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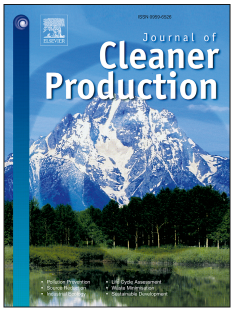

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Comparative analysis of government incentives and game structures on single and two-period green supply chain

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Abstract

The Government organizations provide incentives to the manufacturers for adopting green technologies in different ways. The objective of this study is to generate a decision support framework in perspectives of the selection and successful implementation towards environment-friendly products by comparing profits of each member, greening level, consumer surplus and environmental improvement under two different incentive policies. Twelve analytical models are formulated and analyzed by considering the impact of two game structures, single and two-period procurement decisions on the sustainability goals of supply chain members. The objectives of government's social welfare are optimized here. A comprehensive analysis

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reveals that the manufacturer receives higher profits and the greening level is always at higher end in two-period procurement decision under manufacturer-Stackelberg game. The greening level and profit of the retailer are maximum in single-period procurement decision under retailer-Stackelberg game. As a result, optimal preference is highly sensitive to game structure and procurement decision. When the manufacturer sets a premeditated threshold for greening level, supply chain members receive higher profits under incentive policy on per-unit product because of lower sales price, higher consumer surplus and environmental improvement compared to government incentive policy on total investment in R&D. The greening level is maximum under incentive policy on total investment in R&D that results in higher environmental improvement. Supply chain members can compromise with their sustainable goals to receive higher profits in presence of incentives.

Keywords: Green supply chain; Government incentives; Strategic inventory; Two-period model; Stackelberg game.

1. Introduction

Over the last several years, some important phenomenon such as global warming, energy saving, greenhouse gas emissions and the growing scarcity of resources have attracted the researchers to immerse in their research works on protection of the environment of human civilization. Consequently, the international community (Friedler, 2010; Ahi and Searcy, 2013; Laari et al., 2017) has given priority on these topics for research and development (R&D). The regulatory agencies of several countries like the United States Environmental Protection Agency (EPA), Natural Resources Canada (NRCan), European Commission (EC), China Standard Certification Center (CSC) are working to raise the green awareness of consumers at time of choosing home appliances, office equipments, toys and baby products, etc. (Galitsky et al. 2004). To support manufacturing industries of energy-efficient products, the government as well as the private organizations are sharing R&D investments in cleaner technologies. Those organizations progressively provide funds through green banks, issuing green bonds for energy efficiency, offering assistance to prepare infrastructure, or providing rebates on taxes, etc. For example, the US government is providing maximum subsidies of $ 7500 for the purchase of a plug-in electric vehicle (Helveston et al., 2015). Government of India has lunched subsidize "Unnat Jyoti by Affordable LEDs for All" (UJALA) scheme to encourage the use of LED lights across the country and introduced several financial schemes to support green manufacturing (Ujala Yojana, 2015). Government of Malaysia has introduced incentive schemes like tax incentive, consumer incentive, etc., to promote green products (MIDA, 2018). The Energy Efficiency and Conservation Authority (EECA) in New Zealand has introduced "Low Emission Vehicles Contestable Fund" or "Product Standards and Labelling" programmes in perspective of improving environmental and social benefits (EECA, 2018). Department of Environmental Affairs (DEA) of republic of South Africa has implemented "Green Fund Training Programme" to improve environment awareness and provided financial support through various schemes like "Low Carbon Economy"(Green Fund, 2018). Similarly, the Government of United Kingdom has introduced and successfully implemented numerous incentive schemes to promoting green products (Green Deal, 2018). As a result, the consumers are engrossed to purchase the energy-efficient products such as LED bulbs, inverter air conditioners, etc. (Souri et al. 2018). In 2016, consumptions of LED products have accumulated energy savings of 469 trillion British thermal units, which is equivalent to cost savings around $ 4.7 billion (LED Adoption Report, 2017). The above evidences justify that the green supply chain (GSC) members can receive government incentive in different ways. Therefore, it is necessary to compare outcomes of optimal decisions under different government incentive policies to achieve a robust decision support system. However, a few analytical researches on comparative analysis of government's incentive policies on optimal pricing, greening level(GL) decisions, and corresponding consumer surplus(CS) and environmental improvement(EI) impact are studied under different criterion.

The fundamental aim of this study is to explore the answers of the following research issues:
(i) How do game structures and government incentive policies affect the GL?
(ii) Which type of incentive stimulates the manufacturer to produce greener products?
(iii) Is the motive of the government always contemporaneous with GSC members to enhance GL instead of their respective profits?
(iv) How do the CS, EI, and social welfare(SW) change with the incentive policies?

To find answers to the above research questions, twelve analytical models are formulated to consider the impact of two game structures, single and two-period procurement decisions, and two incentive types along with benchmark no-incentive models. In the literature, the business relationship among supply chain participants are commonly explored in a single period setting. In practice, the interaction continues for multiple number of periods. Consequently, growing interests of the researchers are mentioned to explore characteristics of two-period decision(Hartwig et al. 2015; Mantin and Jiang, 2017; Nielseni et al. 2019). Anand et al. (2008) established that two-period procurement planning in the presence of strategic inventory (SI) under the manufacturer's Stackelberg (MS) game could reduce the double-marginalization effect. Consequently, both the retailer and manufacturer receive higher profits. Therefore, it is necessary to compare the performance of two-period procurement planning by benchmarking single-period model in the presence of different incentive policies. In two-period procurement planning, the manufacturer decides wholesale price and GL, and the retailer decides retail price and volume of SI in first period. In second period, the manufacturer and retailer decide wholesale and retail price respectively. According to Zhu and He (2017), green products can be classified mainly in two categories based on the investment decision. Firstly, the development intensive green products (DIGPs) such as developing LED bulbs, energy star home appliances, high-speed electric cars, those require a substantial amount of R&D investments to adopt new green technologies. Secondly, the marginal cost-intensive green products (MIGPs) like installation of lithium-ion car batteries, an automotive emission control device, usage of scrap aluminum in electronic devices for which manufacturing cost vary with unit product. This study considers two incentive policies. In incentive Policy T, the manufacturer receives incentive on total R&D investment. Therefore, government incentive policy promotes

DIGPs. In contrast, the manufacturer receives incentive on per unit product under incentive Policy U. Therefore, government incentive policy promotes MIGPs. Consequently, manufacturers need to decide how to set GL and wholesale price based on incentive policy. For example, government incentives on electric vehicles are common in several countries, and car manufacturers can receive subsidy on the overall R&D investment or per unit product to reduce emission. Therefore, it is necessary to make the comparative analyses of outcomes of different incentive policies in perspectives of achieving social and environmental gaols. Additionally, pricing decision is highly correlated with the power structure of the GSC members. Consequently, models are formulated under both MS and retailer's Stackelberg (RS) game framework to assess the impact of incentive policy. Optimal selection schemes are determined under three different goals of the manufacturer. The impact of government decision is also analyzed by considering the SW optimization. It is found that, irrespective of whether the manufacturer is receiving incentives from the government or not, the profit of the manufacturer and GL are optimum in a two-period setting under MS game whereas the profits of the retailer and GL are optimum in a single-period setting under RS game. Because, the production green products at the highest level is in sync with optimal profitability.

1.1 Literature review

This study is largely apprehensive with three branches namely supply chain game structure, influence of SI, and government incentives. In the following paragraphs, a brief discussion is provided on these three branches.

Supply chain game structure is correlated with the sequence of actions of participating members. The member who makes decision first is considered to have more power over other members. To model this situation with a power retailer, Xiao et al. (2014); Chen et al. (2017); Li et al. (2018b) etc. used Stackelberg game in which the retailer specifies the retail margin first. Powerful retailers like Wal-Mart, Lowe's, Fotex, HomeDepot, Costco, Kroger etc. have strong bargaining power and dominate the market. In this study, the interactions between GSC members are analyzed under two non-cooperative game structures by assuming that the first mover has more power (Anupindi and Bassok 1999; We and Jing 2018; Dey et al. 2018). From the perspective of GSC, Chen et al. (2017) examined the impact of power relationships and coordination in a GSC, and concluded that dominant members should not exploit their power over the other members, in order to achieve overall sustainability. Hong et al. (2018) compared pricing strategy between green and regular product by considering GL as parameter. The authors found that consumers' environmental awareness and quality of green product are key parameters effecting pricing decision. Jamali and Rasti-Barzoki (2018) studied a GSC model in both centralized and decentralized environment and found that public awareness was required to motivate people to purchase green products. Heydari et al. (2018) studied pricing policy of a three-tier dual channel GSC where the distributor operated a direct channel. The authors proved that the manufacturer needs to produce at higher GL if consumer green-level elasticity for direct channel is higher. Moreover, environmental performance could prolong the perception of value creation beyond purely financial aspects (Joyce and Paquin, 2016; Fang and Zhang, 2018). Therefore, it is necessary to explore the optimal decisions under two game structures to obtain a comparative overview.

In the existing literature on GSC management in deterministic environment, characteristics of optimal decisions are analyzed in a single-period setting (Li et al. 2016; Basiri and Heydari 2017a; Song and Gao 2018). However, in practice, interactions among supply chain members continue more than single period and retailers keep a reasonable amount of inventory to eradicate possibility of shortages in between two consecutive procurements. Anand et al. (2008) suggested that the retailer could keep SI in between two consecutive selling periods to force the manufacturer to reduce wholesale price in the forthcoming period. After the pioneer introduction, SI received considerable attention in supply chain literature (Arya and Mittendorf 2013; Moon et al. 2018; Nielsen and Saha 2018). In practice, excess inventory exists because of strategic purpose (Martínez-de-Albéniz and Simchi-Levi, 2013). Hartwig et al. (2015) studied empirically a two-period supply chain model under MS game with price-sensitive demand and reported that SI had a double benefit: it reduced wholesale prices as well as minimized the double marginalization effect. Mantin and Jiang (2017) investigated the manufacturer-retailer interaction by considering the effect of quality deterioration and SI. The authors reported that product deterioration might be considered from the perspective of overall supply chain and then the retailer needed to reduce SI. Dey and Saha (2018) studied the impact of SI on GSC under MS game setting and concluded that the retailer's strategic decision not only improved the profit of each member but also encouraged the manufacturer to improve GL. Roy et al. (2018) claimed that retailers inventory was important in multiperiod contracts where inventory could be hold by the retailer between successive periods. However, the impact of SI is yet to be explored in presence of government incentives.

Several researchers explored the influence of government incentives to reduce environmental impact and improve sustainable conditions (Hafezalkotob 2015, 2018b; Wei et al.

2018). Rajeev et al. (2017) surveyed the evolution of sustainability in GSC management, and noted that international agreements such as the Kyoto Protocol, the Copenhagen Climate Change Summit along with government interventions had a remarkable effect on the negative impact of poor environmental practices. Dania et al. (2018) reported that the characteristics of products, regulations, socio-economic context and active participation of both government and non-government organizations were major factors affecting sustainable agricultural practices. Jia et al. (2018) conducted a literature review on GSC from the perspective of developing countries like Brazil, China, India, Malaysia, and South Africa. They noted that lack of government support and unsupportive culture were major barriers for GSC. Krass et al. (2013) explored the role of environmental taxes and fixed-cost subsidies on the choice of innovative and green emissions-reducing technologies of a firm. They showed that an initial tax hike encouraged the use of greener technology, but further tax hikes did not promote. Lu and Shao (2016) found that the effects of government subsidies on price sensitivity and performance level sensitivity were noteworthy. Droste et al. (2016) developed a framework to explain the emergence of sustainable innovations and found that government intervention played a stimulating role in achieving a greener economy. Hafezalkotob (2018a) compared the influence of direct and indirect intervention policies of the government under MS game framework and found that the influence of government intervention was lower for tradable permits compared to direct tariffs. He et al. (2019) explored the impact of government incentive policy on the consumers in a dual-channel closed-loop supply chain. The authors found that amount of subsidy was crucial for the manufacturer's to select channel structures and the manufacturer preferred to sell new products directly to consumers if the government's subsidy level was relatively low. Table 1 presents a summary of some recently published research on government incentive policy and highlights the contribution of the present study.

Table 1
Comparison of existing models with the current study

Study	Game structure	Period	GL dependent demand	SI	Nature of government incentive
Yang and Xiao (2017)	MS, RS, and Nash	Single	Yes	No	per unit product to manufacturer
Heydari et al. (2017b)	MS	Single	No	No	per unit product to both manufacturer and retailer
Madani and Rasti-Barzoki (2018a)	MS	Single	Yes	No	per unit product to consumer
Chen et al. (2018)	MS	Single	No	No	per unit product to manufacturer and retailer
Sinayi and Rasti-Barzoki (2018b)	MS	Single	Yes	No	per unit product to consumer
Hafezalkotob (2018a)	MS	Single	No	No	per unit product to consumer
Yuyin and Jinxi (2018)	MS	Single	Yes	No	per unit product to manufacturer
Li et al. (2018a)	MS	Single	No	No	per unit product to consumer
Li et al. (2018c)	MS	Single	No	No	per unit product to manufacturer
He et al. (2019)	MS	Single	No	No	per unit remanufactured product to manufacturer
Giri et al. (2019)	MS and RS	Single	No	No	per unit product to consumer
Safarzadeh and Rasti-Barzoki (2019a)	MS, RS and Nash	Single	No	No	per unit product to both manufacturer and consumer
Safarzadeh and Rasti-Barzoki (2019b)	MS	Single	No	No	R&D investment to manufacturer
Present study	MS and RS	Single and two	Yes	Yes	R&D investment and per unit product to manufacturer

From Table 1, it is observe that government organizations provide incentive in different ways. However, comparative study to explore preferences of the GSC member in presence of the different incentive policies and procurement decisions are not analyzed in the previous literature. Moreover, it is necessary to compare outcomes in the perspective of profits of each GSC members as well as sustainability goal of government organizations. In this study, the behavior patterns of the manufacturer regarding environment-friendly product are explored by correlating optimal decision with three different criterion.

2. Problem description

This study considers a bilateral monopoly in a two-period GSC with single retailer and single manufacturer under both MS and RS games. The manufacturer produces a green product and sells through an independent retailer. The manufacturer receives two types of incentives from the government in producing green products. Figure 1 represents the framework of the proposed study.

Insert Figure 1

Scenarios are indexed by jkl where the first index represents incentive type, i.e., on total R&D investment(t), incentive on per unit product(u), and without incentive(w)($j = t, u, w$). Second index represents game type, i.e., MS(m) and RS(r) games($k = m, r$). Third index represents procurement process in presence of SI in two-period decision model(i) and the benchmark single-period(s) decision ($l = i, s$). In the first procurement process, the retailer determines retail price and amount of SI, and manufacturer determines wholesale price and GL in first-period. In second-period, the retailer and manufacturer determine retail and wholesale price, respectively. In the benchmark single-period decision, the retailer determines retail price and manufacturer determines wholesale price and GL in each period.

To distinguish the outcomes in different scenarios, the following notations are used:

a	potential intrinsic demand in each period
b	price sensitivity
c	GL sensitivity
β	coefficient of R&D investment for the manufacturer
h	per unit holding cost
w_{nk}^{jl}	wholesale price per unit, n= 1,2
p_{nk}^{jl}	retail price per unit, n= 1,2
I_k^{jl}	amount of SI ($I_k^{jl} \geq 0$)
π_{rk2}^{jl}	retailer's profit in second-period
π_{mk2}^{jl}	manufacturer's profit in second-period
π_{rk}^{jl}	retailer's total profit in two consecutive selling periods
π_{mk}^{jl}	manufacturer's total profit in two consecutive selling periods
Q_k^{jl}	total sales volume in two consecutive selling periods
θ_k^{jl}	GL of the product
η	incentive cost coefficient in presence of incentive on per-unit product
γ	incentive cost coefficient in presence of incentive on total R&D investment

The following assumptions are made to formulate analytical models:
(i) Similar to Ghosh and Shah (2015); Yang and Xiao (2017); Song and Gao (2018), it is assumed that the demand functions in each selling period is linearly decreasing in retail price and increasing in GL. The functional forms of market demand are as follows:

$$D_n = a - bp_n + c\theta, \text{ n =1,2}$$

and the corresponding R&D investment cost is considered as $\beta\theta^2$. It ensures that a higher investment is required to produce products with a higher GL. It is assumed that the retail (p_n) and wholesale prices (w_n) in each period satisfy the relations $p_n > w_n$, $n = 1, 2$. Manufacturers like Tesla, General Electric, Ameren, NextEra Energy, Ameren, DentalEZ, Royal Apparel, Samsung Electronics, Godrej Appliances, Electrolux are continuing their business with unchanged product features within the anticipated life cycle, and retailers procure several times before an upgraded/new version is introduced on the market. For example, global electric car manufacturer Tesla rehabilitated electric green car model the Tesla Model S in 2016 although it is available in market from 2012. Clarion launches Eco-Marks products on an approximately yearly basis. Fast-selling electric car variants in 2014 such as Nissan Leaf, Tesla Model S or Renault Zoe are still available on the market. Consequently, it is assumed that the GL is not changed between the two consecutive selling periods until the products are obsolete.

(ii) The impact of two government incentive policies is analyzed. In Policy T, the government offers incentives on the total R&D investment (Yuyin and Jinxi, 2018). Therefore, the contribution from the government at each period is $\gamma\beta\theta^2$, ($0 \leq \gamma \leq 1$)(Dey and Saha 2018). In Policy U, the government provides incentives on per-unit product (Li et al., 2018c). Therefore, the contribution from the government is $\eta\theta(a - bp_n + c\theta)$ at n-th period ($\eta > 0$). The amount of incentive increases with the GL under both policies. In June 2011, the Chinese government offered incentives directly to the car manufacturers up to USD 9,281 for producing each unit of battery electric vehicles and USD 7,634 for plug-in hybrids cars. On the other hand, the Department of Energy (DOE) in USA is helping the manufacturers in producing green products through loans, grants, and financial programmes. To promote the manufacturing of solar photovoltaic cells and modules, in 2017, the Government of India proposed financial support of 1.5 billion USD directly to the manufacturers. Moreover, the Government of India is also providing grants up to 90% of the entire project cost to the electricity distribution companies (DISCOMs) which enable them to sell LED bulbs at a rate of $0.154 each against their market price of $2.3 - 3.08 through the Unnat Jyoti by Affordable LEDs for all (Ujala Yojana, 2015) schemes. Similarly, various green incentive schemes are available in country like Canada (Environment and Business - Canada Business, 2018) where the manufacturers receive incentive directly from the government organizations.

(iii) The delivery lead time between the manufacturer and retailer is negligible (Mantin and Jiang, 2017; Dey and Saha, 2018). It is assumed that the parameters are deterministic and their values are reckoned from common knowledge among the participants of GSC (Yuyin and Jinxi, 2018). Cachon et al. (2018) mentioned that "adding inventory can increase sales for several reasons". Referring to Anand et al. (2008); Hartwig et al. (2015), it is assumed that $a > 4bh$.The relation ensures non-negative profits for GSC members. If holding cost of product is too high, then aggregate demand may be negative. To ensure second order conditions of optimality (Appendices A and B) and avoid infeasible optimal decision for each scenario under incentive Policy T and U, it is assumed that $4b\beta(1-\gamma) > c^2$ and $4b\beta > (c+b\eta)^2$, respectively. By combining two inequalities, one can obtain $\beta > \max\left\{\frac{c^2}{4b(1-\gamma)}, \frac{(c+b\eta)^2}{4b}\right\}$. If $\gamma = \eta = 0$, then the relations are similar to the studies of Ghosh and Shah (2015), Song and Gao (2018), Patra (2018). However, the restrictions among parameters indicates that the government incentive should not be too high if the manufacturer is efficient enough in R&D investment and consumers are less price sensitive but impressively green product sensitive. If consumers are not aware about pros and cons of green product then government subsidy is necessary. Therefore, policy makers needs to develop effective incentive policies for green manufacturing industries with a clear understanding of what drives consumers to procure products and manufacturers to invest on those. For example, in India use of plug-in electric vehicles still remains unpopular in country's overall transport system. Therefore, to stimulate purchase and grow awareness among consumers, the government of India very recently introduced a subsidy plan of \$1.4 billion to promote the electric vehicle industry (Bahree, 2019). The relation ensures that the R&D investment efficiency and consumer sensitivity on green product are critical in perspective of feasible outcomes. Throughout this study, it is assumed that the parameters hold above two inequalities.

(iv) Optimal decisions are derived under MS and RS games. Under MS game, the manufacturer sets wholesale price and GL, and then the retailer sets retail price and amount of SI. Under RS game, the retailer sets the profit margin and amount of SI first, then the manufacturer sets wholesale price and GL. A backward induction method is used to explore the hierarchical game between GSC members.

3. Model

In this section, profit structures for different scenarios are defined and properties of corresponding optimal solutions are discussed.

3.1 Optimal decisions under incentive Policy T

In Scenario TMI, the manufacturer determines wholesale price (w_{1m}^{ti}) and GL (θ_m^{ti}) in first-period. Based on the manufacturer's decisions, the retailer sets retail price (p_{1m}^{ti}) and decides amount of SI ($I_m^{ti} \geq 0$) which is to be carried forward in second-period. In second-period, the manufacturer sets wholesale price (w_{2m}^{ti}), and then retailer sets retail price (p_{2m}^{ti}). The second-period profit functions for the retailer and manufacturer under MS game are as follows:

$$\pi_{rm2}^{ti}(p_{2m}^{ti}) = p_{2m}^{ti}(a - bp_{2m}^{ti} + c\theta_m^{ti}) - w_{2m}^{ti}(a - bp_{2m}^{ti} + c\theta_m^{ti} - I_m^{ti}) \tag{1}$$

$$\pi_{mm2}^{ti}(w_{2m}^{ti}) = w_{2m}^{ti}(a - bp_{2m}^{ti} + c\theta_m^{ti} - I_m^{ti}) - (1-\gamma)\beta(\theta_m^{ti})^2 \tag{2}$$

Finally, the cumulative profit functions for the retailer and manufacturer in two successive periods are obtained as follows:

$$\pi_{rm}^{ti}(p_{1m}^{ti}, I_m^{ti}) = (p_{1m}^{ti} - w_{1m}^{ti})(a - bp_{1m}^{ti} + c\theta_m^{ti}) - (w_{1m}^{ti} + h)I_m^{ti} + \pi_{rm2}^{ti}(\theta_m^{ti}, I_m^{ti}) \tag{3}$$

$$\pi_{mm}^{ti}(w_{1m}^{ti}, \theta_m^{ti}) = w_{1m}^{ti}(a - bp_{1m}^{ti} + c\theta_m^{ti} + I_m^{ti}) - (1-\gamma)\beta(\theta_m^{ti})^2 + \pi_{mm2}^{ti}(\theta_m^{ti}, I_m^{ti}) \tag{4}$$

Profit functions for the GSC members in Scenario TMS are as follows:

$$\pi_{rm2}^{ts}(p_{2m}^{ts}) = (p_{2m}^{ts} - w_{2m}^{ts})(a - bp_{2m}^{ts} + c\theta_m^{ts}) \tag{5}$$

$$\pi_{mm2}^{ts}(w_{2m}^{ts}, \theta_m^{ts}) = w_{2m}^{ts}(a - bp_{2m}^{ts} + c\theta_m^{ts}) - (1-\gamma)\beta(\theta_m^{ts})^2 \tag{6}$$

Therefore, the total profits in two successive periods for the retailer and manufacturer in Scenario TMS are $\pi_{rm}^{ts} = 2\pi_{rm2}^{ts}$ and $\pi_{mm}^{ts} = 2\pi_{mm2}^{ts}$, respectively.
In Scenario TMI, the second period profit functions will be a function of θ_m^{ti} and I_m^{ti}. Therefore, the impact of second-period profit function needs to be considered in order to determine overall profit in two successive periods. Commonly used transformation $m_n = p_n - w_n, (n = 1, 2)$ is employed to obtain the optimal decision under RS game (Chen et al. 2017). Simplified values of equilibrium outcomes for four scenarios are presented in Table 2. Detailed derivations for optimal decision in Scenarios TMI and TRI are presented in Appendix A and B, respectively.

Table 2
Optimal decisions in Scenarios TMI,TMS, TRI, and TRS

Sce.	MI	MS	RI	RS
w_{1k}^{tl}	$\frac{4(9a-2bh)\beta(1-\gamma)}{\Delta_1}$	$\frac{4a\beta(1-\gamma)}{\Delta_2}$	$\frac{512b(a-bh)\beta^2(1-\gamma)^2+4c^2(8a+19bh)\beta(1-\gamma)+c^2h\Delta_4}{128b\beta(1-\gamma)\Delta_3}$	$\frac{a\beta(1-\gamma)}{\Delta_4}$
w_{2k}^{tl}	$\frac{2(2(6a+7bh)\beta(1-\gamma)+3h\Delta_4)}{\Delta_1}$	$\frac{4a\beta(1-\gamma)}{\Delta_2}$	$\frac{32b(4a+bh)\beta^2(1-\gamma)^2+32a\Delta_4\beta(1-\gamma)+56bh\Delta_4\beta(1-\gamma)+c^4h}{64b\beta(1-\gamma)\Delta_3}$	$\frac{a\beta(1-\gamma)}{\Delta_4}$
p_{1k}^{tl}	$\frac{4(13a-2bh)\beta(1-\gamma)+\Delta_4h}{\Delta_1}$	$\frac{6a\beta(1-\gamma)}{\Delta_2}$	$\frac{32b(12a-5bh)\beta^2(1-\gamma)^2+24(4a-bh)\beta(1-\gamma)\Delta_4+3c^4h}{64b\beta(1-\gamma)\Delta_3}$	$\frac{a(6b\beta(1-\gamma)-c^2)}{2b\Delta_4}$
p_{2k}^{tl}	$\frac{2(23a+2bh)\beta(1-\gamma)+4\Delta_4h}{\Delta_1}$	$\frac{6a\beta(1-\gamma)}{\Delta_2}$	$\frac{64b(14a-bh)\beta^2(1-\gamma)^2+16c^2(10a+9bh)\beta(1-\gamma)\Delta_4+5c^4h}{128b\beta(1-\gamma)\Delta_3}$	$\frac{a(36b\beta(1-\gamma)-c^2)}{2b\Delta_4}$
θ_k^{tl}	$\frac{c(9a-2bh)}{\Delta_1}$	$\frac{ac}{\Delta_2}$	$\frac{32c(3a-bh)\beta(1-\gamma)+3c^3h}{64\beta(1-\gamma)\Delta_3}$	$\frac{ac}{2\Delta_4}$
I_k^{tl}	$\frac{5b(2(a-4bh)\beta(1-\gamma)+c^2h)}{\Delta_1}$	-	$\frac{8(ac^2\beta(1-\gamma)-2h{\Delta_2}^2)+c^2(24(a-4bh)\beta(1-\gamma)+h(32b\beta(1-\gamma)+15c^2))}{128\beta\Delta_3}$	-
π_{rk}^{tl}	$\frac{2b\Psi_1}{\Delta_1^2}$	$\frac{8a^2b\beta^2(1-\gamma)^2}{\Delta_2^2}$	$\frac{256((a-2bh)^2+3abh)\beta^2(1-\gamma)^2+64h(a+3bh)h\beta(1-\gamma)\Delta_4+c^4h^2}{256\beta(1-\gamma)\Delta_3}$	$\frac{a^2\beta(1-\gamma)}{\Delta_4}$
π_{mk}^{tl}	$\frac{2(8a^2+(a-2bh)^2)\beta(1-\gamma)+2b\Delta_4h^2}{\Delta 1}$	$\frac{2a^2\beta(1-\gamma)}{\Delta_2}$	$\frac{\Psi_2}{16384b\beta^2(1-\gamma)^2{\Delta_3}^2}$	$\frac{a^2\beta(1-\gamma)}{2\Delta_4}$
Q_k^{tl}	$\frac{b(2(19a-8bh)\beta(1-\gamma)+c^2h)}{\Delta_1}$	$\frac{4ab\beta(1-\gamma)}{\Delta_2}$	$\frac{(32(a-bh)\beta(1-\gamma)+h(28b\beta(1-\gamma)+\Delta_4))(28b\beta(1-\gamma)+\Delta_4)}{128\beta(1-\gamma)\Delta_3}$	$\frac{2ab\beta(1-\gamma)}{\Delta_4}$

where $\Delta_1 = 68b\beta(1-\gamma) - 9c^2$; $\Delta_2 = 8b\beta(1-\gamma) - c^2$; $\Delta_3 = 16b\beta(1-\gamma) - 3c^2$; $\Delta_4 = 4b\beta(1-\gamma) - c^2$.
Appendix K is referred to the reader for the details of all the additional notations used in Table 2 and next two tables. Therefore, second order condition of optimality holds and feasible solution exists in four scenarios under incentive Policy T if $\Delta_x > 0, x = 1, 2, 3, 4$, i.e. if $4b\beta(1-\gamma) > c^2$. Based on the optimal decisions, the following proposition is proposed:

Proposition-1: In incentive Policy T
(i) the cumulative profits for the manufacturer satisfy $\pi^{ti}_{mm} \geq \pi^{ts}_{mm}$ under MS game
(ii) the cumulative profits for the retailer satisfy $\pi^{ts}_{rr} \geq \pi^{ti}_{rr}$ under RS game
(iii) optimal GLs satisfy $\theta^{ti}_{m} \geq \theta^{ts}_{m}$ under MS game, but optimal GLs satisfy $\theta^{ts}_{r} \geq \theta^{ti}_{r}$ under RS game
(iv) under MS game the retail and wholesale prices satisfy $p^{ti}_{1m} \geq p^{ti}_{2m}$ and $w^{ti}_{1m} \geq w^{ti}_{2m}$, respectively
(v) under RS game the retail and wholesale prices satisfy $p^{ti}_{1r} \leq p^{ti}_{2r}$ and $w^{ti}_{1r} \geq w^{ti}_{2r}$, respectively
(vi) amount of SI increases with respect to γ under both game structures
(vii) GLs of the product increase with respect to γ, but decrease with respect to h under both game structures.
Proof: See Appendix C.

Propositions 1 reflects the influence of SI under different game structures. The manufacturer receives higher profits in two-period setting under MS game, but the retailer receives higher profits by executing single-period procurement planning under RS game. The relation between retail prices demonstrates that consumers need to pay less in second-period if the retailer maintains SI under MS game, not in RS game. The retail price of the product and investment cost are crucial drivers of GSCM (Wang et al., 2018). This study also demonstrates the similar nature. The manufacturer is bound to reduce wholesale price in second-period if the retailer maintains SI(Mantin and Jiang, 2017). However, the single-period procurement decision is preferred by the retailer under RS game. The manufacturer has more flexibility in R&D investment in presence of government financial support. Consequently, GLs are also increased with respect to government incentives. If holing cost of the retailer increases, the overall system cost of GSC also increases. In that scenario, the retailer needs to increase retail price to compensate cost and consequently overall demand decreases. Therefore, GLs decrease in both game structures. Finally, in presence of government incentive, the manufacturer has more bargaining power as a stackelberg leader and consequently the retailer needs to carry more products as SI for wholesale price negotiation. The results also demonstrate the fact. The graphical representation of the cumulative profits for the retailer and manufacturer, and GLs under RS game are shown in Figures 2a-2c. Throughout the article, the following parameter values are used for numerical illustration: $a = 200$, $b = 0.5$, $h = 10$(\$/unit/selling period), $\beta = 1$, $c \in (0.2, 0.5)$, $\gamma \in (0, 0.5)$ and $\eta \in (0.1, 0.8)$. Note that technical restrictions on parameters values are considered to ensure second-order optimality conditions for numerical illustration.

Insert Figures 2a- 2c

The above figures support the analytical findings and demonstrate that the GLs and profits of each member increase with the consumer sensitivity with GL and government incentive which are quite realistic. The results suggest that if the retailer is powerful enough and holding cost is too high (see Appendix B), then the retailer should not build up SI. When the manufacturer is leader, two-period planning outperforms single-period decision in terms of GL and individual profits.

3.2 Optimal decisions under incentive Policy U

In this subsection, optimal decisions under the incentive Policy U are derived. The second-period profit functions for the retailer and manufacturer in Scenario UMI are obtained as follows:

$$\pi^{ui}_{rm2}(p^{ui}_{2m}) = p^{ui}_{2m}(a - bp^{ui}_{2m} + c\theta^{ui}_{m}) - w^{ui}_{2m}(a - bp^{ui}_{2m} + c\theta^{ui}_{m} - I^{ui}_{m}) \tag{7}$$

$$\pi^{ui}_{mm2}(w^{ui}_{2m}) = (w^{ui}_{2m} + \eta\theta^{ui}_{m})(a - bp^{ui}_{2m} + c\theta^{ui}_{m} - I^{ui}_{m}) - \beta(\theta^{ui}_{m})^2 \tag{8}$$

The cumulative profits for the GSC members in two successive selling periods are as follows:

$$\pi^{ui}_{rm}(p^{ui}_{1m}, I^{ui}_{m}) = (p^{ui}_{1m} - w^{ui}_{1m})(a - bp^{ui}_{1m} + c\theta^{ui}_{m}) - (w^{ui}_{1m} + h)I^{ui}_{m} + \pi^{ui}_{rm2}(\theta^{ui}_{m}, I^{ui}_{m}) \tag{9}$$

$$\pi^{ui}_{mm}(w^{ui}_{1m}, \theta^{ui}_{m}) = (w^{ui}_{1m} + \eta\theta^{ui}_{m})(a - bp^{ui}_{1m} + c\theta^{ui}_{m} + I^{ui}_{m}) - \beta(\theta^{ui}_{m})^2 + \pi^{ui}_{mm2}(\theta^{ui}_{m}, I^{ui}_{m}) \tag{10}$$

The second-period profit functions for the GSC members in Scenario UMS are obtained as follows:

$$\pi^{us}_{rm2}(p^{us}_{2m}) = (p^{us}_{2m} - w^{us}_{2m})(a - bp^{us}_{2m} + c\theta^{us}_{m}) \tag{11}$$

$$\pi^{us}_{mm2}(w^{ub}_{2m}, \theta^{us}_{m}) = (w^{us}_{2m} + \eta\theta^{us}_{m})(a - bp^{us}_{2m} + c\theta^{us}_{m}) - \beta(\theta^{us}_{m})^2 \tag{12}$$

Therefore, $\pi^{us}_{rm} = 2\pi^{us}_{rm2}$ and $\pi^{us}_{mm} = 2\pi^{us}_{mm2}$. The profit functions under RS game can be obtained by using transformation as mentioned earlier. Simplified values of equilibrium outcomes for four scenarios are presented in Table 3. The detail derivations are similar to the previous subsection and thus are omitted.

Table 3

Optimal decisions in Scenarios UMI, UMS, URI, and URS

Sce.	MI	MS	RI	RS
w_{1k}^{ul}	$\frac{(9a-2bh)(4\beta-\eta(c+b\eta))}{\Delta_5}$	$\frac{a(4\beta-c\eta-b\eta^2)}{\Delta_6}$	$\frac{\Sigma_1}{128b\beta\Delta_7}$	$\frac{a(2\beta-\eta(c+b\eta))}{2\Delta_8}$
w_{2k}^{ul}	$\frac{8(3a+5bh)\beta-c(9a+10bh)\eta-b(9a+4bh)\eta^2-6c^2h}{\Delta_5}$	$\frac{a(4\beta-c\eta-b\eta^2)}{\Delta_6}$	$\frac{\Sigma_2}{64b\beta\Delta_7}$	$\frac{a(2\beta-\eta(c+b\eta))}{2\Delta_8}$
p_{1k}^{ul}	$\frac{52a\beta-4bh\beta-9ac\eta-b(9a-bh)\eta^2-c^2h}{\Delta_5}$	$\frac{a(6\beta-c\eta-b\eta^2)}{\Delta_6}$	$\frac{\Sigma_3}{192\beta\Delta_7}$	$\frac{a(6b\beta-(c+b\eta)(c+2b\eta))}{2b\Delta_8}$
p_{2k}^{ul}	$\frac{(46a+20bh)\beta-3c(3a+2bh)\eta-b(9a+2bh)\eta^2-4c^2h}{\Delta_5}$	$\frac{a(6\beta-c\eta-b\eta^2)}{\Delta_6}$	$\frac{\Sigma_4}{64b\beta\Delta_7}$	$\frac{a(6b\beta-(c+b\eta)(c+2b\eta))}{2b\Delta_8}$
θ_k^{ul}	$\frac{(9a-2bh)(c+b\eta)}{\Delta_5}$	$\frac{a(c+b\eta)}{\Delta_6}$	$\frac{(c+b\eta)(96a\beta-h(32b\beta-3(c+b\eta)^2))}{64\beta\Delta_7}$	$\frac{a(c+b\eta)}{2\Delta_8}$
I_k^{ul}	$\frac{5b(2a\beta-h\Delta_6)}{\Delta_5}$	-	$\frac{256b(6a-bh)\beta^2-\Delta_7\Sigma_5}{1152\beta\Delta_7}$	-
π_{rk}^{ul}	$\frac{2b\Psi_3}{81{\Delta_5}^2}$	$\frac{8a^2b\beta^2}{{\Delta_6}^2}$	$\frac{256(6a-bh)^2\beta^2+h\Delta_7(96a\beta+\Sigma_5)}{2304\beta\Delta_7}$	$\frac{a^2\beta}{\Delta_8}$
π_{mk}^{ul}	$\frac{18a^2\beta-2bh(4a\beta-h\Delta_6)}{\Delta_5}$	$\frac{2a^2\beta}{\Delta_6}$	$\frac{\Psi_4}{16384b\beta^2{\Delta_7}^2}$	$\frac{a^2\beta}{2\Delta_8}$
Q_k^{ul}	$\frac{b(38a\beta+h(16b\beta-(c+b\eta)^2))}{\Delta_5}$	$\frac{4ab\beta}{\Delta_6}$	$\frac{(32b\beta-(c+b\eta)^2)(32a\beta-h(c+b\eta)^2)}{128\beta\Delta_7}$	$\frac{2ab\beta}{\Delta_8}$

where $\Delta_5 = 68b\beta - 9(c+b\eta)^2$, $\Delta_6 = 8b\beta - (c+b\eta)^2$,$\Delta_7 = 16b\beta - 3(c+b\eta)^2$, $\Delta_8 = 4b\beta - (c+b\eta)^2$. Therefore, second order condition of optimality holds and feasible solution exists in four scenarios under incentive Policy U if $\Delta_x > 0$ $(x = 5, 6, 7, 8)$, i.e. if $4b\beta > (c+b\eta)^2$. Based on the optimal decisions in Table 3, the following proposition is proposed:

Proposition-2: In incentive Policy U

(i) the cumulative profits for the manufacturer satisfy $\pi_{mm}^{ui} \geq \pi_{mm}^{us}$ under MS game

(ii) the cumulative profits for the retailer satisfy $\pi_{rr}^{us} \geq \pi_{rr}^{ui}$ under RS game

(iii) optimal GLs satisfy $\theta_m^{ui} \geq \theta_m^{us}$ under MS game, but optimal GLs satisfy $\theta_r^{us} \geq \theta_r^{ui}$ under RS game

(iv) under MS game the retail and wholesale prices satisfy $p_{1m}^{ui} \geq p_{2m}^{ui}$ and $w_{1m}^{ui} \geq w_{2m}^{ui}$, respectively

(v) under RS game the retail and wholesale prices satisfy $p_{1r}^{ui} \leq p_{2r}^{ui}$ and $w_{1r}^{ui} \geq w_{2r}^{ui}$, respectively

(vi) amount of SI increases with respect to η under both game structures

(vii) GLs of the product increase with respect to η, but decrease with respect to h under both game structures.

Proof: See Appendix D.

Similar to the previous subsection, Proposition 2 ensures that the retailer prefers SI under MS game. The single-period procurement decision is preferred by the retailer under RS game. Graphical representations of profits for GSC members and GLs under RS game are given below:

Insert Figures 3a-3c

Figures 3a-3c justify the analytical findings. Similar to incentive Policy T, GL and profits for each member increase with the consumer sensitivity with GL and the rate of the government incentive. Overall, Propositions 1 and 2 imply that a power retailer should not build up SI is holding cost is too large (see Appendix B). The retailer needs to keep SI under MS game to negotiate wholesale price with the manufacturer. Therefore, the retailer should not maintain high amount of SI in expense of additional holding cost under RS game. Additionally, the retail price difference demonstrates that the retailer needs to charge higher price in second-period to compensate increasing cost. Consequently, two-period procurement planning under RS game leads to suboptimal profits for the GSC members. If the government organizations provide incentive, then total investment to improve GL is also increased. The increasing natures of GLs with respect to incentive rates also support the outcomes.

3.3 Optimal decisions in absence of incentives

To analyze the impact of the government incentive more exclusively, the optimal decisions are derived where the manufacturer does not receive any incentive. By substituting $\gamma = 0$ in Equations (1)-(6) and $\eta = 0$ in Equations (7)-(12), the profit functions are obtained for GSC members in absence of any types of incentives and the optimal decisions are shown in Table 4.

Table 4

Optimal decisions in Scenarios WMI, WMS, WRI, and WRS

Sce.	MI	MS	RI	RS
w_{1k}^{wl}	$\frac{4(9a-2bh)\beta}{\Delta_9}$	$\frac{2a\beta}{\Delta_{10}}$	$\frac{512b(a-bh)\beta^2+4c^2(8a+19bh)\beta+c^2h\Delta_{12}}{128b\beta\Delta_{11}}$	$\frac{a\beta}{\Delta_{12}}$
w_{2k}^{wl}	$\frac{2(2(6a+7bh)\beta+3h\Delta_{12})}{\Delta_9}$	$\frac{2a\beta}{\Delta_{10}}$	$\frac{32b(4a+bh)\beta^2+32a\Delta_{12}\beta+56bh\Delta_{12}\beta+c^4h}{64b\beta\Delta_{11}}$	$\frac{a\beta}{\Delta_{12}}$
p_{1k}^{wl}	$\frac{4(13a-2bh)\beta+\Delta_{12}h}{\Delta_9}$	$\frac{3a\beta}{\Delta_{10}}$	$\frac{32b(12a-5bh)\beta^2+24(4a-bh)\beta\Delta_{12}+3c^4h}{64b\beta\Delta_{11}}$	$\frac{a(6b\beta-c^2)}{2b\Delta_{12}}$
p_{2k}^{wl}	$\frac{2(23a+2bh)\beta+4\Delta_{12}h}{\Delta_9}$	$\frac{3a\beta}{\Delta_{10}}$	$\frac{64b(14a-bh)\beta^2+16c^2(10a+9bh)\beta\Delta_{12}+5c^4h}{128b\beta\Delta_{11}}$	$\frac{a(6b\beta-c^2)}{2b\Delta_{12}}$
θ_k^{wl}	$\frac{c(9a-2bh)}{\Delta_9}$	$\frac{ac}{\Delta_{10}}$	$\frac{c(32(3a-bh)\beta+3c^2h)}{64\beta\Delta_{11}}$	$\frac{ac}{2\Delta_{12}}$
I_k^{wl}	$\frac{5b(2(a-4bh)\beta+c^2h)}{\Delta_9}$	-	$\frac{8(ac^2\beta-2h\Delta_{10}{}^2)+c^2(24(a-4bh)\beta+h(32b\beta+15c^2))}{128\beta\Delta_{11}}$	-
π_{rk}^{wl}	$\frac{2b\Psi_5}{\Delta_9^2}$	$\frac{2a^2b\beta}{\Delta_{10}}$	$\frac{256((a-2bh)^2+3abh)\beta^2+64h(a+3bh)h\beta\Delta_{12}+c^4h^2}{256\beta\Delta_{11}}$	$\frac{a^2\beta}{\Delta_{12}}$
π_{mk}^{wl}	$\frac{2(8a^2+(a-2bh)^2)\beta+2b\Delta_{12}h^2}{\Delta 1}$	$\frac{a^2\beta}{\Delta_{10}}$	$\frac{\Psi_6}{16384b\beta^2\Delta_{11}{}^2}$	$\frac{a^2\beta}{2\Delta_{12}}$
Q_k^{wl}	$\frac{b(2(19a-8bh)\beta+c^2h)}{\Delta_9}$	$\frac{2ab\beta}{\Delta_{10}}$	$\frac{(32(a-bh)\beta+h(28b\beta+\Delta_{12}))(28b\beta+\Delta_{12})}{128\beta\Delta_{11}}$	$\frac{2ab\beta}{\Delta_{12}}$

where $\Delta_9 = 68b\beta - 9c^2$, $\Delta_{10} = 8b\beta - c^2$, $\Delta_{11} = 16b\beta - 3c^2$, $\Delta_{12} = 4b\beta - c^2$. Therefore, second order condition of optimality holds and feasible solutions exist in four scenarios in absence of incentive if $4b\beta > c^2$. Next proposition demonstrates the characteristics of optimal decision under no incentive policy.

Proposition-3: If the manufacturer does not receive any incentive, then:
(a) under MS game
(i) the cumulative profits for the manufacturer satisfy $\pi_{mm}^{wi} \geq \pi_{mm}^{ws}$
(ii) optimal GLs satisfy $\theta_m^{wi} \geq \theta_m^{ws}$
(iii) the retail and wholesale prices satisfy $p_{1m}^{wi} \geq p_{2m}^{wi}$ and $w_{1m}^{wi} \geq w_{2m}^{wi}$, respectively
(b) under RS game:
(i) the cumulative profits for the retailer satisfy $\pi_{rr}^{ws} \geq \pi_{rr}^{wi}$
(ii) optimal GLs satisfy $\theta_r^{ws} \geq \theta_r^{wi}$
(iii) the retail and wholesale prices satisfy $p_{1r}^{wi} \leq p_{2r}^{wi}$ and $w_{1r}^{wi} \geq w_{2r}^{wi}$, respectively.
Proof: See Appendix E.

Propositions 1-3 demonstrate that the profits for the manufacturer and GLs are maximum in two-period setting in presence of SI under MS game. In contrast, the profits for the retailer and GLs are maximum in a single-period setting under RS game. It is intuitive that the GLs decrease with respect to holding cost. Although the retailer builds up SI as a strategic move, this does not ensure higher profits under his/her own leadership. Hartwig et al. (2015) identified two positive affect of SI and mentioned that the presence of SI could reduce the average wholesale prices and curtail the double marginalization affect. This study explores another positive affect of SI under government incentive. According to Heydari et al. (2017a), "In the supply chain, a contract is called *Pareto improving* if it can guarantee that after its implementation, the retailer and the supplier are either better off". In this study, it is found that if the retailer maintains SI then both the GSC member receive higher profits. Therefore, retailer's decision generate Pareto-efficient scenario under MS game. The government incentive encourages the retailer to carry high amount of SI, and retailer's strategic decision stimulates the manufacturer to produce product with higher GL under MS game. Generally, retailer carries inventories for products with higher GL in anticipating higher demand. Therefore, the government incentive creates a cascading affect.

Similar to Xie (2016); Sinayi and Rasti-Barzoki (2018); Hong and Guo (2018); one can find the $CS = \sum_{n=1}^{2} \frac{1}{2}(\hat{p}_{nk}^{jl} - {p_{nk}^{jl}}^*){Q_{nk}^{jl}}^*$, where $\hat{p}_{nk}^{jl}$, ${p_{nk}^{jl}}^*$, and ${Q_{nk}^{jl}}^*$ represent the retail price at which no consumer will purchase the green product, optimal retail price, and sales volume at period n respectively. Therefore,the optimal values of CS in Scenarios TMI, UMI, TRS, and URS are respectively obtained as follows:
$CS_m^{ti} = \frac{b(4(a(185a-188bh)+104b^2h^2)\beta^2(1-\gamma)^2+8c^2h(7a-11bh)\beta(1-\gamma)+5c^4h^2)}{2{\Delta_1}^2}$

$CS_m^{ui} = \frac{b(544(9a-2bh)^2\beta^2+(14(9a-2bh)\beta-2h\Delta_5)^2+h^2{\Delta_5}^2)}{162{\Delta_5}^2}$
$CS_r^{ts} = \frac{a^2 b\beta^2(1-\gamma)^2}{{\Delta_4}^2}$
$CS_r^{us} = \frac{a^2 b\beta^2}{{\Delta_8}^2}$
Similarly, $EI = (\hat{\theta_k^{jl}} - \theta_k^{jl^*})Q_k^{jl^*}$ where $\hat{\theta_k^{jl}}$, $\theta_k^{jl^*}$, and $Q_k^{jl^*}$ represent GL in presence of government incentive, GL in absence of incentive, and the optimal sales volume in presence of incentive respectively(Hong and Guo 2018). The optimal values of *EI* in Scenarios TMI, UMI, TRS, and URS are obtained as follows:
$EI_m^{ti} = \frac{68b^2c(9a-2bh)\beta(c^2h+2(19a-8bh)\beta(1-\gamma))\gamma}{{\Delta_1}^2\Delta_9}$
$EI_m^{ui} = \frac{2b^2(9a-2bh)\eta(68b\beta+9c(c+b\eta))((19a\beta-4bh)\beta+\Delta_8)}{{\Delta_5}^2\Delta_9}$
$EI_r^{ts} = \frac{4a^2b^2c\beta^2\gamma(1-\gamma)}{{\Delta_4}^2\Delta_{12}}$,
$EI_r^{us} = \frac{a^2b^2\beta\eta(c^2+4b\beta+bc\eta)}{{\Delta_8}^2\Delta_{12}}$
The amount of government incentive in Scenarios TMI, UMI, TRS, and URS are obtained as follows:
$GI_m^{ti} = 2\gamma\beta{\theta_m^{ti}}^2 = \frac{2(9ac-2bch)^2\beta\gamma}{{\Delta_1}^2}$
$GI_m^{ui} = \eta\theta_m^{ui}Q_m^{ui} = \frac{2b(9a-2bh)\eta(c+b\eta)((19a\beta-4bh)\beta+\Delta_8)}{{\Delta_5}^2}$
$GI_r^{ts} = 2\gamma\beta{\theta_r^{ts}}^2 = \frac{a^2c^2\beta\gamma}{2{\Delta_4}^2}$,
$GI_r^{us} = \eta\theta_r^{us}Q_r^{us} = \frac{a^2b\beta\eta(c+b\eta)}{{\Delta_8}^2}$
Finally, referring to Sheu and Chen (2012), SWs are computed as follows:

$$SW_k^{jl} = EI_k^{jl} + CS_k^{jl} + (\pi_{mk}^{jl} + \pi_{rk}^{jl}) - GI_k^{jl} \tag{13}$$

If one neglects the impact of profits of GSC members, the expression will be similar to Sinayi and Rasti-Barzoki (2018). The graphical representation of SWs in four scenarios are presented in Figures 4a- 4d.

Insert Figures 4a- 4d

One can observe that SWs are concave with respect to government incentive rates. Consequently, it is necessary to compare optimal outcomes when the government sets SW optimization goal. In the next section, comparative analyses are performed in perspective of profits for the GSC members and environmental goal.

4. Managerial insights and discussion

It is observed that, irrespective of game structures, GSC members always receive higher profits in presence of government incentive (See Appendix F) which is consistent with the existing literature. If the government provides incentives, the manufacturer has more flexibility in R&D investment in producing greener product. Because, the demand of the product increases with the GL and profits of the GSC member are also increased. The following proposition is proposed to explore preferences from the perspectives of GSC members and government:

Proposition-4: Irrespective of incentive type, if the manufacturer wants to keep GL unchanged, then:
(i) both the manufacturer and retailer prefer Scenario UMI and URS under MS and RS game, respectively
(ii) the government needs to provide more support under incentive Policy U under both game structures
(iii) the retail price is less, but the CS and EI are higher in incentive Policy U under both game structures.
Proof: See Appendix G.

Proposition 4 demonstrates that incentive Policy U stimulates the manufacturer to produce a greener product. The optimal choices for the GSC members are concurrent under both game structures. For achieving greater sustainability, incentive Policy T leads sub-optimal GL although the government needs to pay less. Graphical representation of GLs is presented in Figure 5.

Insert Figure 5

Figure 5 demonstrates that GL can attain a higher level under RS game. In reality, a powerful retailer always wants to deliver products with higher GL to the consumers for maintaining reputation. Therefore, a shift of power from the manufacturer to retailer can improve sustainability. However, Policy U leads to a superior outcome in general. It is also observed that CS and EI are maximum under the incentive Policy U. These outcomes suggest that a power retailer can force the manufacturer to produce a greener product. Overall, if the manufacturer sets GL, then GSC members can bargain with government organizations to adopt incentive Policy U in order to receive higher profits. Also, the consumers receive products at lower price. In producing and marketing green product, the manufacturer can face financial as well as operational obstacles like more price sensitive or less environmental concerned consumers, threat of implementing complex green technology, compatibility issues with present resource, high cost for technology innovation, etc. Therefore, the manufacturer is bound sometimes to fix GL. Under this circumstances, incentive Policy U can make highest impact on social and environmental measures. The following proposition is proposed to investigate the influence of government incentives when the intention of GSC members is to expand the market.

Proposition-5: Irrespective of incentive type, if the sales volume remains unchanged, then:
(i) profits for the GSC members and CS remain identical under both game structures
(ii) the government needs to provide more support; and GL and EI reach their respective higher end in incentive Policy T under both game structures
(iii) the retail price is less under incentive Policy U in both game structures
Proof: See Appendix H.

Propositions 5 demonstrates that the incentive Policy T encourages GSC members to sell the maximum amount of products with higher GL. This up-selling practice does not ensure higher profitability for GSC members and CS rather it escalates the reputation as they are selling product with higher GL. The optimal sales volumes in four scenarios are presented in Figure 6.

Insert Figure 6

Similar to Figure 5, the sales volume for GSC may also attain higher level under RS game. Combining Figures 5 and 6, one can conclude that GSC members can sell more products with higher profitability under the retailer's leadership. The consumers receive products at lower price under incentive Policy U. Country like India represents large untapped markets. Market expansion strategy is an imperative strategic option for the GSC members to maintain growth. Therefore, the government may adopt incentive Policy T to endorse green product. Additionally, the EI is maximum under this policy. Although, the profits of GSC members remain unaffected, they can establish themselves as a formidable ambassador in perspective of sustainable practice. In the existing literature, only a few studies explore the properties of GSC under RS game. Therefore, further investigation is recommended under RS game in order to obtain greater understanding of GSC practice.

Proposition-6: If government incentive on per-unit product remains indifferent in two incentive policies, then:
(i) GSC members prefer incentive Policy U under both game structures
(ii) optimum GLs satisfy $\theta_m^{ui} \geq \theta_m^{ti}$ if $\gamma \leq \frac{68b\beta\eta+9c\eta(c+b\eta)}{68b\beta(c+b\eta)}$ under MS game and $\theta_r^{us} \leq \theta_r^{ts}$ under RS game

(iii) government needs to provide more support under incentive Policy U under both game structures
(iv) the retail price satisfies $p_{2m}^{ui} \leq p_{2m}^{ti}$ if $\frac{\eta(9c^3+36bc\beta+9bc^2\eta-16b^2\beta\eta)}{4\beta(13c-4b\eta)(c+b\eta)} \leq \gamma$ under MS game and $p_r^{us} \leq p_r^{ts}$ under RS game
(v) CSs satisfies $CS_m^{ui} \geq CS_m^{ti}$ if $\frac{\eta(9c^3+36bc\beta+9bc^2\eta-16b^2\beta\eta)}{4\beta(13c-4b\eta)(c+b\eta)} \leq \gamma$ under MS game and $CS_r^{us} \geq CS_r^{ts}$ under RS game
(vi) EIs reaches its higher end under incentive Policy U and T under MS and RS game, respectively.
Proof: See Appendix I.

Proposition 6 explores the influence of incentive on per-unit product for the manufacturer and overall supply chain. In that circumstance, both GSC members prefer incentive Policy U to receive higher profits. Under RS game, GSC members can prefer incentive Policy U where the GL is always less. Therefore, GSC members' objective to achieve higher profits may reduce GL. The optimal values of incentive on per-unit product in four scenarios are depicted in Figure 7.

Insert Figure 7

Figure 7 shows that per-unit government incentive is high under RS game compared to MS game. It implies that a powerful retailer can insist the manufacturer to promote product with lower GL. EI is also less under the RS game. CS is greater under incentive policy U under RS game which may not true under MS game. Graphical representations of profits, GLs, retail prices, CSs, and EIs under MS and RS game for $h = h_1$ and $\eta = \eta_1$ are depicted in Figures 8 and 9.

Insert Figures 8a -8g and 9a - 9f

The above figures support findings of Propositions 6. In all scenarios, profits of GSC members increase with the rate of incentive and consumer sensitivity with GL. Here, GL may be suboptimal. These findings may open up a new dimension of GSC research. Although the intention of the government is to boost GL by providing incentives, it may improve individual profits for GSC members but not GL in reality. Most importantly, it may cause lower EI. Figures 8c and 9c show that the GSC members may compromise with GL. Therefore, the actual aspiration of GSC members, particularly under RS game, is a critical factor. However, the accountability of the manufacturer is higher compared to the retailer. Therefore, a shift of power from the manufacturer to the retailer may degrade sustainability goal under single-period setting.

Finally, optimal selection scheme is determined by considering objectives of the government. The optimal incentive rates in each of four scenarios (Please See Appendix J) are determined. It is difficult to obtain closed form expressions for the profit functions at optimal incentive rate for all scenarios and consequently graphical approach is used. Graphical representations of the profits of GSC members and GLs at optimal incentive rates in two game structures are presented in Figures 10 -11.

Insert Figures 10a -10c and 11a - 11c

Under both MS and RS game, GSC members receive higher profits, and GL is also higher in incentive Policy U. The outcomes are coincided with Proposition 4 where the manufacturer sets goal on GL. Overall, government organization wants to accomplish sustainability goal by optimizing SW. In this situation, if the manufacturer wish to improve GL, then the resultant can lead to favorable outcomes. Finally, sensitivity analysis with respect to each parameter is performed keeping other parameters as fixed. An overview of sensitivity analysis is presented in Table 5. Exact values are presented in Appendix L.

Table 5
Sensitivity analysis

Game type	Inc. type	Opti. deci.	a	b	c	β	h	γ	Inc. type	Opti. deci.	a	b	c	β	h	η
M	T	I_m^{ti}	$\Uparrow$	$\downharpoonleft$	$\upharpoonleft$	$\downharpoonleft$	$\downharpoonleft$	$\upharpoonright$	U	I_m^{ui}	$\Uparrow$	$\downharpoonleft$	$\uparrow$	$\downarrow$	$\downharpoonleft$	$\upharpoonright$
		θ_m^{ti}	$\Uparrow$	$\Downarrow$	$\Uparrow$	$\Downarrow$	$\downharpoonleft$	$\uparrow$		θ_m^{ui}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\Downarrow$	$\downharpoonleft$	$\uparrow$
		CS_m^{ti}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\downharpoonleft$	$\upharpoonright$		CS_m^{ui}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\downharpoonleft$	$\uparrow$
		EI_m^{ti}	$\Uparrow$	$\Downarrow$	$\Uparrow$	$\Downarrow$	$\downharpoonleft$	$\Uparrow$		EI_m^{ui}	$\Uparrow$	$\downarrow$	$\uparrow$	$\Downarrow$	$\downharpoonleft$	$\Uparrow$
		π_{rm}^{ti}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\downharpoonleft$	$\upharpoonright$		π_{rm}^{ui}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\downharpoonleft$	$\uparrow$
		π_{mm}^{ti}	$\Uparrow$	$\Downarrow$	$\upharpoonright$	$\downharpoonleft$	$\downharpoonleft$	$\upharpoonright$		π_{mm}^{ui}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\downharpoonleft$	$\upharpoonright$
R	T	I_r^{ti}	$\Uparrow$	$\Downarrow$	$\Uparrow$	$\Downarrow$	$\Downarrow$	$\Uparrow$	U	I_r^{ui}	$\Uparrow$	$\Downarrow$	$\Uparrow$	$\Downarrow$	$\downarrow$	$\Uparrow$
		θ_r^{ti}	$\Uparrow$	$\Downarrow$	$\Uparrow$	$\Downarrow$	$\downharpoonleft$	$\uparrow$		θ_r^{ui}	$\Uparrow$	$\Downarrow$	$\Uparrow$	$\Downarrow$	$\downharpoonleft$	$\uparrow$
		θ_r^{ts}	$\Uparrow$	$\Downarrow$	$\Uparrow$	$\Downarrow$	$\leftrightarrow$	$\uparrow$		θ_r^{us}	$\Uparrow$	$\Downarrow$	$\Uparrow$	$\Downarrow$	$\leftrightarrow$	$\uparrow$
		CS_r^{ts}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\leftrightarrow$	$\upharpoonright$		CS_r^{us}	$\Uparrow$	$\Downarrow$	$\Uparrow$	$\Downarrow$	$\leftrightarrow$	$\uparrow$
		EI_r^{ts}	$\Uparrow$	$\Downarrow$	$\Uparrow$	$\Downarrow$	$\leftrightarrow$	$\Uparrow$		EI_r^{us}	$\Uparrow$	$\downarrow$	$\Uparrow$	$\Downarrow$	$\leftrightarrow$	$\Uparrow$
		π_{rr}^{ti}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\downharpoonleft$	$\upharpoonright$		π_{rr}^{ui}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\downharpoonleft$	$\upharpoonright$
		π_{rr}^{ts}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\leftrightarrow$	$\upharpoonright$		π_{rr}^{us}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\leftrightarrow$	$\uparrow$
		π_{mr}^{ti}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\downharpoonleft$	$\upharpoonright$		π_{mr}^{ui}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\downharpoonleft$	$\upharpoonright$
		π_{mr}^{ts}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\leftrightarrow$	$\upharpoonright$		π_{mr}^{us}	$\Uparrow$	$\Downarrow$	$\uparrow$	$\downarrow$	$\leftrightarrow$	$\uparrow$

Note: $\Uparrow\Downarrow$ Highly Sensitive (>25% change); $\uparrow\downarrow$ moderately sensitive (5% - 25% change); $\upharpoonleft\downharpoonleft$ Low sensitive (<5% change); $\leftrightarrow$ Constant

In Table 5, it is observed that the profits of GSC members, CS, EI and GL increase with the increasing values of a, c, γ, and η. The opposite trend is found for b and β. As overall market demand increases with a, profit increases subsequently. In this situation, the manufacturer has greater flexibility to invest in R&D to improve GL and profits of GSC members increase. If price sensitivity increases, then the GSC members need to adjust their respective prices. Consequently, the profits decrease. In such scenario, the manufacturer cannot compensate higher investment to improve GL that results in decrement of CS and EI. The consumers are expected to maximize their utility from consuming green products. In this regards, CS is a measure of the welfare which is widely used in the literature. Similarly, EI represents the measure of green product consumption improvement. Results of sensitivity analysis demonstrate that the efficiency in R&D investment has a strong influence on those two measure as well as respective profits. The manufacturer's

R&D investment efficient is one of the key parameters directly associated with GL of the product. If GL is not high enough, then CS as well as EI are bound to be decreased which are reflected in the results. It is expected that the profits of GSC members and GL increase with respect to government incentive rates γ and η under both game structures. In presence of incentives, the retailer can gain more power under MS game by increasing the volume of SI. These results support the outcomes of Arya and Mittendorf (2013) and Geng et al. (2017). Results also demonstrate that CSs are not increased significantly in presence of incentive. In encouraging manufacturers to produce and promote green products, the government faces the problem in designing the right incentive policies. An excessive incentive amount will lead to financial burden on the government or an inadequate amount may lead to unproductive outcomes. In both scenarios, the government cannot achieve sustainable goals. The results of the proposed model demonstrate that the effect of incentives are not always identical on profits, GLs, CSs and EIs. It depends on factors like game structures, procurement planning and most importantly the way manufacturer receives it.

5. Summary and concluding remarks

Most of the existing literature explored the properties of GSC under the influence of government incentives in a single-period setting. There is a lack of research on two-period setting under both MS and RS games. Additionally, selection of appropriate incentive policy is important in the perspective of the manufacturer. This study analyzes the optimal procurement process of a GSC from the perspective of individual profit maximization, GLs, CSs, and EIs in presence of two different types of government incentives. Equilibrium outcomes are compared in two-period setting under the MS game and single-period setting under the RS game based on three criterions.

The present study specifies that single-period decisions result in a suboptimal outcome under MS game. Therefore, properties of GSC need to be explored in a two-period setting by considering the impact of the retailer's strategic decision to carry SI. Single-period procurement decision is the best strategy from the perspective of profits and GL under RS game. The manufacturer can compensate R&D expenditure in a two-period setting. However, recognizing the evolving behavior of consumers in the modern marketplace, the single-period setting proves to be an optimal strategy for powerful retailer. Even though the purposes of government incentives are indifferent in greater aspect, the inherent consequences may be diverse. The GSC members always receive higher profits and GL is also expected to achieve higher level in presence of incentive. This is the first article where it is reported that government incentives create a dilemma in the manufacturer's mind. If the manufacturer needs to set a premeditated standard for GL, the government incentive Policy U is more profitable for GSC members. CS and EI are also attained its maximum. When the manufacturers goal is to set sales volume, the incentive Policy T proves to be desirable in the perspective of profits and EI. If the government sets SW optimization goal, GSC member can receive higher profits under incentive policy U. If the government keeps a per-unit incentive target, then conflicting outcomes are observed. GSC members can trade with product at lower GL for higher profits. The EI reaches its higher end in incentive Policy U under MS game, but EI is higher in incentive Policy T under RS game. Overall, GSC members may compromise with their sustainable goal to receive higher profits in presence of incentives. Therefore, an agreement between the government organization and the manufacturer and a robust survey work about market conditions are necessary for better selection of incentive types and to create an expectation of desirable outcomes. By comparing outcomes under two different incentive policies, it can be concluded that an appropriate selection of incentive policy is crucial to achieve sustainable goal while the government budget is limited. Whatever the motive of the GSC members or the government is, consumers always receive products at lower price under incentive Policy U. Therefore, if the people of a region or country are price sensitive enough, then the government needs to adopt incentive Policy U to promote green products.

There are several directions to extend this study. One can explore the influence of government incentives in two-period GSC under the Nash game (Yang and Xiao, 2017). It would be appealing to explore the effects of incentives on retail price in the proposed setting (Madani and Rasti-Barzoki, 2017). It will be interesting to compare optimal decisions under different scenarios such as the manufacturer receives incentive on both total R&D investment and per unit product; the manufacturer and retailer both receive inventive from government(Heydari et al. 2017b); the manufacturer and consumer both receive incentive from government(Safarzadeh and Rasti-Barzoki, 2019a). A case study based on product categories could improve the applicability of proposed study. One can extend this study to analyze the influence of coordination contract mechanisms like revenue-sharing, buy-back, quantity discount, etc. to improve individual as well as overall system profits of GSC and generate Pareto improving situation.

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Appendix A. Optimal decision in Scenario TMI

The optimal solution of the retailer's second-period optimization problem defined in Equation (1) is obtained by solving $\frac{d\pi^{ti}_{rm2}}{dp^{ti}_{2m}} = 0$. After simplification, $p^{ti}_{2m}(w^{ti}_{2m}, \theta^{ti}_m) = \frac{a+bw^{ti}_{2m}+c\theta^{ti}_m}{2b}$. The profit function of the retailer in second-period is concave because $\frac{d^2\pi^{ti}_{rm2}}{{dp^{ti}_{2m}}^2} = -2b < 0$. Substituting p^{ti}_{2m} in Equation (2) and solving $\frac{d\pi^{ti}_{mm2}}{dw^{ti}_{2m}} = 0$, wholesale price is obtained as $w^{ti}_{2m}(\theta^{ti}_m) = \frac{a-2I^{ti}_m+c\theta^{ti}_m}{2b}$. The profit function for the manufacturer is concave because $\frac{d^2\pi^{ti}_{mm2}}{{dw^{ti}_{2m}}^2} = -b < 0$.

Substituting the optimal response in Equation (3), the cumulative profit function for the retailer for two consecutive periods are obtained as follows:

$\pi^{ti}_{rm}(p^{ti}_{1m}, I^{ti}_m) = (p^{ti}_{1m} - w^{ti}_{1m})(a - bp^{ti}_{1m} + c\theta^{ti}_m) - (w^{ti}_{1m} + h)I^{ti}_m$
$+\frac{a^2+12aI^{ti}_m-12(I^{ti}_m)^2+2c(a+6I^{ti}_m)\theta^{ti}_m+c^2(\theta^{ti}_m)^2}{16b}$

By solving $\frac{\partial\pi^{ti}_{rm}}{\partial p^{ti}_{1m}} = 0$ and $\frac{\partial\pi^{ti}_{rm}}{\partial I^{ti}_m} = 0$ simultaneously, the retail price in first-period and amount of SI are obtained as follows:

$p^{ti}_{1m}(w^{ti}_{1m}, \theta^{ti}_m) = \frac{a+bw^{ti}_{1m}+c\theta^{ti}_m}{2b}$

$I^{ti}_m(w^{ti}_{1m}, \theta^{ti}_m) = \frac{3a-4b(h+w^{ti}_{1m})+3c\theta^{ti}_m}{6}$

As $\frac{\partial^2\pi^{ti}_{rm}}{{\partial p^{ti}_1}^2} = -2b < 0$ and $\frac{\partial^2\pi^{ti}_{rm}}{{\partial p^{ti}_{1m}}^2} \times \frac{\partial^2\pi^{ti}_{rm}}{{\partial I^{ti}_m}^2} - \left(\frac{\partial^2\pi^{ti}_{rm}}{\partial p^{ti}_{1m}\partial I^{ti}_m}\right)^2 = 3 > 0$, the profit function of the retailer is concave.

Finally, by substituting optimal responses in Equation (4), the profit function for the manufacturer can be obtained as follows:

$$\pi^{ti}_{mm}(w^{ti}_{1m}, \theta^{ti}_m) = (a + c\theta^{ti}_m)w^{ti}_{1m} - 2\beta(1-\gamma)(\theta^{ti}_m)^2 + \frac{b(4h^2 - 4hw^{ti}_{1m} - 17{w^{ti}_{1m}}^2)}{18}$$

By solving $\frac{\partial\pi^{ti}_{mm}}{\partial w^{ti}_{1m}} = 0$ and $\frac{\partial\pi^{ti}_{mm}}{\partial\theta^{ti}_m} = 0$ simultaneously, one can obtain

$w^{ti}_{1m} = \frac{4(9a-2bh)\beta(1-\gamma)}{\Delta_1}$

$\theta^{ti}_m = \frac{9ac-2bch}{\Delta_1}$.

The profit function for the manufacturer is concave because $\frac{\partial^2\pi^{ti}_{mm}}{{\partial w^{ti}_{1m}}^2} = -\frac{17b}{9} < 0$ and $\frac{\partial^2\pi^{ti}_{mm}}{{\partial w^{ti}_{1m}}^2} \times \frac{\partial^2\pi^{ti}_{mm}}{{\partial\theta^{ti}_m}^2} - \left(\frac{\partial^2\pi^{ti}_{mm}}{\partial w^{ti}_{1m}\partial\theta^{ti}_m}\right)^2 = \frac{\Delta_1}{9} > 0$, where $\Delta_1 = 68b\beta(1-\gamma) - 9c^2$. Collectively, one can obtain optimal decision in Scenario TMI as given in Table-1.

Appendix B. Optimal decision in Scenario TRI

First, one needs to substitute $m^{ti}_{2r} = p^{ti}_{2r} - w^{ti}_{2r}$ and $m^{ti}_{1r} = p^{ti}_{1r} - w^{ti}_{1r}$ in Equations (1)-(4) to obtain optimal decision in RS game. Therefore, m^{ti}_{2r} and m^{ti}_{1r} represent profit margin for the retailer in second and first period, respectively. By solving $\frac{d\pi^{ti}_{mr2}}{dw^{ti}_{2r}} = 0$, the wholesale price in second-period is obtained as $w^{ti}_{2r}(m^{ti}_{2r}, \theta^{ti}_r) = \frac{a-I^{ti}_r-bm^{ti}_{2r}+c\theta^{ti}_r}{2b}$. Concavity condition holds because $\frac{d^2\pi^{ti}_{mr2}}{{dw^{ti}_{2r}}^2} = -2b < 0$. Substituting w^{ti}_{2r}, the second-period profit function for the retailer is

$$\pi^{ti}_{rr2}(m^{ti}_{2r}) = \frac{a(I^{ti}_r+bm^{ti}_{2r})+cI^{ti}_r\theta^{ti}_r-bm^{ti}_{2r}(bm^{ti}_{2r}-c\theta^{ti}_r)-(I^{ti}_r)^2}{2b}.$$

Solving, $\frac{d\pi_{rr2}^{ti}}{dm_{2r}^{ti}} = 0$, the profit margin for the retailer is obtained as $m_{2r}^{ti}(\theta_r^{ti}) = \frac{a+c\theta_r^{ti}}{2b}$. As $\frac{d^2\pi_{rr2}^{ti}}{d{m_{2r}^{ti}}^2} = -b < 0$, the profit function of the retailer in second-period is concave.

Substituting the optimal response obtained in second-period in Equation (4), the cumulative profit function for the manufacturer is obtained as follows:

$\pi_{mr}^{ti}(w_{1r}^{ti}, \theta_r^{ti}) = w_{1r}^{ti}(a + I_r^{ti} - b(m_{1r}^{ti} + w_{1r}^{ti}) + c\theta_r^{ti})$
$+\frac{1}{16b}[(a - 2I_r^{ti})^2 + 2c(a - 2I_r^{ti})\theta_r^{ti} + (c^2 - 32b\beta(1-\gamma))(\theta_r^{ti})^2]$

By solving $\frac{\partial\pi_{mr}^{ti}}{\partial w_{1r}^{ti}} = 0$ and $\frac{\partial\pi_{mr}^{ti}}{\partial\theta_r^{ti}} = 0$ simultaneously, the wholesale price in first-period and GL are obtained as follows:

$w_{1r}^{ti}(I_r^{ti}, m_{1r}^{ti}) = \frac{32b(a+I_r^{ti}-bm_{1r}^{ti})\beta(1-\gamma)-c^2(3I_r^{ti}-bm_{1r}^{ti})}{2b(32b\beta(1-\gamma)-5c^2)}$

$\theta_r^{ti}(I_r^{ti}, m_{1r}^{ti}) = \frac{c(5a+2I_r^{ti}-4bm_{1r}^{ti})}{32b\beta(1-\gamma)-5c^2}$

As $\frac{\partial^2\pi_{mr}^{ti}}{\partial{w_{1r}^{ti}}^2} = -2b < 0$ and $\frac{\partial^2\pi_{mr}^{ti}}{\partial{w_{1r}^{ti}}^2} \times \frac{\partial^2\pi_{mr}^{ti}}{\partial{\theta_r^{ti}}^2} - (\frac{\partial^2\pi_{mr}^{ti}}{\partial w_{1r}^{ti}\partial\theta_r^{ti}})^2 = \frac{(32b\beta(1-\gamma)-5c^2)}{4} > 0$, the profit function for the manufacturer is concave.

Substituting optimal responses, the cumulative profit function for the retailer is obtained as follows:

$\pi_{rr}^{ti}(m_{1r}^{ti}, I_r^{ti}) = \frac{1}{2b(\Delta_3+2\Delta_2)^2}\Big[256b^2(a^2 - 8I_r^{ti}(bh + I_r^{ti}) + 4abm_{1r}^{ti} - 4b^2{m_{1r}^{ti}}^2)\beta^2(1-\gamma)^2 + 32bc^2$
$(a(I_r^{ti} - 7bm_{1r}^{ti}) + 20I_r^{ti}(bh + I_r^{ti}) + 2bm_{1r}^{ti}(I_r^{ti} + 3bm_{1r}^{ti}))\beta(1-\gamma) - c^4((7I_r^{ti} + bm_{1r}^{ti})^2 + 50bI_r^{ti}h)]$

Finally, the retailer sets its profit margin of first period and decides SI by solving $\frac{\partial\pi_{rr}^{ti}}{\partial m_{1r}^{ti}} = 0$ and $\frac{\partial\pi_{rr}^{ti}}{\partial I_r^{ti}} = 0$. On simplification, one may obtain the optimal values as shown in Table 1.

As $\frac{\partial^2\pi_{rr}^{ti}}{\partial{m_{1r}^{ti}}^2} = \frac{-b(1024b^2\beta^2(1-\gamma)^2-192bc^2\beta(1-\gamma)+c^4)}{(\Delta_3+2\Delta_2)^2} < 0$ and

$\frac{\partial^2\pi_{rr}^{ti}}{\partial{m_{1r}^{ti}}^2} \times \frac{\partial^2\pi_{rr}^{ti}}{\partial{I_r^{ti}}^2} - \left(\frac{\partial^2\pi_{rr}^{ti}}{\partial m_{1r}^{ti}\partial I_r^{ti}}\right)^2 = \frac{128b\beta\Delta_3(1-\gamma)}{(\Delta_3+2\Delta_2)^2} > 0$,

the cumulative profit function is concave if $\Delta_3 = 16b\beta(1-\gamma) - 3c^2 > 0$.

The retailer can carry SI in Scenario TRI and URI if

$h_r^{ti} < \frac{32ac^2\beta(1-\gamma)}{1024b^2\beta^2(1-\gamma)^2-192bc^2\beta(1-\gamma)+c^4}$

and $h_r^{ui} < \frac{32a\beta(c+b\eta)^2}{b^4\eta^4+4b^3c\eta^3+1024b^2\beta^2-6b^2(32b\beta-c^2)\eta^2-4bc(96b\beta-c^2)\eta-192bc^2\beta+c^4}$

satisfy, respectively.

To verify feasibility of optimal solution, difference between retail and wholesale prices are computed for each scenario. On simplification, one can obtain the following:

$p_{1m}^{ti} - w_{1m}^{ti} = \frac{16a\beta(1-\gamma)+h\Delta_4}{\Delta_1} > 0$

$p_{2m}^{ti} - w_{2m}^{ti} = \frac{2((11a-10bh)\beta(1-\gamma)+c^2h)}{\Delta_1} > 0$

$p_m^{ts} - w_m^{ts} = \frac{2a\beta(1-\gamma)}{\Delta_2} > 0$

$p_{1r}^{ti} - w_{1r}^{ti} = \frac{(4(8a-bh)\beta(1-\gamma)+h\Delta_4)(4b\beta(1-\gamma)+7\Delta_4)}{128b\beta(1-\gamma)\Delta_3} > 0$

$p_{2r}^{ti} - w_{2r}^{ti} = \frac{1}{64b\beta(1-\gamma)\Delta_3}[256b(a + bh)\beta^2(1-\gamma)^2 + 8c^2(4a + 6bh)\beta(1-\gamma) + c^2h\Delta_2] > 0$

$p_r^{ts} - w_r^{ts} = \frac{a}{2b} > 0$

$p_{1m}^{ui} - w_{1m}^{ui} = \frac{16a\beta+h\Delta_8}{\Delta_5} > 0$

$p_{2m}^{ui} - w_{2m}^{ui} = \frac{2((11a-10bh)\beta+(c+b\eta)^2 h)}{\Delta_5} > 0$
$p_{m}^{us} - w_{m}^{us} = \frac{2a\beta}{\Delta_6} > 0$
$p_{1r}^{ui} - w_{1r}^{ui} = \frac{(4(8a-bh)\beta+\Delta_8 h)(4b\beta+7\Delta_8)}{128b\beta\Delta_7} > 0$
$p_{2r}^{ui} - w_{2r}^{ui} = \frac{(4(8a-bh)\beta+\Delta_8 h)(8b\beta+3\Delta_6)}{128b\beta\Delta_7} > 0$
$p_{r}^{us} - w_{r}^{us} = \frac{a}{2b} > 0$
Similarly, demands of second period are obtained as follows:
$D_{2m}^{ti} = \frac{b(4(3a+bh)\beta(1-\gamma)+h\Delta_3)}{\Delta_1} > 0$
$D_{2r}^{ti} = \frac{96b(4a+7bh)\beta^2(1-\gamma)^2+24(4a+7bh)\beta\Delta_4+3c^4h}{192\beta(1-\gamma)\Delta_3} > 0$
$D_{2m}^{ui} = \frac{b(12a\beta+h(4b\beta+\Delta_7))}{\Delta_5} > 0$
$D_{2r}^{ui} = \frac{128b(6a-bh)\beta^2+(96a\beta+136bh\beta+\Delta_7))\Delta_7}{576\beta\Delta_7} > 0$
The above inequalities ensure that the retailer receives nonnegative profits.

Appendix C. Proof of Proposition 1

Proof: The following inequalities ensure the proof:
$\pi_{mm}^{ti} - \pi_{mm}^{ts} = \frac{2b[2(a-4bh)\beta(1-\gamma)+c^2h]^2}{\Delta_1\Delta_2} \geq 0$
$\theta_{m}^{ti} - \theta_{m}^{ts} = \frac{2bc[2(a-4bh)\beta(1-\gamma)+c^2h]}{\Delta_1\Delta_2} \geq 0$
$w_{1m}^{ti} - w_{2m}^{ti} = \frac{6(2(a-4bh)\beta(1-\gamma)+c^2h)}{\Delta_1} \geq 0$
$p_{1m}^{ti} - p_{2m}^{ti} = \frac{3(2(a-4bh)\beta(1-\gamma)+c^2h)}{\Delta_1} \geq 0$
$\pi_{rr}^{ts} - \pi_{rr}^{ti} = \frac{1}{256\beta(1-\gamma)\Delta_3\Delta_4}[256a^2c^2\beta^2(1-\gamma)^2 + (64(ac^2-h\Delta_3)h\beta(1-\gamma) - c^4h^2)\Delta_4] \geq 0$
$\theta_{r}^{ts} - \theta_{r}^{ti} = \frac{c(128ab\beta^2(1-\gamma)^2+h(16b\beta(1-\gamma)+\Delta_3)\Delta_4)}{64\beta(1-\gamma)\Delta_3\Delta_4} \geq 0$
$w_{1r}^{ti} - w_{2r}^{ti} = \frac{c^2((32a-9bh)\beta(1-\gamma)+3h\Delta_4)+64(ac^2-bh\Delta_3)\beta(1-\gamma)}{128b\beta(1-\gamma)\Delta_3} \geq 0$
$p_{1r}^{ti} - p_{2r}^{ti} = -\frac{3c^2(4(8a-bh)\beta(1-\gamma)+h\Delta_4)+192bh\beta(1-\gamma)\Delta_3}{192b\beta(1-\gamma)\Delta_3} \leq 0$
$\frac{\partial\theta_m^{ti}}{\partial\gamma} = \frac{68bc(9a-2bh)\beta}{{\Delta_1}^2} > 0$
$\frac{\partial\theta_r^{ti}}{\partial\gamma} = \frac{512bc(3a-bh)\beta^2(1-\gamma)^2+60bc^3h\beta(1-\gamma)+9c^3h\Delta_4}{64\beta(1-\gamma)^2{\Delta_3}^2} > 0$
$\frac{\partial I_m^{ti}}{\partial\gamma} = \frac{10bc^2(9a-2bh)\beta}{{\Delta_1}^2} > 0$
$\frac{\partial I_r^{ti}}{\partial\gamma} = \frac{1}{64\beta(1-\gamma)^2{\Delta_3}^2}[c^2(512b(a-bh)\beta^2(1-\gamma)^2 + 128bh\beta(1-\gamma)\Delta_4 + 3c^2h(4\Delta_2+5c^2))] > 0$
$\frac{\partial\theta_m^{ti}}{\partial h} = -\frac{2bc}{\Delta_1} < 0$
$\frac{\partial\theta_r^{ti}}{\partial h} = -\frac{16bc\beta(1-\gamma)+c\Delta_3}{64\beta(1-\gamma)\Delta_3} < 0$
Hence the proposition.

Appendix D. Proof of Proposition 2

The following inequalities ensure the proof:
$\pi_{mm}^{ui} - \pi_{mm}^{us} = \frac{2b[2(a-4bh)\beta+h(c+b\eta)^2]^2}{\Delta_5\Delta_6} \geq 0$
$\theta_{m}^{ui} - \theta_{m}^{us} = \frac{2b(c+b\eta)[2(a-4bh)\beta+h(c+b\eta)^2]}{\Delta_5\Delta_6} \geq 0$

$w_{1m}^{ui} - w_{2m}^{ui} = \frac{6[2\beta(a-4bh)+h(c+b\eta)^2]}{\Delta_5} \geq 0$
$p_{1m}^{ui} - p_{2m}^{ui} = \frac{3[2\beta(a-4bh)+h(c+b\eta)^2]}{\Delta_5} \geq 0$
$\pi_{rr}^{us} - \pi_{rr}^{ui} = \frac{1}{2304\beta\Delta_7\Delta_8}[64\beta(36a^2\beta(c+b\eta)^2 + (9ah(c+b\eta)^2 - 4b^2h^2\beta)\Delta_8) - h^2\Delta_8(544b\beta + \Delta_7)\Delta_7] \geq 0$
$\theta_r^{us} - \theta_r^{ui} = \frac{(c+b\eta)[8ab\beta^2+h(16b\beta+\Delta_7)\Delta_8]}{64\beta\Delta_7\Delta_8} \geq 0$
$w_{1r}^{ui} - w_{2r}^{ui} = \frac{48\beta((6a+11bh)(c+b\eta)^2-64b^2h\beta)+3h(c+b\eta)^2\Delta_7}{384b\beta\Delta_7} \geq 0$
$p_{1r}^{ui} - p_{2r}^{ui} = -\frac{48(6a-bh)\beta(c+b\eta)^2+3h(192b\beta+(c+b\eta)^2)\Delta_7}{1152b\beta\Delta_7} \leq 0$
$\frac{\partial\theta_m^{ui}}{\partial\eta} = \frac{b(9a-2bh)(68b\beta+9(c+b\eta)^2)}{{\Delta_5}^2} > 0$
$\frac{\partial\theta_r^{ui}}{\partial\eta} = \frac{1}{64\beta{\Delta_7}^2}[32\beta((3a-bh)(16b\beta+3(c+b\eta)^2)) + 9h(12b\beta+\Delta_8)(c+b\eta)^2] > 0$
$\frac{\partial\theta_m^{ui}}{\partial h} = -\frac{2b(c+b\eta)}{\Delta_5} < 0$
$\frac{\partial\theta_r^{ui}}{\partial h} = -\frac{(16b\beta+\Delta_8)(c+b\eta)}{64\beta\Delta_8} < 0$
$\frac{\partial I_m^{ui}}{\partial\eta} = \frac{20b^2(9a-2bh)\beta(c+b\eta)}{{\Delta_5}^2} > 0$
$\frac{\partial I_r^{ui}}{\partial\eta} = \frac{b(c+b\eta)(256b(6a-bh)\beta^2+h{\Delta_7}^2)}{192\beta{\Delta_7}^2} > 0$
Hence the theorem.

Appendix E. Proof of Proposition 3

The following inequalities ensure the proof:
$\pi_{mm}^{wi} - \pi_{mm}^{ws} = \frac{a^2\beta\Delta_9+2b((a-4bh)\beta+c^2h)^2}{\Delta_9\Delta_{10}} \geq 0$
$\theta_m^{wi} - \theta_m^{ws} = \frac{2bc(2(a-4bh)\beta+c^2h)}{\Delta_9\Delta_{10}} \geq 0$
$w_{1m}^{wi} - w_{2m}^{wi} = \frac{6(2(a-4bh)\beta+c^2h)}{\Delta_9} \geq 0$
$p_{1m}^{wi} - p_{2m}^{wi} = \frac{3(2(a-4bh)\beta+c^2h)}{\Delta_9} \geq 0$
$\pi_{rr}^{ws} - \pi_{rr}^{wi} = \frac{1}{256\beta\Delta_{11}\Delta_{12}}[256a^2c^2\beta^2 + 64h\beta(ac^2 - 16b^2h\beta)\Delta_{12} + c^2h^2(188b\beta + \Delta_{12})\Delta_{12}] \geq 0$
$\theta_r^{ws} - \theta_r^{wi} = \frac{c(128ab\beta^2+h(16b\beta+\Delta_{11})\Delta_{12})}{64\beta\Delta_{11}\Delta_{12}} \geq 0$
$w_{1r}^{wi} - w_{2r}^{wi} = \frac{c^2((32a-9bh)\beta+3h\Delta_{12})+64(ac^2-bh\Delta_{11})\beta}{128b\beta\Delta_{11}} \geq 0$
$p_{1r}^{wi} - p_{2r}^{wi} = -\frac{3c^2(4(8a-bh)\beta+h\Delta_{12})+192bh\beta\Delta_{11}}{192b\beta\Delta_{11}} \leq 0$
Hence the proposition.

Appendix F.

The following relations ensure that the profits for the manufacturer and retailer increase with the growing value of γ and η under MS game:
$\frac{\partial\pi_{mm}^{ti}}{\partial\gamma} = \frac{2c^2(9a-2bh)^2\beta}{{\Delta_1}^2} \geq 0$
$\frac{\partial\pi_{rm}^{ti}}{\partial\gamma} = \frac{2bc^2(9a-2bh)\beta(4(155a-59bh)\beta(1-\gamma)+13c^2h)}{{\Delta_1}^3} \geq 0$
$\frac{\partial\pi_{mm}^{ui}}{\partial\eta} = \frac{4b(9a-2bh)^2\beta(c+b\eta)}{{\Delta_5}^2} \geq 0$

$\frac{\partial \pi_{rm}^{ui}}{\partial \eta} = \frac{4b^2(9a-2bh)\beta(c+b\eta)(620a\beta-h(236b\beta-13(c+b\eta)^2))}{{\Delta_5}^3} \geq 0$

Similarly, one may find the following relations under RS game:

$\frac{\partial \pi_{mr}^{ts}}{\partial \gamma} = \frac{a^2c^2\beta}{2{\Delta_4}^2} \geq 0$

$\frac{\partial \pi_{rr}^{ts}}{\partial \gamma} = \frac{a^2c^2\beta}{{\Delta_4}^2} \geq 0$

$\frac{\partial \pi_{mr}^{us}}{\partial \eta} = \frac{a^2b\beta(c+b\eta)}{{\Delta_8}^2} \geq 0$

$\frac{\partial \pi_{rr}^{us}}{\partial \eta} = \frac{2a^2b\beta(c+b\eta)}{{\Delta_8}^2} \geq 0$

However, Tables 1 and 3 demonstrate that the profits of the manufacturer and retailer in Scenarios TMI and WMI; and in Scenarios TRS and WRB will be equal if $\gamma = 0$; therefore, one can conclude that $\pi_{mm}^{ti} \geq \pi_{mm}^{wi}$, $\pi_{rm}^{ti} \geq \pi_{rm}^{wi}$, $\pi_{mr}^{ts} \geq \pi_{mr}^{ws}$, and $\pi_{rr}^{ts} \geq \pi_{rr}^{ws}$. Similarly, substituting $\eta = 0$ and comparing results in Tables 2 and 3, one can conclude that $\pi_{mm}^{ui} \geq \pi_{mm}^{wi}$, $\pi_{rm}^{ui} \geq \pi_{rm}^{wi}$, $\pi_{mr}^{us} \geq \pi_{mr}^{ws}$, and $\pi_{rr}^{us} \geq \pi_{rr}^{ws}$.

Appendix G. Proof of Proposition 4

The optimal GLs in Scenarios UMI and TMI are

$\theta_m^{ui} = \frac{(9a-2bh)(c+b\eta)}{\Delta_5}$ and $\theta_m^{ti} = \frac{9ac-2bch}{\Delta_1}$,

respectively. Therefore, GLs are equivalent if

$\gamma = \frac{68b\beta\eta+9c\eta(c+b\eta)}{68\beta(c+b\eta)} (= \gamma_1, say)$.

Substituting $\gamma = \gamma_1$, the profits of the manufacturer and retailer, and amount of government incentive (GI_m^{ti}) in Scenario TMI are obtained as follows:

$\pi_{mm}^{ti}|_{\gamma=\gamma_1} = \frac{1}{34\Delta_5}[68(9a^2\beta - bh(4(a-2bh)\beta + c^2h)) - 9b(9a^2 - 4abh + 8b^2h^2)\eta^2 - c(81a^2 - 36abh + 140b^2h^2)\eta]$

$\pi_{rm}^{ti}|_{\gamma=\gamma_1} = \frac{b}{1156{\Delta_5}^2}[23120c^2h^2(c+b\eta)^2 + (155a^2 - 118abh + 304b^2h^2){\Delta_5}^2 + 34ch(13a - 154bh)(c+b\eta)\Delta_5]$

$GI_m^{ti}|_{\gamma=\gamma_1} = \frac{(9a-2bh)^2\eta(c+b\eta)(68b\beta+9c(c+b\eta))}{34{\Delta_5}^2}$

$CS_m^{ti}|_{\gamma=\gamma_1} = \frac{1}{2312{\Delta_5}^2}[b(5780c^2h^2(c+b\eta)^2 + (185a^2 - 188abh + 104b^2h^2)(68\beta - 9\eta(c+b\eta))^2 + 136ch(7a - 11bh)(c+b\eta)(68\beta - 9\eta(c+b\eta)))]$,

$EI_m^{ti}|_{\gamma=\gamma_1} = \frac{1}{34{\Delta_1}^2\Delta_9}[b^2(9a-2bh)\eta(68b\beta + 9c(c+b\eta))(34c^2h - c(171a - 106bh)\eta + (19a - 8bh)(68\beta - 9b\eta^2))]$

Consequently, their differences in Scenarios UMI and TMI are obtained as follows:

$\pi_{mm}^{ui} - \pi_{mm}^{ti}|_{\gamma=\gamma_1} = \frac{(9a-2bh)^2\eta(c+b\eta)}{34\Delta_5} > 0$

$\pi_{rm}^{ui} - \pi_{rm}^{ti}|_{\gamma=\gamma_1} = \frac{1}{1156{\Delta_5}^2}[(9a-2bh)(c\eta + b\eta^2)(155(9a-2bh)(c+b\eta)(2c+b\eta) + 2(155a - 59bh)\Delta_5)] > 0$

$GI_m^{ui} - GI_m^{ti}|_{\gamma=\gamma_1} = \frac{1}{34{\Delta_5}^2}[(9a-2bh)(c\eta+b\eta^2)((9a-2bh)(c+b\eta)(c+10b\eta) + (10a-6bh)\Delta_5)] > 0$

$p_{1m}^{ti}|_{\gamma=\gamma_1} - p_{1m}^{ui} = \frac{4(9a-2bh)\eta(c+b\eta)}{17\Delta_5} > 0$

$p_{2m}^{ti}|_{\gamma=\gamma_1} - p_{2m}^{ui} = \frac{11(9a-2bh)\eta(c+b\eta)}{34\Delta_5} > 0$

$CS_m^{ui} - CS_m^{ti}|_{\gamma=\gamma_1} = \frac{1}{2312{\Delta_5}^2}[b(9a-2bh)\eta(c+b\eta)(136(7c^2h + 185a\beta - 94bh\beta) - 3c(555a -$

$758bh)\eta - b(1665a + 1322bh)\eta^2)] > 0$
$EI_m^{ui} - EI_m^{ti}|_{\gamma=\gamma_1} = \frac{19b^2(9a-2bh)^2\eta^2(c+b\eta)(68b\beta+9c(c+b\eta))}{34{\Delta_5}^2\Delta_9} > 0$
The optimal GLs in Scenarios URS and TRS are
$\theta_r^{us} = \frac{a(c+b\eta)}{2\Delta_8}$ and $\theta_r^{ts} = \frac{ac}{2\Delta_4}$,
respectively. Equality holds if $\gamma = \frac{\eta(c^2+4b\beta+bc\eta)}{4\beta(c+b\eta)}(= \gamma_2, say)$. Substituting $\gamma = \gamma_2$, the profits of the manufacturer and retailer, amount of government incentive(GI_r^{ts}), CSs and EIs in Scenario TRS are
$\pi_{mr}^{ts}|_{\gamma=\gamma_2} = \frac{a^2(4\beta-\eta(c+b\eta))}{8\Delta_8}$
$\pi_{rr}^{ts}|_{\gamma=\gamma_2} = \frac{a^2(4\beta-\eta(c+b\eta))}{4\Delta_8}$
$GI_r^{ts}|_{\gamma=\gamma_2} = \frac{a^2\eta(c+b\eta)(c^2+4b\beta+bc\eta)}{8{\Delta_8}^2}$
$CS_r^{ts}|_{\gamma=\gamma_2} = \frac{a^2b{\Delta_8}^2}{16{\Delta_8}^2}$,
$EI_r^{ts}|_{\gamma=\gamma_2} = \frac{a^2b^2\eta(c^2+4b\beta+bc\eta)(4\beta-\eta(c+b\eta))}{4{\Delta_8}^2\Delta_{12}}$.
Finally, their differences in Scenarios URS and TRS are as follows:
$\pi_{mr}^{us} - \pi_{mr}^{ts}|_{\gamma=\gamma_2} = \frac{a^2\eta(c+b\eta)}{8\Delta_8} > 0$
$\pi_{rr}^{us} - \pi_{rr}^{ts}|_{\gamma=\gamma_2} = \frac{a^2\eta(c+b\eta)}{4\Delta_8} > 0$
$GI_r^{us} - GI_r^{ts}|_{\gamma=\gamma_2} = \frac{a^2\eta(c+b\eta)(4b\beta-bc\eta-c^2)}{8{\Delta_8}^2} > 0$
$p_r^{ts}|_{\gamma=\gamma_2} - p_r^{us} = \frac{a\eta(c+b\eta)}{4\Delta_8} > 0$.
$CS_r^{us} - CS_r^{ts}|_{\gamma=\gamma_2} = \frac{a^2b\eta(c+b\eta)(8\beta-\eta(c+b\eta))}{16{\Delta_8}^2} > 0$.
$EI_r^{us} - EI_r^{ts}|_{\gamma=\gamma_2} = \frac{a^2b^2\eta^2(c+b\eta)(c^2+4b\beta+bc\eta)}{4{\Delta_8}^2\Delta_{12}} > 0$.
Therefore, the proposition is proved.

Appendix H. Proof of Proposition 5

The optimal sales volumes in Scenarios UMI and TMI are
$Q_m^{ui} = \frac{b(38a\beta-h(16b\beta-(c+b\eta)^2))}{\Delta_5}$ and $Q_m^{ti} = \frac{b(c^2h+2(19a-8bh)\beta(1-\gamma))}{\Delta_1}$,
respectively. Therefore, equality holds if $\gamma = \frac{b\eta(2c+b\eta)}{(c+b\eta)^2}(= \gamma_3, say)$, and the corresponding profit of the manufacturer and retailer, GL and total amount of government incentive (GI_m^{ti}), CS, and EI in Scenario TMI are
$\pi_{mm}^{ti}|_{\gamma=\gamma_3} = \frac{18a^2\beta-2bh(4a\beta-h\Delta_6)}{\Delta_5}$
$\pi_{rm}^{ti}|_{\gamma=\gamma_3} = \frac{2b}{{\Delta_5}^2}[2(155a^2-118abh+304b^2h^2)\beta^2+h(13a-154bh)\beta(c+b\eta)^2+10h^2(c+b\eta)^4]$
$\theta_m^{ti}|_{\gamma=\gamma_3} = \frac{(9a-2bh)(c+b\eta)^2}{c\Delta_5}$
$GI_m^{ti}|_{\gamma=\gamma_3} = \frac{2b(9a-2bh)^2\beta\eta(c+b\eta)^2(2c+b\eta)}{c^2{\Delta_5}^2}$
$CS_m^{ti}|_{\gamma=\gamma_3} = \frac{b(544(9a-2bh)^2\beta^2+(14(9a-2bh)\beta-2h\Delta_5)^2+h^2{\Delta_5}^2)}{162{\Delta_5}^2}$
$EI_m^{ti}|_{\gamma=\gamma_3} = \frac{b^2(9a-2bh)\eta(68b\beta+9c(c+b\eta))(38a\beta-h(16b\beta-(c+b\eta)^2))}{{\Delta_5}^2\Delta_9}$
Consequently, their differences in Scenarios UMI and TMI are
$\pi_{mm}^{ui} - \pi_{mm}^{ti}|_{\gamma=\gamma_3} = 0$

$\pi^{ui}_{rm} - \pi^{ti}_{rm}|_{\gamma=\gamma_3} = 0$
$\theta^{ui}_{m} - \theta^{ti}_{m}|_{\gamma=\gamma_3} = -\frac{b(9a-2bh)\eta(c+b\eta)}{c\Delta_5} < 0$
$GI^{ui}_{m} - GI^{ti}_{m}|_{\gamma=\gamma_3} = -\frac{1}{c^2{\Delta_5}^2}[b(9a-2bh)\eta(c+b\eta)[b^2(16a\beta+2(a-4bh)\beta+h\Delta_4)\eta^2+2bc(23a\beta+2(2a-5bh)\beta+h\Delta_4)\eta+2c^2(a-2bh)\beta+c^2h\Delta_4]] < 0$
$p^{ti}_{1m}|_{\gamma=\gamma_3} - p^{ui}_{1m} = \frac{(9a-2bh)\eta(c+b\eta)}{\Delta_5} > 0$
$p^{ti}_{2m}|_{\gamma=\gamma_3} - p^{ui}_{2m} = \frac{(9a-2bh)\eta(c+b\eta)}{\Delta_5} > 0.$
$CS^{ui}_{m} - CS^{ti}_{m}|_{\gamma=\gamma_3} = 0$
$EI^{ui}_{m} - EI^{ti}_{m}|_{\gamma=\gamma_3} = -\frac{b^2(9a-2bh)\eta(c+b\eta)(2(19a-8bh)\beta+(c+b\eta)^2))}{c{\Delta_5}^2} < 0.$
The optimal sales volumes in Scenarios URS and TRS are $Q^{us}_{r} = \frac{ab\beta}{2\Delta_8}$ and $Q^{ts}_{r} = \frac{ab\beta(1-\gamma)}{2\Delta_4}$, respectively. Therefore, equality holds if $\gamma = \frac{b\eta(2c+b\eta)}{(c+b\eta)^2}(=\gamma_4, say)$. Consequently, profits of the manufacturer and retailer, GL, amount of government incentive (GI^{ts}_{r}), CS, and EI in Scenario TRS are as follows:
$\pi^{ts}_{mr}|_{\gamma=\gamma_4} = \frac{a^2\beta}{4\Delta_8}$
$\pi^{ts}_{rr}|_{\gamma=\gamma_4} = \frac{a^2\beta}{2\Delta_8}$
$\theta^{ts}_{r}|_{\gamma=\gamma_4} = \frac{a(c+b\eta)^2}{2c\Delta_8}$
$GI^{ts}_{r}|_{\gamma=\gamma_4} = \frac{a^2b\beta\eta(c+b\eta)^2(2c+b\eta)}{4c^2{\Delta_8}^2}$
$CS^{ts}_{r}|_{\gamma=\gamma_4} = \frac{a^2b(4\beta-\eta(c+b\eta))^2}{16{\Delta_8}^2}$
$EI^{ts}_{r}|_{\gamma=\gamma_4} = \frac{a^2b^2\eta(c^2+4b\beta+bc\eta)(4\beta-\eta(c+b\eta))}{4{\Delta_8}^2\Delta_{12}}$
Finally, their differences in Scenarios URS and TRS are
$\pi^{us}_{mr} - \pi^{ts}_{mr}|_{\gamma=\gamma_4} = 0$
$\pi^{us}_{rr} - \pi^{ts}_{rr}|_{\gamma=\gamma_4} = 0$
$\theta^{us}_{r} - \theta^{ts}_{r}|_{\gamma=\gamma_4} = -\frac{ab\eta(c+b\eta)}{2c\Delta_8} < 0$
$GI^{us}_{r} - GI^{ts}_{r}|_{\gamma=\gamma_4} = -\frac{a^2b^2\beta\eta^2(c+b\eta)(3c+b\eta)}{2c^2{\Delta_8}^2} < 0$
$p^{us}_{r} - p^{ts}_{r}|_{\gamma=\gamma_4} = -\frac{a\eta(c+b\eta)}{2\Delta_8} < 0.$
$CS^{us}_{r} - CS^{ts}_{r}|_{\gamma=\gamma_4} = 0$
$EI^{us}_{r} - EI^{ts}_{r}|_{\gamma=\gamma_4} = -\frac{a^2b^2\beta\eta(c+b\eta)}{c{\Delta_8}^2} < 0$
Therefore, the proposition is proved.

Appendix I. Proof of Proposition 6

The amount of incentive on per-unit product in Scenarios UMI and TMI are
$\eta\theta^{ui}_{m} = \frac{(9a-2bh)\eta(c+b\eta)}{\Delta_5}$ and $\frac{2\gamma\beta(\theta^{ti}_{m})^2}{Q^{ti}_{m}} = \frac{2(9ac-2bch)^2\beta\gamma}{b\Delta_1(2(19a-8bh)\beta(1-\gamma)+c^2h)}$, respectively.
Equality holds if
$h = \frac{2a\beta[81c^4\gamma+1192b^2\beta(1-\gamma)^2\eta(c+b\eta)-9bc^2(68\beta\gamma+\eta(c(19-37\gamma)+b(19-28\gamma)\eta))]}{b(9c^5\eta+1088b^2\beta^2(1-\gamma)^2\eta(c+b\eta)-c^2(4b\beta(68\beta\gamma+\eta(c(53-71\gamma)+b(53-62\gamma)\eta))-9c^2(4\beta\gamma+b\eta^2)))}(=h_1, say).$
Similar to Proposition 4, one can verify that the following differences holds if
$\gamma_6 = \frac{\eta(9c^3+36bc\beta+9bc^2\eta-16b^2\beta\eta)}{4\beta(13c-4b\eta)(c+b\eta)} < \gamma < \frac{68b\beta\eta+9c\eta(c+b\eta)}{68b\beta(c+b\eta)} = \gamma_5.$
$\pi^{ui}_{mm}|_{h=h_1} - \pi^{ti}_{mm}|_{h=h_1} = \frac{2a^2\beta{\Delta_1}^3\eta^2(c+b\eta)^2((c+b\eta)^2(1-\gamma)-c^2)}{\Delta_5{\Phi_3}^2} > 0$

$\pi^{ui}_{rm}|_{h=h_1} - \pi^{ti}_{rm}|_{h=h_1} = \frac{4a^2\beta^2\Delta_1\eta(c+b\eta)((c+b\eta)^2(1-\gamma)-c^2)(13c^2\gamma{\Delta_5}^2+b^2c^2X+bY)}{{\Delta_5}^2{\Phi_3}^2} > 0$
$\theta^{ui}_{m}|_{h=h_1} - \theta^{ti}_{m}|_{h=h_1} = \frac{ab\Delta_1\eta(c+b\eta)(c(68\beta\gamma-9b\eta^2)-(68b\beta(1-\gamma)+9c^2)\eta)}{\Delta_5\Phi_3} > 0$, if $\gamma < \frac{68b\beta\eta+9c\eta(c+b\eta)}{68b\beta(c+b\eta)} = \gamma_5$
$GI^{ui}_{m}|_{h=h_1} - GI^{ti}_{m}|_{h=h_1} = \frac{38a^2b\beta{\Delta_1}^3\eta^3(c+b\eta)^3((c+b\eta)^2(1-\gamma)-c^2)}{{\Delta_5}^2{\Phi_3}^2} \geq 0$
$p^{ti}_{1m}|_{h=h_1} - p^{ui}_{1m}|_{h=h_1} = \frac{a\eta(b\eta+c)\Delta_1(b(\Delta_3-3c^2)\eta^2-9c(4b\beta(1-\gamma)+c^2)\eta+52c^2\beta\gamma)}{\Delta_5\Phi_3} > 0$, if $\gamma > \gamma_6$
$p^{ti}_{2m}|_{h=h_1} - p^{ui}_{2m}|_{h=h_1} = \frac{a\eta(b\eta+c)\Delta_1((b\beta(1-\gamma)(22b\eta+24c)-9c^2(c+b\eta)\eta)\eta+46c^2\beta\gamma)}{\Delta_5\Phi_3}$,
if $\gamma > \frac{\eta(9c^2(c+b\eta)+24bc\beta-22b^2\beta\eta)}{2\beta(23c-11b\eta)(c+b\eta)} = \gamma_7$
$CS^{ui}_{m}|_{h=h_1} - CS^{ti}_{m}|_{h=h_1} = \frac{2a^2\beta^2\Delta_1\eta(c+b\eta)((c+b\eta)^2(1-\gamma)-c^2)}{{\Delta_5}^2{\Phi_3}^2}[bc(83232b^2\beta^2(1-\gamma)^2 + 9c^4(162-1355\gamma) - 68bc^2\beta(324-\gamma(1679-347\gamma)))\eta + b^2(83232b^2\beta^2(1-\gamma)^2 + 9c^4(856-2553\gamma) - 68bc^2\beta(1018-\gamma(2563-1041\gamma)))\eta^2 - 3b^3c(23596b\beta(1-\gamma)^2 - 9c^2(347-683\gamma))\eta^3 - b^4(23596b\beta(1-\gamma)^2 - 9c^2(347-599\gamma))\eta^4 - 28{\Delta_9}^2\gamma] > 0$, if $\gamma > \gamma_6$
$EI^{ui}_{m}|_{h=h_1} - EI^{ti}_{m}|_{h=h_1} = \frac{1}{{\Delta_5}^2\Delta_9{\Phi_3}^2}[2a^2b\beta\eta(c+b\eta)\Delta_5(\Delta_1\eta(c^2\gamma{\Delta_9}^2 + bc^3\gamma(1292b\beta\gamma-55\Delta_9)\eta + b^2c^2(38\Delta_9 + 999c^2\gamma - 68b\beta(113-57\gamma))\eta^2 + b^3(b\eta+3c)(19(1-\gamma)\Delta_1 + 81c^2\gamma)\eta^3)(68b\beta + 9c(c+b\eta)) + 68c^3\beta\gamma^2{\Delta_5}^3)] > 0.$
One can find that $\gamma_5 > \gamma_6 > \gamma_7$. Therefore, all the above inequalities holds if $\gamma_6 < \gamma < \gamma_5$,
where $\Phi_3 = 4bc^2\beta(68\beta\gamma + b(53-62\gamma)\eta^2) - 1088b^2(b\eta+c)\beta^2(1-\gamma)^2\eta + 4bc^3\beta(53-71\gamma)\eta - 9c^4(4\beta\gamma + b\eta^2) - 9c^5\eta$,
$X = 60112\beta^2(2-\gamma)\gamma^2 - 9b\eta^3(12c(23-62\gamma) + b(92-209\gamma)\eta) + 136\beta\eta(b(29-284\gamma+69\gamma^2)\eta - c(63-217\gamma+46\gamma^2))$,
and $Y = 63c^5(9+80\gamma)\eta + 272b^2\beta(1-\gamma)^2\eta(c+b\eta)(119\beta+23b\eta^2) + c(12512b^3\beta(1-\gamma)^2\eta^3 - 9c^3(1768\beta\gamma^2 + b(121-978\gamma)\eta^2))$.
The amount of incentive on per-unit product in Scenarios URS and TRS are
$\eta\theta^{us}_r = \frac{a\eta(c+b\eta)}{2\Delta_8}$ and $\frac{2\gamma\beta(\theta^{ts}_r)^2}{Q^{ts}_m} = \frac{ac^2\gamma}{4b\Delta_4(1-\gamma)}$,respectively.
Therefore, equality holds if
$\eta = \frac{c^3(1-2\gamma)-4bc^2\beta(1-\gamma)^2+c\sqrt{\Phi_4}}{2(1-\gamma)\Delta_4+c^2\gamma} (= \eta_1, say)$,
where $\Phi_4 = [c^4(1-\gamma)^2 + 16b^2\beta^2(1-\gamma)^2(1+\gamma^2) - 4bc^2\beta(2-\gamma(4-3\gamma+2\gamma^2))]$.
Substituting the value $\eta = \eta_1$, the following relations are obtained:
$2\left(\pi^{us}_{mr}|_{\eta=\eta_1} - \pi^{ts}_{mr}\right) = \pi^{us}_{rr}|_{\eta=\eta_1} - \pi^{ts}_{rr}$
$= \frac{a^2\beta(2(1-\gamma)\Delta_4+c^2\gamma)^2\Delta_4+(1-\gamma)(4b\beta(2(1-\gamma)\Delta_4+c^2\gamma)^2-c^2(\Delta_4(1-\gamma)+\sqrt{\Phi_4})^2)}{(4b\beta(2(1-\gamma)\Delta_4+c^2\gamma)^2-b^2c^2(\Delta_4(1-\gamma)+\sqrt{\Phi_4})^2)\Delta_4} > 0$
$\theta^{us}_r|_{\eta=\eta_1} - \theta^{ts}_r = -\frac{ac((1+\gamma)\Delta_4+c^2\gamma-\sqrt{\Phi_4})}{4(1-\gamma)\Delta_4\Delta_{12}} \leq 0$, as $((1+\gamma)\Delta_4 + c^2\gamma)^2 - \Phi_4 = \gamma(\Delta_4 - c^2)\Delta_{12} > 0$
$GI^{us}_r|_{\eta=\eta_1} - GI^{ts}_r = \frac{a^2c^4\gamma(\sqrt{\Phi_4}-(4b\beta(1-2\gamma)+(1-\gamma)\Delta_4))}{16b(1-\gamma)^2{\Delta_4}^2\Delta_{12}} > 0$ as $\Phi_4 - (4b\beta(1-2\gamma) + (1-\gamma)\Delta_4)^2 = 4b\beta\gamma^2(3-4\gamma)\Delta_{12} > 0$
$p^{us}_r|_{\eta=\eta_1} - p^{ts}_r = -\frac{ac^2(4b\beta\gamma+(1+\gamma)\Delta_4-\sqrt{\Phi_4})}{8b(1-\gamma)\Delta_4\Delta_{12}} < 0$
$CS^{us}_r|_{\eta=\eta_1} - CS^{ts}_r = \frac{a^2b\beta^2[(2(1-\gamma)\Delta_4+c^2\gamma)^2{\Delta_4}^2-b^2(1-\gamma)^2(4b\beta(2(1-\gamma)\Delta_4+c^2\gamma)^2-c^2(\Delta_4(1-\gamma)+\sqrt{\Phi_4})^2)^2]}{(4b\beta(2(1-\gamma)\Delta_4+c^2\gamma)^2-b^2c^2(\Delta_4(1-\gamma)+\sqrt{\Phi_4})^2)^2{\Delta_4}^2} > 0$
$EI^{us}_r|_{\eta=\eta_1} - EI^{ts}_r = \frac{-a^2c\beta}{4(32b^2\beta^2(1-\gamma)^2+c^4(1-\gamma)-c^2(4b\beta(3-(5-\gamma)\gamma)+\sqrt{\Phi_4})){\Delta_4}^2\Delta_{12}}[(2(1-\gamma)\Delta_4 + c^2\gamma)^2(4b\beta(1-\gamma)^2 - c^2) + 16b\beta(1-\gamma)^3\gamma(c^4(1-\gamma) + 32b^2\beta^2(1-\gamma)^2 - 4bc^2\beta(3-5\gamma+\gamma^2)) - (16bc^2\beta(1-\gamma)^3\gamma + ((1-\gamma)\Delta_1 - c^2)^2)\sqrt{\Phi_4}] \leq 0.$

For analytical simplicity, the value of h and η are used in Propositions 6. The proposition is proved here.

Appendix J. Optimal incentive rates which maximize SW

Substituting, profits of the GSC members, CS, EI and GI in Equation (13) one can obtain the value of SW in Scenario TMI as:

$SW_m^{ti} = \frac{1}{2{\Delta_1}^2\Delta_9}[2916a^2c^4\beta+2176b^4h^2\beta^2(1-\gamma)(157\beta(1-\gamma)+2c\gamma)-81bc^2(9c^4h^2+4ac^2h\beta(7-3\gamma)-4a^2\beta^2(191-256\gamma-123\gamma^2))+36b^2\beta(8364a^2\beta^2(1-\gamma)^2+34ac^3h\gamma+1292a^2c\beta(1-\gamma)\gamma+c^4h^2(469-312\gamma)+4ac^2h\beta(293-3\gamma(133-58\gamma)))-16b^3h\beta(11832a\beta^2(1-\gamma)^2+17c^3h\gamma+1870ac\beta(1-\gamma)\gamma+2c^2h\beta(4099-3\gamma(1826-471\gamma)))]$

By solving $\frac{\partial SW_m^{ti}}{\partial\gamma}=0$, the optimal values of government incentive rate is obtained as $\gamma_m^{ti}=\frac{(c^2(34b+27c)h+2a(646b+495c)\beta-8b(68b+53c)h\beta)\Delta_9}{2\beta(68b(a(646b+1107c)-c^2(9a(1292b+1107c)-4b(935b+783c)h)-4b(68b+87c)h)\beta)}$.

Because, $\frac{d^2SW_m^{ti}}{d\gamma^2}=-\frac{4b\beta^2[17a(578b+540c)\Delta_4+(a-4bh)(4b(221b+696c)\beta+(935b+783c)\Delta_4)+51abc(640\beta-17c)]^4}{c^2(9a-2bh)^2(1156\Delta_{12}-1292bc+49c^2)^3{\Delta_9}^4}<0$, the SW_r^{ti} is concave.

Similarly, one can obtain the value of SW in Scenario TRS as:

$SW_r^{ts}=\frac{a^2\beta(56b^2\beta^2(1-\gamma)^2+8b^2c\beta(1-\gamma)\gamma-2bc^2\beta(13-\gamma(18-7\gamma))+c^4(3-2\gamma))}{2{\Delta_4}^2\Delta_{12}}$

By solving $\frac{\partial SW_r^{ts}}{\partial\gamma}=0$, the optimal values of government incentive rate is obtained as $\gamma_r^{ts}=\frac{(2b(2b+3c)\beta-c^3)\Delta_{12}}{2b\beta((2b+5c)\Delta_{12}-2bc^2)}$. Because $\frac{d^2SW_r^{ts}}{d\gamma^2}=-\frac{2a^2b\beta^2(8b^2\beta+5c\Delta_{12}-4bc^2)^4}{c^2(2\Delta_{12}-4bc-c^2)^3\Delta_{12}^4}<0$, the SW_r^{ts} is concave.

Similarly, one can find $\eta_r^{us}=\frac{2^{\frac{2}{3}}(\sqrt{Y^2-4\Psi_7^3}+\Psi_8)^{\frac{2}{3}}+2^{\frac{4}{3}}\Psi_7}{6b^3(2b(10\beta-c)-5c^2)\sqrt[3]{\sqrt{\Psi_8^2-4\Psi_7^3}+\Psi_8}}+\frac{4b(b-4c)\beta+c^2(b+4c)}{b(2b(10\beta-c)-5c^2)}$.

Where $\Psi_7=3b^4(640b^3\beta^3+16b^2(3b^2-8bc-17c^2)\beta^2-8b(b-2c)c^2(b+c)\beta+3c^4(b+c)^2)$ and $\Psi_8=54b^6(b+c)(1120b^3\beta^3+16b^2(b-17c)(b+2c)\beta^2+2bc^2(4b^2+26bc+31c^2)\beta+c^4(b+c)^2)\Delta_{12}$.

However, the optimal value of η_m^{ui} can be found by solving the following biquadratic equation:

$9b^4{\eta_m^{ui}}^4h(b+c)\Delta_9+4b^3{\eta_m^{ui}}^3(9\beta c(9a(19b+28c)+bh(30b+19c))+476b\beta^2(7bh-36a)-81c^3h(b+c))+6b^2{\eta_m^{ui}}^2(9\beta c^2(9a(19b+37c)+2bh(15b+4c)))+4b\eta_m^{ui}(136b^2\beta^3(155a-8bh)+2b\beta^2c(9a+2bh(597c-1292b))$
$\Delta_9(2\beta c^2(9a(19b+c)-2bh(19b+8c))+8b\beta^2(a(323b+478c)-8bh(17b+18c)))=0.$

Therefore, one needs to use Ferrari's method to find solution of η_m^{ui} for a particular set of parameter values.

Appendix K. List of notations used in Table 1, 2 and 3 are as follows:

$\Psi_1=30(a-4bh)^2\beta^2(1-\gamma)^2+\beta(1-\gamma)(c^2h(13a+6bh)+4(62a^2+abh+8(a-4bh)(a+4bh))\beta(1-\gamma))+10h^2{\Delta_2}^2$

$\Psi_2=8192b(16(a-4bh)^2\Delta_4+2bh(7c^2(a-4bh)+64(a-2bh)\Delta_4)+b^2(c^2+16\Delta_4)h^2)\beta^3(1-$

$\gamma)^3+32c^2(32(11c^2+6\Delta_4)(a-4bh)^2+1736bc^2h(a-4bh)+5035b^2c^2h^2)\beta^2(1-\gamma)^2+40c^4h(8a+17bh)\beta(1-\gamma)\Delta_4+5c^8h^2$

$\Psi_3 = 10((9a-2bh)\beta - h\Delta_5)^2 + (9a-2bh)\beta(300(9a-2bh)\beta + 7h\Delta_5)$

$\Psi_4 = 5c^8h^2 + 40bc^7h^2\eta + 8bc^3\eta(256(10a^2 + 31abh + 46b^2h^2)\beta^2 - 100b^2h(8a+17bh)\beta\eta^2 + 35b^4h^2\eta^4) + 2c^4(256(10a^2 + 31abh + 46b^2h^2)\beta^2 - 300b^2h(8a+17bh)\beta\eta^2 + 175b^4h^2\eta^4) - 8b^2c\eta(2048(13a^2 + 10abh + 25b^2h^2)\beta^3 - 256b(10a^2 + 31abh + 46b^2h^2)\beta^2\eta^2 + 30b^3h(8a+17bh)\beta\eta^4 - 5b^5h^2\eta^6) - 4bc^2(2048(13a^2+10abh+25b^2h^2)\beta^3 - 768b(10a^2+31abh+46b^2h^2)\beta^2\eta^2 + 150b^3h(8a+17bh)\beta\eta^4 - 35b^5h^2\eta^6) + b^2(524288(a^2+b^2h^2)\beta^4 - 8192b(13a^2+10abh+25b^2h^2)\beta^3\eta^2 + 512b^2(10a^2+31abh+46b^2h^2)\beta^2\eta^4 - 40b^4h(8a+17bh)\beta\eta^6 + 5b^6h^2\eta^8) - 20c^6h(16a\beta + bh(34\beta - 7b\eta^2)) - 40bc^5h\eta(48a\beta + bh(51\beta - 7b\eta^2))$

$\Psi_5 = 30(a-4bh)^2\beta^2 + \beta(c^2h(13a+6bh) + 4(62a^2+abh+8(a-4bh)(a+4bh))\beta) + 10h^2\Delta_{10}^2$

$\Psi_6 = 8192b(16(a-4bh)^2\Delta_{12} + 2bh(7c^2(a-4bh) + 64(a-2bh)\Delta_{12}) + b^2(c^2+16\Delta_{12})h^2)\beta^3 + 32c^2(32(11c^2+6\Delta_{12})(a-4bh)^2 + 1736bc^2h(a-4bh) + 5035b^2c^2h^2)\beta^2 + 40c^4h(8a+17bh)\beta\Delta_{12} + 5c^8h^2$

$\Sigma_1 = b(512(a-bh)\beta^2 - 16b(10a-9bh)\beta\eta^2 - 7b^3h\eta^4) + 8c^2(4a\beta + bh(10\beta - 3b\eta^2)) - 2bc\eta(64a\beta + bh(11b\eta^2 - 112\beta)) - 10bc^3h\eta - c^4h$

$\Sigma_2 = 2b(128(a+bh)\beta^2 - 4b(16a+3bh)\beta\eta^2 - b^3h\eta^4) - 5bc\eta(32a\beta + bh(16\beta + b\eta^2)) - c^2(32a\beta + bh(56\beta + 3b\eta^2)) + bc^3h\eta + c^4h$

$\Sigma_3 = 24b\beta(32(3a-bh)\beta - b(24a-7bh)\eta^2) - 9c^2(32a\beta - bh(8\beta + 3b\eta^2)) - 3bc\eta(288a\beta - bh(80\beta + 3b\eta^2)) + 27bc^3h\eta + 9c^4h$

$\Sigma_4 = b(512(3a+bh)\beta^2 - 16b(22a+5bh)\beta\eta^2 + b^3h\eta^4) - 32bc(16a+7bh)\beta\eta + 2b^3ch\eta^3 - 4c^2(40a\beta - 3bh(b\eta^2 - 12\beta)) + 14bc^3h\eta + 5c^4h$

$\Sigma_5 = 96a\beta + h(560b\beta - 3(c+b\eta)^2).$

Appendix L. Sensitivity analysis

Table A
Sensitivity analysis under MS game

Para.	% change	I_m^{ti}	I_m^{ui}	θ_m^{ti}	θ_m^{ui}	π_{rm}^{ti}	π_{rm}^{ui}	π_{mm}^{ti}	π_{mm}^{ui}
	-30	31.40	33.29	33.72	40.57	13283.31	14865.74	24722.12	26150.79
	-10	40.79	43.22	43.38	52.20	21999.52	24619.42	40913.53	43278.09
a	0	45.48	48.19	48.21	58.01	27177.98	30414.13	50530.77	53451.89
	10	50.18	53.16	53.04	63.82	32903.11	36820.72	61162.28	64697.41
	30	59.57	63.09	62.70	75.45	45994.35	51469.76	85468.15	90407.78
	-30	47.26	49.38	70.87	74.46	41136.80	44848.64	74316.12	77593.94
	-10	45.97	48.51	53.96	62.20	30653.32	34047.11	56570.23	59616.24
b	0	45.48	48.19	48.21	58.01	27177.91	30414.12	50530.98	53451.23
	10	45.06	47.92	43.57	54.62	24405.41	27496.78	45653.28	48454.25
	30	44.35	47.48	36.52	49.48	20261.20	23103.27	38259.45	40850.68
	-30	43.99	46.18	32.67	45.38	25475.05	27998.33	48923.91	51286.56
	-10	44.92	47.46	42.87	53.63	26524.12	29519.62	49919.92	52660.23
c	0	45.48	48.19	48.21	58.01	27177.90	30414.15	50530.72	53451.16
	10	46.13	49.00	53.76	62.58	27929.56	31410.78	51223.48	54318.21
	30	47.66	50.84	65.59	72.40	29767.37	33759.32	52880.45	56310.74
	-30	46.81	51.02	70.83	87.60	28744.45	33986.92	51964.81	56500.03
	-10	45.82	48.90	53.95	65.37	27571.58	31284.33	50894.85	54209.05
β	0	45.48	48.19	48.21	58.01	27177.90	30414.13	50530.71	53451.15
	10	45.21	47.63	43.57	52.14	26862.11	29728.84	50236.65	52846.15
	30	44.80	46.79	36.54	43.36	26386.82	28718.94	49790.72	51941.91
	-30	45.93	48.64	48.24	58.04	27226.90	30467.96	50585.55	53509.25
	-10	45.63	48.34	48.22	58.02	27194.12	30432.08	50548.94	53470.25
h	0	45.48	48.19	48.21	58.01	27177.90	30414.09	50530.75	53451.23
	10	45.34	48.04	48.20	58.00	27161.76	30396.13	50512.58	53431.25
	30	45.04	47.75	48.18	57.98	27129.48	30360.87	50476.41	53393.49
	-30	45.14	48.19	42.41	58.01	26783.09	30414.03	50162.75	53451.08
	-10	45.36	48.19	46.11	58.01	27034.47	30414.19	50397.38	53451.14
γ	0	45.48	48.19	48.21	58.01	27177.90	30414.15	50530.78	53451.16
	10	45.62	48.19	50.52	58.01	27335.51	30414.18	50676.87	53451.05
	30	45.93	48.19	55.85	58.01	27702.46	30414.15	51015.45	53451.16
	-30	45.48	46.87	48.21	49.95	27177.95	28812.82	50530.78	52026.61
	-10	45.48	47.73	48.21	55.25	27177.92	29843.78	50530.77	52948.10
η	0	45.48	48.19	48.21	58.01	27177.91	30414.09	50530.69	53451.14
	10	45.48	48.69	48.21	60.84	27177.95	31024.15	50530.56	53984.08
	30	45.48	49.76	48.21	66.75	27177.96	32375.87	50530.81	55145.90

Table B

Sensitivity analysis under RS game

Para.	% change	I_r^{ti}	I_r^{ui}	θ_r^{ti}	θ_r^{ui}	θ_r^{ts}	θ_r^{us}	π_{rr}^{ti}	π_{rr}^{ui}	π_{rr}^{ts}	π_{rr}^{us}	π_{mr}^{ti}	π_{mr}^{ui}	π_{mr}^{ts}	π_{mr}^{us}
	-30	0.39	2.04	24.52	30.30	33.87	43.26	24112.15	26187.92	24895.19	27955.62	11982.62	12984.71	12447.61	13977.81
	-10	0.86	2.98	31.55	38.99	43.55	55.63	39859.84	43294.28	41153.23	46212.42	19810.85	21471.04	20576.59	23106.19
a	0	1.09	3.46	35.06	43.33	48.39	61.81	49210.22	53451.61	50806.25	57052.33	24459.01	26510.31	25403.21	28526.16
	10	1.33	3.93	38.58	47.68	53.23	67.99	59544.91	64678.35	61475.80	69033.31	29596.73	32080.31	30737.92	34516.64
	30	1.80	4.87	45.61	56.37	62.90	80.35	83167.68	90340.22	85862.91	96418.41	41340.30	44812.74	42931.51	48209.24
	-30	2.61	4.51	52.23	56.05	73.17	80.65	73240.64	78098.24	76829.33	84161.38	36355.19	38742.05	38414.59	42080.75
	-10	1.51	3.73	39.38	46.55	54.55	66.52	55252.80	59698.61	57272.76	63858.09	27451.10	29609.81	28636.41	31929.03
b	0	1.09	3.46	35.06	43.33	48.39	61.81	49210.19	53451.59	50806.51	57052.05	24459.03	26510.29	25403.23	28526.13
	10	0.74	3.22	31.60	40.75	43.48	58.04	44359.12	48412.33	45652.24	51594.45	22056.15	24010.01	22826.11	25797.24
	30	0.14	2.84	26.38	36.85	36.14	52.43	37054.18	40783.65	37951.82	43386.66	18435.42	20224.81	18975.88	21693.32
	-30	-0.15	1.69	23.42	33.23	31.78	46.25	46970.54	50286.71	47669.52	52353.04	23407.40	24972.25	23834.71	26176.54
	-10	0.62	2.80	31.00	39.77	42.51	56.21	48351.28	52280.32	49590.73	55286.03	24053.12	25936.11	24795.33	27643.04
c	0	1.09	3.46	35.06	43.33	48.39	61.81	49210.23	53451.69	50806.55	57052.33	24459.12	26510.30	25403.21	28526.09
	10	1.64	4.18	39.34	47.13	54.71	67.92	50195.94	54756.31	52221.52	59059.09	24928.68	27157.18	26110.68	29529.51
	30	2.98	5.90	48.74	55.56	69.05	82.08	52604.75	57833.12	55772.02	63961.31	26094.51	28711.41	27886.01	31980.71
	-30	2.24	6.06	52.19	67.35	73.17	99.74	51264.88	58131.62	53780.57	64450.09	25442.91	28864.41	26890.21	32225.08
	-10	1.38	4.09	39.37	49.18	54.55	70.78	49726.79	54590.81	51545.55	58802.05	24704.78	27074.60	25772.73	29401.19
β	0	1.09	3.46	35.06	43.33	48.39	61.81	49210.19	53451.64	50806.52	57052.29	24459.03	26510.30	25403.19	28526.11
	10	0.86	2.96	31.61	38.73	43.48	54.85	48795.41	52554.34	50217.41	55696.21	24262.59	26069.83	25108.71	27848.08
	30	0.51	2.22	26.40	31.94	36.14	44.78	48170.85	51231.30	49337.31	53731.32	23968.21	25426.71	24668.75	26865.71
	-30	1.47	3.83	35.09	43.37	48.39	61.81	49212.14	53457.09	50806.58	57052.34	24462.64	26518.31	25403.19	28526.09
	-10	1.22	3.58	35.07	43.35	48.39	61.81	49210.72	53453.31	50806.52	57052.37	24460.05	26512.88	25403.24	28526.11
h	0	1.09	3.46	35.06	43.33	48.39	61.81	49210.24	53451.61	50806.53	57052.35	24459.04	26510.34	25403.23	28526.19
	10	0.97	3.33	35.05	43.32	48.39	61.81	49209.63	53449.91	50806.54	57052.36	24457.81	26507.71	25403.29	28526.21
	30	0.72	3.08	35.03	43.30	48.39	61.81	49208.87	53446.74	50806.52	57052.31	24455.70	26502.52	25403.31	28526.05
	-30	0.80	3.46	30.74	43.33	42.25	61.81	48691.54	53451.63	50070.47	57052.34	24213.51	26510.33	25035.35	28526.24
	-10	0.99	3.46	33.49	43.33	46.15	61.81	49021.80	53451.61	50538.55	57052.32	24369.69	26510.37	25269.34	28526.13
γ	0	1.09	3.46	35.06	43.33	48.39	61.81	49210.21	53451.62	50806.49	57052.35	24459.03	26510.28	25403.21	28526.08
	10	1.21	3.46	36.79	43.33	50.85	61.81	49417.14	53451.69	51101.68	57052.31	24557.21	26510.31	25550.83	28526.11
	30	1.48	3.46	40.80	43.33	56.60	61.81	49898.65	53451.53	51792.52	57052.38	24786.61	26510.27	25896.24	28526.18
	-30	1.09	2.29	35.06	36.83	48.39	51.67	49210.28	51354.36	50806.48	53912.42	24459.04	25486.21	25403.18	26956.52
	-10	1.09	3.04	35.06	41.08	48.39	58.25	49210.24	52704.79	50806.52	55922.31	24459.01	26143.43	25403.24	27961.25
η	0	1.09	3.46	35.06	43.33	48.39	61.81	49210.22	53451.56	50806.53	57052.36	24459.07	26510.31	25403.19	28526.08
	10	1.09	3.90	35.06	45.68	48.39	65.56	49210.23	54250.41	50806.59	58276.04	24459.15	26905.38	25403.31	29138.06
	30	1.09	4.89	35.06	50.67	48.39	73.76	49210.24	56019.89	50806.55	61042.81	24459.21	27790.36	25403.25	30521.44

Table C
Sensitivity analysis for CS and EI under MS and RS game

Para.	% change	CS_m^{ti}	$CS_m{}^{us}$	CS_r^{ti}	CS_r^{us}	EI_m^{ti}	EI_m^{ts}	EI_r^{ti}	EI_r^{us}
	-30	7902.95	8845.98	7026.86	8860.74	1313.09	2290.42	1309.35	2720.82
	-10	13098.00	14659.80	11615.80	14647.30	2174.26	3792.46	2164.44	4497.69
a	0	16185.10	18114.50	14340.50	18083.10	2685.85	4684.75	2672.15	5552.70
	10	19598.50	21934.40	17352.00	21880.60	3251.43	5671.22	3233.30	6718.77
	30	27404.50	30669.60	24235.50	30560.50	4544.61	7926.71	4515.93	9384.07
	-30	24514.90	26728.50	22955.10	27545.50	4142.90	5011.72	4442.92	6336.57
	-10	18259.00	20282.60	16400.80	20389.30	3044.03	4763.77	3085.87	5734.49
b	0	16185.10	18114.50	14340.50	18083.10	2685.85	4684.75	2672.15	5552.70
	10	14530.60	16373.40	12736.30	16267.70	2402.38	4623.86	2354.61	5416.58
	30	12057.40	13751.30	10402.50	13595.10	1982.50	4538.52	1900.21	5233.26
	-30	15169.90	16674.20	12624.30	15226.90	1723.46	4101.06	1576.73	4256.01
	-10	15795.30	17581.20	13662.40	16980.80	2339.47	4464.01	2253.97	5037.76
c	0	16185.10	18114.50	14340.50	18083.10	2685.85	4684.75	2672.15	5552.70
	10	16632.90	18708.70	15150.50	19377.60	3064.52	4936.29	3163.14	6177.78
	30	17728.90	20109.00	17280.60	22728.10	3944.53	5550.02	4453.18	7885.71
	-30	17119.00	20244.70	16068.60	23076.80	4136.40	7833.27	4442.92	11033.20
	-10	16419.70	18633.30	14760.70	19209.40	3042.43	5419.10	3085.87	6702.47
β	0	16185.10	18114.50	14340.50	18083.10	2685.85	4684.75	2672.15	5552.70
	10	15996.80	17705.90	14009.90	17233.70	2403.65	4122.00	2354.61	4723.14
	30	15713.50	17103.80	13523.20	16039.20	1985.66	3318.43	1900.21	3615.40
	-30	16224.80	18157.70	14340.50	18083.10	2690.10	4692.05	2672.15	5552.70
	-10	16198.30	18128.90	14340.50	18083.10	2687.26	4687.18	2672.15	5552.70
h	0	16185.10	18114.50	14340.50	18083.10	2685.85	4684.75	2672.15	5552.70
	10	16171.90	18100.10	14340.50	18083.10	2684.43	4682.32	2672.15	5552.70
	30	16145.40	18071.40	14340.50	18083.10	2681.60	4677.46	2672.15	5552.70
	-30	15949.70	18114.50	13928.00	18083.10	1641.71	4684.75	1609.73	5552.70
	-10	16099.60	18114.50	14189.60	18083.10	2305.69	4684.75	2281.84	5552.70
γ	0	16185.10	18114.50	14340.50	18083.10	2685.85	4684.75	2672.15	5552.70
	10	16279.00	18114.50	14507.70	18083.10	3104.61	4684.75	3106.77	5552.70
	30	16497.80	18114.50	14902.50	18083.10	4084.05	4684.75	4142.55	5552.70
	-30	16185.10	17159.80	14340.50	16147.50	2685.85	3083.64	2672.15	3424.76
	-10	16185.10	17774.50	14340.50	17373.90	2685.85	4126.99	2672.15	4780.19
η	0	16185.10	18114.50	14340.50	18083.10	2685.85	4684.75	2672.15	5552.70
	10	16185.10	18478.30	14340.50	18867.20	2685.85	5269.60	2672.15	6401.00
	30	16185.10	19284.00	14340.50	20701.30	2685.85	6531.00	2672.15	8373.32

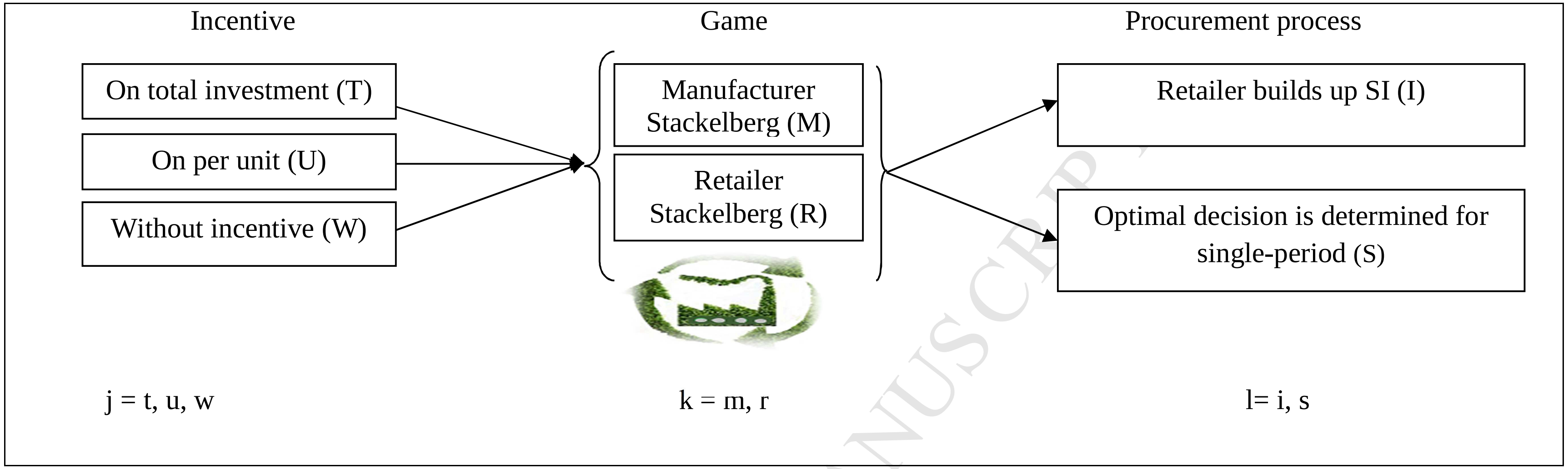

Fig. 1. Procurement Scenarios *jkl*.

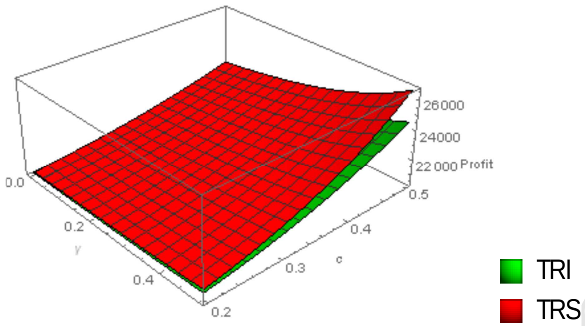

Fig. 2a. Profit functions for the retailer in Scenarios TRI andTRS.

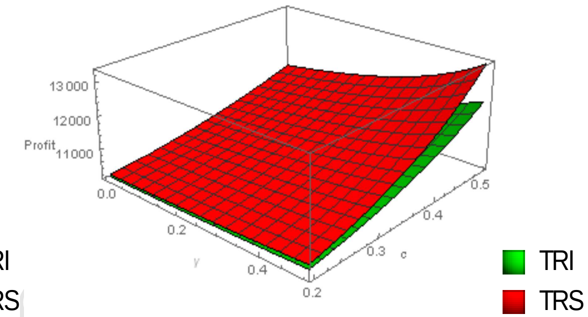

Fig. 2b. Profit functions for the manufacturer in Scenarios TRI andTRS

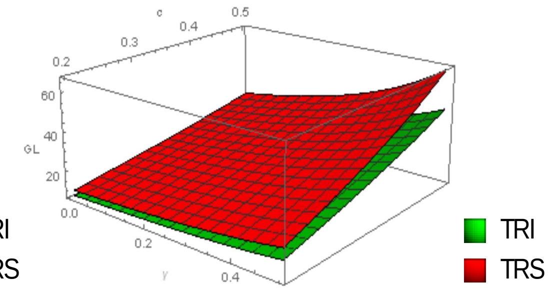

Fig. 2c. GLs in Scenarios TRI and TRS

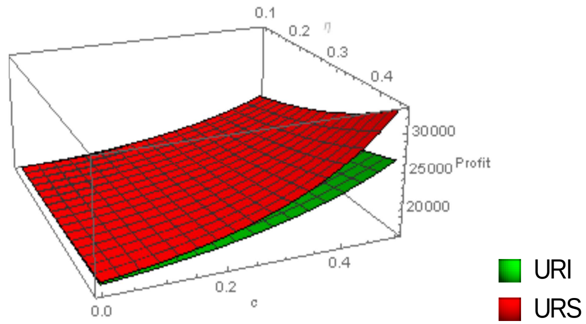

Fig. 3a. Profit functions for the retailer in Scenarios URI and URS

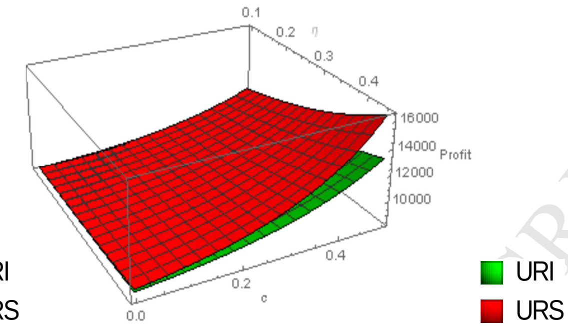

Fig. 3b. Profit functions for the manufacturer in Scenarios URI and URS

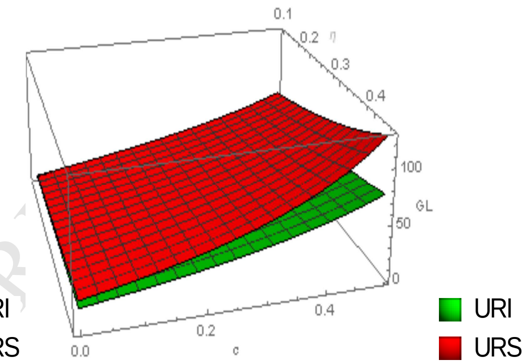

Fig. 3c.GLs in Scenarios URI and URS

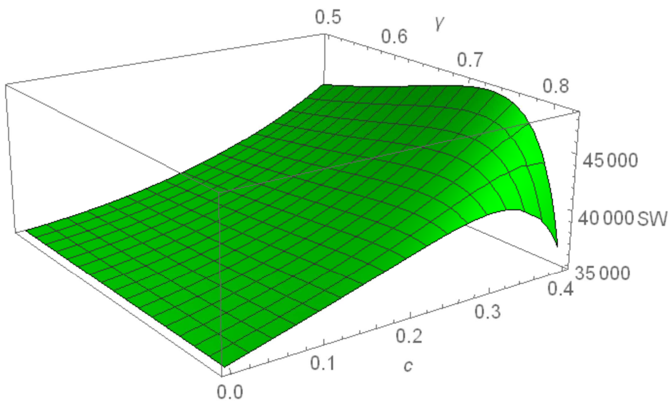

Fig. 4a.SW in Scenarios TRS

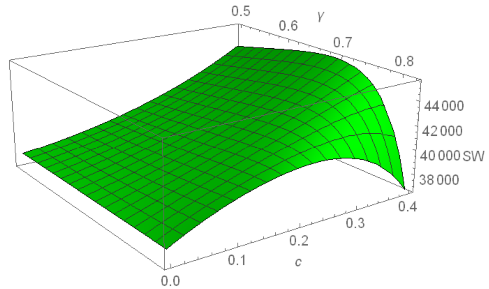

Fig. 4b.SW in Scenarios TMI

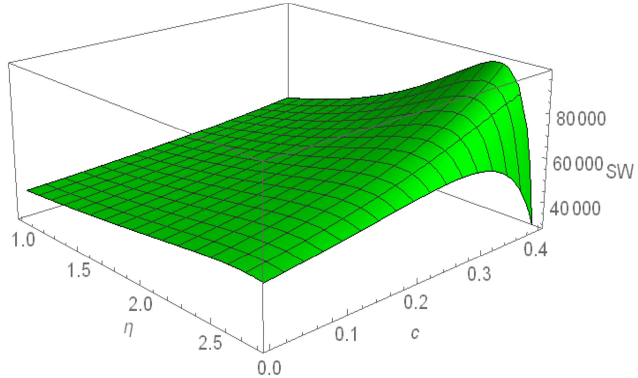

Fig. 4c.SW in Scenarios URS

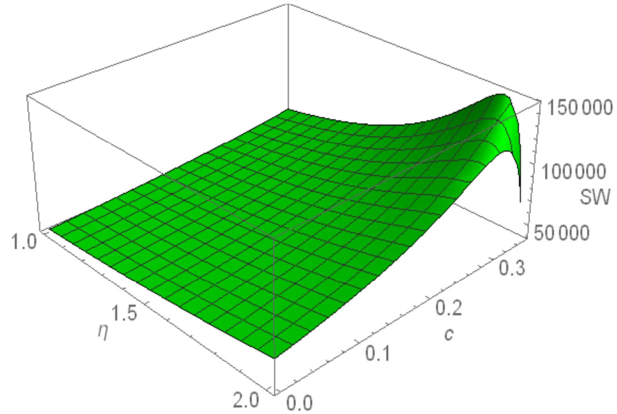

Fig. 4d.SW in Scenarios UMI

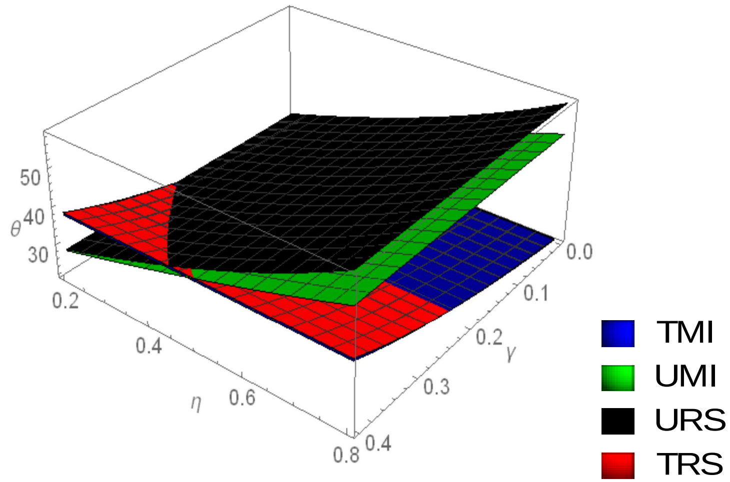

Fig.5. GLs in Scenarios UMI, TMI , URS, and TRS.

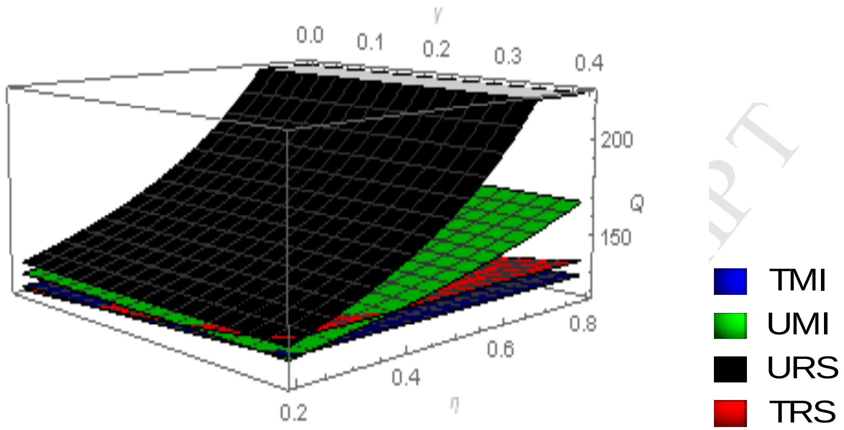

Fig.6. Sales volume in Scenarios UMI, TMI , URS, and TRS.

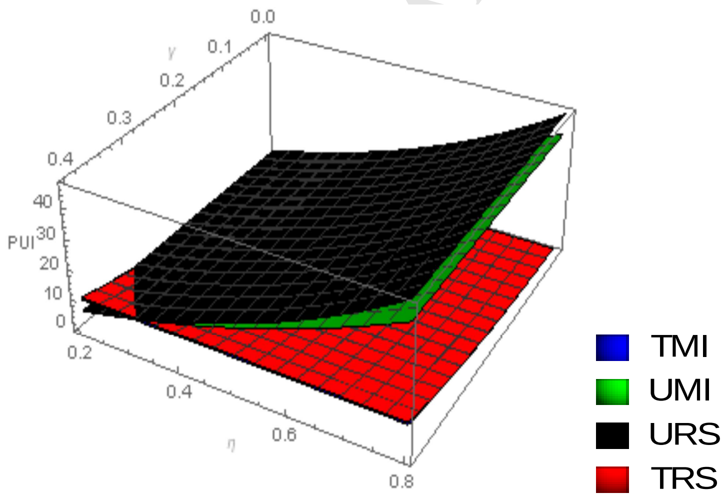

Fig.7. Government incentive on Per-unit product in Scenarios UMI, TMI, URS, and TRS.

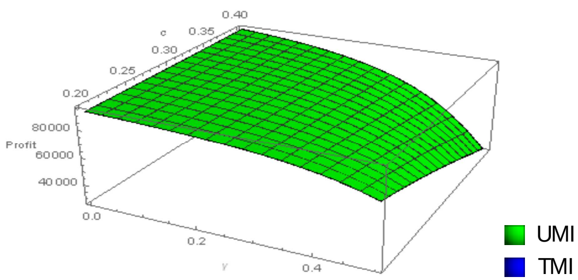

Fig.8a. Profit functions for the retailer in Scenarios UMI and TMI

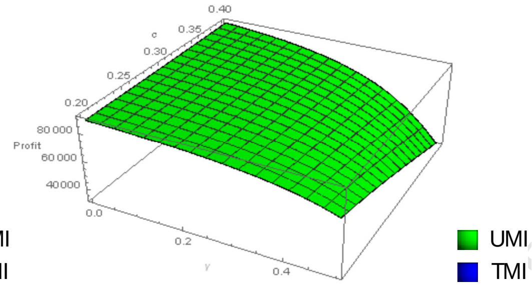

Fig.8b. Profit functions for the manufacturer in Scenarios UMI and TMI

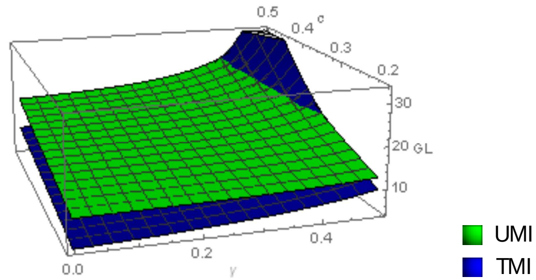

Fig.8c.GLs in Scenarios UMI and TMI

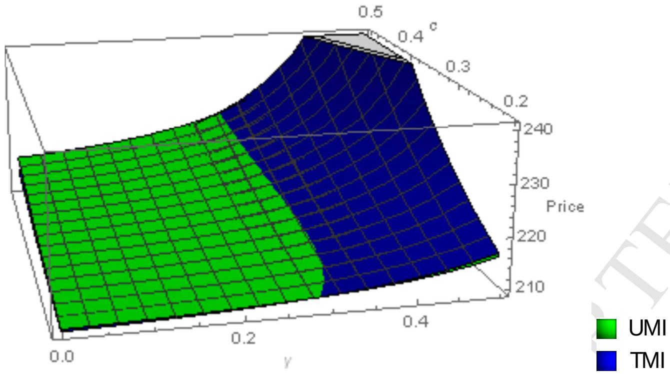

Fig.8d. First period retail price in Scenarios UMI and TMI

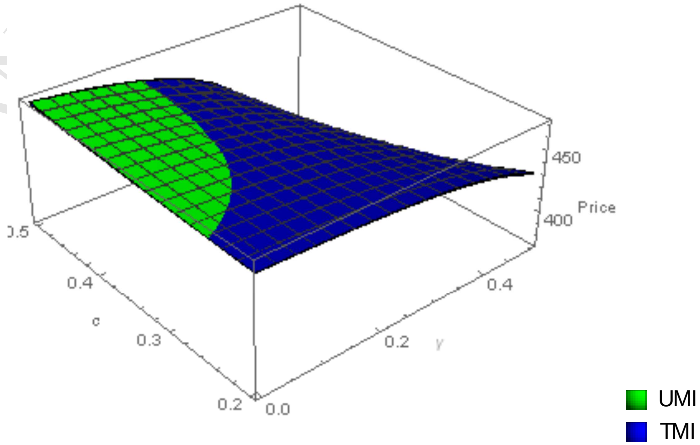

Fig.8c. Second period retail price in Scenarios UMI and TMI

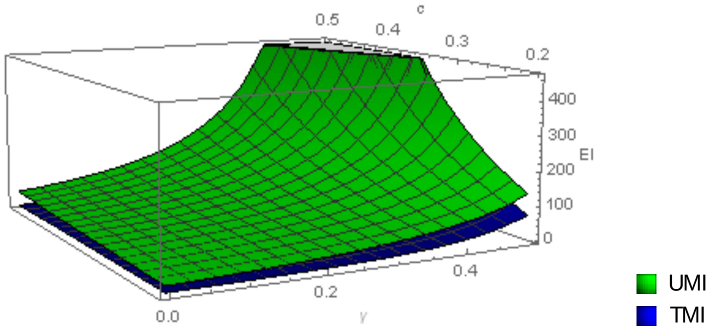

Fig.8f.EIin Scenarios UMI and TMI

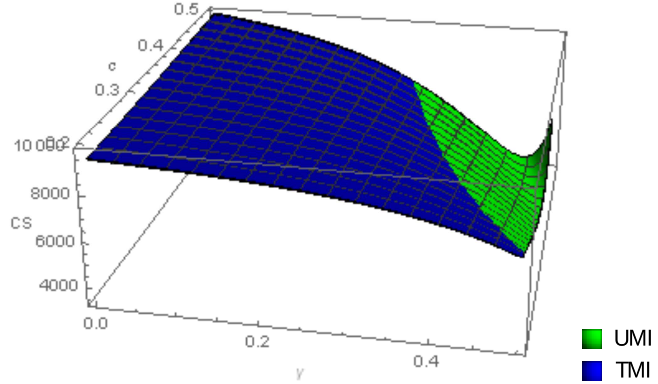

Fig.8g. CS in Scenarios UMI and TMI

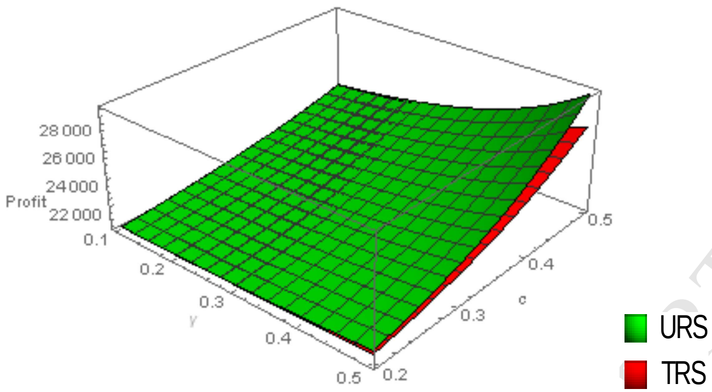

Fig.9a. Profits functions for the retailer in Scenarios URS and TRS

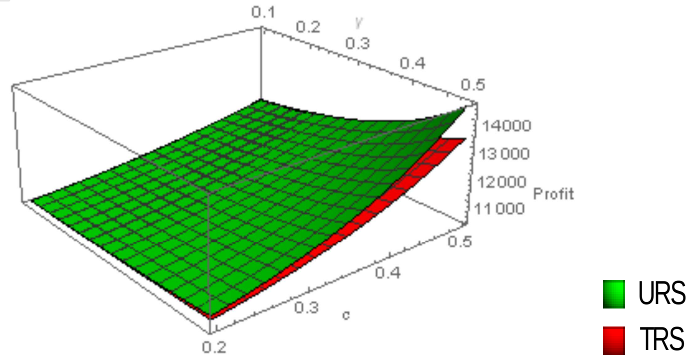

Fig.9b. Profit functions for the manufacturer in Scenarios URS and TRS

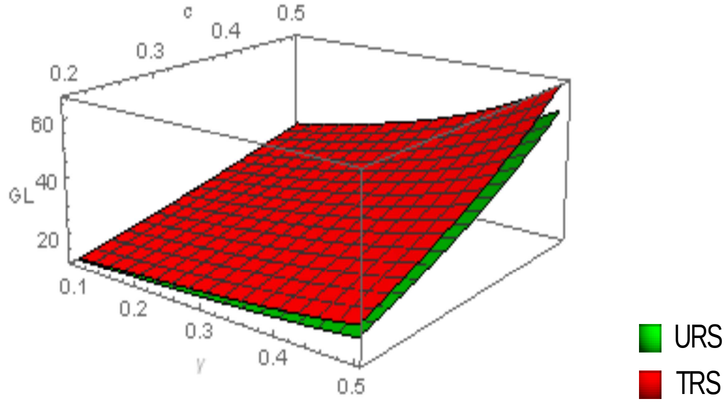

Fig.9c.GLs in Scenarios URB and TRS

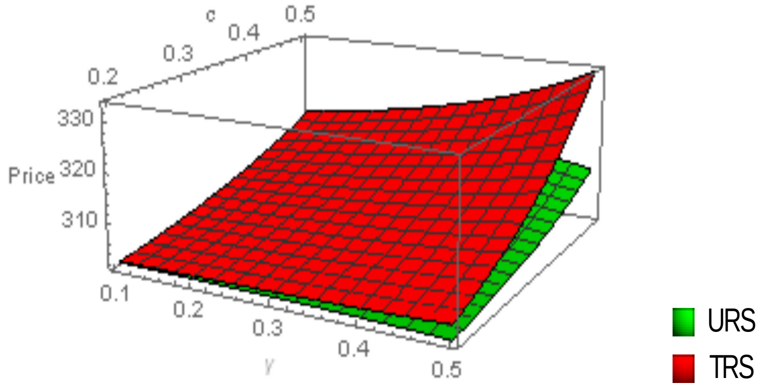

Fig.9d. Retail price in Scenarios URB and TRS

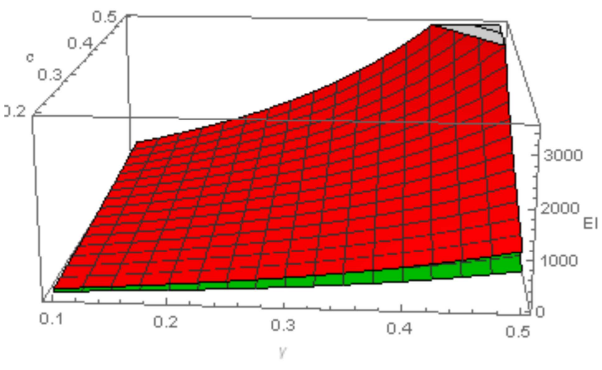

Fig.9e.EIin Scenarios URS and TRS

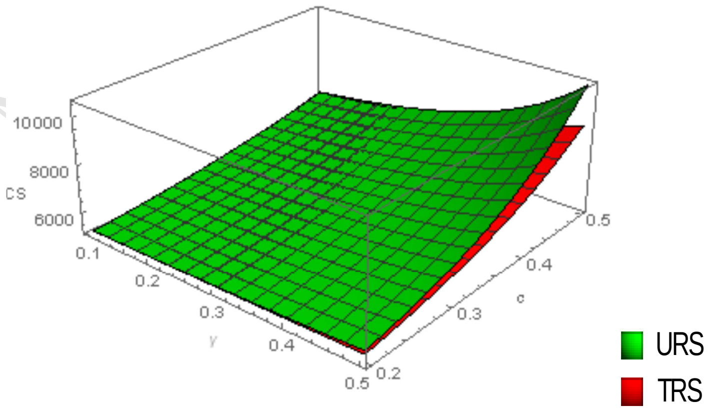

Fig.9f.CS in Scenarios URS and TRS

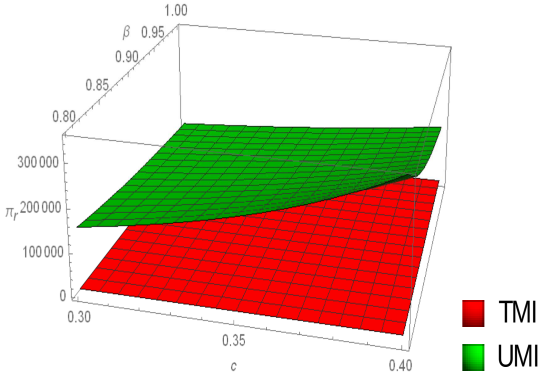

Fig. 10a. Profits for the retailer in Scenarios UMI and TMI

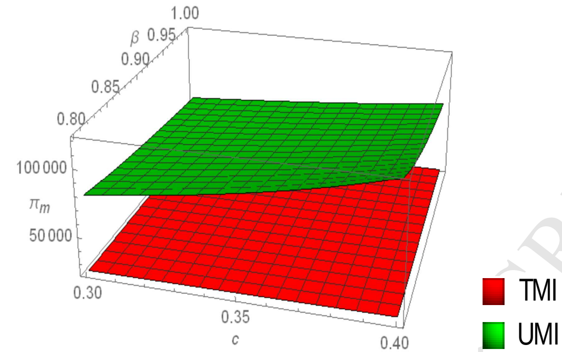

Fig. 10b. Profits for the manufacturer in Scenarios UMI and TMI

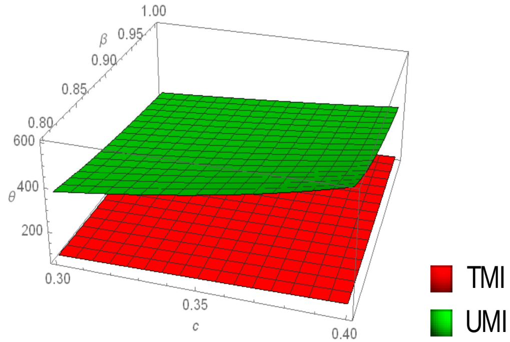

Fig. 10c. GLs in Scenarios UMI and TMI

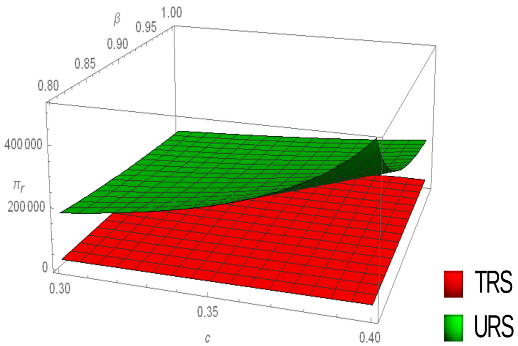

Fig. 11a. Profit for the retailer in Scenarios URS and TRS

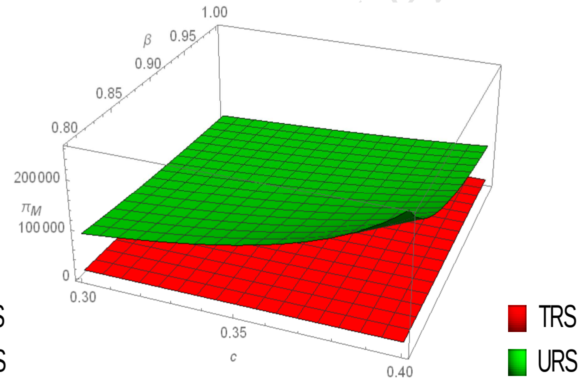

Fig. 11b. Profit for the manufacturer in Scenarios URS and TRS

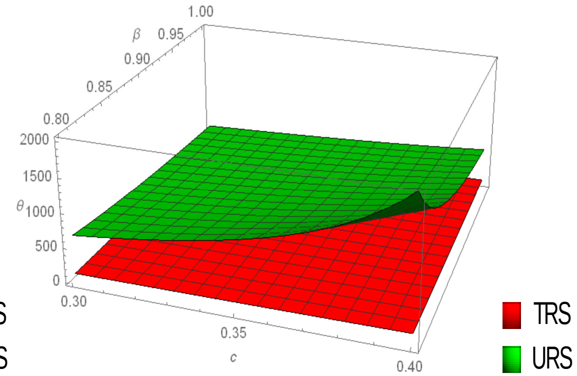

Fig. 11c. GLs in Scenarios URS and TRS

Highlights

We investigate impact of two government incentive policies under two game structures

Two-period planning leads to higher sustainability under manufacturer-stackelberg game

Government incentive on per unit product cause higher consumer surplus

Supply chain members can compromise with sustainability goal for higher profits