and trade mechanism), Wang and Choi (2016) explored a stochastic lot sizing problem in a make to order system. They found, while the emission constraint policy reduces the profitability, the cap and trade regulation not only reduces carbon emission but also it raises the profitability. In a two-echelon sustainable supply chain consisting of a manufacturer and a retailer where the demand function is price and emission sensitive, a two-part tariff contract was proposed by Chen et al. (2017) which is capable of coordinating the channel with different power structures and achieving Pareto-optimal results. Dai et al. (2017), using a Stackelberg game approach, compared cartelization, cost sharing, and non-cooperation mode in a two-echelon channel in presence of price and firm's energy-saving sensitive demand. They found, under a greener market and powerful government subsidy a cartelization mode is more beneficial. Recently, Yang & Chen (2018) analysed a two-echelon supply chain under different combination of revenue sharing and cost sharing contracts to coordinate the channel and encourage the manufacturer for carbon emission abatement. Although Yang & Chen (2018) in all their proposed schemes could improve the whole channel profit and encourage the manufacturer for carbon emission abatement, none of the offered scenarios can improve it to the integrated channel profit level. More recently, Qin et al. (2020) investigated a two-stage supply chain under advance payment financing with and without a capital-constrained manufacturer and then they extended their models to the case of cap and trade regulation. Although they investigated whether the participants accept the advance payment, their model does not guarantee a channel coordination outcome. Recently a review paper by Chelly et al. reviewed supply chain mathematical models under carbon emission (Chelly et al., 2020).

Compared to the above reviewed studies, this study contributes to the literature by providing an analytical approach to address the channel coordination issue in a green supply chain under two conditions: the presence of CEA and the ability of the manufacturer to enhance, with investments, the product's green quality. The most closely related researches are highlighted in Table 1. Although all these researches make attempts to coordinate the channel by applying appropriate contracts considering CEA, some are not capable of coordinating the whole channel. In addition, we know that the manufacturer needs encouragement to enhance the green quality of products as well as the centralized decision-making model; however, no previous study encourages the manufacturer to do so. In this study, in addition to finding a closed-form optimal solution, a hybrid greening cost and revenue sharing (HGRS) contract is developed. It is able to attain channel coordination and results in more profits for both channel members.

Table 1. Differences/Similarities of related prior researches with the current study

Authors	Contract	Demand Dependency			Decision variables						Channel coordination
		Price	Green quality	Emission	Selling Price	Green quality	Order quantity	Wholesale price	Emission reduction	Retailer proportion of emission reduction cost	
Liu et al. (2012)	Game theoretical model	×	×		×	×		×			N/A
Ghosh & Shah (2012)	Two-part tariff	×	×		×	×		×			×*
Xia & He (2014)	Cost sharing and side payment	×		×					×	×	×
Ghosh & Shah (2015)	Cost sharing	×	×		×	×		×			
Zhang et al. (2015)	Return policies	×	×				×	×			×
Chen et al. (2017)	Two-part tariff	×		×	×			×	×		Pareto optimal only
Dai et al. (2017)	cartelization and cost sharing	×	×		×	×		×			Pareto optimal only
Yang & Chen (2018)	Cost sharing and revenue sharing	×		×	×			×			Pareto optimal only
Qin et al. (2020)	Game theoretical model			×			×		×		
This paper	Hybrid revenue and greening cost sharing	×	×		×	×					×

* Although the performance of the proposed two-tariff contract is high as the centralized model, a win-win situation cannot be guaranteed.

According to Table 1, study by Yang & Chen (2018) is the most similar work to the current study. Although, Yang & Chen (2018) in all their proposed schemes could improve the whole channel profit and obtain a Pareto-optimal solution, in contrast to the current study, none of the their offered scenarios could not achieve channel coordination (i.e. performance equal to the centralized solution). Nevertheless, in the related literature, the effect of government subsidy on greening investment was considered by some researchers recently (e.g. Dai et al. 2017) or carbon regulations such as cap and trade are considered in some works (e.g. Luo et al. 2016) which are disregarded in this study.

3. Model descriptions

In this study, a two-echelon supply chain consisting of a single manufacturer and a single retailer is investigated in which the approximated demand is a linear function of selling price p and green quality e. This approximation of real demand function is also assumed by previous models (e.g. Ghosh & Shah, 2015; Liu et al., 2012; Tsay & Agrawal, 2000). Although it is an estimation of a more complicated non-linear demand function, it can be considered as a good approximation of consumers' purchasing behavior. Assuming a non-linear complex demand makes it impossible to trace an exact mathematical approach and either needs other research approaches such as simulation or non-exact mathematical models. Therefore, to avoid mathematical complexity, and make it possible to use an exact mathematical modeling approach, we use an approximated linear demand function.

In the proposed model, we consider some assumptions; some make the model more realistic, and some others are applied for simplification's purposes. However, all of them are consistent with previous literature in this field. To create a sound mathematical model, it is assumed that:

- The investigated channel serves the customers in a single period setting.
- The customers have environmental tendencies and are able to recognize the environmental quality of the offered products.

- Sensitivity of customers to price is known. Furthermore, the CEA level of customer's community is assumed to be measured previously using survey approaches (e.g., see Jafari et al., 2017).
- For simplicity reasons it is considered that all the model parameters are known to both channel members (symmetric information sharing).
- Demand function is deterministic and is assumed a linear function of selling price and greenness level of the product.
- Due to nature of product and business environments, a static pricing scheme is applied in the studied SC.

The optimal solutions are derived under different scenarios: (1) centralized scenario, (2) decentralized scenario, (3) coordination scenario via contracts. Similar to Dey et al. (2019), the demand function is in the form of $D = a - bp + \tau e$; where, a is the basic market size, p is the selling price that affects market demand by price sensitivity coefficient b; τ is the CEA level which is related to the willingness of consumers to buy the product with higher green quality e even at a higher price. The assumed demand function implies there are alternative products in the market to be purchased, and customers have the option to select between them based their offered prices and green qualities. Coefficients b and τ reflect the severity of competition between alternatives; for example, when b is relatively high, any small increase in price results in losing customers who are sensitive to price. All the demand parameters (i.e., a, b, τ) can be estimated using deep market surveys by gathering required data from the consumers' purchasing behavior.

The cost of greening the product burdened to the manufacturer is given by he^2 where h is the investment coefficient of making the product greener (Banker et al., 1998; Liu et al., 2012; Ghosh & Shah, 2015; Guo et al., 2020; Liu & Ke, 2020; Qin et al., 2020). Such a quadratic greening cost function implies that by improving the green quality of product the needed investment for further enhancement of the green quality increases exponentially with a quadratic form.

Notations are used in developing the proposed models are as follows:

Parameters

c	Production cost of the manufacturer per unit
h	Greening cost coefficient
τ	Customer environmental awareness (CEA) level
a	Primary market potential
b	Price sensitivity of demand
w	The unit wholesale price
Π_{sc}	Channel profit
Π_m	Manufacturer's profit
Π_r	Retailer's profit

Decision variables

p	Selling price of the product (decision variable of the retailer)
e	The product green quality (decision variable of the manufacturer)

Coordination model variables

w_r	The unit wholesale price under the contract
φ	Share of greening-cost allocated to the retailer (φ∈[0,1])
v	Share of revenue allocated to the retailer (v∈[0,1])

4. Model formulations and solution

In this section, formulas for both supply chain members' profit functions are derived, and three decision-making scenarios – for centralized, decentralized, and coordinated models – are analyzed. Closed-form solutions for both p and e are derived in all three scenarios.

4.1. Centralized model

In the centralized supply chain, a single decision authority on behalf of all supply chain members makes attempts to optimize the total channel profit. In this condition, Equation (1) shows the supply chain's profit.

$$\Pi_{sc}(p, e) = (p - c)(a - bp + \tau e) - he^2 \quad (1)$$

According to profit function (1), the first term represents profit from selling products and the second term expressing the greening cost.

Theorem 1. *Π_{sc} is concave in both e and p if $4bh - \tau^2 > 0$ and the optimal decision variables e and p in the centralized scenario are derived as Equations (2) and (3), respectively.*

$$e^{c*} = \frac{\tau(p - c)}{2h} = \frac{\tau(a - bc)}{4bh - \tau^2} \quad (2)$$

$$p^{c*} = \frac{a + bc + \tau e}{2b} = \frac{2ah + 2bch - c\tau^2}{4bh - \tau^2} \quad (3)$$

Proof. To prove concavity of Π_{sc} in both e and p, Hessian matrix Π_{sc} is derived as:

$$H(\Pi_{sc}(p, e)) = \begin{bmatrix} -2b & \tau \\ \tau & -2h \end{bmatrix}$$

Hessian matrix must be negative-definite. The first principal minor is negative, and the second principal minor is positive if:

$$4bh - \tau^2 > 0 \quad (4)$$

By holding Equation (4), first-order optimality conditions $\frac{\partial \Pi_{sc}(p,e)}{\partial e} = 0$ and $\frac{\partial \Pi_{sc}(p,e)}{\partial p} = 0$ result in optimal values of decision variables e and p as Equations (2) and (3), respectively. By comparing the denominator of Equations (2) and (3) with Equation (4) one can conclude that we face a concave objective function if the obtained optimal values for both $e \text{ and } p$ are feasible (i.e. positive values). In other words, there is no problem with concavity of the SC profit function as long as the optimal values of decision variables are positive. $\blacksquare$

Substituting p^{c*} and e^{c*} from Equations (2) and (3) into the demand function, we can calculate market demand under the centralized decision-making as:

$$D^{c*} = \frac{2a - 2bc}{4 - \frac{\tau^2}{bh}} \tag{5}$$

Substituting Equations (2) and (3) in the supply chain profit function results in the optimal supply chain profit function under the centralized scenario as:

$$\Pi_{sc}^{c*}(p^{c*}, e^{c*}) = \frac{h(a - bc)^2}{4bh - \tau^2} \tag{6}$$

The profit function of manufacturer is derived as:

$$\Pi_m = (w - c)(a - bp + \tau e) - he^2 \tag{7}$$

where $(w - c)$ is the marginal revenue of the manufacturer from selling each unit, which is multiplied by the market demand to represent revenue of the manufacturer from selling products to the retailer. The second term is the greening cost which imposed to the manufacturer.

By substituting decision variables p^{c*} and e^{c*} from Equations (2) and (3) into Equation (7) we can calculate the optimal profit function of the manufacturer under the centralized decision-making as:

$$\Pi_m^{c*} = w\left(\frac{2abh - 2b^2ch}{4bh - \tau^2}\right) + \frac{\begin{pmatrix} 8b^3c^2h^2 - 8ab^2ch^2 \\ -3b^2c^2h\tau^2 + 4abch\tau^2 - ha^2\tau^2 \end{pmatrix}}{(4bh - \tau^2)^2} \tag{8}$$

The profit function of the retailer under the centralized mode can be expressed as:

$$\Pi_r = (p - w)(a - bp + \tau e) \tag{9}$$

where $(p - w)$ is the retailer's marginal revenue from selling each unit, which is multiplied by the market demand. Substituting p^{c*} and e^{c*} from Equations (2) and (3) into Equation (9) we have the optimal profit of the retailer function under the centralized decision-making as:

$$\Pi_r^{c*} = \frac{2bh(2a^2h - 2b^2c^2h - ac\tau^2 + bc^2\tau^2)}{(4bh - \tau^2)^2} - w\left(\frac{2abh - 2b^2ch}{4bh - \tau^2}\right) \tag{10}$$

4.2. Decentralized model

Under the decentralized mode, each supply chain member intends to optimize his own profit independently and regardless of the other member. Therefore, the manufacturer independently decides on the product's green quality while the retailer decides on the selling price based on its individual profitability. Under the decentralized mode, the retailer is assumed the leader of Stackelberg game and moves first to decide on p while the retailer is assumed to be aware of the manufacturer's decision on e. By backward induction in the retailer-led Stackelberg game model, we first solve the manufacturer's problem and find the optimal e and then we solve the retailer's model to calculate optimal p based on the optimal manufacturer's decision.

Since we follow a retailer-led Stackelberg game, using backward induction, the manufacturer likes to set the wholesale price as high as possible. Therefore, to avoid unrealistic situations, we assume the wholesale price as an exogenous element in our study, which is determined in a competitive environment based on competition between the existing competitors.

Theorem 2. *Π_m is concave in green quality level e, and the optimal e under the decentralized decision-making is:*

$$e_m^{d*} = \frac{(w-c)\tau}{2h} \tag{11}$$

Proof. Since $\frac{\partial^2 \Pi_m}{\partial e^2} = -2h < 0$ then profit function of the manufacturer is concave in e and thus, $\frac{\partial \Pi_m}{\partial e} = 0$ results in Equation (11) as optimal e.■

Theorem 3. *Π_r is concave in p, and the optimal p under the decentralized decision-making is:*

$$p_r^{d*} = \frac{a + wb + \tau e}{2b} = \frac{2h(a+bw) + \tau^2(w-c)}{4bh} \tag{12}$$

Proof. Since $\frac{\partial^2 \Pi_r}{\partial p^2} = -2b < 0$, then profit function of the retailer is concave in p and, thus, first-order optimality condition $\frac{\partial \Pi_r}{\partial p} = 0$ and substituting optimal e from Equation (11) into it, results in Equation (12) as optimal p.■

Substituting p_r^{d*} and e_m^{d*} from Equations (11) and (12) into the demand function, we can calculate market demand under the decentralized framework as:

$$D^{d*} = \frac{2h(a - wb) + \tau^2(w-c)}{4h} \tag{13}$$

Furthermore, by substitution of p_r^{d*} and e_m^{d*} from Equations (11) and (12) into Equation (7), we can calculate the manufacturer's optimal profit under the decentralized scenario as:

$$\Pi_m^{d*} = (w-c)\left(\frac{a - wb}{2}\right) \tag{14}$$

Substitution of p_r^{d*} and e_m^{d*} from Equations (11) and (12) into Equation (9) results in the retailer's optimal profit function in the decentralized model as:

$$\Pi_r^{d*} = \frac{(2h(a - wb) + \tau^2(w-c))^2}{16bh^2} \tag{15}$$

The total profit of the supply chain under the decentralized scenario can be calculated as:

$$\Pi_{sc}^{d*} = \Pi_m^{d*} + \Pi_r^{d*} = \frac{(2h(a - wb) + \tau^2(w - c))^2 + 8bh^2(a - wb)(w - c)}{16bh^2} \qquad (16)$$

The optimal solution of the centralized model results in higher levels of profit for the total supply chain than the decentralized model; however, there is no guarantee that both members benefit. To optimize the entire channel and, at the same time, to assure more profit for both channel members, it is essential to establish an adequate contract between members to initiate them to change decisions from local optimum p_r^{d*} and e_m^{d*} to the global optimum p^{c*} and e^{c*}.

4.3. Hybrid greening cost and revenue sharing contract

Revenue sharing is a well-known strategy to coordinate multi-echelon systems (e.g. Hou et al., 2017; Cao et al., 2015). However, a simple revenue sharing contract may not be able to coordinate a two-variable model and derive a win-win outcome for both channel members. To overcome this shortcoming, we apply a hybrid greening cost and revenue sharing contract (HGRS) to induce channel members to make decisions identical to the centralized model. Under HGRS, at first, the manufacturer offers a new lower wholesale price and instead asks the retailer to share a portion of selling revenue. In the next stage, to ensure better position for both members, the retailer undertakes a portion of greening expenses. Before the proposed contract, the manufacturer undertakes the greening cost alone. Using greening cost sharing, the retailer persuades the other member to enhance the product green quality by undertaking a portion of greening expenses. The retailer's share of greening costs is defined as $\varphi\epsilon[0,1]$. At the same time, a revenue sharing contract is conducted by the manufacturer, in which the manufacturer promises to sell the product to the retailer with a new wholesale price w_r.

The new price is less than the original wholesale price w and, instead, the retailer is committed to pay a portion $(1-v)\epsilon[0,1]$ of the total sales income to the manufacturer at the end of the selling season.

Under the proposed contract, the manufacturer's profit function can be reformulated as:

$$\Pi_m^{HGRS} = \big((1-v)p + w_r - c\big)(a - bp + \tau e) - (1-\varphi)he^2 \tag{17}$$

where, w_r is the new wholesale price, term $(1-v)$ represents the allocated share from the sales income to the manufacturer; and according to the coefficient $(1-\varphi)$, paid quota of the manufacturer from greening cost is determined.

The retailer's profit function under the proposed contract can be expressed as:

$$\Pi_r^{HGRS} = (vp - w_r)(a - bp + \tau e) - \varphi he^2 \tag{18}$$

where, v is the sales income share allocated to the retailer, and φ determines the contribution of the retailer in handling of greening cost.

Theorem 4. Π_m^{HGRS} *is concave in e, and the optimal e under HGRS contract is*:

$$e_m^{HGRS*} = \frac{((1-v)p + w_r - c)\tau}{2h(1-\varphi)} = \frac{\tau(2bv(w_r - c) + (1-v)(va + w_r b))}{4bhv(1-\varphi) - \tau^2 v(1-v)} \tag{19}$$

Proof. Since $\frac{\partial^2 \Pi_m^{HGRS}}{\partial e^2} = -2h(1-\varphi) < 0$ $(h > 0$ and $\varphi\epsilon[0,1])$, the profit function of manufacturer under HGRS contract is a concave function in e. First-order optimality condition $\frac{\partial \Pi_m^{HGRS}}{\partial e} = 0$ results in Equation (19).■

Theorem 5. Π_r^{HGRS} *is concave in p, and the optimal p under HGRS contract is*:

$$p_r^{HGRS*} = \frac{v(a + \tau e) + w_r b}{2bv} = \frac{\tau^2 v(w_r - c) + 2h(1-\varphi)(va + w_r b)}{4bhv(1-\varphi) - \tau^2 v(1-v)} \tag{20}$$

Proof. Since $\frac{\partial^2 \Pi_r^{HGRS}}{\partial p^2} = -2bv < 0$ ($b > 0$ and $v \in [0\ 1]$), the profit function of retailer is a concave function in p and using first-order optimality condition $\frac{\partial \Pi_r^{HGRS}}{\partial p} = 0$, calculation of Equation (20) is straightforward.■

To attain channel coordination, it is necessary for both participants to decide on terms similar to the centralized scenario. We use this rule to calculate parameters of HGRS contract, i.e., $w_r, v,$ and φ, such that decisions on both e and p under HGRS contract are equal to the centralized scenario.

Putting $e_m^{\mathrm{HGRS}*} = e_m^{c*}$ by use of Equations (2) and (19) results in:

$$w_r(v,\varphi) = \frac{cv(1+\varphi)}{1+v} - \frac{v(4ah - c\tau^2)(\varphi - v)}{(4bh - \tau^2)(v+1)} \tag{21}$$

Similarly, $p_r^{\mathrm{HGRS}*} = p_r^{c*}$ using Equations (3) and (20) results in:

$$\begin{aligned} w_r(v,\varphi) &= \frac{cv\tau^2 - 2ah(1-\varphi)}{c\tau^2 + 2bh(1-\varphi)} \\ &\quad + \left(\frac{4bh(1-\varphi) - \tau^2 v(1-v)}{b(v\tau^2 + 2bh(1-\varphi))}\right)\left(\frac{a+bc}{2} + \frac{\tau^2(a-bc)}{2(4bh-\tau^2)}\right) \end{aligned} \tag{22}$$

Equations (21) and (22) represent the new wholesale price w_r as functions of contract parameters v and φ. Now, if we equate the right hand sides of these two equations, we will have a relation between v and φ as follows:

$$\varphi(v) = \frac{\left(\begin{array}{c} v^2(-a\tau^2 + 4abh - 4b^2ch + bc\tau^2) + \\ v(a\tau^2 + 4abh - 4b^2ch - bc\tau^2) \\ \pm(v-1)\left(v(a-bc)\left(\begin{array}{c} 32b^2ch\tau^2 - 8bc\tau^4 + \\ v(a\tau^4 - 9bc\tau^4 + 16ab^2h^2 \\ -16b^3ch^2 + 24b^2ch\tau^2 \\ +8abh\tau^2 \end{array}\right)\right)^{\frac{1}{2}} \end{array}\right)}{8bhv(a-bc)} \tag{23}$$

Now, substituting Equation (23) into one of the Equations (21) and (22), we can derive a relation that represents w_r as a function of v as:

$$w_r(v) = \frac{\left(\begin{array}{c} v^2(a\tau^2 + 4abh + 4b^2ch - 3bc\tau^2) + \\ v(-a\tau^2 - 4abh + 12b^2ch - bc\tau^2) \\ \mp(v-1)\left(v(a-bc)\left(\begin{array}{c} 32b^2ch\tau^2 - 8bc\tau^4 + \\ v(a\tau^4 - 9bc\tau^4 + 16ab^2h^2 \\ -16b^3ch^2 + 24b^2ch\tau^2 \\ +8abh\tau^2 \end{array} \right) \right)^{\frac{1}{2}} \end{array} \right)}{2b(1+v)(4bh-\tau^2)} \quad (24)$$

According to Equation (23), we have two values for φ, and subsequently, we have also two values for w_r according to Equation (24). Each pair of answers which is infeasible (e.g., for a solution set, it may happen that φ is out of the interval [0, 1]) should be ignored.

We set the third contract parameter v such that both channel members are willing to participate in HGRS contract. For this purpose, both members' profit after participating in HGRS contract should be greater than their profit under the decentralized decision-making model. From the manufacturer's perspective, we should have $\Pi_{\mathrm{m}}^{HGRS*}(\mathrm{p_r^{c*}}, \mathrm{e_m^{c*}}, \mathrm{w_r}, \varphi, \mathrm{v}) \geq \Pi_{\mathrm{m}}^{\mathrm{d}^*}\left(\mathrm{p_r^{d*}}, \mathrm{e_m^{d*}}, \mathrm{w}\right)$ that by some simplifications it results in:

$$v \leq \frac{\left(\begin{array}{c} (\mathrm{p_r^{c*}} - \mathrm{c})(\mathrm{a} - \mathrm{bp_r^{c*}} + \tau\mathrm{e_m^{c*}}) - (\mathrm{w} - \mathrm{c})\left(\mathrm{a} - \mathrm{bp_r^{d*}} + \tau\mathrm{e_m^{d*}}\right) \\ -\mathrm{h}\left((\mathrm{e_m^{c*}})^2 - \left(\mathrm{e_m^{d*}}\right)^2\right) + \varphi\mathrm{h}(\mathrm{e_m^{c*}})^2 + \mathrm{w_r}(\mathrm{a} - \mathrm{bp_r^{c*}} + \tau\mathrm{e_m^{c*}}) \end{array} \right)}{\mathrm{p_r^{c*}}(\mathrm{a} - \mathrm{bp_r^{c*}} + \tau\mathrm{e_m^{c*}})} \quad (25)$$

From the retailer's viewpoint, participation in HGRS contract is acceptable if we have $\Pi_{\mathrm{r}}^{HGRS*}(\mathrm{p_r^{c*}}, \mathrm{e_m^{c*}}, \mathrm{w_r}, \varphi, \mathrm{v}) \geq \Pi_{\mathrm{r}}^{\mathrm{d}^*}\left(\mathrm{p_r^{d*}}, \mathrm{e_m^{d*}}, \mathrm{w}\right)$ that by some simplifications it results in:

$$v \geq \frac{\left(\left(\mathrm{p_r^{d*}} - w\right)\left(a - b\mathrm{p_r^{d*}} + \tau\mathrm{e_m^{d*}}\right) + \varphi h(\mathrm{e_m^{c*}})^2 + w_r(a - b\mathrm{p_r^{c*}} + \tau\mathrm{e_m^{c*}})\right)}{\mathrm{p_r^{c*}}(a - b\mathrm{p_r^{c*}} + \tau\mathrm{e_m^{c*}})} \quad (26)$$

From Equations (25) and (26), it is possible to extract an acceptable interval for v using numerical methods. If there is a feasible set for contract parameters φ and v (i.e. $\varphi \in [0,1]$ and $\varphi \in [0,1]$), then one can conclude that HGRS can coordinate the SC with a win-win outcome for both SC members.

5. Numerical analyses

To investigate the models numerically, in this section, we analyze HGRS contract using a set of numerical examples and determine the acceptable and non-empty interval for the contract parameter v based on Equations (25) and (26). We also calculate the two other contract parameters, i.e., v and φ. For all test problems, the value of optimal decision variables, i.e., e and p, are calculated for decentralized, centralized, and coordinated scenarios. Finally, the optimum profit of both supply chain members and the whole supply chain are derived. To create more insights regarding the investigated problem and proposed models, some sensitivity analyses are also conducted.

5.1. Members' profit, decision variables, and contract parameters

We present a set of numerical analyses to numerically regenerate some of the results obtained analytically. Since it is difficult to access the accurate real industry data, some hypothetical datasets were considered that are consistent with datasets used in related literature (see Table 2). Most previous researchers in this field have used hypothetical datasets which are compatible with their models' assumptions and limitations. To be consistent with previous literature, we have tried to use datasets consistent with previous studies as much as possible (see Ghosh and Shah, 2012; Liu et al., 2012; Ghosh and Shah, 2015; Zhang et al., 2015; Zheng et al., 2015); however, since the current models' assumptions and limitations are somehow different with previous models some changes (e.g. using data with different scales) are applied in datasets. All the investigated datasets meet the expectations of our models' assumptions and requirements, and the assumed test problems are general enough to allow an analysis of the suggested models under various situations. In addition, investigated datasets do not violate the logical relationships between the models' parameters.

Table 2. Numerical examples' data.

	a	***b***	***τ***	***w***	***c***	***h***
Ex. 1	1000	50	10	10	≅0	2
Ex. 2	60	1	1.5	31.5	3	2
Ex. 3	400	25	5	9	2	3

After calculating optimal decision variables under the decentralized and centralized scenarios, to calculate HGRS contract parameters, we first explore acceptable intervals for the parameter v that satisfies constraints (25) and (26). The acceptable intervals are illustrated graphically for all the investigated numerical examples in Fig. (1).

As Fig. 1(A) shows, the acceptable interval for the contract parameter v is [0.422, 0.624] in Example 1. The upper threshold is extracted from the manufacturer's viewpoint, while the lower threshold is pulled out from the retailer's point of view. We do not treat the bargaining power of channel members in our model, so we use an arbitrary value from the extracted feasible interval as $v = 0.523$ to calculate other contract parameters. The amount of other parameters, decision variables, and profits, under all three investigated scenarios, are shown in Table 3. It is notable that, for each value of v, there are two values for φ, so whichever falls in the feasible interval (i.e., $\varphi \epsilon [0,1]$) is selected and the other one is ignored.

Fig. 1(B) illustrates acceptable intervals for v based on the manufacturer's and retailer's points of view, in Example 2. According to Fig. 1(B), the manufacturer's profit goes beyond the decentralized model for $v \leq 0.640$. Fig. 1(B) reveals that the retailer gains more profit than the decentralized model only when $v \geq 0.439$. The intersection of acceptable intervals for both the retailer and the manufacturer results in $v \epsilon [0.439, 0.640]$. Again, we choose an arbitrary value $v = 0.54$ from the feasible interval. The amount of other parameters, decision variables, and profits are shown in Table 3.

Fig. 1(C) shows the acceptable interval for the contract parameter v from the manufacturer's and retailer's points of view in Example 3. The intersection of acceptable intervals results in the non-empty interval $v \epsilon [0.312, 0.541]$. Choosing an arbitrary value $v = 0.426$ from this passable interval, the amount of other parameters, decision variables, and profits can be calculated are depicted in Table 3.

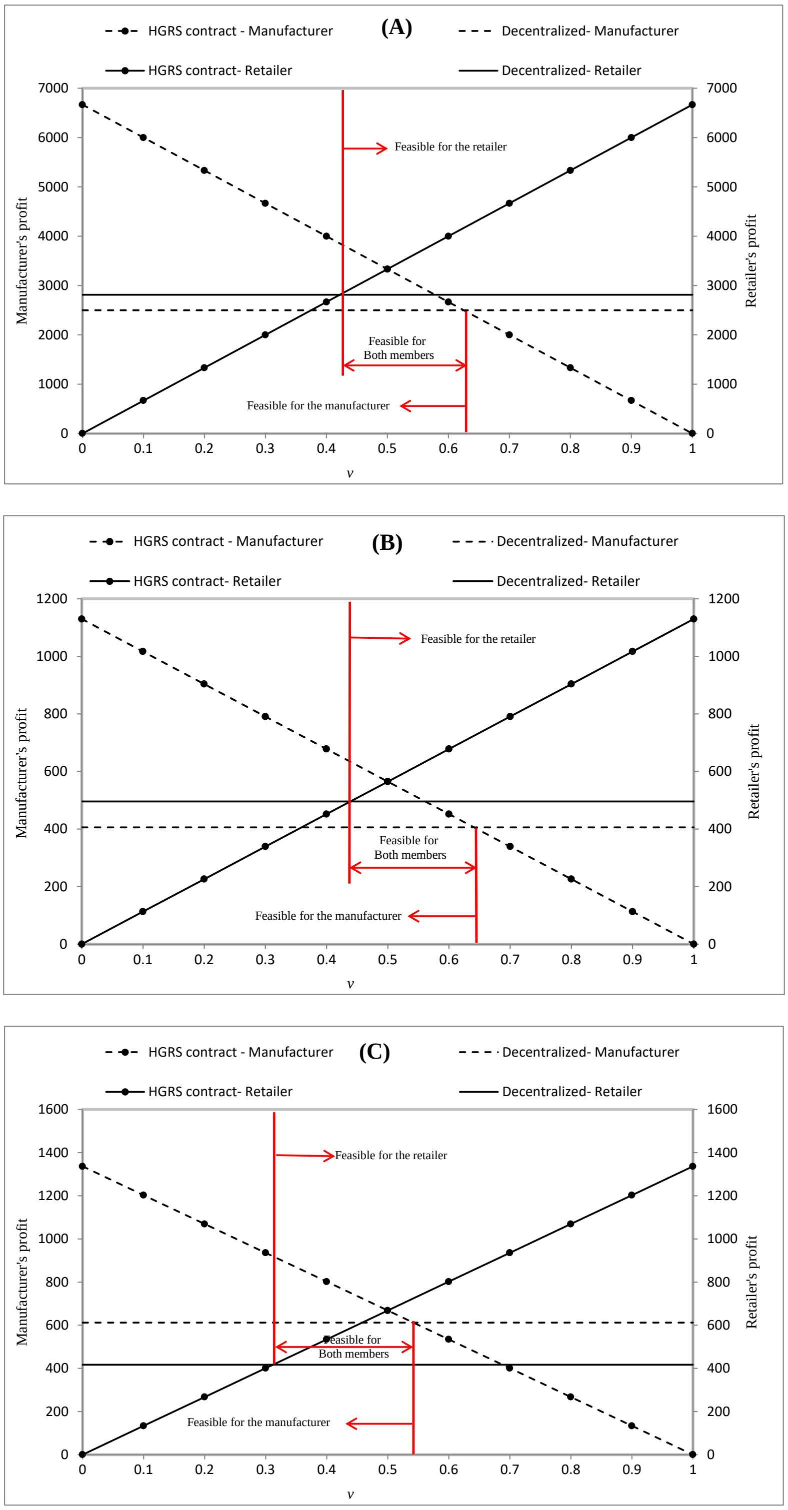

Fig. 1. Feasible intervals for the contract parameter v in (A) Ex.1, (B) Ex. 2, (C) Ex. 3.

Table 3. Results of three investigated scenarios.

	Example (1)	Example (2)	Example (3)
Decentralized scenario			
p_r^{d*}	17.5	53.77	13.08
e_m^{d*}	25	10.68	5.82
D^{d*}	375	22.27	102.08
Π_m^{d*}	2500	406.1	612.5
Π_r^{d*}	2812.5	495.8	416.8
Π_{sc}^{d*}	5312.5	901.9	1029.3
Centralized scenario			
p^{c*}	13.33	42.65	9.64
e^{c*}	33.33	14.87	6.36
D^{c*}	666.66	39.65	190.91
Π_{m}^{c*}	4444.4	687.9	1214.9
Π_{r}^{c*}	2222.3	442.2	121.5
Π_{sc}^{c*}	6666.7	1130.1	1336.4
HGRS contract			
p_r^{HGRS*}	13.33	42.65	9.64
e_m^{HGRS*}	33.33	14.87	6.36
D^{HGRS*}	666.66	39.65	190.91
w_r	0	1.620	0.852
φ	0.523	0.54	0.426
v	0.523	0.54	0.426
Π_m^{HGRS*}	3180	519.8	767.1
Π_r^{HGRS*}	3486.7	610.3	569.3
Π_{sc}^{HGRS*}	6666.7	1130.1	1336.4

As Table 3 illustrates, centralized decision-making results in a higher profit for the whole SC than the decentralized scenario. However, comparison of the retailer's profit in decentralized scenario versus the centralized model discloses that the retailer is worse off when he moves to the centralized scenario. Therefore, it is obvious that the retailer, as a for-profit corporation, refuses to take part in the centralized decision-making. The proposed HGRS contract resolves this problem by sharing the benefits of coordinated decision-making between both members in a fair manner. As shown in

Table 3, HGRS contract assures both members gain more than their profit under the decentralized decision structure. It should be observed that the values of decision variables under HGRS are equal to the centralized model, which means achieving optimal performance for the whole channel. In addition, HGRS results in higher environmental quality ($e_m^{HGRS*} > e_m^{d*}$) and lower prices ($p_r^{HGRS*} < p_r^{d*}$) compared to the decentralized decision-making for all the investigated test problems. Therefore, the obtained values of decision variables under HGRS ensure more satisfied customers.

5.3. Sensitivity analyses

In order to analyze the performance of the developed models, some sensitivity analyses on the cost parameter h, the consumer environmental coefficient τ, and also price sensitivity coefficient b are conducted. We have observed the same behavior of the developed models for all the three investigated test problems and therefore we only present the sensitivity analyses based on data from Example 3.

5.3.1. The impact of greening cost

To create insights regarding greening costs, some sensitivity analyses on h are conducted. As illustrated in Fig. 2(A), for all values of h, HGRS contract creates higher profit for the manufacturer in comparison with the decentralized decision-making, which implies that HGRS is suitable from the manufacturer's viewpoint. In addition, as illustrated in Fig. 2(A), the manufacturer's profitability under the decentralized mode is non-sensitive to changes in h. In fact, by increase of h, the manufacturer selects lower values of e (see Fig. 2(B)) to prevent additional costs. This behavior neutralizes the impact of increasing h under the decentralized model and prevents more decrease of the manufacturer's profit. Under the centralized mode, of by the increase of h the manufacturer's profitability is raised but it is not due to h's increase. In fact, the manufacturer's profitability increases because of the stimulation of demand that is resulted from the reduction of the retailer's decision on p (see Fig. 3(B)). As shown in Fig. 2(B), the green quality of the product in HGRS contract model is higher than the decentralized mode. From the applied point of view, this behavior implies that the developed contract is able to enhance green level of the channel compared to the decentralized decision-making. Furthermore, as expected, by increase of h, due to high greening costs, the channel becomes less green in all the investigated decision models.

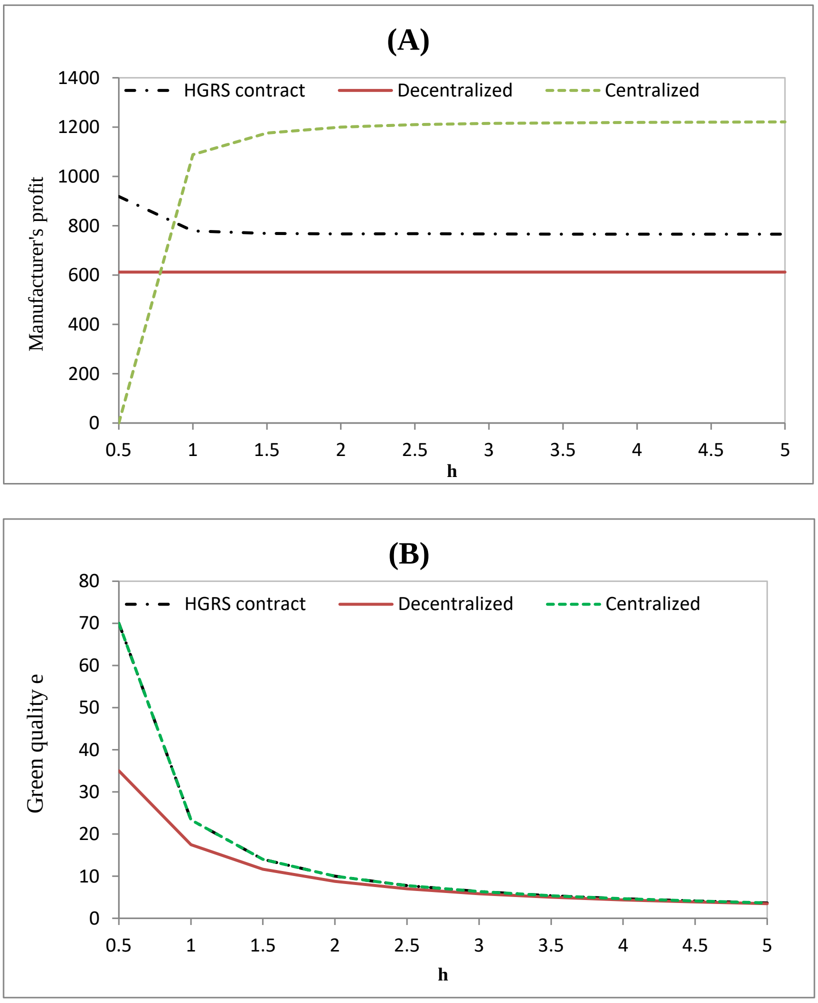

Fig. 2. Impact of greening cost coefficient h on (A) the manufacturer's profit (B) the manufacturer's decision variable e in Ex. 3.

Fig. 3(A) shows the retailer's profit by changing h. The retailer's profit decreases in all the three scenarios with the increase of greening cost coefficient h. For all the investigated values of h, the retailer's profit under HGRS contract is higher than the decentralized model and, thus, the contract is interesting from the retailer's point of view. Fig. 3(B) illustrates that increase of h leads the retailer to set p to a lower value in all models. Such behavior may be adjudged as the response of the retailer to the reduction of e by the manufacturer (see Fig. 2(B)). Nevertheless, for all the investigated values of h, HGRS contract results in a lower selling price (see Fig. 3(B)) and a higher green quality (see Fig. 2(B)) than the decentralized model. This feature of the proposed contract implies that the supply chain under HGRS contract offers less expensive greener products to the market. This is a privileged characteristic of the developed hybrid contract.

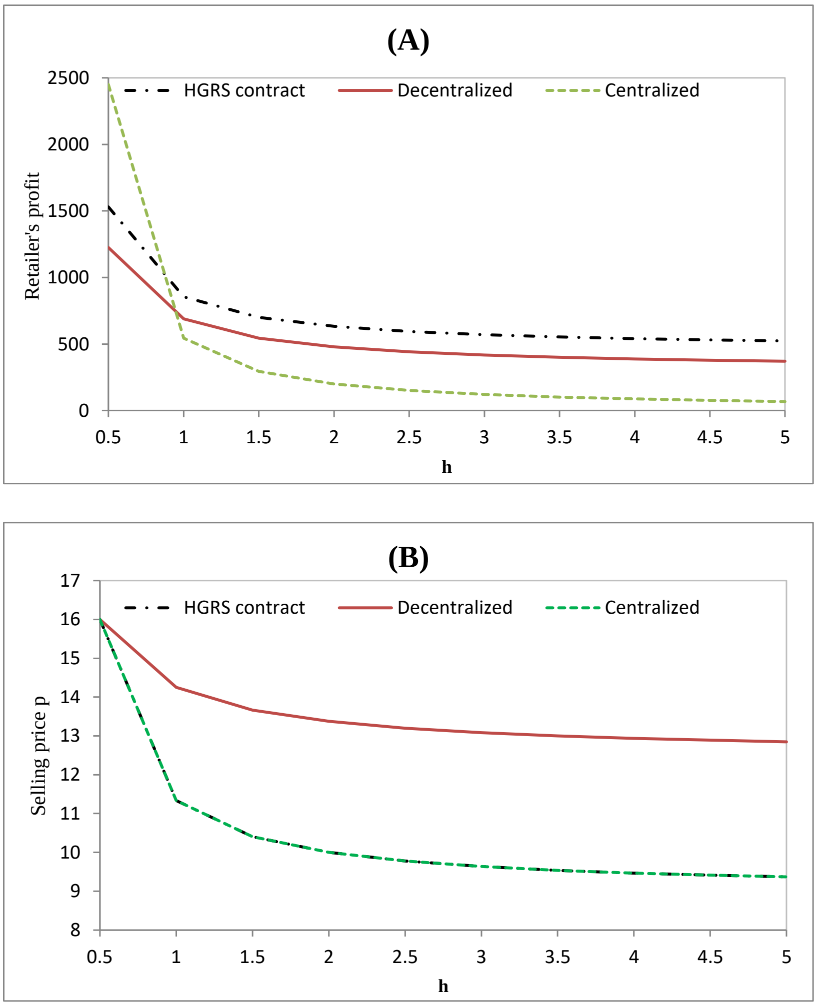

Fig. 3. Impact of greening cost coefficient h on (A) the retailer's profit (B) the retailer's decision variable p in Ex. 3.

5.3.2. Impact of CEA level

CEA is a major parameter that greatly affects demand in the investigated supply chain. CEA depends on consumers' attitude and it varies from one market to another, so to study its impact, we change its value from low (for relatively less environmentally aware consumers) to high values (for more environmentally concerned consumers) and perceive the supply chain members' decisions under the decentralized, centralized, and coordinated models.

According to Fig. 4(A), for all values of τ, HGRS contract yields more profit to the manufacturer compared to the decentralized mode, which implies that HGRS contract sounds good from the manufacturer's viewpoint. In addition, as illustrated in Fig. 4(A), the manufacturer's profit under the decentralized mode is non-sensitive to changes in τ. In fact, by increase of τ, the manufacturer sets higher values for e (see Fig. 4(B)) to exploit the increased demand of environmentally aware consumers. However, at the same time, the retailer also sets the selling price p in higher values (see Fig. 5(B)) and this behavior neutralizes the impact of increasing e on demand under the decentralized model.

Fig. 4(B) shows the value of e under all three models. For all CEA levels the HGCRS contract creates higher green qualities than the decentralized mode. Furthermore, based on Fig. 4(B), increase of CEA increases e in all three scenarios. In fact, a higher CEA means higher levels of environmental concerns in customers who prefer to buy a more green product. To respond the expectations of environmentally aware consumers, the manufacturer try to enhance the green quality of products.

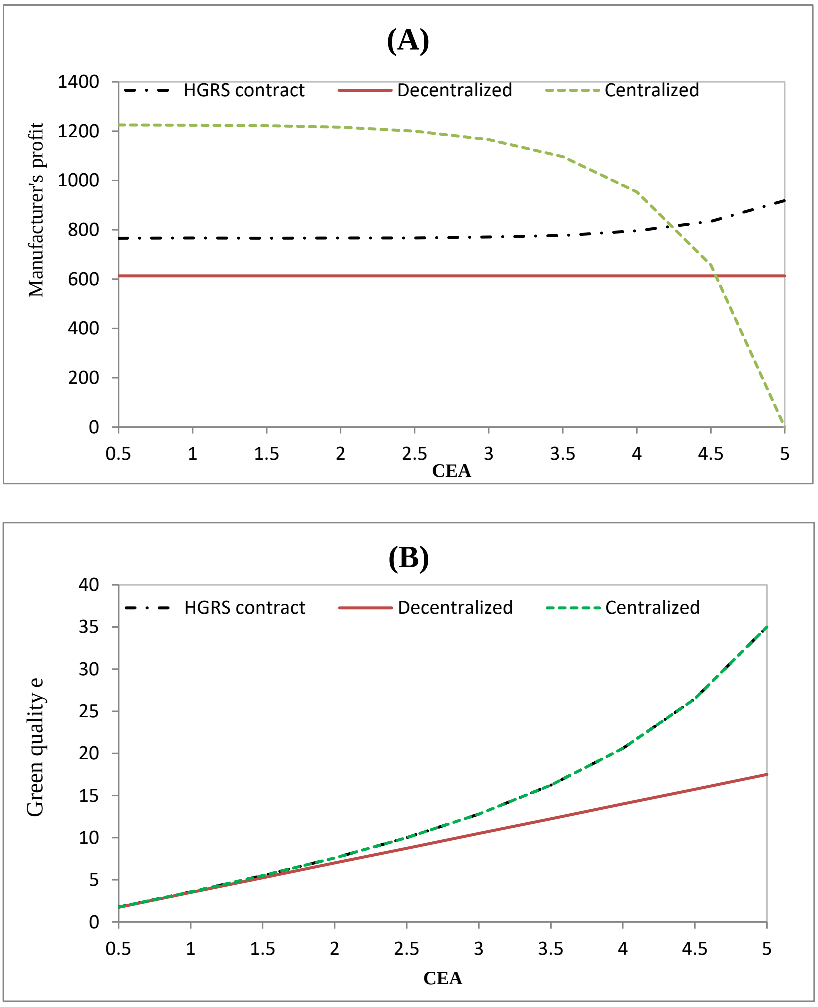

Fig. 4. Impact of CEA on (A) the manufacturer's profit (B) the manufacturer's decision variable e in Ex. 3.

Fig. 5(A) demonstrates the changes of the retailer's profitability by changing τ. In all three scenarios, by increase of CEA, the profit of the retailer increases, and with all values of τ, the retailer's profit under HGRS contract is higher than its profit under the decentralized model; hence, the contract is interesting for the retailer for all values of τ. At the same time, increase of CEA affects the retailer's decisions on p. However, for all values of τ, HGRS contract results in a lower selling price (see Fig. 5(B)) but a higher green quality (see Fig. 4(B)) than the decentralized model. This characteristic of the developed contract implies that the channel under HGRS offers less price greener products to the market. Also, according to Fig. 5(B), by increase of τ, the retailer adjusts

p in higher values in all three decision models. In fact, in this situation, increase of p can be considered as a consequence of increasing e.

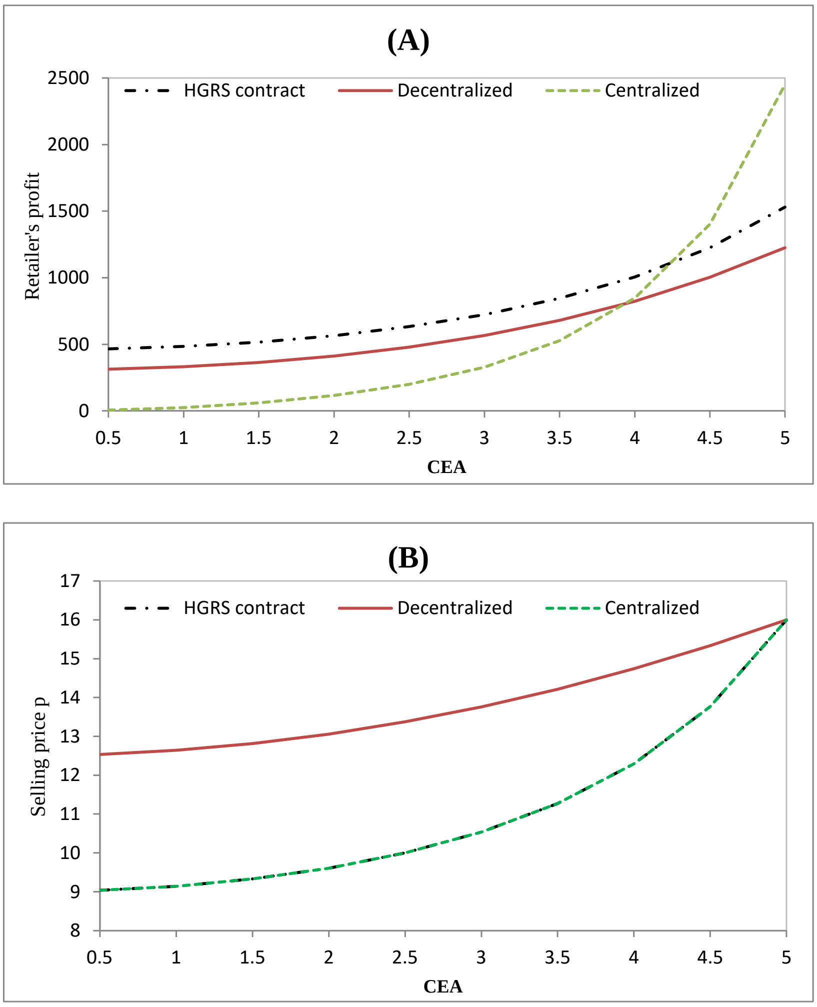

Fig. 5. Impact of CEA on (A) the retailer's profit (B) the retailer's decision variable p in Ex. 3.

5.3.3. Impact of price sensitivity

Price is another important factor that affects the demand directly. To observe the effect of price sensitivity, an analysis on b is conducted for three investigated scenarios.

According to Fig. 6(A), for all values of b, HGRS contract yields more profit to the manufacturer compared to the decentralized decision-making, which implies that HGRS is always interesting for the manufacturer. In addition, Fig. 6(A) confirms that the manufacturer's profit under all decision-making scenarios is decreasing by increase of *b*.

Based on Fig. 6(B), the decided green quality level under HGRS contract is always more than the decentralized model. From the applied point of view, this behavior implies that HGRS is able to enhance the greenness level of product compared to the decentralized decision-making scenario. Moreover, according to Fig. 6(B), increase of *b* causes a decrease in *e* in all three scenarios.

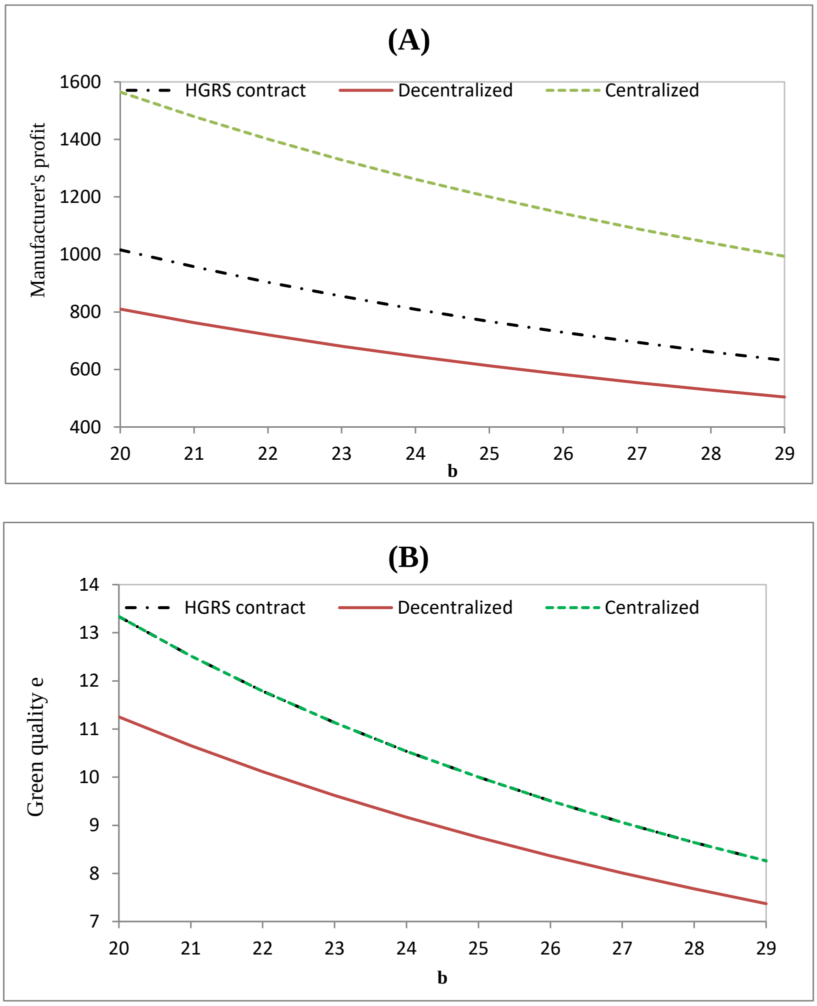

Fig. 6. Impact of price sensitivity *b* on (A) the manufacturer's profit (B) the manufacturer's decision variable *e* in Ex. 3.

Based on Fig. 7(A), in all different values of *b*, the retailer's profit under HGRS contract is higher in comparison with its profit under the decentralized model, hence; HGRS is interesting for the retailer for all values of b. Fig. 7(B) illustrates the equilibrium amount of p against b. It shows by increase of b; the retailer adjusts p in lower values (see Fig. 7(B)) to prevent a significant decrease on the channel selling amount. Indeed, increasing b implies that the SC faces the more price-sensitive consumers and therefore the retailer has to set the selling price at lower values.

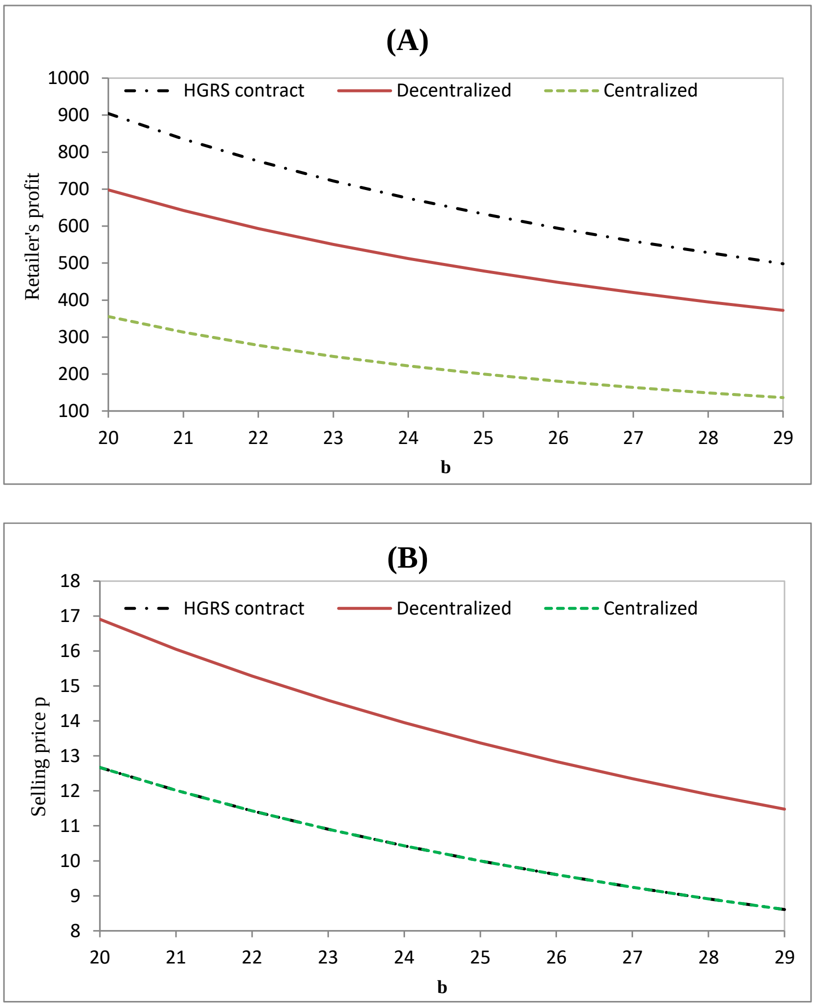

Fig. 7. Impact of price sensitivity b on (A) the retailer's profit (B) the retailer's decision variable p in Ex. 3.

Finally, for all values of b, HGRS contract yields a lower selling price (see Fig. 7(B)) and a higher green quality (see Fig. 6(B)) compared to the decentralized model. This feature of the proposed model implies that the channel under HGRS contract, regardless to the value of b, offers less expensive greener products to the market.

6. Conclusion and future research directions

In this paper, we address the issue of channel coordination taking into account consumer environmental awareness. The green quality of products is a critical factor when environmentally aware customers choose which products to purchase. In this study, we first model a two-echelon supply chain where demand is dependent to the selling price as well as the product's green quality. Then, a hybrid greening cost and revenue sharing (HGRS) contract is proposed to initiate channel coordination. In the investigated model, the manufacturer determines the green quality of products while the retailer decides the selling price. Our investigation reveals that HGRS contract is capable of achieving channel coordination and allowing both channel members to gain more profit than the decentralized scenario. Closed-form solutions for both decision variables are derived, and the contract is also assessed using some numerical investigations. Our numerical investigations demonstrate that the developed HGRS contract can stimulate demand and create higher earnings for both supply chain members by an optimized tuning of two decision variables: selling price and green quality of products. In addition, HGRS contract results in more satisfied customers (by offering lower prices) as well as more sustainable operations (by increasing greenness level) at the same time.

There are some managerial implications for supply chain managers and sustainability professionals from this study; the most important one regards balancing price and green quality of products. Our study reveals that the SC managers can offer more green products with lower prices by using the proposed contract. Indeed, appropriate cooperation between the SC decision makers under the proposed mechanism not only reduces the selling price but also makes environmentally aware customers more satisfied. Although some SC managers are worried about consumers who are more sensitive to the environmental issues, our analyses show that the proposed contract in this paper makes higher profits for the SC members when the level of CEA increases. HGRS contract can guarantee more profit for both members and, at the same time, can stimulate demand by reducing price and enhancing the green quality of products. From managerial implications, stimulating demand means lower costs due to economies of scale.

For future research studies, we suggest a consideration of this issue under competitive supply chains facing sales-effort dependent demand. An investigation into the coordination problem under asymmetric information sharing, where the retailer does not know the greening costs at the manufacturer's site, promises an interesting issue. Conducting a survey research to determine some parameters of the mathematical model like CEA is another interesting study that can help to make the model more realistic. Because CEA level may not be measured as a definite parameter in many situations, another potential extension to this study would be to consider stochastic demand functions based on an uncertain CEA level. Another approach might consider competition between multiple manufacturers who produce green products with different environmental qualities to be offered to customers. In addition, competition/cooperation between the retailers in a single-manufacturer multiple-retailer system can affect the decision process of all SC members (especially pricing decisions of the retailers) and can be considered as another interesting future research.

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