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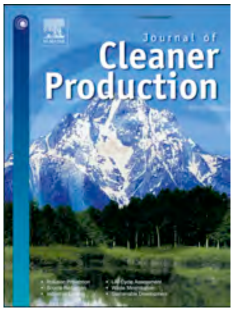

Influence of procurement decisions in two-period green supply chain

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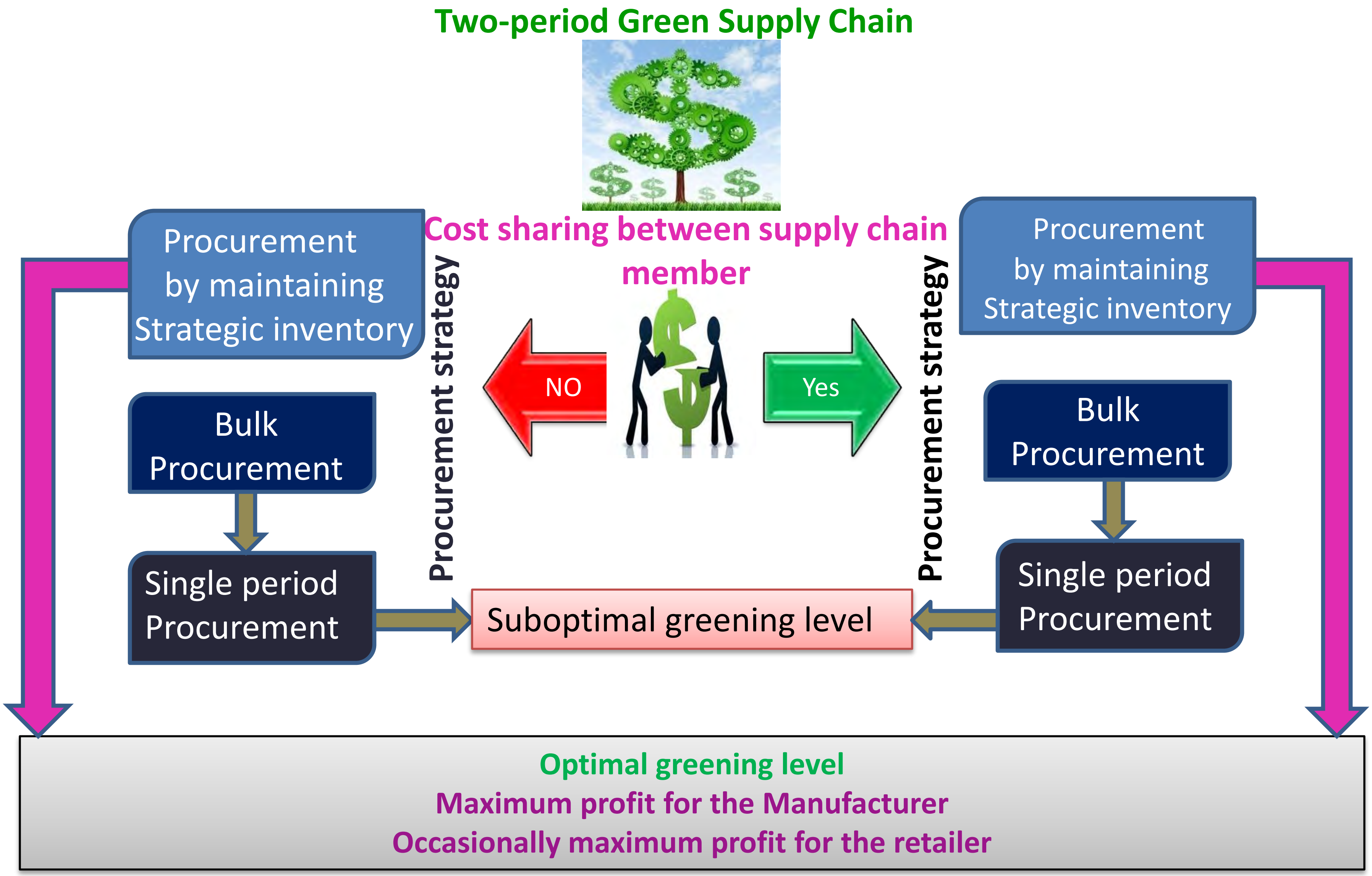
Two-period Green Supply Chain
Cost sharing between supply chain member
NO
Yes
Procurement strategy
Procurement strategy
Procurement by maintaining Strategic inventory
Bulk Procurement
Single period Procurement
Procurement by maintaining Strategic inventory
Bulk Procurement
Single period Procurement
Suboptimal greening level
Optimal greening level
Maximum profit for the Manufacturer
Occasionally maximum profit for the retailer

Influence of procurement decisions in two-period green supply chain

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April 14, 2018

Abstract

This paper focuses on optimal retail pricing and procurement decision of a retailer, and wholesale pricing and product's greening level decision of a manufacturer under two-period supply chain frameworks. In manufacturer-Stackelberg vertical game setting, three procurement scenarios are considered. It is found that the product greening level cannot achieve its optimum level if the retailer and manufacturer remains strict to imply the conventional single period procurement decision. If the retailer decides to buildup strategic inventory then the supply chain members receive higher profits and the manufacturer can invest more in improving product greening level. The consumer also receives product at its highest greening level. If the retailer procures products in a single lot to satisfy demand of two selling consecutive periods, then consumer receives the product at its lowest greening level and the manufacturer receives lowest amount of profits among three procurement scenarios. If the retailer participates with the manufacturer's green supply chain initiatives then the retailer can receive highest amount of profit, but the greening

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level of the product reaches at its lowest level. Therefore, the retailer's participation does not always motivate the manufacturer to produce greener product. Overall, the retailer's procurement decision is a key factor for the green supply chain initiatives of the manufacturer.

Keywords: Two-period green supply chain; Inventory; Green sensitive; Cost sharing; Game theory.

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1. Introduction

Consumer demand for green products has achieved growing attention for years. For example, products such as energy star home appliances, phosphate-free detergents, green cars or green fashionable ornaments are gaining rapid popularity among consumer due to the use of less amount of environment-damaging chemicals, energy, or recyclable materials. Therefore, Green Supply Chain Management (GSCM) becomes an emerging research topic because of rising consumer awareness about manufacturing processes and corresponding carbon footprint, logistics design, way of recycling, business partner selection, raw material selection etc. Some regulatory agencies such as United States Environmental Protection Agency (USEPA) or Bureau of Energy Efficiency (BEE) are also serving consumer to recognize home appliances and electronic product that reduce greenhouse gas emissions and consume less energy by introducing Energy Star programs. European Environment Agency (EPA) publishes white paper on regular basis to intensify consumer awareness. To make the supply chain greener, global manufacturers are giving consistent effort to integrate innovative and environment friendly technologies while designing the supply chain process. It induces many companies to assimilate technologies for improving resource utilization efficiency and reducing the impact of manufacturing on the environment (Sancha et al. 2016). For example, companies such as Apple Inc. helps their suppliers in reducing the amount of energy they use. As a part of clean energy program, in 2015 Apple has installed 485 megawatts of wind and solar projects across six provinces of China so that their suppliers can get rid of the difficulty in accessing clean energy. The government of several nations are also providing continuous subsides to motivate companies to introduce green initiative (Albared et al. 2008).

There is large body of literature on GSCM from various perspectives such as supply chain coordination, game theoretic models, dual-channel supply chain, government influences. For example, Ghosh and Shah (2015) explored green supply chain coordination issues under price and greening level sensitive demand. They found that cost sharing contract always increases the product greening levels. Li et al. (2016) analyzed a dual-channel green supply chain and noted that the opening of online channel decision is greatly influenced on the greening cost. Song and Gao (2017) applied retailer-led revenue-sharing and bargaining revenue-sharing contracts on manufacturers and retailers green supply chains and concluded that revenue-sharing contract is the exemplary way to promote the cooperation among green supply chain members. Liu and Yi (2017) formulated four different game models to explore optimal pricing policies. The authors proved that optimal retail and wholesale price correlated negatively with the degree of greening level and the retailer can earn higher revenue in a green supply chain compared to the manufacturer. Basiri and Heydari (2017) investigated green supply chain coordination issue where the demand is a function of the retail price, products' green quality, and retailer's sales efforts. It is found that the coordinated scenario always provides higher environmental quality product. Xing et al. (2017) compared the pricing decision of two distribution structures; where one manufacturer sells a green product and other sells conventional product in a same consumer market. They claimed that if the green product is preferred by high-end consumers then channel integration is always profitable for the manufacturer. Dai et al. (2017) compared the effect of cartelization and cost-sharing contract in a two echelon green supply chain and identified that the manufacturer generally prefers a Cartelization and the retailer prefers cost-sharing contract. Yang and Xiao (2017) proposed three game model to find the impact of governmental interventions on green supply chain. They found that the retailer Stackelberg game outperforms the manufacturer Stackelberg game in perspective of achieving higher degree of product greening level. Jamali and Rasti-Barzoki (2018) evaluated the performance of two-competitor green supply chains with dual-distribution channels. They found that selling green products always bring competitive advantages. We referred the review articles on GSCM in the perspective of Triple Bottom Line (Mishra et al. 2017) and various performance measures employed in GSCM (Rajeev et al. 2017) for more detail discussion. Additionally, one can obtain the details of more than 1000 published articles on GSCM in the review work done by Fahimnia et al. (2015). However, till date no research has been conducted on the green supply chain initiatives in the presence of the retailer's strategic decision to maintain inventory under two-period setting.

Efficient inventory management is one of the key issues in retailing. Retailers commonly maintain inventory for several reasons, such as, to reduce transportation cost, take advantage of quantity discounts, ensure continuity of selling activities, evade variations in wholesale price and consumer demand, smooth-out retail operation etc. However, Anand et al. (2008) were the first to report that retailer's decision to maintain inventory in multi-period supply chain interactions under non-cooperative scenarios can reduce the degree of double marginalization. They found that the retailer can enforce the manufacturer to reduce the wholesale price of forthcoming period by maintaining surplus order quantities as strategic inventory(SI). Arya and Mittendorf (2013) proved that the manufacturer may introduce consumer rebates to curtail this advantage of the retailer in building SI. In presence of consumer rebate, the retailer cannot maintain high amount of products as SI, although both members enjoy profit surplus. Arya et al. (2014) extended this enticing stream of research to determine and compare the effect of SI on centralization and decentralization procurement decision in the presence of multiple retail outlets. Hartwig et al. (2015) conducted the first empirical study to explore the effect of SI on supply chain performance. They found that if the holding cost is sufficiently low, the retailer can immensely induce differentiated pricing behaviour imposed by the manufacturer by building up SI. Mantin and Jiang (2017) explored the impact of the product quality deterioration in the presence of SI. Moon et al. (2018) analyzed the impact of SI in perspective of supply chain coordination. They found that if the retailer wants to maintain SI, the optimal supply chain profit cannot be achieved by implementing quadratic quantity discount contract mechanism. All the above cited literatures considered multi-period interaction among supply chain members to explore the consequences of the strategic decision of the retailer.

However, several researchers studied two-period supply chain model in the absence of SI by observing some pragmatic frameworks. For example, Pan et al. (2009) formulated a two-period model and found that it is desirable to obtain tangible pricing decision for electronic goods such as PCs, mobile phones under multi-period interactions. Chen and Xiao (2011) proposed a two-period supply chain game model with single manufacturer and single retailer. The authors analyzed the efficiency of two coordination mechanisms, namely the price-protection mid-life and end-of-life returns and the only mid-life and end-of-life returns. It is analytically found that the former always outperforms the later. He et al. (2014) studied the influence of the manufacturer quality improvement on the fashion and textiles products and formulated a two period supply chain model to find the optimal investment strategy of the manufacturer. Wang et al. (2015) formulated a two-period supply chain model and employed revenue-sharing contract mechanism for short-life-cycle products. Yang et al. (2016)explored the role of trade credit financing in a two-period supply chain model and showed that retailer's early payment can improve the efficiency of a two echelon supply chain and reduce supplier's trade credit risks. Danusantoso and Moses (2016) analyzed the effect of disruption on a two-period supply chain under linear and exponential price sensitive demand. Maiti and Giri (2017) argued that two-period supply chain is also a common framework in fashion and textile industries and the authors considered four different scenarios to investigate the impact of reference price under price-dependent linear demand. Table 1 demonstrates the contribution of this study.

Table 1. Articles on investment decision under two-echelon supply chain.

Articles	Price	Greening level	Selling period	Demand	Strategic Inventory	Bulk procurement	Cost sharing	information
Anand et al. (2008)	✓	×	two	deterministic	✓	×	×	symmetric
Chen an Xiao (2011)	×	×	two	stochastic	×	×	×	symmetric
Ghosh and Shah (2012)	✓	✓	single	deterministic	×	×	×	symmetric
Arya and Mittendorf (2013)	✓	×	two	deterministic	✓	×	×	symmetric
Arya et al. (2014)	✓	×	two	deterministic	✓	×	×	symmetric
Ghosh and Shah (2015)	✓	✓	single	deterministic	×	×	✓	symmetric
Hartwig et al. (2015)	✓	×	two	deterministic	✓	×	×	symmetric
Wang et al. (2015)	✓	×	two	stochastic	×	×	×	symmetric
Basiri and Heydari (2017)	✓	✓	single	deterministic	×	×	×	symmetric
Dai et al. (2017)	✓	✓	single	deterministic	×	×	✓	symmetric
Maiti and Giri (2017)	✓	×	two	deterministic	×	×	×	symmetric
Mantin and Jiang (2017)	×	×	single	deterministic	✓	×	×	symmetric
Song and Gao (2017)	✓	✓	single	deterministic	×	×	×	symmetric
Yang and Xiao (2017)	✓	✓	single	fuzzy	×	×	×	symmetric
Hong and Guo (2018)	✓	✓	single	deterministic	×	×	×	symmetric
Moon et al. (2018)	✓	×	two	deterministic	✓	×	×	symmetric
Raj et al. (2018)	✓	✓	single	deterministic	×	×	×	symmetric
Present study	✓	✓	two	deterministic	✓	✓	✓	symmetric

Table 1 demonstrates that the present study generalizes existing research on single period green supply chain to the multiple-period supply chain framework. In practice, the retailer procures products several times through its life cycle and typically some products are also carried from one period to another. We added a new dimension in GSCM literature by comparing the outcomes under three procurement strategies. A step further, we extend the green supply chain model by considering the influence of SI and retailer participation in improving greening level of the product. If the retailer carries product from one period to another, it is necessary to determine the optimal amount of SI. Because the wholesale price of forthcoming period decreases and amount of holding cost increases with respect to escalating amount of SI. However, the manufacturer can simply charge monopoly wholesale price if the retailer does not carry SI in multi-period interactions. Therefore, it is an interesting research area to explore the mutual influence of the retailer's decision to maintain SI and greening cost sharing on the product's greening level. By comparing results analytically, a number of interesting managerial insights are identified on product greening level and procurement decision in a GSCM. Our study affirms that the single period planing does not reflect the true nature of the product greening level. Greening level of the product is optimal under multi-period interactions. In contrast to existing literature, it is observed that the retailer's participation in green supply chain initiatives of the manufacturer can reduce the greening level of the product.

2. Model description, notation and assumptions

This study considers a two-level supply chain where a manufacturer sells its product through an independent retailer in a 'green' sensitive consumer market. Two-period supply chain models are developed for three different procurement scenarios to identify the influence of SI. The pictorial representation of three scenarios are presented in Fig 1.

Please insert Fig 1.

In Scenario TS, the retailer procures products at the beginning of each period and maintain SI. Newly procured products at the beginning of the second period and surplus products from previous period are used to fulfil the demand of the second period. In Scenario T, the retailer procures at the beginning of each period but does not maintain SI. Therefore, in first two scenarios the retailer procures two times to satisfy the consumer demand in two periods. However, in third scenario, the retailer procures the products at the beginning of first period to satisfy the demand of two consecutive selling periods. We named it as Scenario S.

The following assumptions are made to formulate analytical models:

(i) The consumer demand in each period is considered as a linearly decreasing in retail price and increasing in product greening level. The functional form of market demand in each period is given as

$$D_i = a - bp_i + c\theta, \text{ i=1,2} \tag{1}$$

Where a represents the market potential in each period, b reflects price sensitivity of consumer demand and c characterizes the consumer sensitivity to greening level. p_i, i=1,2 represents the retail price of the product at period i and θ represents greening level. The manufacturer invests in improving greening level of the product. The investment required for green product R&D is $\beta\theta^2$, where β represents sensitivity for the green investment. The demand function of such form is appeared extensively in the literature (Ghosh and Shah 2012; Ghosh and Shah 2015; Song and Gao 2017).

(ii) It is assumed that the unit cost for the manufacturer is a liner function of greening level. In addition to bulk investment in improving greening level, the manufacturer needs to incorporate additional costs to fulfill environmental compliance during packaging, product handling etc. Therefore, the unit marginal cost of the manufacturer is considered as $c_m + \alpha\theta$, where c_m($/unit) is the fixed cost and α is a positive parameter measures unit efficiency of the manufacturer (Bhargava et al. 2013).

(iii) The unit conversion cost of the retailer is normalized to zero (Hartwig et al. 2015; Song and Gao 2017) for analytical simplicity. It is assumed that the retail prices (p_i) and wholesale prices (w_i) at each period satisfy the following relations $p_i > w_i, \forall i = 1, 2$, otherwise, the retailer cannot make profit. The unit holding cost of products for the retailer is h($/unit/unit) and $I(\geq 0)$ represents the amount of SI in procurement Scenario TS or TSC.

(iv) It is assumed that the manufacturer acts as the Stackelberg leader (Sarkar, 2013; Gao et al. 2016; Dai et al. 2017). Empirical research also support this assumption (Ru et al. 2015). Two-stage game in each period is used to find out the optimal decisions in first two scenarios. To verify the retailer initiatives to encourage manufacturers for developing the green supply chain, we formulate models for all three scenarios where the retailer shares a proportion of the total cost of greening $(1 - \delta), 0 \leq \delta \leq 1$ with the manufacturer. The retailer involvements support the growing trend of 'sharing economy'. Retail giants such as Wal-Mart, Tesco, Home Depot, J Sainsbury plc etc. have taken steady initiatives to reduce carbon emission levels jointly with their suppliers (Zhou et al. 2016; Dai et al. 2017). In order to differentiate the outcomes of scenarios where the retailer participates with the manufacturer in cost sharing, additional subscript 'c' is used.

(v) Distribution of product in each selling period is instantaneous; that is, the lead times between the manufacturer and retailer at in Scenarios TS and S are negligible. The capacity of the manufacturer is infinite (Hartwig et al. 2015). All the parameters related to market demand are common knowledge between the supply chain members (Ghosh and Shah, 2012; Hafezalkotob, 2017; Ahmed and Sarkar, 2018).

In next section we formulate mathematical models for three procurement scenarios in the presence of retailer participation.

3. Greening improvement cost sharing models

3.1. Two-period model in presence of SI (TSC)

At the beginning of the first period, the manufacturer sets the unit wholesale price w_1^{tsc} and greening level θ^{tsc}. Based on the manufacturer's decision, the retailer procures $D_1^{tsc}(p_1^{tsc}, \theta^{tsc}) + I^{tsc}, (I^{tsc} \geq 0)$ units of the product and sets the retail price (p_1^{tsc}). The retailer needs to invest hI^{tsc} as a holding cost. In the second period, the manufacturer sets the unit wholesale price, w_2^{tsc} for the retailer. The retailer procures $D_2^{tsc}(p_2^{tsc}, \theta^{tsc}) - I^{tsc}$ units of the product and sets the retail price, p_2^{tsc}. We determine the unique Stackelberg equilibrium of the game by employing backward induction. The second-period profit maximization problems of the retailer and manufacturer are as follows:

$$\pi_{r2}^{tsc}(p_2^{tsc}) = p_2^{tsc} D_2^{tsc}(p_2^{tsc}, \theta^{tsc}) - w_2^{tsc}(D_2(p_2^{tsc}, \theta^{tsc}) - I^{tsc}) - (1-\delta)\beta(\theta^{tsc})^2 \tag{2}$$

$$\pi_{m2}^{tsc}(w_2^{tsc}) = (w_2^{tsc} - (c_m + \alpha\theta^{tsc}))(D_2^{tsc}(p_2^{tsc}, \theta^{tsc}) - I^{tsc}) - \delta\beta(\theta^{tsc})^2 \tag{3}$$

Similarly, the first-period profit maximization problems of the retailer and manufacturer are given as follows:

$$\pi_{r1}^{tsc}(p_1^{tsc}, I^{tsc}) = p_1^{tsc} D_1^{tsc}(p_1^{tsc}, \theta^{tsc}) - w_1^{tsc}(D_1^{tsc}(p_1^{tsc}, \theta^{tsc}) + I^{tsc}) - (1-\delta)\beta(\theta^{tsc})^2 - hI^{tsc} + \pi_{r2}^{tsc} \tag{4}$$

$$\pi_{m1}^{tsc}(w_1^{tsc}, \theta^{tsc}) = (w_1^{tsc} - (c_m + \alpha\theta^{tsc}))(D_1^{tsc}(p_1^{tsc}, \theta^{tsc}) + I^{tsc}) - \delta\beta(\theta^{tsc})^2 + \pi_{m2}^{tsc} \tag{5}$$

The following proposition provides the optimal solutions in each period, sales volume in two periods, and the corresponding profits of supply chain members in Scenario TSC.

Proposition 1. In Scenario TSC, the optimal wholesale prices and product greening levels are obtained as

$$w_1^{tsc} = \frac{\Upsilon(9a\alpha - 9cc_m - 2bh\alpha) + 4Y\delta\beta}{X}, \quad \theta^{tsc} = \frac{Y\Upsilon}{X}$$

$$w_2^{tsc} = \frac{\Upsilon(9a\alpha + 4bh\alpha - 9cc_m - 6ch) + 4(6a + 11bc_m + 10bh)\delta\beta}{X}$$

and the corresponding profit of the manufacturer in two periods is

$$\pi_{m1}^{tsc} = \frac{2(9(a - bc_m)^2 - 4b(a - bc_m)h + 8b^2h^2)\delta\beta - 2bh^2\Upsilon^2}{X}$$

The optimal retail prices and the amount of SI for the retailer are

$$p_1^{tsc} = \frac{\Upsilon(9a\alpha - c(9c_m + h) - bh\alpha) + 4(13a + b(4c_m - h))\delta\beta}{X}$$

$$p_2^{tsc} = \frac{\Upsilon(9a\alpha + 2bh\alpha - 9cc_m - 4ch) + 2(23a + 11bc_m + 10bh)\delta\beta}{X}$$

$$I^{tsc} = \frac{5bh\Upsilon^2 + 10b(a - b(c_m + 4h))\delta\beta}{X}$$

and the corresponding sales volume and profit of the retailer in two periods are

$$Q^{tsc} = \frac{2b(19a - 19bc_m - 8bh)\delta\beta + bh\Upsilon^2}{X}$$

$$\pi_{r1}^{tsc} = \frac{1}{X^2}[20bh^2\Upsilon^4 - 2(X^2 - (81(a-bc_m)^2 - 23b(a-bc_m)h - 150b^2h^2)\delta)\Upsilon^2\beta + 4b(155(a-bc_m)^2 - 118b(a - bc_m)h + 304b^2h^2)\delta^2\beta^2]$$

where $\Upsilon = c - b\alpha$, $X = 68b\delta\beta - 9\Upsilon^2$, and $Y = 9a + 8bc_m - 2bh$.
Proof. See Appendix A .

From the expression of θ^{tsc}, one can see that the product greening level is non-negative if $\Upsilon > 0$ and the optimal solution exists if $X > 0$ (See Appendix A). Therefore, we assume $c > b\alpha$ and $68b\delta\beta > 9\Upsilon^2$ throughout the study. Note that, the difference between the wholesale prices and retail prices in two periods are $w_1^{tsc} - w_2^{tsc} = \frac{12(a-b(c_m+4h))\delta\beta+6h\Upsilon^2}{X} > 0$ and $p_1^{tsc} - p_2^{tsc} = \frac{6(a-b(c_m+4h))\delta\beta+3h\Upsilon^2}{X} > 0$, respectively. Therefore, the manufacturer charges higher wholesale price in first-period. Similar findings are also reported in the existing literature (Anand et al. 2008; Hartwig et al. 2015). The retailer can enforce the manufacturer to reduce wholesale price in forthcoming period by maintaining products as SI. It provides an opportunity for the retailer to reduce retail price in second-period and stimulate market demand. The amount of SI (I^{tsc}) and product greening level (θ^{tsc}) decrease as the unit cost for greening increases; because $\frac{\partial I^{tsc}}{\partial\alpha} = \frac{-20b^2(9a-9bc_m-2bh)\delta\Upsilon\beta}{X^2} < 0$ and $\frac{\partial\theta^{tsc}}{\partial\alpha} = \frac{-b(9a-9bc_m-2bh)(9\Upsilon^2+68b\delta\beta)}{X^2} < 0$. These results are not at all surprising. The increasing cost for greening not only prevents the manufacturer to increase the product greening level but impedes the opportunity of the retailer's to build SI. Moreover, the amount of SI and the product greening level both decrease with respect to δ; because $\frac{\partial I_r}{\partial\delta} = -\frac{10b(9a-9bc_m-2bh)\Upsilon^2\beta}{X^2} < 0$ and $\frac{\partial\theta}{\partial\delta} = -\frac{68b(9a-9bc_m-2bh)\Upsilon\beta}{X^2} < 0$, respectively. Therefore, the retailer decisions to buildup SI and participate in cost sharing encourage green supply chain initiatives of the manufacturer.
In the next subsection, we develop the model where the retailer does not maintain SI.

3.2. Two-period model in absence of SI (TC)

This scenario is analogous with the existing literature on green supply chain management. The retailer does not build SI and procures products for each period. The decision sequence remains identical with the conventional single period supply chain model. As a

Stackelberg leader, the manufacturer decides the wholesale price ($w_1^{tc} = w_2^{tc}$) and green improvement level (θ^{tc}) first, then the retailer decides the retail price ($p_1^{tc} = p_2^{tc}$) for the product. Note that, the optimal retail price, wholesale price, and product greening level remain identical in each period. The profit functions of the retailer and manufacturer for second period under Scenario TC are as follows:

$$\pi_{r2}^{tc} = (p_2^{tc} - w_2^{tc})D(p_2^{tc}, \theta^{tc}) - (1-\delta)\beta(\theta^{tc})^2 \tag{6}$$

$$\pi_{m2}^{tc} = (w_2^{tc} - (c_m + \alpha\theta^{tc}))D(p_2^{tc}, \theta^{tc}) - \delta\beta(\theta^{tc})^2 \tag{7}$$

The following proposition gives the optimal outcomes in scenario TC.

Proposition 2. In Scenario TC, the optimal wholesale price and product greening level in each period are obtained as

$$w_2^{tc} = \frac{(a\alpha - cc_m)\Upsilon + 4(a + bc_m)\delta\beta}{M}; \ \theta^{tc} = \frac{(a - bc_m)\Upsilon}{M}$$

and the corresponding profit of the manufacturer in two periods is

$$\pi_{m1}^{tc} = 2\pi_{m2}^{tc} = \frac{4(a - bc_m)^2\delta\beta}{M}$$

The optimal retail price in each period is

$$p_2^{tc} = \frac{(a\alpha - cc_m)\Upsilon + 2(3a + bc_m)\delta\beta}{M}$$

and the corresponding sales volume and profit of the retailer in two periods are

$$Q^{tc} = \frac{2b(a - bc_m)\delta\beta}{M}; \ \pi_{r1}^{tc} = 2\pi_{r2}^{tc} = \frac{2(a - bc_m)^2\beta(4b\delta^2\beta - (1-\delta)\Upsilon^2)}{M^2}$$

where $M = 8b\delta\beta - \Upsilon^2$.

Similar to the previous scenario, the product greening level decreases with respect to α and δ because $\frac{\partial\theta^{tc}}{\partial\alpha} = \frac{-b(a-bc_m)((c-b\alpha)^2+8b\delta\beta)}{X^2} < 0$ and $\frac{\partial\theta^{tc}}{\partial\delta} = \frac{-8b(a-bc_m)\Upsilon\beta}{X^2} < 0$, respectively. The retail and wholesale price of the product also decrease with respect to α; because $\frac{\partial p_2^{tc}}{\partial\alpha} = \frac{-(c(a-bc_m)\Upsilon^2+4b(a-bc_m)\delta(c+b\alpha)\beta)}{X^2} < 0$ and $\frac{\partial w_2^{tc}}{\partial\alpha} = \frac{-(a-bc_m)(c\Upsilon^2+8b^2\delta\alpha\beta)}{X^2} < 0$, respectively. It implies that the retailer or manufacturer needs to decrease their respective prices although the cost of the product increases.

3.3 Two-period model with single procurement (SC)

In this scenario, the retailer procures all the products required for two consecutive selling periods at the beginning of first period and carries products required in second-period. If the retailer employs such decision then the manufacturer cannot employ wholesale price differentiation. The holding cost of the retailer in this scenario is higher compared to Scenario TSC. Note that, if the retailer builds SI then the manufacturer can employ wholesale price differentiation. In the present scenario, at the beginning of the first period, the manufacturer sets the unit wholesale price w^{sc} and decides product greening level θ^{sc}. Based on the manufacturer decision, the retailer procures $D_1(p_1^{sc},\theta^{sc})+D_2(p_2^{sc},\theta^{sc})$ units of the product, sets retail prices in each period, and carries $D_2(p_2^{sc},\theta^{sc})$ units of product to satisfy the demand of second period. The cumulative profit functions of the retailer and manufacturer in this scenario are obtained as follows:

$$\pi_r^{sc} = p_1^{sc}D_1^{sc}(p_1^{sc},\theta^{sc}) + p_2^{sc}D_2^{sc}(p_2^{sc},\theta^{sc}) - w^{sc}(D_1^{sc}(p_1^{sc},\theta^{sc}) + D_2^{sc}(p_2^{sc},\theta^{sc})) - hD_2^{sc}(p_2^{sc},\theta^{sc})$$
$$-2(1-\delta)\beta(\theta^{sc})^2 \quad (8)$$
$$\pi_m^{sc} = (w^{sc} - (c_m + \alpha\theta^{sc})(D_1^{sc}(p_1^{sc},\theta^{sc}) + D_2^{sc}(p_2^{sc},\theta^{sc})) - 2\delta\beta(\theta^{sc})^2 \quad (9)$$

The detail of equilibrium outcomes in this scenario are presented in Proposition 3.

Proposition 3. In Scenario SC, the optimal wholesale price and product greening level are obtained as

$$w^{sc} = \frac{\Upsilon(2a\alpha - 2cc_m - bh\alpha) + 4(2(a+bc_m) - bh)\delta\beta}{2M}; \;\; \theta^{sc} = \frac{N\Upsilon}{2M}$$

and the corresponding profit of the manufacturer in two periods is

$$\pi_m^{sc} = \frac{N^2\delta\beta}{2M}$$

The optimal retail prices in first and second period are

$$p_1^{sc} = \frac{\Upsilon(4a\alpha - c(4c_m+h) - bh\alpha) + 4(6a - b(h-2c_m))\delta\beta}{4M}$$
$$p_2^{sc} = \frac{\Upsilon(4a\alpha - c(4c_m+3h) + bh\alpha) + 4(6a + 2bc_m + 3bh)\delta\beta}{4M}$$

and the corresponding sales volume and profit of the retailer in two consecutive selling periods are

$$Q^{sc} = \frac{2bN\delta\beta}{M}; \;\; \pi_r^{sc} = \frac{bh^2\Upsilon^4 - 4(N^2 - (N^2 - 4b^2h^2)\delta)\Upsilon^2\beta + 16b(N^2 + 4b^2h^2)\delta^2\beta^2}{8M^2}$$

where $N = 2a - b(2c_m + h)$.
Proof. See Appendix B .

Similar to the previous two scenarios, it is found that the greening level decreases with respect to δ and α; because $\frac{\partial \theta^{sc}}{\partial \delta} = \frac{-4b(2a-b(2c_m+h))\Upsilon\beta}{X^2} < 0$ and $\frac{\partial \theta^{sc}}{\partial \alpha} = \frac{-b(2a-b(2c_m+h))(\Upsilon^2+8b\beta\delta)}{X^2} < 0$, respectively. Therefore, the market demand of the product also decreases. Moreover, the retail prices also decrease with respect to δ; because $\frac{\partial p_1^{sc}}{\partial \delta} = \frac{-(2a-b(2c_m+h))\Upsilon(3c+b\alpha)\beta}{X^2} < 0$ and $\frac{\partial p_2^{sc}}{\partial \delta} = \frac{-(2a-b(2c_m+h))\Upsilon(3c+b\alpha)\beta}{X^2} < 0$, respectively. By analyzing all the three scenarios, one can observe that the retailer participation encourages the manufacturer to enhance the greening level. Therefore, we derive the optimal decisions for both the manufacturer and retailer to explore the detail implication of retailer's participation in the manufacturer green supply chain initiative.

4. Optimal decision without cost sharing

In previous section, we derive the optimal decisions for three scenarios where the retailer participates in cost sharing. To compare the influence of the retailer decisions more explicitly, we derive optimal results for all three scenarios where the retailer does not participate with the manufacturer. Substituting $\delta = 1$ in Equations (2)$\sim$(9), one can obtain the objective functions of the retailer and manufacturer in all three scenarios. Table 2 represents the simplified values of equilibrium outcomes for the three scenarios. The detail derivations are similar to previous section, hence omitted.

Table 2: Optimal retail prices, wholesale prices, greening level, amount of SI, profit of the retailer and manufacturer, and sales volume in scenarios TS, T, and S.

Sce.	TS	T	S
p_1	$\frac{\Upsilon(9a\alpha-bh\alpha-c(9c_m+h))+4(13a+b(4c_m-h))\beta}{X_1}$	$\frac{(a\alpha-cc_m)\Upsilon+2(3a+bc_m)\beta}{M_1}$	$\frac{\Upsilon(4a\alpha-c(4c_m+h)-bh\alpha)+4(6a-b(2c_m-h))\beta}{4M_1}$
p_2	$\frac{\Upsilon(9a\alpha+2bh\alpha-9cc_m-4ch)+2(23a+11bc_m+10bh)\beta}{X_1}$	$\frac{(a\alpha-cc_m)\Upsilon+2(3a+bc_m)\beta}{M_1}$	$\frac{\Upsilon(4a\alpha+bh\alpha-c(4c_m+3h))+4(6a+b(2c_m+3h))\beta}{4M_1}$
w_1	$\frac{\Upsilon(9a\alpha-9cc_m-2bh\alpha)+4Y\beta}{X_1}$	$\frac{(a\alpha-cc_m)\Upsilon+4(a+bc_m)\beta}{M_1}$	$\frac{\Upsilon(2a\alpha-2cc_m-bh\alpha)+8(a+bc_m)\beta-4bh\beta}{2M_1}$
w_2	$\frac{\Upsilon(9a\alpha+4bh\alpha-9cc_m-6ch)+4(6a+11bc_m+10bh)\beta}{X_1}$	$\frac{(a\alpha-cc_m)\Upsilon+4(a+bc_m)\beta}{M_1}$	-
θ	$\frac{\Upsilon(9a-9bc_m-2bh)}{X_1}$	$\frac{(a-bc_m)\Upsilon}{M_1}$	$\frac{N\Upsilon}{2M_1}$
I	$\frac{5bh\Upsilon^2+10b(a-b(c_m+4h))\beta}{X_1}$	-	-
π_r	$\frac{\Psi_1}{X_1^2}$	$\frac{8b(a-bc_m)^2\beta^2}{M_1^2}$	$\frac{b(h^2\Upsilon^4-16bh^2\Upsilon^2\beta+16(N_1^2+4b^2h^2)\beta^2)}{8M_1^2}$
π_m	$\frac{2(9(a-bc_m)^2-4b(a-bc_m)h+8b^2h^2)\beta-2bh^2\Upsilon^2}{X_1}$	$\frac{2(a-bc_m)^2\beta}{M_1}$	$\frac{N^2\beta}{2M_1}$
Q	$\frac{bh\Upsilon^2+2b(19a-19bc_m-8bh)\beta}{X_1}$	$\frac{4b(a-bc_m)\beta}{M_1}$	$\frac{2bN\beta}{M_1}$

where $X_1 = 68b\beta - 9\Upsilon^2$, $M_1 = 8b\beta - \Upsilon^2$, and $\Psi_1 = 2b(10h^2\Upsilon^4 + h(13a - 13bc_m -$

$154bh)\Upsilon^2\beta + 2(155(a-bc_m)^2 - 118b(a-bc_m)h + 304b^2h^2)\beta^2$.

In Scenario TS, the difference between wholesale prices is $w_1^{ts} - w_2^{ts} = \frac{6(a-b(c_m+4h))\beta+3h\Upsilon^2}{X_1} > 0$ and retail prices is $p_1^{ts} - p_2^{ts} = \frac{12(a-b(c_m+4h))\beta+6h\Upsilon^2}{X} > 0$. These findings also consistent with the existing literature on SI (Anand et al. 2008). The manufacturer charges less wholesale price in second period. Moreover, the difference between the retail prices in Scenario S is $p_1^s - p_2^s = -\frac{h}{2} < 0$. Therefore, the retail pricing behavior is highly affected by the procurement decisions of the retailer. If the retailer maintains SI then consumer gets benefit in the second period but the consumer needs to pay more if the retailer procures products in a single lot. Consumer remains unaffected in Scenario T. In the next section, we draw implications of this study and compare the profit functions for all scenarios to shade light on the profitability of both the manufacturer and retailer..

5. Managerial implication

In this section, first we investigate the influence of procurement decision and participation rate on greening level.

Theorem 1.
According to participation in cost sharing,
(i) with retailer participation in cost sharing, the optimal greening levels satisfy

$$\theta^{ts} \geq \theta^t \geq \theta^s$$

(ii) without retailer participation in cost sharing, the optimal greening levels satisfy

$$\theta^{tsc} \geq \theta^{tc} \geq \theta^{sc}$$

.

Proof. In the presence of the retailer participation, the difference among greening levels in Scenarios TSC, TC, and SC are obtained as follows:

$$\theta^{tsc} - \theta^{tc} = \frac{\Upsilon(4b(a-b(c_m+4h))\delta\beta + 2bh\Upsilon^2)}{2XM} > 0 \text{ and } \theta^{tc} - \theta^{sc} = \frac{bh\Upsilon}{2M} > 0$$

Similarly, in absence of the retailer participation, the difference among product greening levels in Scenarios TS, T, and S are obtained as follows:

$$\theta^{ts} - \theta^{t} = \frac{\Upsilon(4b(a-b(c_m+4h))\beta + 2bh\Upsilon^2)}{M_1X_1} > 0 \text{ and } \theta^{t} - \theta^{s} = \frac{bh\Upsilon}{2M_1} > 0$$

Above inequalities ensure the proof of Theorem 1.

Theorem 1 implies that the retailer's participation rate does not change the nature of greening levels. The consumers get the products at its highest greening level if the retailer maintains SI. Therefore, the retailer's strategic decision is also beneficial for the consumer. If the retailer procures product at a time, then the manufacturer cannot make wholesale price differentiation, as a result, the manufacturer cannot invest more in improving greening level and the product greening level reaches to its lowest level. We present numerical illustrations in support of analytical discussions. The following parameters are used for the illustration: $a = 1000$(units), $b = 50$, $c = 40$, $\beta = 15$, $c_m = 6$(\$/unit), $h = 1$(\$/unit/selling period), $\alpha = 0.4$(\$/unit), and $\delta = 0.5$. The parameters related to demand function and fixed marginal cost are considered based on previous studies (e.g., Ghosh and Shah 2012; Ghosh and Shah, 2015).

Please insert Fig 2.

Fig 2. justifies the analytical findings. The product greening level decreases with respect to δ. In the presence of SI, the product greening level is always higher if the retailer shares cost with the manufacturer. Therefore, the retailer involvements and strategic decisions to carry inventory simultaneously bring benefits for the consumer. Next, we derive relations among optimal sales volumes in different scenarios.

Theorem 2.
According to participation in cost sharing,
(i) with retailer participation in cost sharing, the optimal sales volumes satisfy

$$Q^{tsc} \geq Q^{tc} \geq Q^{sc}$$

(ii) without retailer participation in cost sharing, the optimal sales volumes satisfy

$$Q^{ts} \geq Q^{t} \geq Q^{s}$$

Proof. In the presence of the retailer participation, the difference among sales volumes are obtained as follows:

$$Q^{tsc} - Q^{tc} = \frac{b(16b\delta\beta - \Upsilon^2)(h\Upsilon^2 + 2(a - b(c_m + 4h))\delta\beta)}{MX} > 0 \text{ and } Q^{tc} - Q^{sc} = \frac{2b^2h\beta\delta}{M} > 0$$

Similarly, in the absence of the retailer participation, the difference among sales volumes in two periods are obtained as follows:

$$Q^{ts} - Q^{t} = \frac{b(16b\beta - \Upsilon^2)(h\Upsilon^2 + 2(a - b(c_m + 4h))\beta)}{M_1} > 0 \text{ and } Q^{t} - Q^{s} = \frac{2b^2h\beta}{M_1} > 0$$

Hence the theorem.

In a green sensitive market, the demand of the product increases with respect to product greening level. The analytical relations obtain in Theorem 2 also justify the intuition. The sales volume of the product is maximum in Scenario TS or TSC. The graphical representation of sales volumes are shown in Fig 3.

Please insert Fig 3.

Fig 3. also demonstrates that the sales volume of the green supply chain is maximum in Scenario TSC. Previously, it is found that the product greening level is maximum in Scenario TSC, as a result the sales volume is also maximum in that scenario. However, the retailer decision to share a proportion of the manufacturer greening cost does not always assure that the sales volume is also greater. Fig 3. demonstrates that the sales volume in Scenario SC, where it is lowest when the retailer shares greening cost to the manufacturer, sometime less compares to sales volume in scenario TS. Simple implication of this findings is that if the manufacturer and retailer strict to single period planning then the supply chain members always lose the opportunity to sell maximum amount of products. Next we compere the profits of the manufacturer.

Theorem 3.
According to participation in cost sharing,
(i) with the retailer participation in cost sharing, the manufacturer profits satisfy

$$\pi_{m1}^{tsc} \geq \pi_{m1}^{tc} \geq \pi_{m}^{sc}$$

(ii) without retailer participation in cost sharing, the manufacturer profits satisfy

$$\pi_{m1}^{ts} \geq \pi_{m1}^{t} \geq \pi_{m}^{s}$$

Proof. The following inequalities ensure the proof of Theorem 3:

$\pi_{m1}^{tsc} - \pi_{m1}^{tc} = \frac{2b(2(a-b(c_m+4h)\delta\beta+h\Upsilon^2)^2}{XM} > 0$

$\pi_{m1}^{tc} - \pi_{m}^{sc} = \frac{bh(4a-b(4c_m+h))\delta\beta}{2M} > 0$

$\pi_{m1}^{ts} - \pi_{m1}^{t} = \frac{2b(2(a-b(c_m+4h)\beta+h\Upsilon^2)^2}{X_1M_1} > 0$

$\pi_{m1}^{t} - \pi_{m}^{s} = \frac{bh(4a-b(4c_m+h))\beta}{2M_1} > 0$

This completes the proof of Theorem 3.

The graphical representation of profits of the manufacturer in Scenarios TSC, SC, and TS are shown in Fig 4.

Please insert Fig 4.

Analytical results demonstrate that the retailer's decision to maintain SI is always profitable for the manufacturer. The result is consistent with the findings of Hartwig et al. (2015). Fig 4. demonstrates that the profit functions exhibit similar decreasing patterns with respect to α. If α increases the marginal cost of the product increases, as a consequence the profit of the manufacturer decreases. Additionally, the profit of the manufacturer decreases with respect to δ. The structure of the manufacturer profit also justifies the phenomenon. In Scenario SC, the profit of the manufacturer is minimum if the retailer shares cost and in Scenario TS profit of the manufacturer is maximum when the retailer does no share cost but maintains SI. Therefore, one can conclude that if the retailer procures in bulk and shares a proportion of manufacturer investment cost then the manufacturer sometime gets additional benefits. Exceptionally, Fig 4. also demonstrates that the single period procurement strategy (Scenario T), which is commonly discussed in literature is completely outperformed by the Scenario SC. This finding also supports growing trend of bulk procurement in retailing. Finally, we compare the profits of the retailer and the following theorem is proposed.

Theorem 4.
(i) With retailer participation, optimal profits of the retailer satisfy

$$\text{(a) } \pi_{r1}^{tsc} \geq \pi_{r1}^{tc} \ \forall h \geq h_1$$
$$\text{(b) } \pi_{r1}^{tc} \geq \pi_{r}^{sc} \ \forall h \geq h_2$$

(ii) Without retailer participation, optimal profits of the retailer satisfy

$$\pi_{r1}^{ts} \geq \pi_{r1}^{t} \geq \pi_{r}^{s} \text{ if } h \geq h_3$$

Proof. In the presence of the retailer participation, the difference between the profits of the retailer in Scenarios TSC and TC is

$$\pi_{r1}^{tsc} - \pi_{r1}^{tc} = \frac{\Psi_2}{X^2 M^2}[h(10\Upsilon^6 - 2b(2+115\delta)\Upsilon^4\beta + 16b^2\delta(2+113\delta)\Upsilon^2\beta^2 - 4864b^3\delta^3\beta^3) - (a-bc_m)\beta((36-43\delta)\Upsilon^4 - 8b\delta(35-31\delta)\Upsilon^2\beta + 672b^2\delta^3\beta^2)]$$

where $\Psi_2 = 2b(h\Upsilon^2 + 2(a-b(c_m+4h))\beta\delta) > 0$. Therefore, $\pi_{r1}^{tsc} \geq \pi_{r1}^{tc}$ if $h > h_1 = \left(\frac{(a-bc_m)\beta((36-43\delta)\Upsilon^4-8b\delta(35-31\delta)\Upsilon^2\beta+672b^2\delta^3\beta^2))}{10\Upsilon^6-2b(2+115\delta)\Upsilon^4\beta+16b^2\delta(2+113\delta)\Upsilon^2\beta^2-4864b^3\delta^3\beta^3}\right)$. Similarly, the profit difference of the retailer between Scenarios TC and SC is

$$\pi_{r1}^{tc} - \pi_{r}^{sc} = \frac{bh(16b(4a-4bc_m+5bh)\delta^2\beta^2) - h\Upsilon^4 - 4(4a(1-\delta) - b(h+4c_m(1-\delta)+3h\delta))\Upsilon^2\beta}{8M^2} > 0$$

Therefore, $\pi_{r1}^{tc} > \pi_{r1}^{sc}$ if $h > h_2 = \frac{16(a-bcm)\beta(4b\delta^2\beta-(1-\delta)\Upsilon^2)}{\Upsilon^4-4b(1+3\delta)\Upsilon^2\beta+80b^2\beta^2\delta^2}$. The above two inequalities ensure the relation among the profits of the retailer.
The profit difference of the retailer between Scenarios TS and T is obtained as follows:

$$\pi_{r1}^{ts} - \pi_{r1}^{t} = \frac{\Psi_3}{X_1^2 M_1^2}[h(10\Upsilon^6 - 234b\Upsilon^4\beta + 1840b^2\Upsilon^2\beta^2 - 4864b^3\beta^3) - (a-bc_m)\beta(7\Upsilon^4 + 32b\Upsilon^2\beta - 672b^2\beta^2)]$$

where $\Psi_3 = 2b(2(a-b(c_m+4h))\beta + h\Upsilon^2) > 0$. Therefore, $\pi_{r1}^{tsc} \geq \pi_{r1}^{tc}$ if $h > h_3 = \left(\frac{(a-bc_m)\beta(7\Upsilon^4+32b\Upsilon^2\beta-672b^2\beta^2)}{10\Upsilon^6-234b\Upsilon^4\beta+1840b^2\Upsilon^2\beta^2-4864b^3\beta^3}\right)$. Similarly, the profit difference of the retailer between Scenarios T and S is

$$\pi_{r1}^{t} - \pi_{r}^{s} = \frac{bh(h\Upsilon^2(16b\beta - \Upsilon^2) + 16b(4a-4bc_m-5bh)\beta^2)}{8M_1^2} > 0$$

This completes the proof of Theorem 4.

The graphical representation of the retailer profits in Scenarios TSC, SC, and TC are shown in Fig 5.

Please insert Fig 5.

Fig 5. demonstrates that if the retailer procures all the products required to satisfy demand of two consecutive periods in a single order then Scenario TSC or TC may not be an optimal procurement strategy. In the existing literature, researchers and practitioners claim that cost sharing or buildup SI is an optimal strategy for the retailer. Through bulk procurement, a retailer can maintain inventory of products such as electronic goods and home appliances, dry rice and lentils, detergents, dry pasta, soap, office supplies, plastic household items etc. Bulk procurement can be suitable for a retailer to reduce per unit purchase, ordering and staffing cost significantly over the long haul. Due to rapid development and easily accessible information technology, a retailer may calmly adopt Product Information Manager (PIM) to incorporate newly procured products in the existing catalogue and pinpoint age of existing product purchased previously. Bulk procurement can also help the retailer to ride out any possible rush of sales. This study discusses and compares three scenarios where the retailer is able to procure additional products in the present period to satisfy demand of upcoming period like real world practice. It is found that the retailer's procurement decision makes a fateful impact on the manufacturer green supply chain initiatives. The graphical representation of the retailer profits in Scenario TSC and TS are shown in Fig 6.

Insert Fig 6.

Fig 6. justifies that if the consumer sensitivity in greening level is greater compared to price sensitivity and the retailer's involvement in cost sharing is higher, then carrying SI is not the optimal strategy for the retailer. In some recent studies (Anand et al. 2008, Arya and Mittendorf 2013), it is suggested that the retailer should maintain SI to gain maximum profit. However, present study suggests that if the consumer is extremely sensitive to the product greening level then build up SI is not profitable because the retailer cannot take the advantage of the retail price differentiation to skim profits. High greening level sensitivity motivates the manufacturer to invest more, therefore the manufacturer needs to increase unit wholesale price of the product to compensate the investment cost. As a result, the retailer losses opportunity to gain additional profits. Differentiating wholesale prices in Scenario TSC, one can find that $\frac{\partial w_1^{tsc}}{\partial c} = \frac{(9a-9bc_m-2bh)(9\alpha\Upsilon^2+4\delta(18c-b\alpha)\beta)}{X^2} > 0$ and $\frac{\partial w_2^{tsc}}{\partial c} = \frac{(9a-9bc_m-2bh)(9\alpha\Upsilon^2+4\delta(12c+b\alpha)\beta)}{X^2} > 0$, respectively. The analytical results also support the intuition.

We conduct sensitivity analysis for the profit functions of the Green Supply chain members and greening level of the product in Scenarios TSC and TC. The graphical representations are presented in Appendix C. When the value of one parameter varies, all others remain unchanged. The results indicate that as the market potential (a) increases, the greening level and the profit of both the supply chain members increase. However, the greening level and the profit of supply chain members all decrease with respect to b, c_m, and h. Because c_m and h represent cost parameters and b represents price sensitively, therefore, the results reflect the reality. Green technology provides benefits to the environment but often at a much higher cost. Therefore, higher sensitivity on greening level sometimes discourages the retailer to sell the green product. The sensitivity analysis also reflects that fact. Higher green sensitivity motivates the manufacturer to increase the greening level of the product, but the retailer receives less amount of profits because the retailer cannot employ price differentiation. It is also found that both the greening level and profit of the manufacturer decrease with respect to the efficiency of greening investment sensitive parameters. The profits of the manufacturer and retailer exhibit reverse trend with respect to δ and α. The profit structures of the supply chain members justify this finding. Whatever the values of parameters, the manufacturer always receives higher profits if the retailer maintains SI. However, if the retailer participates in cost sharing, then build-up SI is not always optimal procurement strategy for the retailer. The outcomes of sensitivity analysis justify the analytical finding presented in Theorem 4.

5.1 Implications for theory and practice

With the extensive awareness of consumer for green products, manufacturers make persistent effort to produce greener products by integrating expensive green technologies and retailers faced difficulties in the process of implementing a green supply chain because sometime a considerable gap exists between consumers' green claims and purchasing power (Govindan et al. 2014). Scur and Barbosa (2017) also identified some critical issues through empirical research to imply green supply chain management in the home appliance industry. This study explores properties of green supply chain by considering two period interactions. It is established that multi period planning can outperform single period decision model. In multi period interaction, retailers have the opportunity to employ various procurement decisions. If the retailer procures product by maintaining SI then each supply chain member receives higher profit and the manufacturer can produce products with a higher greening level. However, if the retailer procures products in bulk, the retailer may receive a higher profit, but the greening level of the product reaches its lowest value. Although several authors report about the conflict between profit and sustainability, in this study, perhaps this is the first time, it is identified that conflicts may arise in the choice of procurement decision, number of selling periods, and participation. In single period decision making model, researchers argued in favour of participation (Ma et al. 2018), but in multi period interactions, participation can be harmful in perspective of producing greener products. The Just-in-Time (JIT) experts argue that inventory is an evil. Whereas, similar to existing literature (Hartwig et al. 2015; Mantin and Jiang, 2017), in green supply chain it is also established that the retailer's decision to maintain SI under multi period interactions proves to be blessings in the perspective of producing green product and receiving higher profits.

6. Conclusion

In multi period supply chain environment, the retailer maintains SI to accomplish higher wholesale price negotiation power. However, the consequences of the retailer's strategic decision are not investigated in the literature on GSCM. Therefore, in this paper we discuss the joint impact of the retailer's strategic decision and consumer continuous expectation on the investment and wholesale pricing decision of the manufacturer in improving greening level of the product. Perhaps, this is the first study on GSCM where three businesslike procurement strategies are discussed analytically to explore the consequences of the manufacturer investment decision to improve greening level of the product.

Making energy efficient electronic products, reducing amount of preservatives and minimizing food waste, or producing eco-friendly and eco-healthy detergents are some well recognized areas where manufacturers are continuously focusing to enhance products greening level by integrating modern technologies. This study reveals that the retailer's strategic decision not only improves the profits of the supply chain members but encourages the manufacturer to improve product greening level also. The manufacturer always gets higher profit if the retailer maintains SI. However, if the retailer participates in greening level improvement cost sharing, then the single ordering decision for each period is sometimes proved to be the optimal procurement policy for the retailer. In that situation, the consumer gets the product at its lowest greening level and the manufacturer receives the least amount of profits. Moreover, the retailer's decision to procure products at each period in the absence of SI prevents the manufacturer in producing products to its highest greening level. The single period procurement and pricing policy is discussed extensively in the existing literature, the analytical results indicate that the properties of GSCM should be studied under the multi-period environment. The retailer's decision to procure products required for two consecutive periods in single order is a real obstruction for the manufacturer to improve the product greening level. Similarly, higher consumer sensitivity on greening level of the product sometime discourages the retailer to participate in GSCM.

Results derived in this study are based on some assumptions, which also demonstrate the limitations of this work. Commonly, companies like Apple, Samsung, Procter & Gamble do not make frequent change of their product characteristics, and in between the retailer procures products several times. This observation insists us to analyze the models by keeping the product's greening level unchanged. One of the immediate extensions of the proposed study is to extend the model by considering the effect of changes in the product's greening level in each period. It is assumed that the information about the green technology investment is known among supply chain members and demand parameters are also common knowledge. However, such information might be asymmetric (Osburg et al. 2017; Plank and Teichmann 2018). Therefore, the model can be extended by considering the influence of asymmetry information. The concepts addressed in the study can also be advanced in several ways. One can extend the proposed model by incorporating the impact of carbon emission as seen in (Sarkar et al. 2016; Sarkar et al. 2018), reference-price (Lin 2016; Saha et al. 2017), imperfect quality items (Tayyab and Sarkar 2016; Sarkar and Saren 2016); lead time (Kim and Sarkar 2017; Yu et al. 2016). Finally, one might study the influence of SI in close-loop green supply chain environment, as presented in (Liu et al. 2017; Sarkar et al. 2017).

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Appendix A

The first order condition for maximization is obtained as follows:

$$\frac{\partial \pi_{r2}^{tsc}}{\partial p_2^{tsc}} = a - 2bp_2^{tsc} + bw_2^{tsc} + c\theta^{tsc} = 0$$

Therefore, $p_2^{tsc} = \frac{a+bw_2^{tsc}+c\theta^{tsc}}{2b}$. The profit function of the retailer is strictly concave because $\frac{d^2\pi_{r2}^{tsc}}{dp_2^{tsc^2}} = -2b < 0$. We substitute the value of p_2^{tsc} in Equation (3), the profit function of the manufacturer in second-period is obtained as

$$\pi_{m2}^{tsc} = \frac{(a-2I_r^{tsc}-bw_2^{tsc}+c\theta^{tsc})(w_2^{tsc}-c_m-\alpha\theta^{tsc})}{2} - \delta\beta(\theta^{tsc})^2$$

The first order condition for optimization is

$$\frac{\partial \pi_m^{tsc}}{\partial w_2^{tsc}} = a - 2I^{tsc} + c\theta^{tsc} + b(c_m - 2w_2^{tsc} + \alpha\theta^{tsc}) = 0$$

After solving, we get $w_2^{tsc} = \frac{a+bc_m-2I^{tsc}+c\theta^{tsc}+b\alpha\theta^{tsc}}{2b}$. The profit function of the manufacturer is also concave because $\frac{d^2\pi_m^{tsc}}{dw_2^{tsc^2}} = -b < 0$. Substituting the response of second period, the profit of the retailer in first-period is obtained as follows:

$$\pi_{r1}^{tsc} = \frac{1}{16b}\,[a^2 + 4bI^{tsc}(c_m - 4(h + w_1^{tsc})) + 12cI^{tsc}\theta^{tsc} - 2b(c(c_m - 8p_1^{tsc} + 8w_1^{tsc}) - 2I^{tsc}\alpha)\theta$$
$$-12(I^{tsc})^2 + c^2(\theta^{tsc})^2 - 2b(c\alpha + 16(1-\delta)\beta)(\theta^{tsc})^2 + b^2(16p_1^{tsc}(w_1^{tsc} - p_1^{tsc}) + (c_m + \alpha\theta^{tsc})^2)$$
$$-2a(b(c_m - 8p_1^{tsc} + 8w_1^{tsc} + \alpha\theta^{tsc}) - 6I^{tsc} - c\theta^{tsc})]$$

The profit function of the retailer in first-period is also concave because

$$H_r^{tsc} = \begin{pmatrix} \frac{\partial^2\pi_{r1}^{tsc}}{\partial p_1^{tsc^2}} & \frac{\partial^2\pi_r^{tsc}}{\partial p_1^{tsc}\partial I^{tsc}} \\ \frac{\partial^2\pi_r^{tsc}}{\partial p_1^{tsc}\partial I^{tsc}} & \frac{\partial^2\pi_r^{tsc}}{\partial (I^{tsc})^2} \end{pmatrix} = \begin{pmatrix} -2b & 0 \\ 0 & -3/2b \end{pmatrix}$$

The values of the leading principal minors of the Hessian matrix are $m_1 = -2b < 0$ and

$m_2 = 3 > 0$. After solving first order conditions one can obtain the optimal response of the retailer as $p_1^{tsc} = \frac{a+bw_1^{tsc}+c\theta^{tsc}}{2b}$ and $I^{tsc} = \frac{1}{6}(3a + 3c\theta^{tsc} + b(c_m - 4(h + w_1^{tsc}) + \alpha\theta^{tsc}))$. Finally, the profit function of the manufacturer is obtained as

$$\pi_{m1}^{tsc} = \frac{2b}{9}(w_1^{tsc} + h - c_m - \alpha\theta^{tsc})^2 - 2\delta\beta(\theta^{tsc})^2$$
$$-\frac{1}{6}(c_m - w_1^{tsc} + \alpha\theta^{tsc})(6a + 6c\theta^{tsc} + b(c_m - 4h - 7w_1^{tsc} + \alpha\theta^{tsc}))$$

The profit function of the manufacturer is also concave because

$$H_m^{tsc} = \begin{pmatrix} \frac{\partial^2\pi_{m1}^{tsc}}{\partial(w_1^{tsc})^2} & \frac{\partial^2\pi_{m1}^{tsc}}{\partial w_1\partial\theta^{tsc}} \\ \frac{\partial^2\pi_{m1}^{tsc}}{\partial w_1\partial\theta^{tsc}} & \frac{\partial^2\pi_{m1}^{tsc}}{\partial(\theta^{tsc})^2} \end{pmatrix} = \begin{pmatrix} -17b/9 & (8b\beta + 9c)/9 \\ (8b\alpha + 9c)/9 & -2c\alpha - 4\delta\beta + \frac{b\alpha^2}{9} \end{pmatrix}$$

and $|H_m^{tsc}| = X = 68b\delta\beta - 9\Upsilon^2 > 0$ and $\frac{\partial^2\pi_m^{tsc}}{\partial {w_1}^2} = -17b/9 < 0$. Therefore, the optimal value of w_1 and θ will be obtained by solving $\frac{\partial\pi_{m1}^{tsc}}{\partial w_1^{tsc}} = 0$ and $\frac{\partial\pi_{m1}^{tsc}}{\partial\theta^{tsc}} = 0$. The optimal solutions are presented in Proposition 1. By using back-substitution, we obtain all the remaining values.

Appendix B

The first order conditions for maximization are obtained as follows:

$$\frac{\partial\pi_r^{sc}}{\partial p_1^{sc}} = a - b(2p_1^{sc} + w^{sc}) + c\theta^{sc} = 0$$
$$\frac{\partial\pi_r^{sc}}{\partial p_2^{sc}} = a + b(h - 2p_2^{sc} + w^{sc}) + c\theta^{sc} = 0$$

Solving above two equations simultaneously, we get $p_1^{sc} = \frac{a+bw^{sc}+c\theta^{sc}}{2b}$ and $p_2 = \frac{a+b(h+w^{sc})+c\theta^{sc}}{2b}$. The profit function of the retailer is strictly concave because $\frac{\partial^2\pi_r^{sc}}{\partial p_1^{sc2}}\frac{\partial^2\pi_r^{sc}}{\partial p_2^{sc2}} - \frac{\partial^2\pi_r^{sc}}{\partial p_1^{sc}\partial p_2^{sc}} = 4b^2 > 0$ and $\frac{\partial^2\pi_r^{sc}}{\partial p_1^{sc2}} = -2b < 0$.

We substitute the values of p_1^{sc} and p_2^{sc} into the profit function of the manufacturer and derive

$$\pi_m^{sc} = \frac{(2a - b(h + 2w^{sc}) + 2c\theta^{sc})(w^{sc} - c_m - \alpha\theta^{sc})}{2} - 2\delta\beta(\theta^{sc})^2$$

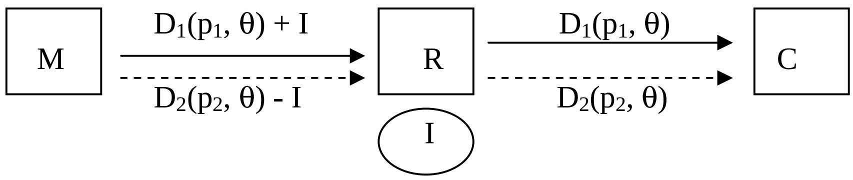
The first order conditions for optimization are

$$\frac{\partial\pi_m^{sc}}{\partial w^{sc}} = a + c\theta^{sc} + b(c_m - 2w^{sc} + \alpha\theta^{sc}) - \frac{bh}{2} = 0$$
$$\frac{\partial\pi_m^{sc}}{\partial\theta^{sc}} = -a\alpha + \frac{bh\alpha}{2} + bw^{sc}\alpha - 4\delta\beta\theta^{sc} + c(w^{sc} - c_m - 2\alpha\theta^{sc}) = 0$$

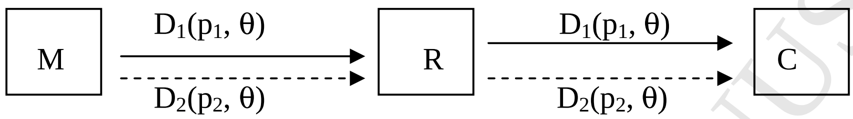
As the first-period profit function of the retailer is a function of three variables, we compute the Hessian matrix(H^{sc}) as follows:

$$H^{sc} = \begin{pmatrix} \frac{\partial^2\pi_m^{sc}}{\partial w^{sc2}} & \frac{\partial^2\pi_m^{sc}}{\partial w^{sc}\partial\theta} \\ \frac{\partial^2\pi_m^{s}}{\partial\theta^{sc}\partial w^{sc}} & \frac{\partial^2\pi_m^{sc}}{\partial\theta^{sc2}} \end{pmatrix} = \begin{pmatrix} -2b & c + b\alpha \\ c + b\alpha & -2(c\alpha + 2\delta\beta) \end{pmatrix}$$

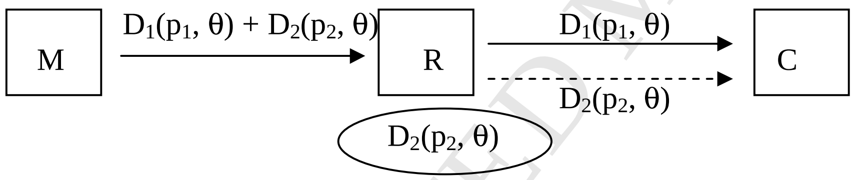
The values of the leading principal minors of the Hessian matrix are $m_{11} = -2b < 0$ and $m_{22} = 8b\delta\beta - \Upsilon^2 > 0$; that is, the profit function of the manufacturer is also concave.



Scenario TS: The retailer maintains strategic inventory and procures product in each period

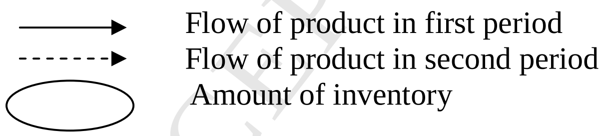


Scenario T: The retailer does not maintain any inventory but procures product in each period



Scenario S: The retailer procures product in first period

Fig 1. Procurement decision of the retailer



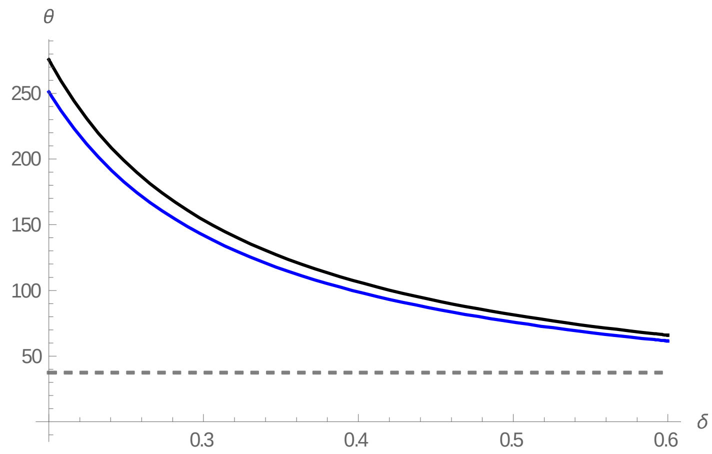


Fig 2. The optimal vales of greening level in Scenario TSC(black), SC(blue), and TS(gray)

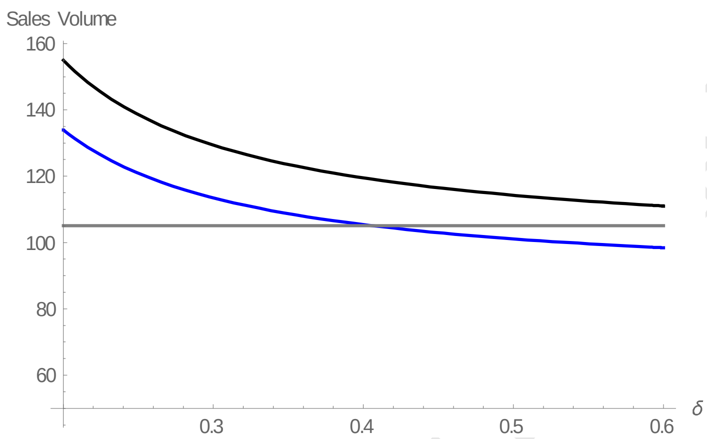


Fig 3. The optimal sales volumes level in Scenario TSC(black), SC(blue), and TS(gray)

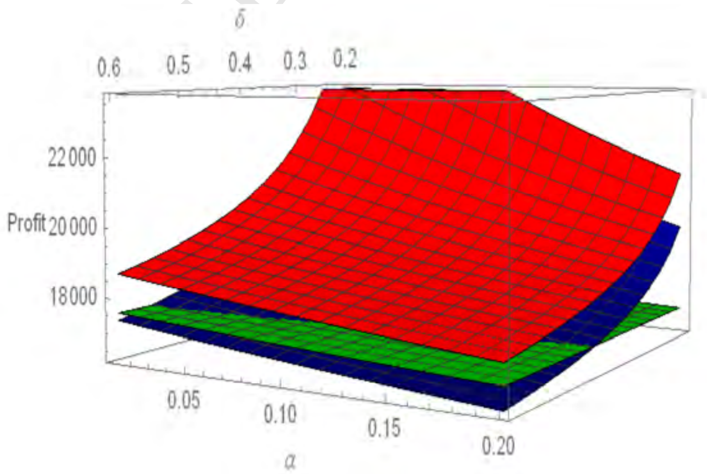


Fig 4. Optimal profits of the manufacturer in Scenario TSC(Red), SC(blue), and TS(Green)

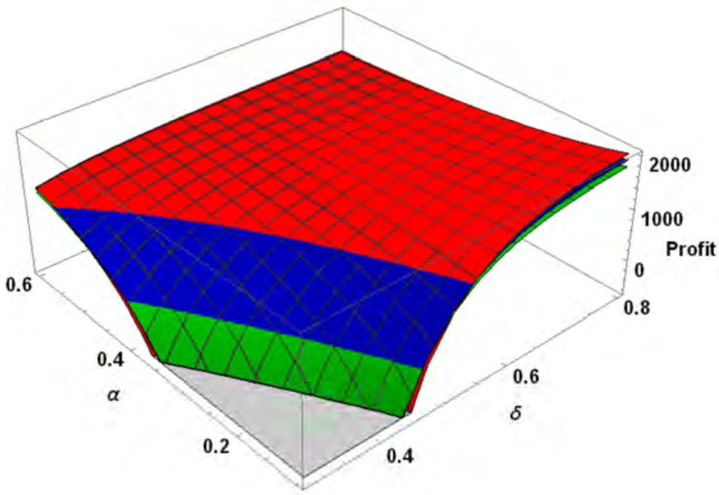


Fig 5. Optimal profits of the retailer in Scenario TSC(Red), SC(blue), and TC(Green)

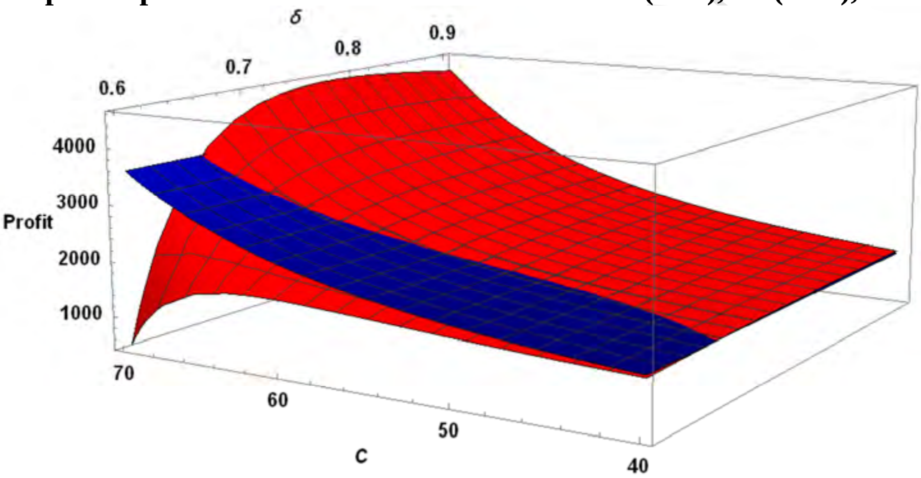


Fig 6. Optimal profits of the retailer in Scenario TSC(Red) and S(Blue)

Appendix C: Sensitivity analysis with respect to key parameters.

Optimal greening level in Scenarios TSC and TC are represented by θ^{tsc}(blue) and θ^{tc}(green), respectively. Similarly, optimal profits of the manufacturer and retailer in Scenarios TSC and TC are represented by π_{r1}^{tsc}(black), π_{r1}^{tc}(Green), π_{m1}^{tsc}(blue), and π_{r1}^{tc}(pink).

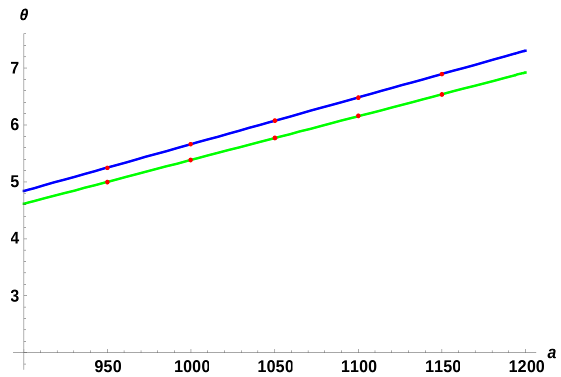


Fig C1a. Optimal greening level with respect to a

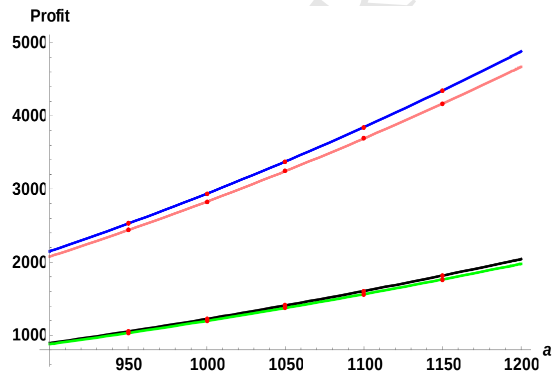


Fig C1b. Optimal profits of the retailer and manufacturer with respect to a

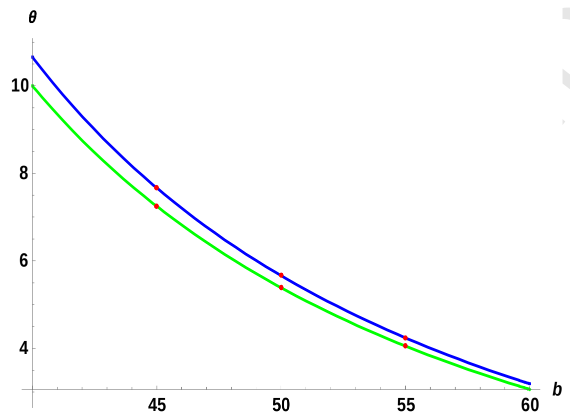


Fig C2a. Optimal greening level with respect to b

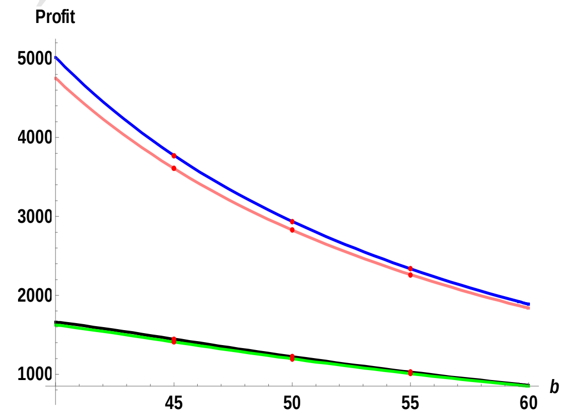


Fig C2b. Optimal profits of the retailer and manufacturer with respect to b

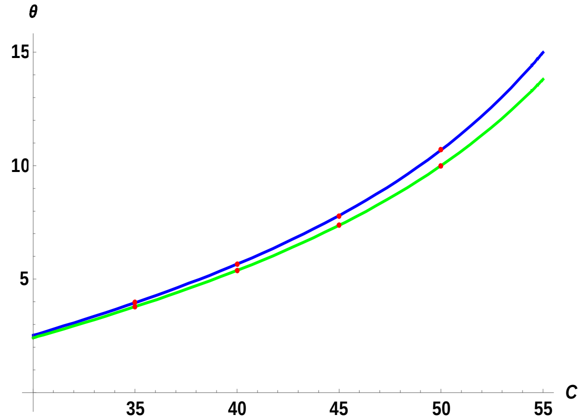


Fig C3a. Optimal greening level with respect to c

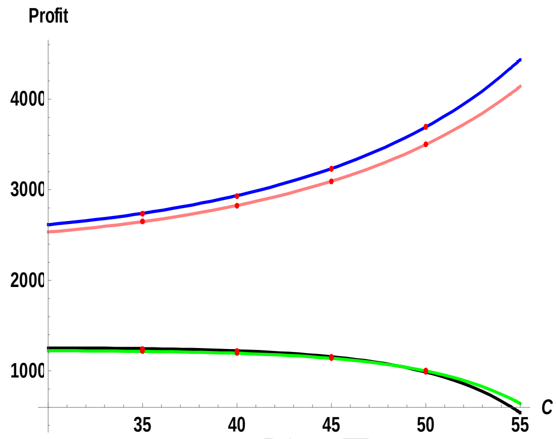


Fig C3b. Optimal profits of the retailer and manufacturer with respect to c

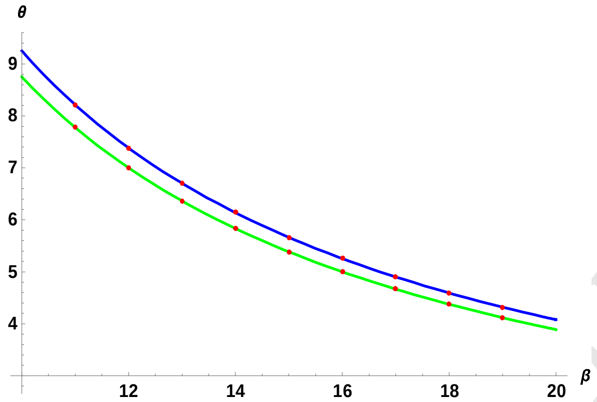


Fig C4a. Optimal greening level with respect to β

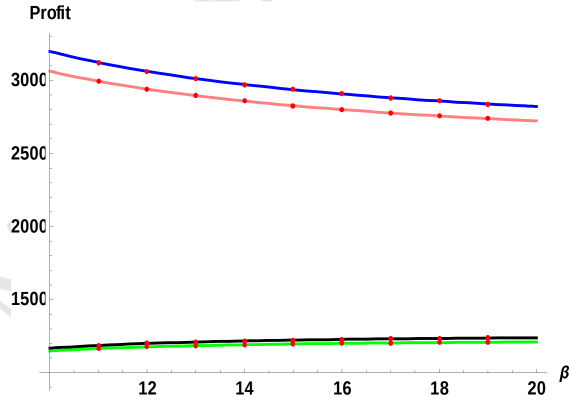


Fig C4b. Optimal profits of the retailer and manufacturer with respect β

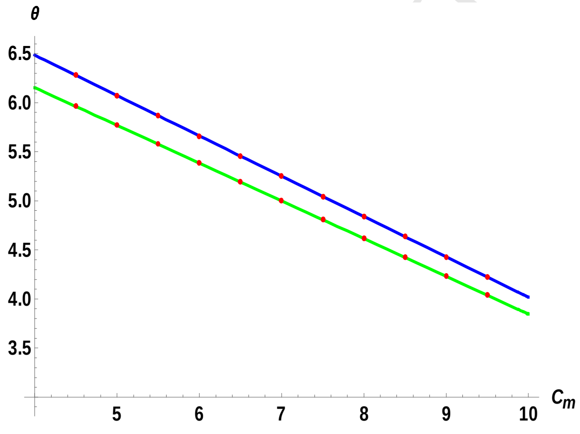


Fig C5a. Optimal greening level with respect to c_m

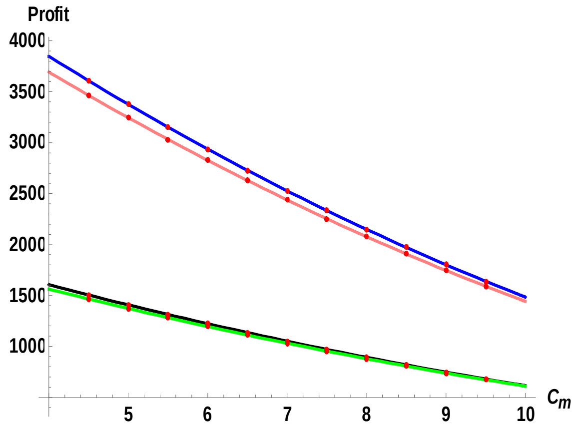


Fig C5b. Optimal profits of the retailer and manufacturer with respect to c_m

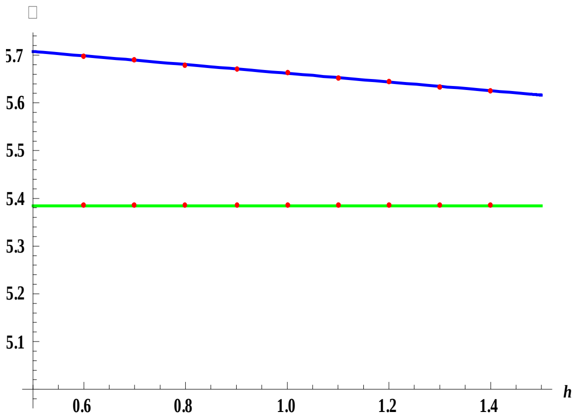


Fig C6a. Optimal greening level with respect to h

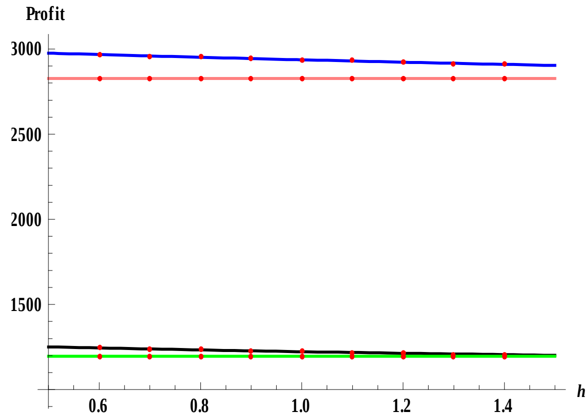


Fig C6b. Optimal profits of the retailer and manufacturer with respect to h

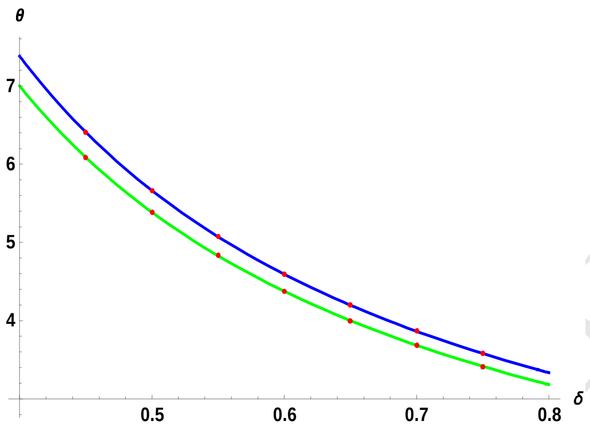


Fig C7a. Optimal greening level with respect to δ

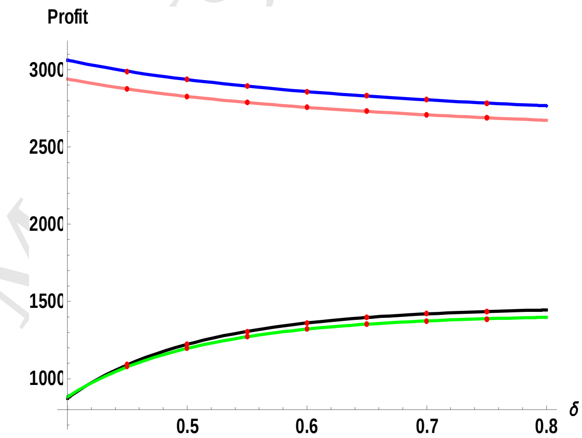


Fig C7b. Optimal profits of the retailer and manufacturer with respect to δ

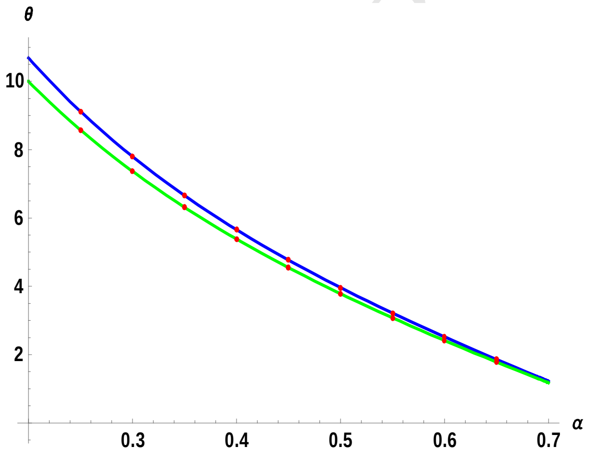


Fig C8a. Optimal greening level with respect to α

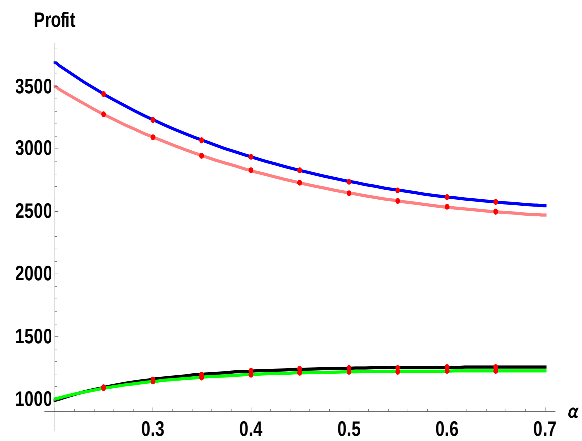


Fig C8b. Optimal profits of the retailer and manufacturer with respect to α