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Is It a Strategic Move to Subsidized Consumers Instead of the Manufacturer?

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ABSTRACT Government organizations design and offer subsidy to achieve objectives such as ensuring positive environmental externalities, stimulating sustainable product consumption, improving social welfare. Motivated by two such pragmatic subsidy policies, consumers subsidy and manufacturer subsidy, we formulate parsimonious models under centralized and decentralized settings in a three-stage game framework to obtain a fair understanding about the circumstances under which it is beneficial for the government to subsidize consumers or manufacturer. The effect of two contract mechanisms, namely revenue sharing and green-marketing effort sharing contracts are examined to explore characteristics of supply chain decisions under subsidy. Our study reveals that the effectiveness subsidy program significantly depends on the participating member's intentions to further the cooperation. We find that consumers subsidy leads to an exceptional outcomes, total profits of the supply chain is always less when supply chain members cooperate with each other compared to decentralized setting. Profits for individual decreased considerably under both contract mechanisms. Government also reduces per unit subsidy to consumers. However, subsidy to manufacturer leads to higher profits when supply chain members cooperate. Amount of government subsidy is also higher. Consumers also receive higher quality products. Furthermore, both the contract mechanisms are able to generate Pareto-efficient scenario and higher social welfare of government.

INDEX TERMS Supply chain management, game theory, contract mechanisms, government subsidies, green market, social welfare.

I. INTRODUCTION

The evidence of various government subsidies are common in industry such as energy-efficient home appliances [1]; energy-efficient LED [2], electric or hybrid plug in vehicles [3]. For instance, major car manufacturers such as Renault, Nissan Tesla, Hyundai, Audi, Volkswagen are engaged in developing electric vehicles (EVs) to reduce reliance on fossil fuels, minimize air and noise pollution, satisfy growing demand of environment conscious consumers and others. However, innovations such as developing battery electric vehicles (BEVs) or plug-in hybrid vehicles (PHEVs) need expensive green components. Fortunately, many governments offer subsidies for cultivating innovation and invest heavily in developing charging infrastructure to stimulate the use of EVs [4]. In 2015, Zhengzhou Yutong Group Company Ltd., a leading EV manufacturer received subsidy up to 60%

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unit cost from government of China [5]. Government also promotes consumption of sustainable home appliances to improve consumer welfare. For instance, it was reported by the USA Environmental Protection Agency (EPA) [6] that about $258 and $270 million in the year 2016 and 2017, respectively were invested across the United States to stimulate consumption of ENERGY STAR appliances including clothes washers and dryers, dishwashers, dehumidifiers, freezers, room air conditioners and cleaners, purifiers, etc. Such initiatives are also common and well-practiced in country like Romania [7], China [8], India [9] and others. Besides EVs or home appliances, government-funded energy efficient lighting to cover cost of upgradation or subsidy to promote consumption is also common. It helps considerable reduction of energy-use and embeds significant savings in long term. For instance, the Government of India provided grants up to 75% through Ujwal DISCOM Assurance Yojana (UDAY) to sell LED bulbs at a subsidized rate compared to market price [10]. The government practice is also common in the

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European Union countries like, Ireland [11], France [12] and others. The above evidences explain that government subsidy policies are made in different ways and in different industry.

Despite the vast literature and mass media reports on subsidy schemes and its outcomes to increase social welfare (SW) and consumption, there has been little research attention paid to compare how government SW optimization goal affect characteristics of supply chain (SC) decision under influence of contract mechanisms. Researchers mainly focus on how a subsidy policy can influence characteristic of pricing and investment decision of SC members and purchasing decision of consumers under decentralized settings [13]. It is well documented that SC members can improve their individual as well as overall SC profits through implementing various contract mechanisms and get rid of double marginalization effect. However, best of authors knowledge characteristics of SC decision is not explored and compared if the members try to cooperate through contract mechanisms. We studied the effects of revenue sharing(RS) and green-marketing cost sharing (ES) contracts. The main objective of this study is to explore the following key questions:

1) Does the cooperation between two participating firms affect government decision to set subsidy rates? If so, what are the effects of cooperation through RS and ES contracts on the green-marketing effort for the retailer, greening levels (GL) of the product, and profits for SC members?
2) How do system parameters affect two participating member's individual performance and the overall SC performance under cooperation?
3) Which subsidy improves SW for government organization and consumer surplus under cooperation?

In this study, we seek to answer the above questions by formulating analytical models and analyzing their optimal decisions under consumers subsidy (Policy C) and manufacturer subsidy (Policy M) policies. It is well documented in literature that consumers subsidy have several advantages such as sudden increase in consumption, economic growth [14], as well as have adverse social and political effects also [15]. According to Post [16], consumers subsidy programs come to form "policy traps". On the other hand, subsidy to manufacturer is also practiced to compensate higher investment cost of development sustainable technologies or product quality improvement. To examine the strategic influence of SC members on optimal subsidy rates, we investigate the outcomes of both subsidy policies when the manufacturer and retailer cooperate through RS and ES contracts. Our study differs from the existing literature, the influence of retailer's green-marketing effort; pricing and the green awareness of consumers are considered in demand function under three-stage game structure. Consequences of two SC contracts are examined to show how the cooperation between SC participants influences the manufacturer's investment decision in producing greener product and the retailer's green-marketing effort decision, and most importantly how optimal subsidy

decision of government evolve. Perhaps, this is the first study where it is reported that outcomes of subsidy policy largely depend on the way SC members cooperate with each other. In literature, researchers explained how RS contract can improve profits of SC members in pragmatic scenarios. However, our study reveals that both the RS and ES contracts degrade the performance of each member in Policy C, but it looks promising under Policy M. It is also found that SW can increase if manufacturer participates with the retailer by sharing green-marketing expenditure in the presence of subsidy to manufacturer, not to consumers.

A. LITERATURE REVIEW

The precise question examined in this study related to the literature on subsidies and coordination mechanisms is how government initiatives can affect the equilibrium outcomes in centralized and decentralized supply chain settings.

Collaboration between SC members becomes one of the key pivotal for success. In this direction, RS contract has been acknowledged as an effective means to arbitrarily allocate the total supply chain profit among participants by preserving interest of individuals and the overall SC [17]. In RS contract, the retailer shares a percentage of revenue with the manufacturer for wholesale price negotiation. In pragmatic scenario, Blockbuster Inc. [17], Apple [18] applies RS contract in their SC. In literature, performance of the RS contract has studied extensively from both academicians and practitioners in various supply chain settings ([19]–[27]).

According to Taylor [28], marketing effort decision for retailer is important because the retailer better understands about local market conditions and can thereby stimulate sales and profitability. In such a scenario, manufacturers share a fraction of retailer's sales effort expenditure, commonly known as the participation rate. Higher participation works as a stimulant for the retailers to promote products([29], [30]). He *et al.* [31] reported that cooperative marketing activities are common practice in the United States and joint expenditure is about $50 billion in 2008. According to Xie and Wei [32], the participation rates of the manufacturers is around 25%-75% in reality. In a recent survey by JØrgensen and Zaccour [33] stated that manufacturer participation in retailer sales-stimulating efforts increases overall performance of SC. Zhao *et al.* [34] showed that the manufacturer can also receive benefits from providing percentage reimbursement for the retailer's expenditure. Recently, some authors ([35], [36]) extended the concept of retailer's sales effort to green sales-effort where the retailer invests in green advertising. We refer the articles ([37]–[40]) where the authors highlighted the essence of retailer's expenditure on demand expansion in various supply chain settings. In this study, we make no assumption about the specific type of expenditure, it refers to the dollars invested by the retailer on demand-enhancing activities of green product, such as pre-sales advice, after-sales service, in-store advertising (shelf space, promotional displays, well-trained sales persons), and local media advertising etc., and we call it green-marketing effort.

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TABLE 1. Compression of existing models with the present study.

Study	Demand function	Contract mechanism	Nature of government subsidy	SW optimization
Hafezalkotob[13]	Price; Energy saving level	×	To manufacturer	×
Guo et al. [45]	Price; Marketing effort	×	To manufacturer	✓
Madani and Rasti-Barzoki [46]	Price; Marketing effort	×	To consumers	×
Yang and Xiao [47]	Price; GL	×	To manufacturer	×
Zhang and Wang [48]	Price	×	To consumer	×
Fu et al. [49]	Price	×	To manufacturer and consumer	×
Li et al. [50]	Price	×	To consumers	×
Mahmoudi and Rasti-Barzoki[51]	Price; Marketing effort	×	To manufacturer	×
Sinayi and Rasti-Barzoki [52]	Price; GL	×	To consumers	×
Tong and Li [53]	Price; GL	×	To manufacturer	×
Yuyin and Jinxi [54]	Price, Energy-saving levels; Carbon emissions level	✓	To manufacturer	×
Chen et al.[55]	Price; Marketing effort	×	Jointly to retailer and manufacturer	✓
Giri et al.[56]	Price; GL	×	To manufacturer	×
Liu et al.[57]	Price; CSR	×	To the retailer	✓
Peng and Pang[58]	Constant	×	To manufacturer	×
Safarzadeh and Rasti-Barzoki[59]	Price; Energy price	×	Jointly to manufacturer and consumer	×
Present Study	Price; GL; Marketing effort	✓	To manufacturer and consumers	✓

During past few decades, concerns related to environmental sustainability issues has been transformed from a trendy issue to a realistic priority for consumers, industry and government organization. Thus, green subsidy scheme becomes an emerging topic of interest for practitioners and academic researchers [41]–[44]. Mass media reports also supported that subsidy provided by national or local governments affects the growth of almost every industry. Table 1 presents a summary of recently published research on government subsidy and highlights the contribution of the present study.

Table 1 demonstrates that most of existing studies consider single subsidy policy, therefore, comparative overview of influence of subsidies are missing on pricing, green-marketing effort, and investment in green product development under SW optimization goal for government organization. It is always important to explore how optimal decision alter and which subsidy improve profits for SC members or product consumption. In addition, it is noteworthy to analyze whether the cooperation among SC members pressurized government organizations to provide more subsidy. However, existing literature fails to shade light on those issues. This study contributes to our understanding on the influence of cooperation between SC members on optimal subsidy decision of government organization.

II. PREREQUISITES AND ASSUMPTIONS

We consider a two-echelon SC composed of a manufacturer and a retailer, and examine interaction among the government and SC members in a three-stage Stackelberg game framework where the government determines optimal subsidy rate. The manufacturer invests in producing green products and sells those to consumers through a retailer. Meanwhile, the government proposes subsidy policies for the manufacturer to compensate their growing R&D cost or directly to consumers encouraging them to procure green products.

TABLE 2. Decision and auxiliary variables.

w_j^i	wholesale price
p_j^i	market price of the product
e_j^i	green-marketing effort
θ_j^i	greening level
δ_c^i	per unit consumer subsidy, $\delta_c^i \in (0, p_j^i)$
ρ_m^i	subsidy received by the manufacturer, $\rho_m^i \in (0, 1)$
π_{kj}^i	player k's profit, $k \in m, r$
Π_{cj}^i	centralized supply chain profit
SW_j^i	SW of government
TS_j^i	total amount of subsidy
Q_j^i	sales volume

We formulate models to analyze single-period decision and consider a full-information setting. To examine the optimal pricing, green-marketing effort for the retailer and R&D investment for the manufacturer under influence of government subsidy policies, we consider twelve scenarios, namely Scenarios ij. Superscript $i \in \{c, d, rs, es\}$ signifies optimal decisions under different SC setting, namely centralized(c), decentralized (d), RS contract(rs), and ES contract(es), respectively. Subscript $j \in \{b, c, m\}$ refers to the benchmark(b) model where either consumers or the manufacturer do not receive any subsidy, consumers receive subsidy(c), and manufacture receives subsidy(m), respectively. Table 2 represents list of notations used to differentiate decision auxiliary variables in different scenarios:

The following assumptions are made to establish proposed models:

1) The market demand is linearly dependent on the retail price, GL, and green-marketing effort; and its functional form is $D_j^i = a - bp_j^i + c\theta_j^i + d\sqrt{e_j^i}$, where a, b, c, and d are non-negative parameters, represent potential intrinsic demand, and price; GL, green-marketing effort sensitivities, respectively. Therefore, higher value

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for a means the consumer has better perception about the product. If $c = 0$, the demand function is similar to the previous study by Desiraju and Moorthy [60]. If $d = 0$, the demand function become similar to the studies where demand function becomes price-greening level sensitive([61]–[64]).

2) The manufacturer bears cost for green innovation [61] and investment cost is considered as $\lambda\theta_j^{i2}$ and per unit manufacturing cost (c_m). Retailer bears cost for green-marketing effort. In practice, retailers can stimulate market demand through investment in local advertising, in-store product demonstrations, improve personal selling strategies by recruiting skilled professionals, and so forth ([28], [65]). Therefore, it is important to identify the optimal green-marketing effort decision for the retailer because of additional investment. The function of investment effort cost for the retailer is e_j^i. For feasibility and ensuring optimal solution, it is assumed that the green-marketing effort sensitivity satisfies, $d < \sqrt{2}$ [60].

3) In consume subsidy, we call it Policy C, the government provide subsidy δ_c^i, ($0 < \delta_c^i < p_c^i$) on per unit product. Therefore, the effective price paid by the consumer to the retailer will be $p_c^i - \delta_c^i$ ([52], [66]). In Policy M, the manufacturer receives a fraction (ρ_m^i, $0 < \rho_m^i \leq 1$) of the total R&D investment subsidy from the government ([67], [68]) to improve GL of the product.

4) Optimal decisions are derived in a three-stage game framework in the presence of subsidy and the decision sequence are defined as follows:

Step 1: The government decides subsidy rate (δ_c^i or ρ_m^i) by maximizing SW;

Step 2: The manufacturer decides wholesale price (w_j^i) and GL (θ_j^i);

Step 3: The retailer decides retail price (p_j^i) and green-marketing effort (e_j^i).

However, in absence of subsidy, optimal decisions are derived through last two steps.

5) Objectives for the government is to maximize SW. In this study, SW function is considered as sum of profits for the manufacturer and retailer, Consumer Surplus (CS), and net government expenditures([49], [57], [69]). CS is commonly used as a measure to estimate product consumption in the presence of subsidy([70], [71]).

III. THE MODELS

The scenario where government provides consumer subsidy is discussed in Subsection A. Characteristics of optimal decisions under R&D investment subsidy to the manufacturer are examined in Subsection B. Finally, when the government does not provide any subsidy is discussed in Subsection C as benchmark.

A. OPTIMAL DECISIONS IN POLICY C

Due to direct subsidy to consumers, market demand in Policy C is $D_c^i = a - b(p_c^i - \delta_c^i) + c\theta_c^i + d\sqrt{e_c^i}$, $i = c, d$. The evidences

are reported in the context of The US, where the Victorian Energy Upgrades program is introduced where consumers can enjoy rebate on purchasing LED lamp. In decentralized SC setting, the manufacturer and retailer wants to optimize their respective profits, and profit functions for the retailer, manufacturer and SW for the government organization can be described as follows:

$$\pi_{rc}^d = (p_c^d - w_c^d)D_c^d - e_c^d \tag{1}$$
$$\pi_{mc}^d = (w_c^d - c_m)D_c^d - \lambda(\theta_c^d)^2 \tag{2}$$
$$SW_c^d = \pi_{rc}^d + \pi_{mc}^d + CS_c^d - \delta_c^d D_c^d \tag{3}$$

However, in a centralized setting, the manufacturer and retailer jointly determine price, green-marketing effort and GL that optimizes total SC profits. In this scenario, wholesale price does not make any impact on optimal decision. Therefore, profit function for centralized SC and SW for government organization are obtained as follows:

$$\Pi_{cc}^c = (p_c^c - c_m)D_c^c - e_c^c - \lambda(\theta_c^c)^2 \tag{4}$$
$$SW_c^c = \Pi_{cc}^c + CS_c^c - \delta_c^c D_c^c \tag{5}$$

Optimal decisions for the decentralized and centralized setting in Policy C are presented in Propositions 1 and 2, respectively. For simplicity, we use additional notations and those are presented in Appendix A. We refer to Appendix B for the detailed derivation.

Proposition 1: Decentralized optimal decision in Policy C is obtained as follows:

$$\delta_c^d = \frac{AM_3\lambda}{b\Delta_3}; \quad w_c^d = \frac{aM_2\lambda - bc_m(2\,b\lambda + c^2)}{b\Delta_3};$$
$$p_c^d = \frac{aM_3\lambda - bc_m(4\,b\lambda + c^2)}{b\Delta_3}; \quad \theta_c^d = \frac{Ac}{\Delta_3};$$
$$e_c^d = \frac{A^2\,d^2\lambda^2}{\Delta_3^2}; \quad \pi_{mc}^d = \frac{A^2\lambda\Delta_2}{\Delta_3^2}; \quad \pi_{rc}^d = \frac{A^2\,M_2\lambda^2}{\Delta_3^2};$$
$$\Pi_{cc}^d = \frac{A^2\lambda(M_2\lambda + \Delta_2)}{\Delta_3^2}; \quad CS_c^d = \frac{2\,A^2\,b\lambda^2}{\Delta_3^2};$$
$$TS_c^d = \frac{2\,A^2\,M_3\lambda^2}{\Delta_3^2}; \quad SW_c^d = \frac{A^2\lambda}{\Delta_3}; \quad Q_c^d = \frac{2\,Ab\lambda}{\Delta_3}.$$

Proposition 2: Centralized optimal decision in Policy C is obtained as follows:

$$\delta_c^c = \frac{2\,A\lambda}{\Delta_3}; \quad p_c^c = \frac{2\,a\lambda - c_m(c^2 + d^2\lambda)}{\Delta_3}; \quad \theta_c^c = \frac{Ac}{\Delta_3};$$
$$e_c^c = \frac{A^2\,d^2\lambda^2}{\Delta_3^2}; \quad \Pi_{cc}^c = \frac{A^2\lambda\Delta_1}{\Delta_3^2}; \quad CS_c^c = \frac{2\,A^2\,b\lambda^2}{\Delta_3^2};$$
$$TS_c^c = \frac{4\,A^2\,b\lambda^2}{\Delta_3^2}; \quad SW_c^c = \frac{A^2\lambda}{\Delta_3}; \quad Q_c^c = \frac{2\,Ab\lambda}{\Delta_3}.$$

One can found that optimal subsidy rate, GL, green-marketing effort, SW, profits of each members in decentralized setting or centralized supply chain profit increased with consumers green product sensitivity and green-marketing effort; and decreased with efficiency of the manufacturer's in R&D investment (See Appendix B). Consumers sensitivity

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with green product can improve overall supply chain performance. By comparing optimal decisions obtained under centralized and decentralized scenarios in Policy C, the following theorem is proposed:

Theorem 1: In Policy C

1) Per unit subsidy, and retail price, total SC profit, and TS always higher in decentralized supply chain.
2) GL, green-marketing effort for the retailer, sales volume, and SW remain identical in both centralized and decentralized settings.

We refer Appendix D for the proof of Theorem 1. In the context of SCM literature, the results are noteworthy. It is expected that the total SC profit is always higher in centralized setting, but it is not true in Policy C. Moreover, GLs, green-marketing efforts, and sales volumes remain uniform in both centralized and decentralized settings. Consumers also pay the same price, because $(p_c^c - \delta_c^c) - (p_c^d - \delta_c^d) = 0$. Therefore, cooperation of two members does not improve performance of SC and fail to ensure higher amount of total subsidy from the government. Although, per unit subsidy is always higher in decentralized setting, but it does not guarantee higher product consumption.

B. OPTIMAL DECISIONS IN POLICY M

In Policy M, government subsidy goes to the manufacturer. As an example, in the USA, \$2 billion worth of grants for the manufacturers was provided to stimulate sustainability initiatives and increase energy efficiency businesses environment through the American Recovery and Reinvestment Act (ARRA)to produce advanced batteries and components [72]. The market demand in Policy M is $D_m^i = a - bp_m^i + c\theta_m^i + d\sqrt{e_m^i}$, $i = c, d$. The profit functions for the retailer and manufacturer in decentralized setting, and SW for the government organization are obtained as follows:

$$\pi_{rm}^d = (p_m^d - w_m^d)D_m^d - e_m^d \tag{6}$$

$$\pi_{mm}^d = (w_m^d - c_m)D_m^d - (1 - \rho_m^d)\lambda(\theta_m^d)^2 \tag{7}$$

$$SW_m^d = \pi_{rm}^d + \pi_{mm}^d + CS_m^d - \rho_m^d\lambda(\theta_m^d)^2 \tag{8}$$

Therefore, profit function for centralized setting and SW for government organization are obtained as follows:

$$\Pi_{cm}^c = (p_m^c - c_m)D_m^c - e_m^c - (1 - \rho_m^c)\lambda(\theta_m^c)^2 \tag{9}$$

$$SW_m^c = \Pi_{cm}^c + CS_m^c - \rho_m^c\lambda(\theta_m^c)^2 \tag{10}$$

Similar to Policy C, we derive optimal decisions in Policy M, hence detail derivations are omitted. We present optimal decisions in decentralized and centralized settings in Propositions 3 and 4, respectively.

Proposition 3: Decentralized optimal decision in Policy M is obtained as follows:

$$\rho_m^d = \frac{M_3}{M_4}; \quad w_m^d = \frac{4(a + bc_m)M_2{}^2\lambda - 2\,bc^2\,c_mM_4}{2b\Delta_4};$$

$$p_m^d = \frac{2\,M_2(aM_3 + bc_mM_1)\lambda - bc^2\,c_mM_4}{b\Delta_4}; \quad \theta_m^d = \frac{AcM_4}{\Delta_4};$$

$$e_m^d = \frac{4\,A^2\,d^2M_2{}^2\lambda^2}{\Delta_4{}^2}; \quad \pi_{mm}^d = \frac{2\,A^2\,M_2\lambda}{\Delta_4};$$

$$\pi_{rm}^d = \frac{4\,A^2M_2{}^3\lambda^2}{\Delta_4{}^2}; \quad \Pi_{cm}^d = \frac{2\,A^2\,M_2\lambda(2M_2{}^2\lambda + \Delta_4)}{\Delta_4{}^2};$$

$$CS_m^d = \frac{8\,A^2\,bM_2{}^2\lambda^2}{\Delta_4{}^2}; \quad TS_m^d = \rho_m^d\lambda(\theta_m^d)^2 = \frac{A^2\,c^2\,M_3\,M_4\lambda}{\Delta_4{}^2};$$

$$SW_m^d = \frac{A^2\,M_4\lambda}{\Delta_4}; \quad Q_m^d = \frac{4\,AbM_2\lambda}{\Delta_4}.$$

Proposition 4: Centralized optimal decision in Policy M is obtained as follows:

$$\rho_m^c = \frac{2\,b}{M_3}; \quad p_m^c = \frac{M_2(2\,a + c_mM_1)\lambda - c^2\,c_mM_3}{\Delta_5};$$

$$\theta_m^c = \frac{AcM_3}{\Delta_5}; \quad e_m^c = \frac{A^2\,d^2M_2{}^2\lambda^2}{\Delta_5{}^2}; \quad \Pi_{cm}^c = \frac{A^2\,M_2\lambda}{\Delta_5};$$

$$CS_m^c = \frac{2\,A^2\,bM_2{}^2\lambda^2}{\Delta_5{}^2}; \quad TS_m^c = \rho_m^c\lambda(\theta_m^c)^2 = \frac{2\,A^2\,bc^2\,M_3\lambda}{\Delta_5{}^2};$$

$$SW_m^c = \frac{A^2\,M_3\lambda}{\Delta_5}; \quad Q_m^c = \frac{2\,AbM_2\lambda}{\Delta_5}.$$

Characteristics of optimal decisions in Policy M are almost similar with Policy C. The main difference is that optimal subsidy rate does not change with green-marketing effort or consumer sensitivity. The expressions of optimal subsidy rates in Propositions 3 and 4 also demonstrate that the market potential does not make any impact on the subsidy rate. Apart from that, one can find out that GL, green-marketing effort, SW, profits of each members in decentralized setting or total SC profit in centralized setting increased with consumers green product sensitivity and green-marketing effort; and decreased with efficiency of the manufacturer's R&D investment(See Appendix E). By comparing optimal decisions obtained under centralized and decentralized SCs in Policy M, the following proposition is proposed:

Theorem 2: In Policy M

1) per unit subsidy and retail price always higher in decentralized SC.
2) GL, total SC profit, investment in green-marketing, sales volume, SW and TS always higher in centralized supply chain.

We refer Appendix F for the proof of Theorem 2. Unlike in Policy C, the results are consistent. Overall performance of SC increased in centralized setting and consumers also need to pay less. It is noteworthy that under both policies government reduces subsidy rate in centralized setting. By comparing Theorems 1 and 2, one can find an indication that the government subsidy rate might less if SC members cooperate with each other. We would discuss this issue in Section IV.

C. OPTIMAL DECISIONS IN ABSENCE OF GOVERNMENT SUBSIDY

We consider this scenario as benchmark to compare pros and cons of subsidies. In this scenario, manufacturer or consumers do not receive subsidy. Market demand function in absence

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of subsidy is $D_b^i = a - bp_b^i + c\theta_b^i + d\sqrt{e_b^i}$ $i = c, d$. The profit functions for the retailer and manufacturer in decentralized scenario, and corresponding centralized SC profits are obtained as follows:

$$\pi_{rb}^d(p_b^d, e_b^d) = (p_b^d - w_b^d)D_b^d - e_b^d \tag{11}$$

$$\pi_{mb}^d(w_b^d, \theta_b^d) = (w_b^d - c_m)D_b^d - \lambda(\theta_b^d)^2 \tag{12}$$

$$\Pi_{cb}^c(p_b^c, \theta_b^c, e_b^c) = (p_b^c - c_m)D_b^c - \lambda(\theta_b^c)^2 \tag{13}$$

The following Propositions 5 and 6 represent decentralized and centralized optimal decision, respectively. Note that, optimal decision in the absence of subsidy is derived in two-stage game setting and derivation is similar and hence omitted.

Proposition 5: Decentralized optimal decision in absence of government subsidy is obtained as follows:

$$w_b^d = \frac{aM_2 + bc_m\Delta_1}{b\Delta_2}; \quad p_b^d = \frac{aM_3 + bc_m\Delta_3}{b\Delta_2}; \quad \theta_b^d = \frac{Ac}{\Delta_2};$$

$$e_b^d = \frac{A^2 d^2\lambda^2}{\Delta_2^2}; \quad \pi_{mb}^d = \frac{A^2\lambda}{\Delta_2}; \quad \pi_{rb}^d = \frac{A^2 M_2\lambda^2}{\Delta_2^2};$$

$$\Pi_{cb}^d = \frac{A^2\lambda(M_2\lambda + \Delta_2)}{\Delta_2^2}; \quad Q_b^d = \frac{2 Ab\lambda}{\Delta_2}.$$

Proposition 6: Centralized optimal decision in absence of government subsidy is obtained as follows:

$$p_b^c = \frac{2 a\lambda + c_m\Delta_3}{\Delta_1}; \quad \theta_b^c = \frac{Ac}{\Delta_1}; \quad e_b^c = \frac{A^2 d^2\lambda^2}{\Delta_1^2};$$

$$\Pi_{cb}^c = \frac{A^2\lambda}{\Delta_1}; \quad Q_b^c = \frac{2 Ab\lambda}{\Delta_1}.$$

By comparing optimal decisions, one can find that the GL, investment in green-marketing, total SC profit, and sales volume are higher and retail price is lower in centralized SC compared to decentralized SC, because $\theta_b^c - \theta_b^d = \frac{AcM_2\lambda}{\Delta_1\Delta_2} > 0$, $\sqrt{e_b^c} - \sqrt{e_b^d} = \frac{AdM_2\lambda^2}{\Delta_1\Delta_2} > 0$, $\Pi_{cb}^c - \Pi_{cb}^d = \frac{A^2 M_2^2\lambda^3}{\Delta_1\Delta_2^2} > 0$, $Q_b^c - Q_b^d = \frac{2 AbM_2\lambda^2}{\Delta_1\Delta_2} > 0$, and $p_b^c - p_b^d = -\frac{AM_2\lambda\Delta_3}{b\Delta_1\Delta_2} < 0$, respectively. The result is consistent with the existing literature. One may verify that profits for the manufacturer and retailer in decentralized setting and total profits in centralized setting are higher in Policy C or M compared to benchmark scenarios(see Appendix G) where SC members does not receive any subsidy. The results make sense. Government subsidy can boost profits for each SC members, the results also demonstrate the fact. To verify, which subsidy policy improve performance of overall SC in both centralized and decentralized decision settings, we propose the following theorem:

Theorem 3: Under both centralized and decentralized settings, GL, investment in green-marketing, retail price, total SC profit, SW, total amount of subsidy, and sales volume always higher in Policy C compared to Policy M.

We refer Appendix H for the proof of Theorem 3. Theorem 2 reveals positive impact of consumer subsidy on sales, profits and SW. However, Theorem 1 demonstrates that integration of two members in Policy C always reduces the

overall SC profits. By comparing Theorems 1 and 2, one can observe that TS is higher in Policy C under decentralized setting, but it is reverse in Policy M. Outcomes are in the spirit of Bagnoli and Watts [73], where the authors noted that selling to environmental conscious consumers always affect pricing decision of SC. In Section 4, we examine the effect of two coordination mechanisms in detail to highlight behavior of government subsidy if SC members cooperates.

IV. BEHAVIOR OF COLLABORATIVE DECISION

In this section, we analyze optimal decisions under two contract mechanisms, RS and ES contract, in the perspective of improving overall performance. In RS contract, the retailer share a fraction of revenue ($\phi_j^{rs}, 0 \leq \phi_j^{rs} < 1$) with the manufacturer for wholesale price negotiation. In ES contract, the manufacturer shares a fraction ($\psi_j^{es}, 0 \leq \psi_j^{es} < 1$) of retailer's green-marketing expenditure to stimulate demand. Demand functions in Policy C and M are

$$D_c^i = a - b(p_c^i - \delta_c^i) + c\theta_c^i + d\sqrt{e_c^i}$$

and

$$D_m^i = a - bp_m^i + c\theta_m^i + d\sqrt{e_m^i}$$

($i = rs, es$), respectively. Under two mechanisms, profit functions for the retailer and manufacturer, and SW for the government are obtained as follows:

In Policy C:

$$\left.\begin{array}{l} \pi_{rc}^i = [(1 - \phi_c^{rs})p_c^i - w_c^i]D_c^i - (1 - \psi_c^{es})e_c^i \\ \pi_{mc}^i = (w_c^i - c_m + \phi_c^{rs}p_c^i)D_c^i - \psi_c^{es}e_c^i - \lambda\theta_c^{i2} \\ SW_c^i = \pi_{rc}^i + \pi_{mc}^i + CS_c^i - \delta_c^iD_c^i \end{array}\right\} \tag{14}$$

In Policy M:

$$\left.\begin{array}{l} \pi_{rm}^i = [(1 - \phi_m^{rs})p_m^i - w_m^i]D_m^i - (1 - \psi_m^{es})e_m^i \\ \pi_{mm}^i = (w_m^i - c_m + \phi_m^{rs}p_m^i)D_m^i - \psi_m^{es}e_m^i \\ \qquad - (1 - \rho_m)\lambda\theta_m^{i2} \\ SW_m^i = \pi_{rm}^i + \pi_{mm}^i + CS_m^i - \rho_m^i\lambda\theta_m^{i2} \end{array}\right\} \tag{15}$$

If one substitutes $\psi_j^{es} = 0$ or $\phi_j^{rs} = 0$ in (14)-(15), respectively, then profit functions for the manufacturer, retailer, and SW for government in RS or ES contract will be obtained. Optimal decisions under two contract mechanism are presented in Table 3. The detail derivation of optimal decision under the RS contract is presented in Appendix I and proof of ES contract is omitted due to similarity.

The following theorem explores behavior of optimal decision in perspective of obtaining Pareto-optimal solution in Policy C.

Theorem 4: In Policy C, profits for the manufacturer and retailer decreased in both contract mechanisms with increasing values of contract parameters.

We refer to Appendix J for the detail derivation. Similarly, the following theorem is proposed for Policy M.

Theorem 5: Under Policy M

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TABLE 3. Optimal decisions in Scenarios CRS, CES, MRS and MES.

| Sce.	CRS	CES	MRS	MES
δ_c^i	$\frac{A\lambda(M_3-2M_1\phi_c^{rs}-d^2\phi_c^{rs2})}{b\Delta_c^{rs}}$	$\frac{A\lambda(M_3-6b\psi_c^{es})(1-\psi_c^{es})}{b\Delta_c^{es}}$	-	-
ρ_m^i	-	-	$\frac{M_3-2M_1\phi_m^{rs}-d^2\phi_m^{rs2}}{M_4-4M_1\phi_m^{rs}-d^2\phi_m^{rs2}}$	$\frac{(M_3-6b\psi_m^{es})(1-\psi_m^{es})}{\Sigma_7}$
w_j^i	$\frac{(AM_2\lambda(1-\phi_c^{rs})+bc_m\Delta_c^{rs})(1-\phi)}{b\Delta_c^{rs}}$	$\frac{A(M_2(1-\psi_c^{es})^2+d^2\psi_c^{es2})\lambda+M_5}{b\Delta_c^{es}}$	$\frac{(2AM_2M_6\lambda(1-\phi_m^{rs})+bc_m\Delta_m^{rs})(1-\phi_m^{rs})}{b\Delta_m^{rs}}$	$\frac{A\lambda\Sigma_3+bc_m\Delta_m^{es}}{b\Delta_m^{es}}$
p_j^i	$\frac{A(2b+M_2(1-\phi_c^{rs}))+bc_m\Delta_c^{rs}}{b\Delta_c^{rs}}$	$\frac{A(M_3(1-\psi_c^{es})^2+d^2\psi_c^{es2})\lambda+M_5}{b\Delta_c^{es}}$	$\frac{2AM_2M_6(M_3-M_2\phi_m^{rs})\lambda+bc_m\Delta_m^{rs}}{b\Delta_m^{rs}}$	$\frac{A\lambda\Sigma_4+bc_m\Delta_m^{es}}{b\Delta_m^{es}}$
θ_j^i	$\frac{Ac}{\Delta_c^{rs}}$	$\frac{Ac(1-\psi_c^{es})^2}{\Delta_c^{es}}$	$\frac{Ac(M_4-4M_1\phi_m^{rs}-d^2\phi_m^{rs2})}{\Delta_m^{rs}}$	$\frac{Ac\Sigma_7(1-\psi_m^{es})^2}{\Delta_m^{es}}$
e_j^i	$\frac{A^2d^2\lambda^2(1-\phi_c^{rs})^2}{\Delta_c^{rs2}}$	$\frac{A^2d^2\lambda^2(1-\psi_c^{es})^2}{\Delta_c^{es2}}$	$\frac{4A^2d^2\lambda^2M_6^2(1-\phi_m^{rs})^2}{\Delta_m^{rs2}}$	$\frac{A^2d^2\lambda^2(1-\psi_m^{es})^2\Sigma_5^2}{\Delta_m^{es2}}$
π_{mj}^i	$\frac{A^2\lambda(2M_1\lambda(1-\phi_c^{rs})+4b\lambda-c^2)}{\Delta_c^{rs2}}$	$\frac{A^2\lambda\Upsilon_2(1-\psi_c^{es})^2}{\Delta_c^{es2}}$	$\frac{2A^2\lambda M_6}{\Delta_m^{rs2}}$	$\frac{A^2\lambda\Sigma_5(1-\psi_m^{es})^2}{\Delta_m^{es}}$
π_{rj}^i	$\frac{A^2\lambda^2(M_2+d^2\phi_c^{rs})(1-\phi_c^{rs})}{\Delta_c^{rs2}}$	$\frac{A^2\lambda^2(M_2-4b\psi_c^{es})(1-\psi_c^{es})^3}{\Delta_c^{es2}}$	$\frac{4A^2\lambda^2(M_2+d^2\phi_m^{rs})M_6^2(1-\phi_m^{rs})}{\Delta_m^{rs2}}$	$\frac{A^2\lambda^2(M_2-4b\psi_m^{es})\Sigma_5^2(1-\psi_m^{es})^3}{\Delta_m^{es2}}$
Π_{cj}^i	$\frac{A^2\lambda\Upsilon_1}{\Delta_c^{rs2}}$	$\frac{A^2\lambda\Upsilon_3(1-\psi_c^{es})^2}{\Delta_c^{es2}}$	$\frac{2A^2\lambda\Sigma_1}{\Delta_m^{rs2}}$	$\frac{A^2\lambda\Sigma_5\Sigma_6(1-\psi_m^{es})^2}{\Delta_m^{es2}}$
CS_j^i	$\frac{2A^2b\lambda^2}{\Delta_c^{rs2}}$	$\frac{2A^2b\lambda^2(1-\psi_c^{es})^4}{\Delta_c^{es2}}$	$\frac{8A^2b\lambda^2M_6^2}{\Delta_m^{rs2}}$	$\frac{2A^2b\lambda^2(1-\psi_m^{es})^4\Sigma_5^2}{\Delta_m^{es2}}$
TS_j^i	$\frac{2A^2\lambda^2(M_3-2M_1\phi_c^{rs}-d^2\phi_c^{rs2})}{\Delta_c^{rs2}}$	$\frac{2A^2\lambda^2(M_3-6b\psi_c^{es})(1-\psi_c^{es})^3}{\Delta_c^{es2}}$	$\frac{A^2c^2\lambda\Sigma_2}{\Delta_m^{rs2}}$	$\frac{A^2c^2\lambda(M_3-6b\psi_m^{es})\Sigma_7(1-\psi_m^{es})^5}{\Delta_m^{es2}}$
SW_j^i	$\frac{A^2\lambda}{\Delta_c^{rs}}$	$\frac{A^2\lambda(1-\psi_c^{es})^2}{\Delta_c^{es}}$	$\frac{A^2\lambda(M_4-4M_1\phi_m^{rs}-d^2\phi_m^{rs2})}{\Delta_m^{rs}}$	$\frac{A^2\lambda\Sigma_7(1-\psi_m^{es})^2}{\Delta_m^{es}}$
Q_j^i	$\frac{2Ab\lambda}{\Delta_c^{rs}}$	$\frac{2Ab\lambda(1-\psi_c^{es})^2}{\Delta_c^{es}}$	$\frac{4Ab\lambda M_6}{\Delta_m^{rs}}$	$\frac{2Ab\lambda\Sigma_5(1-\psi_m^{es})^2}{\Delta_m^{es}}$

1) In RS contract,
   a) $\pi_{mm}^{rs} \geq \pi_{mm}^d$ if $\phi_m^{rs} \in \left[0, \min\left\{\frac{M_1(4M_2^2\lambda-c^2M_1)}{M_2(4M_1^2\lambda+c^2d^2)}, 1\right\}\right]$
   b) $\pi_{rm}^{rs} \geq \pi_{rm}^d$ if $\phi_m^{rs} \in [0, \phi_m^{rs*}]$
      where ϕ_m^{rs*} is the positive root of the cubic equation,
      $\alpha_0\phi_m^{rs3} - \alpha_1\phi_m^{rs2} + \alpha_2\phi_m^{rs} - \alpha_3 = 0$
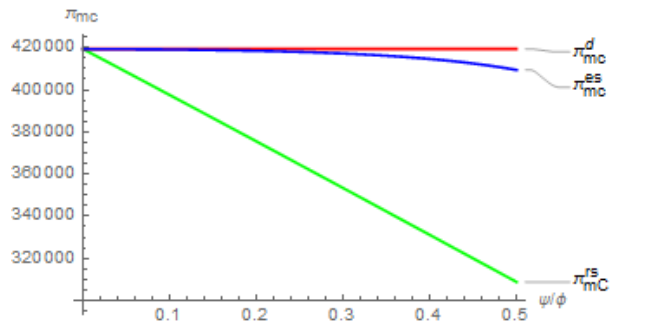
2) In ES contract,
   a) $\pi_{mm}^{es} \geq \pi_{mm}^d$ if $\psi_m^{es} \in [0, \psi_m^{es*}]$,
      where ψ_m^{es*} is the positive root of the cubic equation,
      $4b(8M_2\lambda + c^2)\psi_m^{es3} - (c^2(6b+d^2) + 4M_2(6b+M_4)\lambda)\psi_m^{es2} + (256b^2\lambda - 2d^2(28b\lambda + 2M_4\lambda + \Delta_1))\psi_m^{es} - \Delta_4 = 0$
   b) $\pi_{rm}^{es} \geq \pi_{rm}^d$ if $\psi_m^{es} \in [0, \psi_m^{es**}]$,
      where ψ_m^{es**} is the positive root of the equation,
      $\alpha_0'\psi_m^{es7} - \alpha_1'\psi_m^{es6} + \alpha_2'\psi_m^{es5} - \alpha_3'\psi_m^{es4} + \alpha_4'\psi_m^{es3} - \alpha_5'\psi_m^{es2} + \alpha_6'\psi_m^{es} - \alpha_7' = 0$

Note that after solving a polynomial equation of degree seven, one can always find at least one real root. We refer Appendix K for the detailed derivation. Theorem 4 demonstrates that the cooperation through RS or ES contract degrade the profits of each member. It is not acceptable for the SC members if the cooperation degrades performance of each members, consequently, it is concluded that SC members should not imply RS or ES contracts in presence of Policy C. Theorem 5 reveals that cooperation between members can improve profits for each member in Policy M. The graphical representations of profits for the retailer, manufacturer under decentralized settings, RS and ES contracts in Policies C are presented in Fig. 1. The following parameter values are used for numerical verification : $a = 300$, $b = 0.5$, $c = 0.4$, $d = 0.1$, $c_m = \$50$, $\lambda = 1$.

The above figures justify Theorem 4. Profits for retailer and manufacturer in Policy C decreases with the increasing values of contract parameters as shown in Fig. 1a-1b.
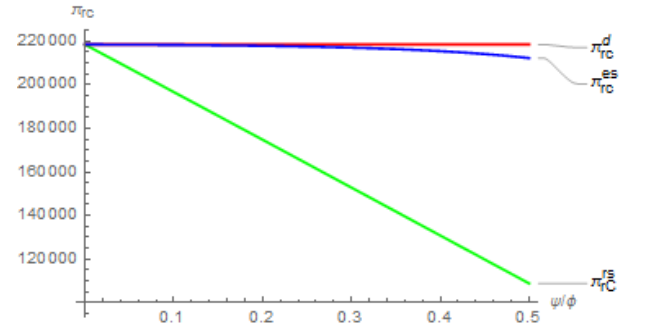
(a) Profits for the retailer in RS, ES contracts and decentralized scenario in Policy

(b) Profits for the manufacturer in RS, ES contracts and decentralized scenario in Policy C

FIGURE 1. Profits for the SC members in Policy C.

Similarly, graphical representations of profits for the retailer, manufacturer under decentralized settings, RS and ES contracts in Policy M are presented in Fig. 2.

Therefore, both SC members can receive higher profits in Policy M by implementing RS or ES contracts as shown in Fig. 2. By solving cubic equation for RS contract in Policy
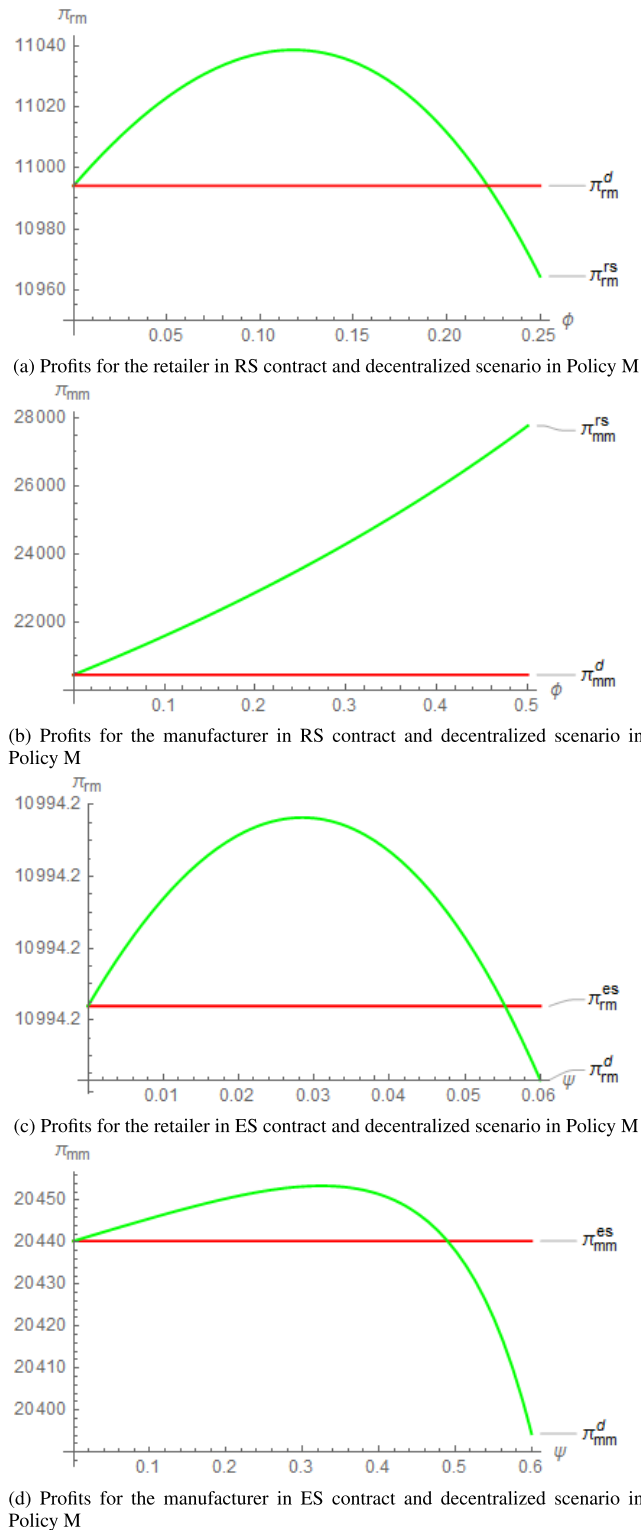
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(a) Profits for the retailer in RS contract and decentralized scenario in Policy M

(b) Profits for the manufacturer in RS contract and decentralized scenario in Policy M

(c) Profits for the retailer in ES contract and decentralized scenario in Policy M

(d) Profits for the manufacturer in ES contract and decentralized scenario in Policy M

FIGURE 2. Profits for the supply chain members in Policy M.

M and comparing limits, one can find that RS contract leads to win-win outcomes if $\phi_m^{rs} \in (0, 0.2219)$. Similarly, ES contract leads to win-win outcomes if $\psi_m^{rs} \in (0, 0.0553)$. Therefore, the analysis provides following two insights, first,

SC members can receive higher profits through cooperation in Policy M, but not in Policy C. Second, the optimal rate of subsidy reduced if SC members cooperate. Next we discuss the nature of optimal decision under RS and ES contracts in absence of subsidy.

Proposition 7: Optimal decision in RS contract in absence of subsidy is as follows:

$$w_b^{rs} = \frac{(AM_2\lambda(1 - \phi_b^{rs}) + bc_m\Delta_b^{rs})(1 - \phi_b^{rs})}{b\Delta_b^{rs}}; \quad \theta_b^{rs} = \frac{Ac}{\Delta_b^{rs}};$$

$$p_b^{rs} = \frac{A(M_3 - M_2\phi_b^{rs})\lambda + bc_m\Delta_b^{rs}}{b\Delta_b^{rs}};$$

$$e_b^{rs} = \frac{A^2 d^2\lambda^2(1 - \phi_b^{rs})^2}{\Delta_b^{rs2}}; \quad \pi_{mb}^{rs} = \frac{A^2\lambda}{\Delta_b^{rs}};$$

$$\pi_{rb}^{rs} = \frac{A^2(M_2 + d^2\phi_b^{rs})\lambda^2(1 - \phi_b^{rs})}{\Delta_b^{rs2}};$$

$$\Pi_{cb}^{rs} = \frac{A^2((M_2 + d^2\phi_b^{rs})\lambda + \Delta_b^{rs})\lambda}{\Delta_b^{rs2}} : Q_b^{rs} = \frac{2\,Ab\lambda}{\Delta_b^{rs}}.$$

Proposition 8: Optimal decision in ES contract in absence of subsidy is as follows:

$$w_b^{es} = \frac{A\lambda(M_2(1 - \psi_b^{es})^2 + d^2\psi_b^{es2}) + bc_m\Delta_b^{es}}{b\Delta_b^{es}};$$

$$\theta_b^{es} = \frac{Ac(1 - \psi_b^{es})^2}{\Delta_b^{es}};$$

$$p_b^{es} = \frac{A\lambda(M_3(1 - \psi_b^{es})^2 + d^2\psi_b^{es2}) + bc_m\Delta_b^{es}}{\Delta_b^{es}};$$

$$e_b^{es} = \frac{A^2 d^2\lambda^2(1 - \psi_b^{es})^2}{\Delta_b^{es2}}; \quad \pi_{mb}^{es} = \frac{A^2\lambda(1 - \psi_b^{es})^2}{\Delta_b^{es}};$$

$$\pi_{rb}^{es} = \frac{A^2(M_2 - 4\,b\psi_b^{es})\lambda^2(1 - \psi_b^{es})^3}{\Delta_b^{es2}};$$

$$\Pi_{cb}^{es} = \frac{A^2\lambda((M_2 - 4\,b\psi_b^{es})\lambda(1 - \psi_b^{es}) + \Delta_b^{es})(1 - \psi_b^{es})^2}{\Delta_b^{es2}};$$

$$Q_b^{es} = \frac{2\,bA\lambda(1 - \psi_b^{es})^2}{\Delta_b^{es}}.$$

Based on the results in above two propositions, we propose the following theorem to illustrate the influences of RS and ES contracts in the absence of subsidy.
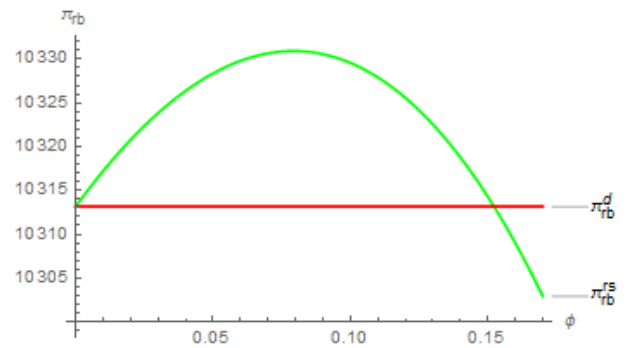
Theorem 6: 1) In RS contract,
   a) $\pi_{mb}^{rs} \geq \pi_{mb}^d$ if $\phi_b^{rs} > 0$
   b) $\pi_{rb}^{rs} \geq \pi_{rb}^d$ if
      $\phi_b^{rs} \in \left[0, \min\left\{\frac{2\,c^2 M_1\Delta_2}{16\,b^2\lambda\Delta_1 + c^2(4M_1{}^2\lambda + c^2\,d^2)}, 1\right\}\right]$
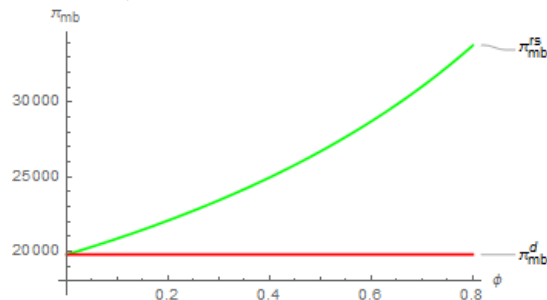2) In ES contract,
   a) $\pi_{mb}^{es} \geq \pi_{mb}^d$ if $\psi_b^{es} \in [0, 1/2]$
   b) $\pi_{rb}^{es} \geq \pi_{rb}^d$ if $\psi_b^{es} \in [0, \psi_b^{es*}]$,
      where ψ_b^{es*} is the real root of the equation, $\alpha_0''\psi_b^{es3} - \alpha_0''\psi_b^{es2} + \alpha_0''\psi_b^{es} - c^2\Delta_2 = 0$

See Appendix L for the detail of Theorem 6. The graphical representations of profits for the manufacturer and retailer in

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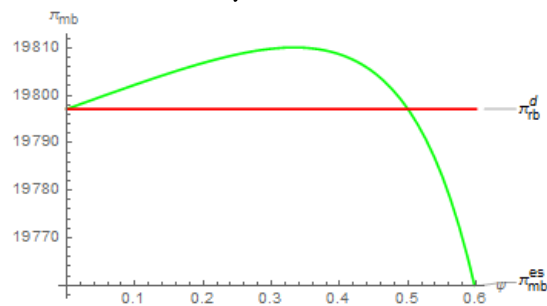
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(a) Profits for the retailer in RS contract and decentralized scenario in absence of subsidy

(b) Profits for the manufacturer in RS contract and decentralized scenario in absence of subsidy
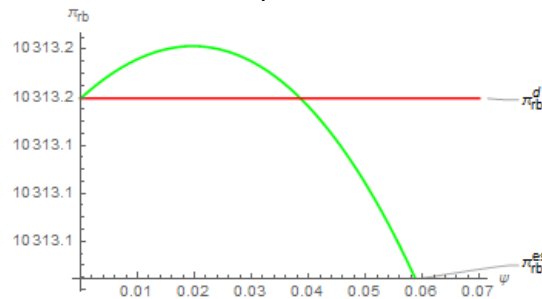
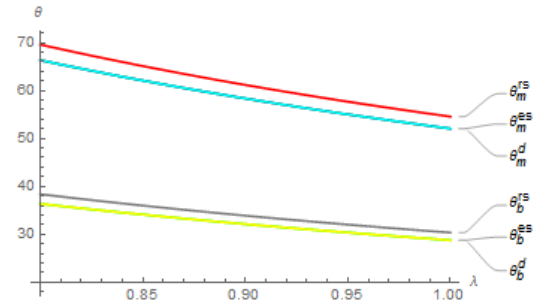(c) Profits for the retailer in ES contract and decentralized scenario in absence of subsidy

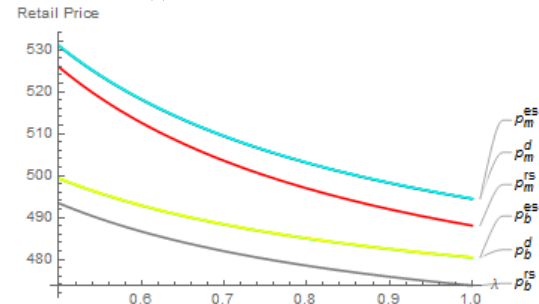(d) Profits for the retailer in ES contract and decentralized scenario in absence of subsidy

FIGURE 3. Profits for the supply chain members in absence of subsidy.

(a) GLs in six different scenarios

(b) Retail prices in six different scenarios
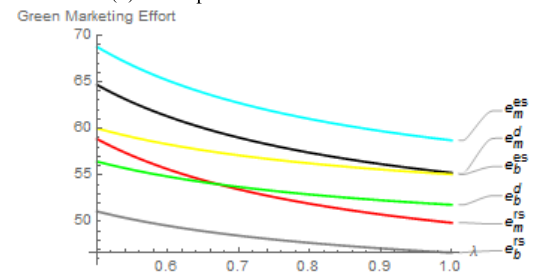
(c) Green-marketing efforts in six different scenarios

FIGURE 4. Comparisons of the optimal retail prices, GLs, and green-marketing efforts for the retailer in Policy M and benchmark scenario.

way overall profits is also improved. Graphical representations of profit function as shown in Fig. 3a-3d also support the claim. One can find that RS contract leads to win-win outcomes if $\phi_b^{rs} \in (0, 0.1522)$. Similarly, ES contract leads to win-win outcomes if $\psi_b^{rs} \in (0, 0.0386)$. Note that, how to design contract so that each SC member can receive higher profits compared to decentralized setting and total profits would be equal to centralized profits is not the main objective of this study. One can employ several hybrid contract mechanisms, for example, revenue-and-green-marketing cost sharing (RSES) contract(see Appendix M) in this regards for SC coordination.

V. MANAGERIAL INSIGHTS AND DISCUSSION

This study explores the characteristics of optimal decisions in two contract mechanisms under two government subsidy policies. Results obtained in presence of consumers subsidy contradict the common believe that optimal decision under centralized setting or under RS or ES contract mechanisms outperforms decision under decentralized decision. However,

RS and ES contracts in the absence of subsidy are presented in Fig. 3. The parameter values remain unchanged.

Theorem 6 also supports the findings of existing literature, each member can receive higher profits compared to decentralized setting if they collaborate with each others, in this

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(a) Optimal subsidy rates in Policy C

(b) TSs in Policy C

(c) Optimal subsidy rates in Policy M

(d) TSs in Policy M
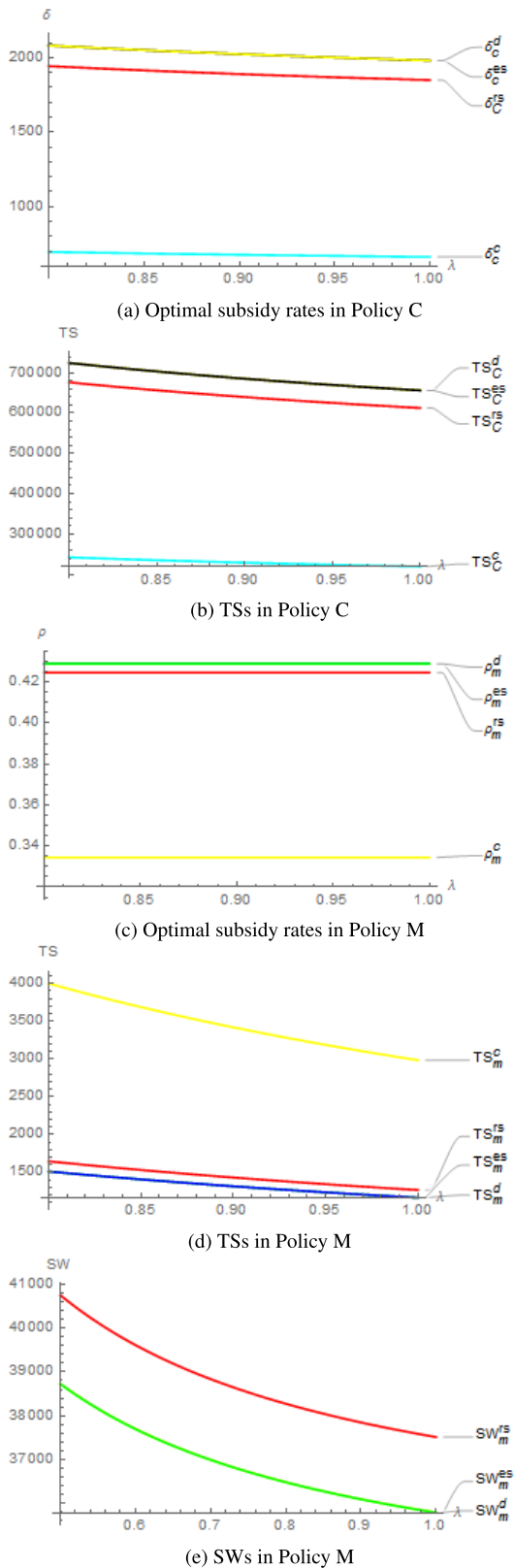

(e) SWs in Policy M

FIGURE 5. The optimal subsidy rates and TSs in Policy C and Policy M, and SWs in Policy M.

performances of SC members improve under manufacturer subsidy. The optimal retail prices, GLs, and green-marketing efforts for the retailer in Policy M and benchmark scenario

are shown in Fig. 4.

From Fig. 4, one can observe that GLs of the product improves under contract mechanisms. Moreover, consumers can receive green products at less prices with higher GL if SC members implement contract mechanisms. The retailer can also invest more in green-marketing effort under cooperation due to higher demand. Consequently, cooperation between SC members improve performance under Policy M. The optimal subsidy rates and TSs in Policy C and Policy M; and SWs in Policy M are shown in Fig. 5.

Figures 5a-5b demonstrate that optimal subsidy rates and TSs always higher in decentralized setting compared to other four scenarios in Policy C. TSs are decreased under RS and ES contracts. If per-unit subsidy decreases, consumers demand also decreases. However, the nature of optimal subsidy rates is remain similar in Policy M, but TSs are increased. Therefore, government organizations adjusted subsidy rate and total amount of subsidy according to cooperation. In policy M, one can observe that cooperation does not degrade the performance. There are numerous issues such as high cost of environmental technologies associated with new product manufacturing or product up-gradation, lack of perception in implementing complex environmental management system, legislation restriction, hiring specialized labour, highly price sensitive consumers etc. [74] that a manufacturer can experience in a pragmatic scenario to integrate sustainability measures. In this regards, researchers highlighted the influence of contract mechanism and government subsidies. However, present study reveals that SC performance may worse off if members imply contract mechanism in presence of consumer subsidy. In contrast, overall performance, SWs, GLs are increased if SC members coordinates and government provides subsidy to manufacturer.

VI. CONCLUSION
Issues related with government subsidy to encourage green product manufacturing and consumption have received considerable attention from both academics and practitioners. However, the influence of cooperation between SC members in presence of subsidy is not as clear. It is noteworthy to analyze whether the cooperation forces government organizations to redefine subsidy rates. This study investigates the interaction between two SC members in price-GL and green-marketing effort sensitive demand under SW optimization goal of government organizations. Optimal decisions are derived for twelve scenarios, and results are compared to explore effectiveness of consumer and manufacturer subsidy in presence of RS and ES contracts. The following outcomes are of managerial significance.

It is found that the effectiveness of cooperation between two members are highly correlated with subsidy policies. Contract mechanisms such as RS and ES contracts fail to improve performance in presence of consumers subsidy. Jia *et al.* [75] found that the absence of government support is one of the key obstructions in countries like Brazil, India, Malaysia for green SC practice. In this direction, perhaps this

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is the first articles, where it is found that the cooperation through RS or ES contracts in presence of consumer subsidy can produce sub-optimal outcomes. Therefore, cooperative motive of SC members is pivotal for successful implementation of consumer subsidy. Due to higher demand under cooperation, government reduces per-unit subsidy, which can discourage consumers also. However, characteristics of optimal decision is totally different in Policy M. In that policy, consumers receive product at less price with higher GL. SW maximization goal for government is also improved and each SC member receives higher profits. Although, the optimal government subsidy rates decreased if SC members cooperate, till amount of government subsidy is higher compered to decentralized scenario. Apart from short-term benefits, the technology innovation or product development through subsidy to manufacturers can help to ensure future sustainability. Overall, an appropriate mix of supply chain coordination mechanisms and subsidy policy is crucial to achieve sustainability goal.

The main focus of this study is to explore the behavior of contract mechanisms under two subsidy policies. Therefore, one of the immediate extension of this study is to design contract mechanisms in presence of government SW optimization goal. In practice, direct selling channel for the manufacturer or closed-loop supply chain for re-manufacturing is common, therefore, it will be interesting to explore characteristics of optimal decision under those settings. One can analyze other subsidy schemes where both the consumer and manufacture or retailer and manufacturer jointly receive subsidy.

APPENDIX A
LIST OF NOTATIONS

$A = a - bc_m$; $M_1 = 2b - d^2$; $M_2 = 4b - d^2$;
$M_3 = 6b - d^2$; $M_4 = 14b - 3d^2$; $M_5 = bc_m\Delta_c^{es}$;
$M_6 = M_2 - M_1\phi_m^{rs}$
$\Upsilon_1 = 2(b + (M_2 + d^2\phi_c^{rs})(1 - \phi_c^{rs}))\lambda + \Delta_c^{rs}$
$\Upsilon_2 = \Delta_2(1 - \psi_c^{es})^2 - d^2\lambda\psi_c^{es}(1 - 2\psi_c^{es})$
$\Upsilon_3 = 2(5b(1 - \psi_c^{es}) - d^2)\lambda(1 - \psi_c^{es}) + \Delta_c^{es}$
$\Sigma_1 = (M_2 - d^2\phi_m^{rs})(2\lambda M_6(M_2 + d^2\phi_m^{rs})(1 - \phi_m^{rs}) + \Delta_m^{rs})$
$\Sigma_2 = (M_3 - 2M_1\phi_m^{rs} - d^2\phi_m^{rs2})(M_4 - 4M_1\phi_m^{rs} - d^2\phi_m^{rs2})$
$\Sigma_3 = 2(4b(1 - \psi_m^{es})^2 - d^2)^2 + 7d^2 M_2\psi_m^{es}(7 - 6\psi_m^{es})$
$\qquad + 4bd^2\psi_m^{es2}(7\psi_m^{es} - 8)$
$\Sigma_4 = 3(4b(1 - \psi_m^{es})^2 - d^2)^2 + 2bd^2(1 - \psi_m^{es})^2(2 + 17\psi_m^{es})$
$\qquad - d^4(1 + \psi_m^{es}(7 - 6\psi_m^{es}))$
$\Sigma_5 = 2M_2 - (2b + M_4)\psi_m^{es} + 8b\psi_m^{es2}$
$\Sigma_6 = 96b^2\lambda(1 - \psi_m^{es})^4 - d^2(d^2\lambda(2 - 3\psi)$
$\qquad + c^2(1 - \psi_m^{es})^2)(3 - 4\psi) - 2b(2d^2\lambda(12 - 17\psi_m^{es})$
$\qquad + 7c^2(1 - \psi_m^{es})^2)(1 - \psi_m^{es})^2$
$\Sigma_7 = 14b(1 - \psi_m^{es})^2 - d^2(3 - 4\psi_m^{es})$
$\Delta_1 = M_2\lambda - c^2$

$\Delta_2 = M_2\lambda + \Delta_1$
$\Delta_3 = M_1\lambda - c^2$
$\Delta_4 = 4M_2^2\lambda - c^2 M_4$
$\Delta_5 = M_2^2\lambda - c^2 M_3$
$\Delta_c^{rs} = \Delta_3 + d^2\phi_c^{rs2}$
$\Delta_c^{es} = \Delta_3(1 - \psi_c^{es})^2 + d^2\lambda\psi_c^{es2}$
$\Delta_m^{rs} = \Delta_4 - 4M_1\Delta_2\phi_m^{rs} + (4M1^2\lambda + c^2 d^2)\phi_m^{rs2}$
$\Delta_m^{es} = \Delta_4(1 - 2\psi_m^{es})^4 - 2d^2\Delta_2\psi_m^{es}(1 - \psi_m^{es})^2 + d^2(c^2$
$\qquad + d^2\lambda - 16b\lambda\psi_m^{es} - (16b\lambda - c^2 + 2\Delta_2)\psi_m^{es2})\psi_m^{es2}$
$\Delta_b^{rs} = \Delta_2 - 2M_1\lambda\phi_b^{rs}$
$\Delta_b^{es} = \Delta_2(1 - \psi_b^{es})^2 - d^2\lambda\psi_m^{es}(1 - 2\psi_b^{es})$

APPENDIX B
OPTIMAL DECISION IN DECENTRALIZED AND CENTRALIZED SUPPLY CHAIN IN POLICY C
The optimal solution of the retailer's optimization problem defined in (1) is obtained by solving

$$\frac{\partial \pi_{rc}^d}{\partial p_c^d} = a - b(2p_c^d - w_c^d - \delta_c^d) + c\theta_c^d + d\sqrt{e_c^d} = 0$$

and

$$\frac{\partial \pi_{rc}^d}{\partial e_c^d} = \frac{d(p_c^d - w_c^d) - 2\sqrt{e_c^d}}{2\sqrt{e_c^d}} = 0$$

After simplification, retail price and green-investment effort are obtained as $p_c^d = \frac{2a + 2b(w + \delta_c^d) + c^2\theta_c^d - d^2 w_c^d}{M_2}$ and $e_c^d = \frac{d^2(a - b(w_c^d - \delta_c^d) + c\theta_c^d)^2}{M_2^2}$. Profit function for the retailer is concave because $\frac{\partial^2 \pi_{rc}^d}{\partial p_c^{d2}} = -2b < 0$ and

$$\frac{\partial^2 \pi_{rc}^d}{\partial p_c^{d2}} \times \frac{\partial^2 \pi_{rc}^d}{\partial e_c^{d2}} - \left(\frac{\partial^2 \pi_{rc}^d}{\partial p_c^d \partial e_c^d}\right)^2$$
$$= \frac{M_2^3}{4d^2(a - b(w_c^d - \delta_c^d) + c\theta_c^d)^2} > 0$$

Substituting optimal responses for the retailer, profit function for the manufacturer is obtained as

$$\pi_{mc}^d = \frac{2b(w_c^d - c_m)(a - b(w_c^d - \delta_c^d) + c\theta_c^d)}{M_2} - \lambda\theta_c^{d2}$$

Solving first-order conditions, $\frac{\partial \pi_{mc}^d}{\partial w_c^d} = \frac{2b(a + b(c_m - 2w_c^d + \delta_c^d) + c\theta_c^d)}{M_2}$ $= 0$ and $\frac{\partial \pi_{mc}^d}{\partial \theta_c^d} = \frac{2bc(w_c^d - c_m)}{M_2} - 2\lambda\theta_c^d = 0$, simultaneously, the wholesale price and GL are obtained as $w_c^d = \frac{(a + b(c_m + \delta_c^d))M_2\lambda - bc^2 c_m}{b\Delta_2}$ and $\theta_c^d = \frac{c(A + b\delta_c^d)}{\Delta_2}$. Profit function for the manufacturer is also concave because $\frac{\partial^2 \pi_{mc}^d}{\partial w_c^{d2}} = -\frac{4b^2}{M_2} < 0$ and

$$\frac{\partial^2 \pi_{mc}^d}{\partial w_c^{d2}} \times \frac{\partial^2 \pi_{mc}^d}{\partial \theta_c^{d2}} - \left(\frac{\partial^2 \pi_{mc}^d}{\partial w_c^d \partial \theta_c^d}\right)^2 = \frac{M_2\Delta_2^2}{4d^2(A - b\delta_c^d))^2\lambda^2} > 0$$

respectively.

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Substituting, optimal responses in (3), SW_c^d is obtained as follows:

$$SW_c^d$$
$$= \frac{(a+b(c_m-\delta_c^d))\lambda((a-b(c_m+\delta_c^d)c^2)+(AM_3-bM_1\delta_c^d)\lambda)}{\Delta_2{}^2}$$

Therefore, optimal value of δ_c^d is obtained by solving $\frac{dSW_c^d}{d\delta_c^d} = 0$. On simplification, optimal subsidy rate is obtained as $\delta_c^d = \frac{AM_3\lambda}{b\Delta_2}$. SW_c^d is concave because $\frac{d^2\ SW_c^d}{d\delta_c^{d2}} = -\frac{2\ b^2\lambda\Delta_3}{\Delta_2{}^2} < 0$.

Similarly optimal decision for centralized supply chain is obtained by solving

$$\frac{\partial\Pi_{cc}^c}{\partial p_c^c} = a - b(2\ p_c^c - c_m - \delta_c^c) + c\theta_c^c + d\sqrt{e_c^c} = 0$$
$$\frac{\partial\Pi_{cc}^c}{\partial e_c^c} = \frac{d(p_c^c - c_m) - 2\sqrt{e_c^c}}{2\sqrt{e_c^c}} = 0$$

and

$$\frac{\partial\Pi_{cc}^c}{\partial\theta_c^c} = c(p_c^c - c_m) - 2\lambda\theta_c^c = 0$$

simultaneously. One simplification, one can obtain optimal decision as $p_c^c = \frac{2(a+b\delta_c^c)\lambda+c_m\Delta_3}{\Delta_1}$, $e_c^c = \frac{d^2(A+b\delta_c^c)^2\lambda^2}{\Delta_1{}^2}$, and $\theta_c^c = \frac{(A+b\delta_c^c)c}{\Delta_1}$. Note that the Hessian matrix(H_c^c) for the centralized supply chain profit function can be found as:

$$H_c^c = \begin{bmatrix} \dfrac{\partial^2\Pi_{cc}^c}{\partial p_c^{c2}} & \dfrac{\partial^2\Pi_{cc}^c}{\partial p_c^c\partial e_c^c} & \dfrac{\partial^2\Pi_{cc}^c}{\partial p_c^c\partial\theta_c^c} \\ \dfrac{\partial^2\Pi_{cc}^c}{\partial p_c^c\partial e_c^c} & \dfrac{\partial^2\Pi_{cc}^c}{\partial e_c^{c2}} & \dfrac{\partial^2\Pi_{cc}^c}{\partial e_c^c\partial\theta_c^c} \\ \dfrac{\partial^2\Pi_{cc}^c}{\partial p_c^c\partial\theta_c^c} & \dfrac{\partial^2\Pi_{cc}^c}{\partial e_c^c\partial\theta_c^c} & \dfrac{\partial^2\Pi_{cc}^c}{\partial\theta_c^{c2}} \end{bmatrix}$$

$$= \begin{vmatrix} -2b & \dfrac{d}{2\sqrt{e_c^c}} & c \\ \dfrac{d}{2\sqrt{e_c^c}} & \dfrac{-d(p_c^c - c_m)}{2e_c^{c3/2}} & 0 \\ c & 0 & -2\lambda \end{vmatrix}$$

The values of principal minors of H_c^c are $H_{c1}^c = -2b < 0$; $H_{c2}^c = \frac{M_1\Delta_1{}^2}{4\ A^2\ d^2\lambda^2} > 0$; and $H_{c3}^c = -\frac{\Delta_1{}^3}{2(A+b\delta_c^c)^2\ d^2\lambda^2} < 0$, respectively. Consequently, the centralized profit function will be concave if $\Delta_1 > 0$.

Substituting, optimal values in (5), SW_c^c is obtained as

$$SW_c^c = \frac{(A+b\delta_c^c)\lambda(a(M_3\lambda-c^2)+b((c^2+d^2\lambda)(c_m+\delta_c^c)-2\ b(3\ c_m+\delta_c^c)\lambda))}{\Delta_1{}^2}$$

Therefore, optimal value of δ_c^c is obtained by solving $\frac{dSW_c^c}{d\delta_c^c} = \frac{2\ b^2\lambda(c^2\delta_c^c+(2\ a+d^2\delta_c^c-2\ b(c_m+\delta_c^c))\lambda)}{\Delta_1{}^2} = 0$. On simplification one can obtain $\delta_c^c = \frac{2\ A\lambda}{\Delta_3}$. SW_c^c is concave if $\frac{d^2\ SW_c^c}{d\delta_c^{c2}} = -\frac{2\ b^2\lambda\Delta_3}{\Delta_1{}^2} < 0$, i.e. $\Delta_3 > 0$.

APPENDIX C
PROPERTIES OF OPTIMAL DECISION UNDER IN POLICY C

1) In centralized decision setting, differentiating decision and auxiliary variables (in Proposition 2) with respect to
   a) consumer sensitivity with GL(c), the followings are obtained:

   $$\frac{\partial\delta_c^c}{\partial c} = \frac{4\ Ac\lambda}{\Delta_3{}^2} > 0; \qquad \frac{\partial\theta_c^c}{\partial c} = \frac{A(2\ c^2 + \Delta_3)}{\Delta_3{}^2} > 0;$$
   $$\frac{\partial\sqrt{e_c^c}}{\partial c} = \frac{2\ Acd\lambda}{\Delta_3{}^2} > 0; \qquad \frac{\partial SW_c^c}{\partial c} = \frac{2\ A^2\ c\lambda}{\Delta_3{}^2} > 0;$$
   $$\frac{\partial\Pi_{cc}^c}{\partial c} = \frac{2\ A^2\ c(4\ b\lambda + \Delta_3)\lambda}{\Delta_3{}^3} > 0.$$

   b) consumer sensitivity with green-marketing effort(d), the followings are obtained:

   $$\frac{\partial\delta_c^c}{\partial d} = \frac{4\ Ad\lambda^2}{\Delta_3{}^2} > 0; \qquad \frac{\partial\theta_c^c}{\partial d} = \frac{2\ Acd\lambda}{\Delta_3{}^2} > 0;$$
   $$\frac{\partial\sqrt{e_c^c}}{\partial d} = \frac{A(2\ d^2\lambda + \Delta_3)\lambda}{\Delta_3{}^2} > 0;$$
   $$\frac{\partial SW_c^c}{\partial d} = \frac{2\ A^2\ d\lambda^2}{\Delta_3{}^2} > 0;$$
   $$\frac{\partial\Pi_{cc}^c}{\partial d} = \frac{2\ A^2\ d(4\ b\lambda + \Delta_3)\lambda^2}{\Delta_3{}^3} > 0.$$

   c) to manufacturer investment efficiency (λ), the followings are obtained:

   $$\frac{\partial\delta_c^c}{\partial\lambda} = -\frac{2\ Ac^2}{\Delta_3{}^2} < 0; \qquad \frac{\partial\theta_c^c}{\partial\lambda} = -\frac{AcM_1}{\Delta_3{}^2} < 0;$$
   $$\frac{\partial\sqrt{e_c^c}}{\partial\lambda} = -\frac{Ac^2\ d}{\Delta_3{}^2} < 0; \qquad \frac{\partial SW_c^c}{\partial\lambda} = -\frac{A^2\ c^2}{\Delta_3{}^2} < 0;$$
   $$\frac{\partial\Pi_{cc}^c}{\partial\lambda} = -\frac{A^2\ c^2(4\ b\lambda + \Delta_3)}{\Delta_3{}^2} < 0.$$

2) In decentralized decision setting, differentiating decision and auxiliary variables (in Proposition 1) with respect to
   a) consumer sensitivity with GL(c), the followings are obtained:

   $$\frac{\partial\delta_c^d}{\partial c} = \frac{2\ AcM_3\lambda}{b\Delta_3{}^2} > 0; \qquad \frac{\partial\theta_c^d}{\partial c} = \frac{A(2\ c^2 + \Delta_3)}{\Delta_3{}^2} > 0;$$
   $$\frac{\partial\sqrt{e_c^d}}{\partial c} = \frac{2\ Acd\lambda}{\Delta_3{}^2} > 0; \qquad \frac{\partial SW_c^d}{\partial c} = \frac{2\ A^2\ c\lambda}{\Delta_3{}^2} > 0;$$
   $$\frac{\partial\pi_{mc}^d}{\partial c} = \frac{2\ A^2\ c\lambda(M_3\lambda + \Delta_2)}{\Delta_3{}^3} > 0;$$
   $$\frac{\partial\pi_{rc}^d}{\partial c} = \frac{4\ A^2\ cM_2\lambda^2}{\Delta_3{}^3} > 0.$$

   b) consumer sensitivity with green-marketing effort(d), the followings are obtained:

   $$\frac{\partial\delta_c^d}{\partial d} = \frac{2\ Ad\lambda(c^2 + 4\ b\lambda)}{b\Delta_3{}^2} > 0; \qquad \frac{\partial\theta_c^d}{\partial d} = \frac{2\ Acd\lambda}{\Delta_3{}^2} > 0;$$

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$$\frac{\partial \sqrt{e_c^d}}{\partial d} = \frac{A(2\,d^2\lambda + \Delta_3)\lambda}{\Delta_3^2} > 0; \quad \frac{\partial SW_c^d}{\partial d} = \frac{2\,A^2\,d\lambda^2}{\Delta_3^2} > 0;$$

$$\frac{\partial \pi_{mc}^d}{\partial d} = \frac{4\,A^2\,dM_3\lambda^3}{\Delta_3^3} > 0;$$

$$\frac{\partial \pi_{rc}^d}{\partial d} = \frac{2\,A^2\,d(M_3\lambda + c^2)\lambda^2}{\Delta_3^3} > 0.$$

c) manufacturer investment efficiency (λ), the followings are obtained:

$$\frac{\partial \delta_c^d}{\partial \lambda} = -\frac{Ac^2\,M_3}{b\Delta_3^2} < 0; \quad \frac{\partial \theta_c^d}{\partial \lambda} = -\frac{AcM_1}{\Delta_3^2} < 0;$$

$$\frac{\partial \sqrt{e_c^d}}{\partial \lambda} = -\frac{Ac^2\,d}{\Delta_3^2} < 0; \quad \frac{\partial SW_c^d}{\partial \lambda} = \frac{A62\,c^2}{\Delta_3^2} < 0;$$

$$\frac{\partial \pi_{mc}^d}{\partial c} = \frac{A^2\,c^2(M_3\lambda + \Delta_2)}{\Delta_3^3} < 0;$$

$$\frac{\partial \pi_{rc}^d}{\partial c} = \frac{2\,A^2\,c^2\,M_2\lambda}{\Delta_3^3} < 0.$$

Above inequalities ensure the claim.

APPENDIX D
PROOF OF THEOREMS 1

By comparing optimal decisions for centralized and decentralized SC settings in Policy C, the following inequalities are obtained:

$$\delta_c^c - \delta_c^d = -\frac{AM_2\lambda}{b\Delta_3} < 0; \quad p_c^c - p_d^c = -\frac{AM_2\lambda}{b\Delta_3} < 0;$$

$$\theta_c^c - \theta_c^d = 0; \quad \sqrt{e_c^c} - \sqrt{e_c^d} = 0;$$

$$\Pi_c^c - \Pi_c^d = -\frac{2\,A^2\,M_2\lambda^2}{\Delta_3^2} < 0;$$

$$Q_c^c - Q_c^d = 0; \quad SW_c^c - SW_c^d = 0;$$

$$TS_c^c - TS_c^d = -\frac{2\,A^2\,M_2\lambda^2}{\Delta_3^2} < 0.$$

Above inequalities ensures the proof.

APPENDIX E
PROPERTIES OF OPTIMAL DECISION IN POLICY M

1) In centralized decision setting, differentiating decision and auxiliary variables (in Proposition 4) with respect to
   a) consumer sensitivity with GL(c), the followings are obtained:

$$\frac{\partial \rho_m^c}{\partial c} = 0; \quad \frac{\partial \theta_m^c}{\partial c} = \frac{AM_3(M_2^2\lambda + M_3\,c^2)}{\Delta_5^2} > 0;$$

$$\frac{\partial \sqrt{e_m^c}}{\partial c} = \frac{2\,AcdM_2\,M_3\lambda}{\Delta_5^2} > 0; \quad \frac{\partial SW_m^c}{\partial c} = \frac{2\,A^2\,cM_3^2\lambda}{\Delta_5^2} > 0;$$

$$\frac{\partial \Pi_{cm}^c}{\partial c} = \frac{2\,A^2\,CM_2\,M_3\lambda}{\Delta_5^2} > 0.$$

   b) consumer sensitivity with green-marketing effort(d), the followings are obtained:

$$\frac{\partial \rho_m^c}{\partial d} = \frac{4\,bd}{M_3^2} > 0; \quad \frac{\partial \theta_m^c}{\partial d} = \frac{2\,AcdM_2(2\,b + M_3)\lambda}{\Delta_5^2} > 0;$$

$$\frac{\partial \sqrt{e_m^c}}{\partial d} = \frac{AM_2((4\,b + d^2)M_2\lambda - c^2(6\,b + M_3))\lambda}{\Delta_5^2} > 0;$$

$$\frac{\partial SW_m^c}{\partial d} = \frac{2\,A^2\,dM_2(2\,b + M_3)\lambda^2}{\Delta_5^2} > 0;$$

$$\frac{\partial \Pi_{cm}^c}{\partial d} = \frac{2\,A^2\,d(M_2^2\lambda + 2\,bc^2)\lambda}{\Delta_5^2} > 0.$$

   c) manufacturer investment efficiency (λ), the followings are obtained:

$$\frac{\partial \rho_m^c}{\partial \lambda} = 0; \quad \frac{\partial \theta_m^c}{\partial \lambda} = -\frac{AcM_2^2\,M_3}{\Delta_5^2} < 0;$$

$$\frac{\partial \sqrt{e_m^c}}{\partial \lambda} = -\frac{Ac^2\,dM_2\,M_3}{\Delta_5^2} < 0; \quad \frac{\partial SW_m^c}{\partial \lambda} = -\frac{A^2\,c^2M_3^2}{\Delta_5^2} < 0;$$

$$\frac{\partial \Pi_{cm}^c}{\partial \lambda} = -\frac{A^2\,c^2\,M_2\,M_3}{\Delta_5^2} < 0.$$

2) In decentralized decision setting, differentiating decision and auxiliary variables (in Proposition 3) with respect to
   a) consumer sensitivity with GL(c), the followings are obtained:

$$\frac{\partial \rho_m^d}{\partial c} = 0; \quad \frac{\partial \theta_m^d}{\partial c} = \frac{AM_4(4M_2^2\lambda + c^2\,M_4)}{\Delta_4^2} > 0;$$

$$\frac{\partial \sqrt{e_m^d}}{\partial c} = \frac{4\,AcdM_2\,M_4\lambda}{\Delta_4^2} > 0;$$

$$\frac{\partial SW_m^d}{\partial c} = \frac{2\,A^2\,cM_4^2)\lambda}{\Delta_4^2} > 0;$$

$$\frac{\partial \pi_{mm}^d}{\partial c} = \frac{4\,A^2\,cM_2\,M_4\lambda}{\Delta_4^2} > 0;$$

$$\frac{\partial \pi_{rm}^d}{\partial c} = \frac{16\,A^2\,cM_2^3\,M_4\lambda^2}{\Delta_4^3} > 0.$$

   b) consumer sensitivity with green-marketing effort (d), the followings are obtained:

$$\frac{\partial \rho_m^d}{\partial d} = \frac{8\,bd}{M_4^2} > 0; \quad \frac{\partial \theta_m^d}{\partial d} = \frac{8\,AcdM_2(2\,b + M_4)\lambda}{\Delta_4^2} > 0;$$

$$\frac{\partial \sqrt{e_m^d}}{\partial d} = \frac{2\,A(4M_2^2(4\,b + d^2)\lambda - c^2(M_2\,M_4 - 4\,bd^2))\lambda}{\Delta_4^2}$$

$$> 0; \quad \frac{\partial SW_m^d}{\partial d} = \frac{8\,A^2\,M_2(2\,b + M_4)\lambda^2}{\Delta_4^2} > 0;$$

$$\frac{\partial \pi_{mm}^d}{\partial d} = \frac{8\,A^2\,d(2M_2^2\lambda + bc^2)\lambda}{\Delta_4^2} > 0;$$

$$\frac{\partial \pi_{rm}^d}{\partial d} = \frac{8\,A^2\,dM_2^2(4M_2^2\lambda + 3\,c^2\,M_3)\lambda^2}{\Delta_4^3} > 0.$$

   c) to manufacturer investment efficiency (λ), the followings are obtained:

$$\frac{\partial \rho_m^d}{\partial \lambda} = 0; \quad \frac{\partial \theta_m^d}{\partial \lambda} = -\frac{4\,AcM_2^2\,M_4}{\Delta_4^2} < 0;$$

$$\frac{\partial \sqrt{e_m^d}}{\partial \lambda} = -\frac{2\,Ac^2\,dM_2\,M_4}{\Delta_4^2} < 0;$$

$$\frac{\partial SW_m^d}{\partial \lambda} = -\frac{A^2 \, c^2 M_4{}^2}{\Delta_4{}^2} < 0;$$

$$\frac{\partial \pi_{mm}^d}{\partial \lambda} = -\frac{2 \, A^2 \, c^2 \, M_2 \, M_4}{\Delta_4{}^2} < 0;$$

$$\frac{\partial \pi_{rm}^d}{\partial \lambda} = -\frac{8 \, A^2 \, c^2 M_2{}^3 \, M_4 \lambda}{\Delta_4{}^2} < 0.$$

Above inequalities ensure the claim.

APPENDIX F
PROOF OF THEOREMS 2
By comparing optimal decision between centralized and decentralized decisions in Policy M, the following inequalities are obtained, $\rho_m^c - \rho_m^d$, $\sqrt{e_m^c} - \sqrt{e_m^d}$, $Q_m^c - Q_m^d$, and $TS_m^c - TS_m^d$, as shown at the bottom of the next page.

Above inequalities ensures the proof.

APPENDIX G
PROFIT DIFFERENCE IN PRESENCE AND ABSENCE OF SUBSIDY
Difference between profits of SC member in the presence of subsidy (Propositions 1-4) and absence of subsidy(Propositions 5-6) are obtained as follows:

$$\pi_{mc}^d - \pi_{mb}^d = \frac{A^2 \, M_3 \lambda^2 (\Delta_2 + \Delta_3)}{\Delta_2 \Delta_3{}^2} > 0,$$

$$\pi_{rc}^d - \pi_{rb}^d = \frac{A^2 \, M_2 \, M_3 \lambda^3 (\Delta_2 + \Delta_3)}{\Delta_2{}^2 \Delta_3{}^2} > 0,$$

$$\pi_{mm}^d - \pi_{mb}^d = \frac{A^2 \, c^2 \, M_3 \lambda}{\Delta_2 \Delta_4} > 0,$$

$$\pi_{rm}^d - \pi_{rb}^d = \frac{A^2 \, c^2 \, M_2 \, M_3 \lambda^2 (c^2 \, M_3 + 2\Delta_4)}{\Delta_2{}^2 \Delta_4{}^2} > 0,$$

$$\Pi_{cc}^c - \Pi_{cb}^c = \frac{4 \, A^2 \, b\lambda^2 (2 \, b\lambda + \Delta_3)}{\Delta_1 \Delta_3{}^2} > 0,$$

$$\Pi_{cm}^c - \Pi_{cb}^c = \frac{2 \, A^2 \, bc^2 \lambda}{\Delta_1 \Delta_5} > 0.$$

Above inequalities ensure the claim.

APPENDIX H
PROOF OF THEOREM 3
By comparing centralized optimal decisions between Policy C and M, the following relations are obtained:

$$p_c^c - p_m^c = \frac{4 \, Ab\lambda \Delta_1}{\Delta_3 \Delta_5} > 0; \quad \theta_c^c - \theta_m^c = \frac{4 \, Ab^2 \, c\lambda}{\Delta_3 \Delta_5} > 0;$$

$$\sqrt{e_c^c} - \sqrt{e_m^c} = \frac{2 \, Abd\lambda \Delta_1}{\Delta_3 \Delta_5} > 0;$$

$$\Pi_c^c - \Pi_m^c = \frac{2 \, A^2 \, b\lambda (M_2 \lambda \Delta_3 + \Delta_1{}^2)}{\Delta_3{}^2 \Delta_5} > 0;$$

$$Q_c^c - Q_m^c = \frac{4 \, Ab^2 \lambda \Delta_1}{\Delta_3 \Delta_3} > 0;$$

$$SW_c^c - SW_m^c = \frac{4 \, A^2 \, b^2 \lambda^2}{\Delta_3 \Delta_5} > 0;$$

$$TS_c^c - TS_m^c = \frac{2 \, A^2 \, b\lambda}{\Delta_3{}^2 \Delta_5{}^2} [2 \, M_2{}^3 \lambda^2 \Delta_1 - 3 \, c^2 \, M_2 \lambda \Delta_4 + c^4 \, M_3 \Delta_1 \\ - 2bc^2 (12 \, b^2 + 8 \, bM_2 - d^2 \, M_4)] > 0.$$

Similarly, by comparing decentralized optimal decisions between Policy C and M, the following relations are obtained,
$p_c^d - p_m^d, \pi_{rc}^d - \pi_{rm}^d, \Pi_c^d - \Pi_m^d, \lambda)] > 0;$
$Q_c^d - Q_m^d$, and $TS_d^c - TS_m^d$, as show at the bottom of the next page.

The above inequalities ensure the proof.

APPENDIX I
OPTIMAL DECISION UNDER RS CONTRACT IN POLICY C
The optimal solution of the retailer's optimization problem defined in Equation (14) is obtained by solving $\frac{\partial \pi_{rc}^{rs}}{\partial p_c^{rs}} = 0$ and $\frac{\partial \pi_{rc}^{rs}}{\partial e_c^{rs}} = 0$, simultaneously. After simplification, one can obtain the price and green-marketing effort as $p_c^{rs} = \frac{4 \, a + 4 \, b\delta_c^{rs} + 4 \, c\theta_c^{rs} - d^2 \, w_c^{rs}}{2(M_2 + d^2 \phi_c^{rs})} + \frac{w_c^{rs}}{2(1 - \phi_c^{rs})}$ and $e_c^{rs} = \frac{d^2((a + b\delta_c^{rs} + c\theta_c^{rs})(1 - \phi_c^{rs}) - bw_c^{rs})}{(M_2 + d^2 \phi_c^{rs})^2}$. Profit function for the retailer is concave because $\frac{\partial^2 \pi_{rc}^{rs}}{\partial p_c^{rs2}} = -2 \, b(1 - \phi_c^{rs}) < 0$ and $\frac{\partial^2 \pi_{rc}^{rs}}{\partial p_c^{rs2}} \times \frac{\partial^2 \pi_{rc}^{rs}}{\partial e_c^{rs2}} - \left(\frac{\partial^2 \pi_{rc}^{rs}}{\partial p_c^{rs} \partial e_c^{rs}}\right)^2 = \frac{(M_2 + d^2 \phi_c^{rs})^3 (1 - \phi_c^{rs})}{4 \, d^2((a + b\delta_c^{rs} + c\theta_c^{rs})(1 - \phi_c^{rs}) - bw_c^{rs})^2} > 0.$

Using retailer's response, profit function for the manufacturer is obtained as $\pi_{mc}^{rs} = \frac{1}{(M_2 + d^2 \phi_c^{rs})^2 (1 - \phi_c^{rs})^2} [2 \, b((a + b\delta_c^{rs} + c\theta_c^{rs})(1 - \phi_c^{rs}) - bw_c^{rs})((2a + 2b\delta_c^{rs} + 2 \, c\theta_c^{rs} - c_m d^2)\phi_c^{rs2} - (2a + 2b\delta_c^{rs} + 2 \, c\theta_c^{rs} - M_1(w_c^{rs} - 2 \, c_m))\phi_c^{rs}) - M_2(w_c^{rs} - c_m)] - \lambda \theta_c^{rs2}$. Therefore, by solving $\frac{\partial \pi_{mc}^{rs}}{\partial w_c^{rs}} = 0$ and $\frac{\partial \pi_{mc}^{rs}}{\partial \theta_c^{rs}} = 0$, the optimal wholesale price and GL are obtained as $w_c^{rs} = \frac{(aM_2 + bc_m \Delta_1 + bM_2)(1 - \phi_c^{rs})}{b(\Delta_2 - 2 \, M_1 \phi_c^{rs})}$ and $\theta_c^{rs} = \frac{(A + b\delta_c^{rs})c}{2\Delta_2 - 2 \, M_1 \phi_c^{rs}}$ Profit function for the manufacturer is concave because $\frac{\partial^2 \pi_{mc}^{rs}}{\partial w_c^{rs2}} = -\frac{4 \, b^2(M_2 - M_1 \phi_c^{rs})}{(M_2 + d^2 \phi_c^{rs})^2 (1 - \phi_c^{rs})^2} < 0$ and $\frac{\partial^2 \pi_{mc}^{rs}}{\partial w_c^{rs2}} \times \frac{\partial^2 \pi_{mc}^{rs}}{\partial \theta_c^{rs2}} - \left(\frac{\partial^2 \pi_{mc}^{rs}}{\partial w_c^{rs} \partial \theta_c^{rs}}\right)^2 = \frac{4 \, b^2(\Delta_2 - 2 \, M_1 \phi_c^{rs})}{(M_2 + d^2 \phi_c^{rs})^2 (1 - \phi_c^{rs})^2} > 0.$

Finally, optimal value of subsidy rate is obtained by solving $\frac{dSW_c^{rs}}{d\delta^{rs}} = 0$. On simplification one can obtain $\delta_c^{rs} = \frac{A(M_3 - 2 \, M_1 \phi_c^{rs} - d^2 \phi_c^{rs2})\lambda}{b\Delta_c^{rs}}$. SW function under coordination is concave because $\frac{d^2 \, SW_c^{rs}}{d\delta_c^{rs2}} = -\frac{2 \, b^2 \lambda \Delta_c^{rs}}{(\Delta_2 - 2 \, M_1 \phi_c^{rs})^2} < 0.$

APPENDIX J
PROOF OF THEOREM 4
Differentiating profit functions for the supply chain members with respect to contract parameters, the following relations are obtained, $\frac{\partial \pi_{mc}^{rs}}{\partial \phi_c^{rs}}, \frac{\partial \pi_{rc}^{rs}}{\partial \phi_c^{rs}}, \frac{\partial Q_c^{rs}}{\partial \phi_c^{rs}}, \frac{\partial \pi_{mc}^{es}}{\partial \psi_c^{es}}, \frac{\partial \pi_{rc}^{es}}{\partial \psi_c^{es}},$ and $\frac{\partial Q_c^{es}}{\partial \psi_c^{es}}$, as shown at the bottom of the next page.

The above inequalities ensure the proof.

APPENDIX K
PROOF OF THEOREM 5
1) In RS contract
   a) The difference between profits for the retailer in Table 3 and decentralized scenario (Proposition 3) is obtained as

$$\pi_{mm}^{rs} - \pi_{mm}^d \\ = \frac{2A^2 \lambda \phi_m^{rs}(M_1(4M_2{}^2 \lambda - c^2 \, M_1) - M_2(4M_1{}^2 \lambda + c^2 d^2)\phi_m^{rs})}{\Delta_4 \Delta_m^{rs}} > 0.$$

Therefore, $\pi_{mm}^{rs} \geq \pi_{mm}^{d}$ holds if $\phi_m^{rs} \leq \frac{M_1(4M_2^2\lambda - c^2\,M_1)}{M_2(4M_1^2\lambda + c^2\,d^2)}$

b) The difference between profits for the manufacturer in Table 3 and decentralized scenario (Proposition 3) is obtained as $\pi_{rm}^{rs} - \pi_{rm}^{d} = \frac{4\,A^2\lambda^2((M_2 - d^2\phi_m^{rs})(M_2 - M_1\phi_m^{rs})\Delta_4^2 - M_2^3\Delta_m^{rs2})}{\Delta_4^2\Delta_m^{rs2}} > 0$. Therefore, $\pi_{rm}^{rs} \geq \pi_{rm}^{d}$ holds if $\phi_m^{rs} \leq \phi_m^{rs*}$, where ϕ_m^{rs*} is the positive root of the cubic equation $\alpha_0\phi_m^{rs3} - \alpha_1\phi_m^{rs2} + \alpha_2\phi_m^{rs} - \alpha_3 = 0$ where, $\alpha_0 = 16\,b^2\,M_1^2\,M_2^3\lambda^2 - 4\,c^2\,d^2\,M_1^2M_2^2(b+M_2)\lambda + c^4\,d^2(2\,b^2(2\,b^2+d^2\,M_2) + M_2^3(M_1-d^2))$; $\alpha_1 = M_1(32\,b^2\,M_2^4\lambda^2 + 4\,c^2M_2^2(8\,b^3 + M_2(bM_2 - b^2\,d^2 - d^2\,M_4))\lambda - c^4(8\,b^3(b+M_2) + (11\,bM_1 - bd^2 + 7\,d^2\,M_2)M_2^2))$; $\alpha_2 = 16\,b^2\,M_2^5\lambda^2 + 4\,c^2(b+M_1)M_2^3(8\,bM_1 - 3\,d^2\,M_2)\lambda - c^4\,M_2(20\,b^4 + 9\,b^2\,d^2\,M_2 + (10\,b^2 + 17\,bM_1 - 8\,d^2\,M_2)M_2^2)$; $\alpha_3 = 4\,c^2M_2^2(b^2 + 4\,bM_1 - d^2\,M_2)\Delta_4$.

2) In ES contract

a) The difference between profits for the retailer in Table 3 and decentralized scenario (Proposition 3) is obtained as $\pi_{mm}^{es} - \pi_{mm}^{d} = \frac{A^2\lambda}{\Delta_4^2\Delta_m^{es2}}[(8\,b(1 - \psi_m^{es})^2 - d^2(2 - 3\psi_m^{es}))(1 - \phi_m^{rs})^2\Delta_4^2 - 2\,M_2\Delta_m^{es2}]$. Therefore, $\pi_{mm}^{es} \geq \pi_{mm}^{d}$ holds if $\phi_m^{es} \leq \phi_m^{es**}$, where ϕ_m^{es*} is the positive root of the cubic equation $4\,b(8\,M_2\lambda + c^2)\eta_m^{es3} - (c^2(6\,b + d^2) + 4\,M_2(6\,b + M_4)\lambda)\eta_m^{es2} + (256\,b^2\lambda - 2\,d^2(28\,b\lambda + 2\,M_4\lambda + \Delta_1))\eta_m^{es} - \Delta_4 = 0$.

b) The The difference between profits for the manufacturer in Table 3 and decentralized scenario (Proposition 3) is obtained as $\pi_{rm}^{es} - \pi_{rm}^{d} = \frac{1}{\Delta_4^2\Delta_m^{es2}}[A^2\lambda^2((M_2 - 4\,b\psi_m^{es})(8\,b(1 - \psi_m^{es})^2 - d^2(2 - 3\psi_m^{es}))(1 - \phi_m^{rs})^3\Delta_4^2 - 4\,M_2^3\Delta_m^{es2})] > 0$. Therefore, $\pi_{rm}^{es} \geq \pi_{rm}^{d}$ holds if $\psi_m^{es} \leq \psi_m^{es***}$, where ψ_m^{es***} is the real root of the equation, $a_0\psi_m^{es7} - a_1\psi_m^{es6} + a_2\psi_m^{es5} -$

$$\rho_m^c - \rho_m^d = -\frac{M_2\,M_1}{M_3\,M_4} < 0; \quad p_m^c - p_m^d = -\frac{2\,A\lambda M_2(M_2^2\Delta_3 - bc^2(2\,b + M_2))}{b\Delta_5\Delta_4} < 0; \quad \theta_m^c - \theta_m^d = \frac{AcM_2^2(4\,b + M_3)\lambda}{\Delta_4\Delta_5} > 0;$$

$$\sqrt{e_m^c} - \sqrt{e_m^d} = \frac{AdM_2\lambda(2M_2^2\lambda - c^2\,M_1)}{\Delta_4\Delta_5} > 0; \quad \Pi_{cm}^c - \Pi_{cm}^d = \frac{A^2\,M_2\lambda((2M_2^2\lambda - c^2\,M_1)^2 - 2\,c^2\,M_1\Delta_5)}{\Delta_4^2\Delta_5} > 0;$$

$$Q_m^c - Q_m^d = \frac{2\,AbM_2\lambda(2M_2^2\lambda - c^2\,M_1)}{\Delta_4\Delta_5} > 0; \quad SW_m^c - SW_m^d = \frac{A^2(4\,b + M_3)M_2^2\lambda^2}{\Delta_4\Delta_5} > 0;$$

$$TS_m^c - TS_m^d = \frac{A^2\,c^2\,M_2\,M_3\lambda[(4\,b + d^2)M\lambda\Delta_4 + M_1(M_2^3\lambda^2 - c^4M_4) - c^2\,d^2\,M_2\,M_4\lambda]}{\Delta_4^2\Delta_5} > 0.$$

$$p_c^d - p_m^d = \frac{AM_3^2\lambda\Delta_2}{b\Delta_4\Delta_3} > 0; \quad \theta_c^d - \theta_m^d = \frac{AcM_3^2\lambda}{\Delta_3\Delta_4} > 0; \quad \sqrt{e_c^d} - \sqrt{e_m^d} = \frac{Ad\lambda M_3\Delta_2}{\Delta_3\Delta_4} > 0;$$

$$\pi_{rc}^d - \pi_{rm}^d = \frac{A^2\,M_2\,M_3\Delta_2\lambda^2(M_2(5\Delta_1 - d^2\lambda) - 2\,bc^2)}{\Delta_3^2\Delta_4^2} > 0; \quad \pi_{mc}^d - \pi_{mm}^d = \frac{A^2\,M_3\lambda(M_2\lambda(4\Delta_1 - d^2\lambda) + \Delta_1^2)}{\Delta_3^2\Delta_4} > 0;$$

$$\Pi_c^d - \Pi_m^d = \frac{1}{\Delta_3^2\Delta_4^2}[A^2\,M_3\lambda(3\,M_2(M_1 + 2\,M_2)\lambda^2\Delta_4 + c^4(14\,bM_2\lambda + \Delta_4) - c^2\,M_2\lambda(23\,M_2\Delta_1 + 4(b^2 + 2M_2^2)\lambda))] > 0;$$

$$Q_c^d - Q_m^d = \frac{2\,AM_3\lambda\Delta_2}{\Delta_3\Delta_4} > 0; \quad SW_c^d - SW_m^d = \frac{A^2\,M_3^2\lambda^2}{\Delta_3\Delta_4} > 0;$$

$$TS_d^c - TS_m^d = \frac{A^2\,M_3\lambda(8M_2^2\lambda^2\Delta_4 - c^2\,M_4(M_1^2\lambda^2 + 8\,M_2\lambda\Delta_1 + c^4))}{\Delta_3^2\Delta_4^2} > 0.$$

$$\frac{\partial\pi_{mc}^{rs}}{\partial\phi_c^{rs}} = \frac{-2\,A^2\lambda^2(2\,d^2\lambda(2\,b + (M_2 + d^2\phi_c^{rs})(1 - \phi_c^{rs}))\phi_c^{rs} + (M_1 + 2\,d^2\phi_c^{rs})\Delta_c^{rs})}{\Delta_c^{rs3}} < 0$$

$$\frac{\partial\pi_{rc}^{rs}}{\partial\phi_c^{rs}} = \frac{-2\,A^2\lambda^2(2\,d^2\lambda(M_2 + d^2\phi_c^{rs})\phi_c^{rs}(1 - \phi_c^{rs}) + (M_1 + d^2\phi_c^{rs})\Delta_c^{rs})}{\Delta_c^{rs3}} < 0$$

$$\frac{\partial Q_c^{rs}}{\partial\phi_c^{rs}} = \frac{-4\,Abd^2\lambda^2\phi_c^{rs}}{\Delta_c^{rs2}} < 0$$

$$\frac{\partial\pi_{mc}^{es}}{\partial\psi_c^{es}} = \frac{-A^2\,d^2\lambda2^2(1 - \psi_c^{es})(4\lambda(M_3 - 6\,b\psi_c^{es}))(1 - \psi_c^{es})\psi_c^{es} + (1 + \psi_c^{es})\Delta_c^{es})}{\Delta_c^{er3}} < 0$$

$$\frac{\partial\pi_{rc}^{es}}{\partial\psi_c^{es}} = \frac{-A^2\,d^2\lambda^2(1 - \psi_c^{es})^2(4\lambda(M_2 - 4\,b\psi_c^{es}))\psi_c^{es} + \Delta_c^{es})}{\Delta_c^{es3}} < 0$$

$$\frac{\partial Q_c^{es}}{\partial\psi_c^{es}} = \frac{-4\,Abd^2\lambda^2\psi_c^{es}(1 - \psi_c^{es})}{\Delta_c^{es2}} < 0$$

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$a_3 \psi_m^{es4} + a_4 \psi_m^{es3} - a_5 \psi_m^{es2} + a_6 \psi_m^{es} - a_7 = 0$, where $a_0 = 16\, b^2(256\, bM_2^3\lambda^2 + 64\, bc^2 M_2^2\lambda - c^4(1008\, b^2 - 444\, bd^2 + 49\, d^4))$; $a_1 = 64\, b(64\, bM_2^3 M_3\lambda^2 + 4\, bc^2 M_2^2(6\, b + 5\, M_3)\lambda - c^4(1680\, b^3 - 888\, b^2\, d^2 + 146\, bd^4 - 7\, d^6))$; $a_2 = 192\, bM_2^3(320\, b^2 - 100\, bd^2 + 7\, d^4)\lambda^2 + 16\, bc^2 M_2^2(2112\, b^2 - 560\, bd^2 + 33\, d^4)\lambda - 4\, c^4(76608\, b^4 - 46636\, b^3\, d^2 + 9676\, b^2\, d^4 - 759\, bd^6 + 16\, d^8)$; $a_3 = 16\, M_2^3(5120\, b^3 - 2240\, b^2\, d^2 + 284\, bd^4 - 9\, d^6)\lambda^2 + 8\, c^2 M_2^2(8320\, b^3 - 3136\, b^2\, d^2 + 338\, bd^4 - 9\, d^6)\lambda - c^4(483840\, b^4 - 329408\, b^3\, d^2 + 79964\, b^2\, d^4 - 8028\, bd^6 + 271\, d^8)$; $a_4 = 4\, M_2^3(15360\, b^3 - 8320\, b^2\, d^2 + 1424\, bd^4 - 75\, d^6)\lambda^2 + 16\, c^2 M_2^2(4800\, b^3 - 2272\, b^2\, d^2 + 335\, bd^4 - 15\, d^6)\lambda - c^4(456960\, b^4 - 340192\, b^3\, d^2 + 92452\, b^2\, d^4 - 10796\, bd^6 + 453\, d^8)$; $a_5 = 16\, M_2^4(384\, b^2 - 144\, bd^2 + 13\, d^4)\lambda^2 + 8\, c^2(4\, b + M_2)M_2^2(816\, b^2 - 350\, bd^2 + 37\, d^4)\lambda - c^4(258048\, b^4 - 206272\, b^3\, d^2 + 60916\, b^2\, d^4 - 7860\, bd^6 + 373\, d^8)$; $a_6 = 16\, M_2^5(2\, b + M_6)\lambda^2 + 32\, c^2 M_2^3(152\, b^2 - 56\, bd^2 + 5\, d^4)\lambda - c^4 M_2(20160\, b^3 - 11996\, b^2\, d^2 + 2348\, bd^4 - 151\, d^6)$; and $a_7 = 8\, c^2\, d^2 M_2^2\, M_3\Delta_4$.

APPENDIX L
PROOF OF THEOREM 6

1) In RS contract,

a) The difference between profits for the retailer in Proposition 7 and decentralized scenario in Proposition 5, satisfies $\pi_{mb}^{rs} - \pi_{mb}^d = \frac{2\, A^2\, M_1\lambda^2\phi_b^{rs}}{\Delta_2\Delta_b^{rs}} > 0$ if $\phi_b^{rs} > 0$

b) The difference between profits for the manufacturer in Proposition 7 and decentralized scenario in Proposition 5, satisfies $\pi_{rb}^{rs} - \pi_{rb}^d = \frac{A^2\lambda^2\phi_b^{rs}(2\, c^2\, M_1\Delta_2 - (16\, b^2\lambda\Delta_1 + c^2(4M_1^2\lambda + c^2\, d^2))\phi_b^{rs})}{\Delta_2^2\Delta_b^{rs2}} > 0$ if $\phi_b^{rs} \leq \frac{2\, c^2\, M_1\Delta_2}{16\, b^2\lambda\Delta_1 + c^2(4M_1^2\lambda + c^2\, d^2)}$.

2) In ES contract

a) The difference between profits for the retailer in Proposition 8 and decentralized scenario in Proposition 5, satisfies $\pi_{mb}^{es} - \pi_{mb}^d = \frac{A^2\, d^2\lambda^2\psi_b^{es}(1 - 2\psi_b^{es})}{\Delta_2\Delta_b^{es}} > 0$ if $\psi_b^{es} \leq 1/2$.

b) The difference between profits for the manufacturer in Proposition 8 and decentralized scenario in Proposition 5, satisfies $\pi_{rb}^{es} - \pi_{rb}^d = \frac{1}{\Delta_2^2\Delta_b^{es2}}[A^2\, d^2\lambda^2\psi_b^{es}(M\lambda\psi_b^{es}(2\Delta_b^{es} - d^2\lambda(1 - 2\psi_b^{es})) + c^2(1 - \psi_b^{es})^3\Delta_2)]$ if $\psi_b^{es} \leq \psi_b^{es*}$, where ψ_b^{es*} is the real root of the equation, $(16\, bM_2\lambda^2 - c^4)\psi_b^{es3} - 4(M_2(2\, b + M_3)\lambda^2 + 2\, c^2\, M_2\lambda - 3\, c^4)\psi_b^{es2} + (M_2(2\, b + M_4)\lambda^2 - 4\, c^2\, M_2\lambda + 3\, c^4)\psi_b^{es} - c^2\Delta_2$.

APPENDIX M
RSES CONTRACT

In RSES contract, the retailer shares a percentage revenue with the manufacturer and the manufacturer also shares a percentage of green marketing-expenditure with the retailer.

The profit functions for the manufacturer and retailer are as follows:

$$\pi_{mb}^{rees} = (w_b^{rees} - c_m + \phi_b^{rees} p_b^{rees})D_b^{rees} - \psi_b^{rees} e_b^{rees}$$
$$\pi_{rb}^{rees} = ((1 - \phi_b^{rees})p_b^{rees} - w_b^{rees})D_b^{rees} - (1 - \psi_b^{rees})e_b^{rees} - \lambda\theta_b^{rees2}$$

The outcome in RSES contract is presented in Corollary 1.

Corollary 1: RSES contract coordinates the GSC if $\phi_b^{rses} = \psi_b^{rses}$ and $\phi_b \in \left(\frac{M_2\lambda}{\Delta_1}, \frac{M_2\lambda(3\lambda M_2 - 2\, c^2)}{\Delta_1^2}\right)$. In that scenario, wholesale price for the manufacturer is $w_b^{rees} = c_m(1 - \phi_b^{rses})$ and profits for the manufacturer and retailer are $\pi_{mb}^{rees} = \frac{A^2\lambda(M_2\lambda\phi_b^{rses} - c^2)}{\Delta_1^2}$ and $\pi_{rb}^{rees} = \frac{A^2\, M_2\lambda^2(1 - \phi_b^{rses})}{\Delta_1^2}$, respectively.

Proof: The optimal solution of the retailer's optimization problem is obtained by solving the following first order conditions $\frac{\partial\pi_{rb}^{rees}}{\partial p_b^{rees}} = 0$ and $\frac{\partial\pi_{rb}^{rses}}{\partial e_b^{rses}}0$, simultaneously. After simplification, one can obtain retail price and green-marketing effort as $p_b^{rses} = \frac{1}{(1 - \phi_b^{rses})(4\, b(1 - \psi_b^{rses}) - d^2(1 - \phi_b^{rses}))}[(2\, a(1 - \phi_b^{rses}) + 2\, bw_b^{rses})(1 - \psi_b^{rses}) - (1 - \phi_b^{rses})(d^2\, w_b^{rses} - 2\, c(1 - \psi_b^{rses})\theta_b^{rses})]$ and $e_b^{rses} = \frac{d^2((a + c\theta_b^{rses})(1 - \phi_b^{rses}) - bw_b^{rses})^2}{(4\, b(1 - \psi_b^{rses}) - d^2(1 - \phi_b^{rses}))^2}$, respectively. Based on the retailer's response, the manufacturer can coordinate the retailer's decision in pricing and green-marketing effort by setting $p_b^{rses} = p_c^c$ and $\sqrt{e_b^{rses}} = \sqrt{e_c^c}$. Therefore, the wholesale prices are obtained as $w_b^{rses}|_{(p_b^{rses} = p_c^c)} = \frac{(1 - \phi_b^{rses})}{\Delta_1(M_1 - 2\, bw_b^{rses} - d^2\phi_b^{rses})}[2\, a(c^2(1 - \psi_b^{rses}) + d^2\lambda(\phi_b^{rses} - \psi_b^{rses})) + 2\, b(((4\, b + d^2)\lambda + 2\, c^2)c_m(1 - \psi_b^{rses}) + \lambda(4\, c\theta(1 - \psi_b^{rses}) + c_m d^2(2 - \phi_b^{rses} - \psi_b^{rses}))) + (c^2 + d^2\lambda)(c_m d^2(1 - \phi_b^{rses}) + 2\, c\theta_b^{rses}(1 - \psi_b^{rses}))]$ and $w_b^{rses}|_{\sqrt{e_b^{rses}} = \sqrt{e_c^c}} = \frac{1}{b\Delta_1}[a(4\, b\lambda(\psi_b^{rses} - \phi_b^{rses}) - c^2(1 - \phi_b^{rses})) + bc_m\lambda(M_2 - 4\, b\psi_b^{rses} - d^2\phi_b^{rses}) + c(M_2\lambda - c^2)\theta_b^{rses}(1 - \phi_b^{rses})]$. Because, the wholesale prices must be unique so by equating $w_b^{rses}|_{(p_b^{rses} = p_c^c)} = w_b^{rses}|_{\sqrt{e_b^{rses}} = \sqrt{e_c^c}}$, one can obtain $\theta_b^{rses} = \frac{A(2\, b\lambda(\phi_b^{rses} - \psi_b^{rses}) + c^2(1 - \phi_b^{rses}))}{c(1 - \phi_b^{rses})\Delta_1}$. Now, supply chain coordination can be achieved if $\theta_b^{rses} = \theta_c^c$. On simplification, one can obtain $\phi_b^{rses} = \psi_b^{rses}$. By using back-substitution, one can obtain the optimal decision as presented in Corollary 1. Note that, the manufacturer needs to set lower wholesale price compared to marginal cost [17], which is well documented in existing literature. The total supply chain profits is also equal to centralized supply chain profit.

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