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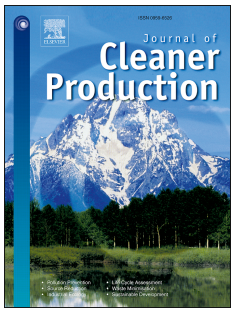

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A Game Theoretic Approach for Pricing, Greening, and Social Welfare Policies in a Supply Chain with Government Intervention

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Abstract

It is undeniable that every organization and company will eventually need to move toward sustainability if they wish to survive and remain competitive. In order to attain sustainability, it is very important to optimize all its dimensions at the same time. In this paper, we consider a two-tier model consists of a supply chain and government that government in a higher level role as a leader for the whole supply chain. For both levels, three dimensions of sustainability, namely economic, social and environmental dimensions, are defined and each is considered in modeling. In this paper, consumer surplus is considered as an indicator of social welfare for the social dimension of sustainability, and for the first time, consumer surplus is modeled based on two variables that one is price and other is greening level of the product. Our findings show how the consumer surplus may increase as product price rises. Our findings also show that cooperation between the manufacturer and retailer always lead to produce a greener product, increase the profit of the entire supply chain and increase consumer surplus of customers. Also in models with government intervention, the government imposes (pays) a lower (greater) tax (subsidy) on the final price of the product. We also find that the retail price in the cooperation models always is not lower than that in the noncooperation models which contrasts with the result of 'double marginalization'. Results also show that different government policies have significant impacts on the profit of the supply chain members as well as on the environment. Incorporating a fraction of consumer surplus in the government utility function has a greater effect on the supply chain members' profit, and on the green degree of the product, than considering environmental concerns. We also propose a contract to coordinate the decentralized supply chain.

Keywords: Pricing; Sustainable supply chain; Game theory; Government intervention; Green product.

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1 Introduction

We live on a planet that has seen a lot of changes and transformations. Over and over, scientists and researchers have found that human activities jeopardize the future of mankind and the planet. Worldwide, there are many organizations, companies, and factories that use a significant share of resources and produce necessities for daily life, and their activities affect the future life of the population. This has led governments to seek solutions to these problems, and they have found that sustainability is a good solution. There is no consensus among researchers on the definition and dimensions of sustainability. The most well-known definition of sustainability and sustainable development is offered by the Brundtland-Commission (1987): "development that meets the needs of the present without compromising the ability of future generations to meet their needs." There are also various concepts of sustainability. One central concept that can help organizations or businesses to operationalize and move toward sustainability it is the triple bottom line approach (Seuring and Müller, 2008). This approach encompasses the three generally accepted dimensions of sustainability: social, economic and environmental (Elkington, 2002). Based on this approach, organizations should not focus just on their economic goals; they must also take the social and environmental aspects of their activities into account.

In today's global market, organizations increasingly recognize that addressing the issue of sustainability in their operations is very important (Xie, 2016). There are many definitions of sustainable supply chain management. Carter and Rogers (2008) defined it as "the strategic, transparent integration and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key inter-organizational business processes for improving the long-term economic performance of the individual company and its supply chains." One thing that is common in all definitions of sustainable supply chain is that they emphasize that all three dimensions of sustainability should be considered simultaneously. Improving social and environmental aspects must be considered along with economic aspects of supply chains (Chen and Andresen, 2014). Research values the advantages of integration of economic, environmental and social sustainability (Ashby et al., 2012).

While there are a lot of supply chain models that consider the economic and environmental dimensions of sustainability, few deal with its social aspects (Chen and Andresen, 2014). The general and operations management literature has been critiqued before because it focuses on the environmental aspect, neglecting the social side. Seuring (2013) reviewed more than 300 articles about green and sustainable supply chain management for the period 1990 to 2010. The studies were sorted according to the research methodologies employed; only 36 created or used quantitative models.

Governments are integral to operationalizing and moving toward sustainability, especially in the area of policymaking. Supply chain operation involve social demands and legislative requirements rather than just stakeholder participation (Gouda et al., 2016; Tang and Zhou, 2012). Sustainability has been a major topic globally among legislators, practitioners, broad-based media and academics (Golini et al., 2014; Munda, 2009). It is very important to simultaneously optimize the three dimensions of sustainability taking government policies into account.

A closer look at studies done in the field of sustainable supply chain, reveals that the majority of this research focuses on the economic and environmental dimensions of sustainability (e.g., see: (Choi, 2013; Govindan et al., 2016; Jafari et al., 2017; Li et al., 2016; Sun et al., 2014; Wang et al., 2014; Zailani et al., 2017; Zhu and He, 2017)). Most of the studies that investigate social sustainability discuss the topic theoretically, and the social aspect of sustainability is neglected in optimization models. There is an obvious research gap regarding social aspects and overall integration of the three sustainability dimensions. Most of the optimization models that have been developed cover environmental and economic aspects of sustainability. In this paper for the first time pricing (economy), greening (environment) and social welfare (society) policies are considered for both supply chain and government level simultaneously, and all three dimensions of sustainability for both government and supply chain are simultaneously optimized. To the best of our knowledge, there are no studies that model and optimize economic, social and environmental dimensions of sustainability simultaneously in a supply chain using a game theoretic approach, nor do any studies include government policies and consumer surplus based on two variables in optimization modeling. In the present paper, a mathematical model that simultaneously considers all three dimensions of sustainability and different government policies will be developed.

Tsoulfas and Pappis (2008) developed environmental performance indicators to support making decisions about the design and operation of supply chains when the objective is to apply environmental principles. Xie (2016) considered the running and decision-making of a decentralized supply chain with two rival suppliers so as to improve sustainability in a competitive situation through cooperative strategies and parameters adjustments. Environmental performance was measured by the energy efficiency of the industry for eco-friendly products. Tseng and Hung (2014) presented a model for calculating both the operational and social costs of carbon dioxide. The results showed a decrease in the amount of carbon dioxide emitted with the increase in the social cost of carbon dioxide. This showed that there is an improvement in reduction of carbon dioxide emissions with a strict rule to pay for the those emissions by their economic activities. Panda (2014) investigates coordination of a corporate social responsible manufacturer–retailer chain with considering consumer surplus as an index of social welfare for both manufacturer and retailer. Hänsel and Quaas (2018) have examined the effects of the intertemporal distribution of well-being on the social cost of carbon.

Huang et al. (2016) considered a green supply chain with multiple suppliers, one manufacturer, and multiple retailers to study the effects of product line design, supplier selection, transportation mode selection and pricing on profit and greenhouse gas emissions. Ghosh and Shah (2012) developed a game theoretic model to show how prices, greening levels, and profits are affected by channel structures. They considered a green supply chain that consists of one producer and one retailer; the producer manufactures a green product and supplies it to customers through the retailer. Chen and Hao (2015) considered two competing firms that have different operational efficiencies and produce the same product for customers. They investigated the effect of taxes imposed on greenhouse gas emissions by the government on the pricing of the final product. They found that the retail price of the high-efficiency firm would still be lower compared to the low-efficiency firm regardless of the same carbon emission tax. Hafezalkotob (2015) developed a mathematical model based on price competition of two supply chains, one green and one regular, under the influence of government financial intervention. He analyzed the effect of government tariffs on the players' optimal strategies. Li et al. (2016) considered a dual-channel supply chain where the manufacturers make eco-friendly products for the environmentally conscious. They discussed pricing and greening strategies for the manufacturer and retailer in both centralized and decentralized supply chains. The results showed that if the greening cost is greater than a threshold, the manufacturer does not open a direct channel. They also found that in the centralized green supply chain, the retail price is higher than in the decentralized supply chain, which contrasts with the results of "double marginalization." Other studies have investigated two or three dimensions of sustainability in the supply chain with multi-criteria decision-making methods (e.g. see: (Boukherroub et al., 2015; Mota et al., 2015; Pinto et al., 2015)).

In most previous studies, one or two dimensions of sustainability in the supply chain along with the government have been modeled or sustainability dimensions are modeled only for the supply chain and different dimensions of sustainability have not been modeled for government. Also in previous studies, So far, consumer surplus has always been defined and evaluated only based on price. In this paper for the first time we develop an integrated model that simultaneously considers three major dimensions of sustainability (utility as an economic indicator, greening as an environmental indicator and consumer surplus as a social indicator) for both supply chain and government level; and for the first time, consumer surplus is modeled based on two variables that one is price and other is greening level of the product.

The game theory tools is used to model and solve the problem in this paper especially centralized, decentralized and the Stackelberg competitions are used in this article (For further reading please refer to Osborne (2004).

In this article, we answer the following questions.

- How we can simultaneously model three major dimensions of sustainability in a supply chain with and without government intervention?

- What is the effects of different government policies on profits of the supply chain member, consumer and environment?
- Is it possible that green degree of the product affect the consumer surplus?
- How can the decentralized supply chain be coordinated?

The rest of the paper is organized as follows. Section 2 presents the model structure and its assumptions. In Section 3, the supply chain without government intervention in a centralized model and a decentralized model is investigated. Also in this section, a contract is used to coordinate the decentralized supply chain. Section Corollary 4 considers the supply chain with government intervention in a centralized and a decentralized model. Numerical examples and sensitivity analysis are given in Section 5. Finally, conclusions and future extension of the proposed model are presented in Section 6.

2 Modeling framework

In this section we present the model structure and its assumptions. List of the notations that used to develop the model are located in the appendix.

2.1 Model Structure

This paper considers a supply chain that consists of one manufacturer and one retailer. The manufacturer produces a green product at a unit cost c. The manufacturer supplies the green product to the retailer at a wholesale price w. The retailer sells the product to customers at price p (in the model without government intervention). It is assumed that the manufacturer has social concerns in addition to environmental concerns and cares about the social welfare of the customers in line with its corporate social responsibility; therefore, the manufacturer considers consumer surplus as an index of social welfare in its profit function. This assumption can also be made for the retailer and the government. The topology of the considered supply chain is given in Figure. 1.

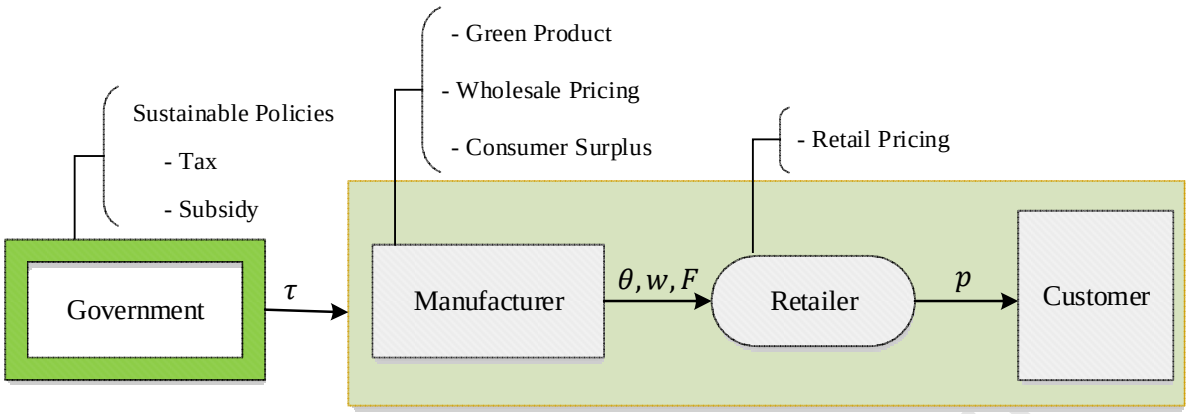


Figure. 1. The topology of the studied supply chain

2.2 Assumptions

To formulate the problem, some assumptions are made:

Assumption 1. The demands faced by the channel members are linear functions of the retail price p and the green degree of the product θ, which is common in the literature. Demands are assumed to be downward sloping in retail price and upward sloping in green degree. This assumption is similar to Ghosh and Shah (2012) and Li et al. (2016). Thus, the demand function is as follows:

$$D(p,\theta) = \alpha - \beta p + \lambda\,\theta \tag{1}$$

Assumption 2. Taxes are the single most important way of raising revenue for governments (Clayton et al., 2003). Governments can impose taxes or pay subsidies on products in order to protect the environment, support producers of green products (Ritzenhofen et al., 2016), raise revenue for public projects (Mankiw, 2007) and improve social welfare. Depending on different government policies, governments may impose a tax ($\tau > 0$) or pay a subsidy ($\tau < 0$) on the products. So in this paper it is assumed that governments impose (pay) a tax (subsidy) on the final price of the product; the demand function with regard to this tax (subsidy) can be rewritten as:

$$D(p,\tau,\theta) = \alpha - \beta(p+\tau) + \lambda\,\theta \tag{2}$$

This demand function is consistent with those considered in economics books, such as Lovell (2004) and Mankiw (2007), as well as research papers, such as Hafezalkotob (2015) and Madani and Rasti-Barzoki (2017). Note that, if the government imposes (pays) tax (subsidy) τ on the manufacturer's product, it causes a difference between the price paid by the customer and the price received by the seller (retailer). If p is the price received by the seller, $p' = p + \tau$ will be the price paid by the customer. Note that it does not matter whether a tax or subsidy on a product is levied on the seller or buyer of the product. In the end, the buyer and seller of the product share the burden or gain of the tax or subsidy, regardless of how it is levied (Mankiw, 2007).

Assumption 3. Similar to Ghosh and Shah (2012) and Li et al. (2016), it is assumed that the production of a green product doesn't affect the manufacturer's traditional marginal cost. To produce the green product, the manufacturer must make extra investments to get the green innovation based on the original production process. The cost is a quadratic function of the green degree; the extra investment is $C(\theta) = \eta\theta^2/2$, in which η is the cost coefficient of the green degree per unit. This kind of cost is common in the literature (Ghosh and Shah, 2012; Li et al., 2016; Swami and Shah, 2013).

Assumption 4. It is assumed that the manufacturer has social concerns in addition to environmental concerns and cares about the social welfare of customers; therefore the manufacturer considers consumer surplus as an index of social welfare in its profit function. Consumer surplus is the difference between the total amount that customers are willing and able to pay for a good or service and the total amount that they actually pay (i.e., the market price). If $\mu \in [0,1]$ is the fraction of the consumer surplus that is the socially responsible manufacturer's concern, then the amount of consumer surplus incorporated in the manufacturer profit in the models without government intervention is:

$$\mu\, CS = \mu \int_{p_{market}}^{p_{max}} D(p,\theta)dp = \mu \int_{p}^{\frac{\alpha+\lambda\,\theta}{\beta}} [\alpha - \beta\, p + \lambda\, \theta]\, dp = \frac{\mu[\alpha - \beta\, p + \lambda\, \theta]^2}{2\,\beta} \tag{3}$$

And in the models with government intervention is:

$$\mu\, CS = \mu \int_{p_{market}}^{p_{max}} D(p,\tau,\theta)dp = \mu \int_{p}^{\frac{\alpha+\lambda\,\theta}{\beta}-\tau} [\alpha - \beta(p+\tau) + \lambda\, \theta]\, dp = \frac{\mu[\alpha - \beta(p+\tau) + \lambda\, \theta]^2}{2\,\beta} \tag{4}$$

Note that when $\mu = 0$ the firm is a pure profit maximizer, whereas $\mu = 1$ indicates that the firm is a perfect welfare maximizer. Consumer surplus is considered as the social aspect of sustainability and corporate social responsibility in many studies (Panda, 2014; Swami and Shah, 2013; Xie, 2016) and is an economic measure of consumer benefit.

3 Supply chain without government intervention: modeling and solutions

In this section, it is supposed that the government or policymakers have not intervened in the supply chain. The supply chain consists of the manufacturer and the retailer, so the demand function is shown by Equation. (1).

3.1 Decentralized model

In decentralized decision-making, the channel members operate independently and maximize their individual profit functions. In this section, we first solve the base model without government intervention and consider a manufacturer Stackelberg game based on demand function without a tax (subsidy), where the manufacturer is the leader of the channel and the retailer is the follower. The manufacturer and retailer make their decisions in sequence; the order of events is as follows. First, the retailer determines the retail price of the product in response to a given green degree of the product

and a wholesale price. Then, the manufacturer takes the retailer's response function into account for an optimal green degree of the product and an optimal wholesale price to maximize profit. As previously mentioned, the manufacturer or the retailer, or both, act in line with their sustainability goals to incorporate the consumer surplus into their profit functions. Now suppose that only the manufacturer incorporates consumer surplus in its profit function, so the profit functions of the supply chain members will be as follows:

$$\pi_R^{DC} = (p - w)\, D(p, \theta) \tag{5}$$

$$\pi_M^{DC} = (w - c)\, D(p, \theta) - \frac{\eta\, \theta^2}{2} \tag{6}$$

$$V_M^{DC} = (w - c)\, D(p, \theta) - \frac{\eta\, \theta^2}{2} + \mu_1\, \mathrm{CS} \tag{7}$$

Equation (5) represents the retailer profit function and Equation (6) represent the manufacturer's pure profit function. Equation (7) is the manufacturer's utility function: the first term in this equation is an economic goal, the second an environmental goal, and the last term represents a fraction of consumer surplus as a social goal for the manufacturer.

Theorem 1. The optimal solutions for the manufacturer and retailer (based on equation (5) and equation (7)) in a decentralized model without government intervention will be as follows:

$$\theta^{DC} = \frac{c\beta\lambda - \alpha\lambda}{\lambda^2 - 4\beta\eta + \beta\eta\mu_1} \tag{8}$$

$$w^{DC} = \frac{c\lambda^2 - 2(\alpha + c\beta)\eta + \alpha\eta\mu_1}{\lambda^2 - 4\beta\eta + \beta\eta\mu_1} \tag{9}$$

$$p^{DC} = \frac{\alpha\eta\mu_1 - 3\alpha\eta + c(-\beta\eta + \lambda^2)}{\beta\eta\mu_1 - 4\beta\eta + \lambda^2} \tag{10}$$

Proof of all theorems and corollaries are located in the appendix (Supplementary file).

From Theorem 1, the following corollary will be achieved:

Corollary 1. p^{DC} and w^{DC} are increasing in α and λ and are decreasing in η. Also, θ^{DC} is increasing in α, λ and μ_1, and is decreasing in η and c. The results obtained from Theorem 1 are consistent with the results obtained in some previous studies, such as Ghosh and Shah (2012), Swami and Shah (2013) and Ghosh and Shah (2015).

We know from this corollary, that if the primary demand for the green product and the demand expansion effectiveness coefficient of the green degree per unit of green product are high, the retailer and manufacturer will set a high retail price and a high wholesale price. On the other hand, if the cost coefficient of the green degree per unit is high, the retailer and manufacturer will set a low retail price and a low wholesale price.

In addition, if the primary demand for the green product and the demand expansion effectiveness coefficient of the green degree per unit of green product, and the fraction of consumer surplus that is the socially responsible manufacturer's concern, are high, the manufacturer will set a high green

degree of the green product. On the other hand, if the cost coefficient of the green degree per unit and the unit production cost of the manufacturer are high, the manufacturer will set a low green degree of the green product.

The manufacturer's maximum utility and the retailer's maximum profit will be obtained from Theorem 1 and Equations (7) and (5) as:

$$V_M^{DC*} = \frac{(c\beta - \alpha)^2 \eta}{2(\lambda^2 - 4\beta\eta + \beta\eta\mu_1)} \tag{11}$$

$$\pi_R^{DC*} = \frac{\beta(\alpha\eta - c\beta\eta)^2}{(\lambda^2 - 4\beta\eta + \beta\eta\mu_1)^2} \tag{12}$$

In a decentralized model with a manufacturer Stackelberg game, when the manufacturer incorporates a fraction of consumer surplus in its profit function, it causes the manufacturer to lower its wholesale price and as a result, the retailer will benefit it more than customers. So in order to ensure that the gains of considering consumer surplus in its profit function are really passed on to customers, the manufacturer can set a two-part tariff contract with the retailer. A two-part tariff contract is a coordination mechanism usually offered by the manufacturer to the retailer that modifies the retailer's profit function (and also that of the manufacturer) so as to incentivize the retailer to make decisions coherent with supply chain total optimization (Modak et al., 2015).

Now suppose that in a decentralized model without government intervention and under a two-part tariff contract, the manufacturer supplies the green product to the retailer at a wholesale price w and charges a lump sum fee F. Then, the profit function of the retailer is:

$$\pi_R^{DC} = (p - w)\, D(p, \theta) - F \tag{13}$$

The pure profit function and utility function of the manufacturer will be:

$$\pi_M^{DC} = (w - c)\, D(p, \theta) + F - \frac{\eta\theta^2}{2} \tag{14}$$

$$V_M^{DC} = (w - c)\, D(p, \theta) + F - \frac{\eta\theta^2}{2} + \mu_1 \frac{D(p, \theta)^2}{2\beta} \tag{15}$$

So in this mode, the following theorem and corollary will be achieved.

Theorem 2. The optimal solutions (based on equation (13) and equation (15)) in a decentralized model and under a two-part tariff contract will be as follows:

$$w^{DC} = \frac{c(\lambda^2 - 2\beta\eta) + \alpha\eta\mu_1}{\lambda^2 - 2\beta\eta + \beta\eta\mu_1} \tag{16}$$

$$\theta^{DC} = \frac{(c\beta - \alpha)\lambda}{\lambda^2 - 2\beta\eta + \beta\eta\mu_1} \tag{17}$$

$$p^{DC} = \frac{c\lambda^2 - (\alpha + c\beta)\eta + \alpha\eta\mu_1}{\lambda^2 - 2\beta\eta + \beta\eta\mu_1} \tag{18}$$

$$F = \frac{\beta^2(\alpha - c\beta)^2\eta^3(2 + \mu_1)(-6\beta\eta + 2\lambda^2 + \beta\eta\mu_1)}{(4\beta\eta + \lambda^2)^2(-2\beta\eta + \lambda^2 + \beta\eta\mu_1)^2} \tag{19}$$

From Theorem 2, the following corollary will be achieved:

Corollary 2. p^{DC} is increasing in α and λ and is decreasing in η. Also, θ^{DC} and F are increasing in α, λ, and μ_1 and are decreasing in η and c. Finally, w^{DC} is increasing in η and c and is decreasing in α, λ, and μ_1. The results obtained from Theorem 2 are consistent with the results obtained in some previous studies, such as Ghosh and Shah (2012), Swami and Shah (2013) and Ghosh and Shah (2015).

We can also achieve similar results from this corollary to that from corollary 1.

The manufacturer's maximum utility and the retailer's maximum profit in a decentralized model under a two-part tariff contract will be obtained from Theorem 2 and Equations (15) and (13) as:

$$V_M^{DC*} = \frac{(\alpha - c\beta)^2\eta(12\beta^2\eta^2 - 6\beta\eta\lambda^2 + \lambda^4 + 2\beta^2\eta^2\mu_1)}{2(4\beta\eta - \lambda^2)^2(-2\beta\eta + \lambda^2 + \beta\eta\mu_1)} \tag{20}$$

$$\pi_R^{DC*} = \frac{\beta(\alpha - c\beta)^2\eta^2}{(-4\beta\eta + \lambda^2)^2} \tag{21}$$

3.2 Centralized model

In the centralized model, the manufacturer and retailer decide to work together and act as a centralized unit. In this case, the manufacturer and the retailer determine the green level of the product and the final price together. So the pure profit function and utility function of the centralized supply chain will be:

$$\pi^C = (p - c)\, D(p, \theta) - \frac{\eta\theta^2}{2} \tag{22}$$

$$V^C = (p - c)\, D(p, \theta) - \frac{\eta\theta^2}{2} + \mu_1 \frac{D(p, \theta)^2}{2\beta} \tag{23}$$

Theorem 3. The optimal solutions for the supply chain (based on equation (23)) in a centralized model without government intervention will be as follows:

$$\theta^C = \frac{(c\beta - \alpha)\lambda}{\lambda^2 - 2\beta\eta + \beta\eta\mu_1} \tag{24}$$

$$p^C = \frac{c\lambda^2 - (\alpha + c\beta)\eta + \alpha\eta\mu_1}{\lambda^2 - 2\beta\eta + \beta\eta\mu_1} \tag{25}$$

From Theorem 3, the following corollary will be achieved:

Corollary 3. p^C is increasing in α and λ and is decreasing in η. Also, θ^C is increasing in α, λ and μ_1, and is decreasing in η and c.

We can also achieve similar results from this corollary to that from corollary 1.

The supply chain's utility in a centralized model without government intervention will be obtained from Theorem 3 and Equation (23) as:

$$V^{C*} = \frac{(\alpha - c\beta)^2 \eta}{2(2\beta\eta - \lambda^2 - \beta\eta\mu_1)} \tag{26}$$

Corollary 4. In the supply chain without government intervention, the following relationships exist between the solutions of the problem.

1. For the wholesale prices in the decentralized supply chain with and without two-part tariff contract we have:
   $w_{woc}^{DC} > w_{wc}^{DC}$.
2. For the green degrees of the product in the decentralized supply chains and centralized supply chain we have:
   $\theta_{woc}^{DC} < \theta_{wc}^{DC} = \theta^{C}$.
3. For the prices that seller receives in different models of the supply chain without government intervention we have:
   If $\eta < \frac{\lambda^2}{\beta}$, then $p_{woc}^{DC} < p_{wc}^{DC} = p^{C}$;
   If $\eta > \frac{\lambda^2}{\beta}$, then $p_{woc}^{DC} > p_{wc}^{DC} = p^{C}$;
   and if we have $\eta = \frac{\lambda^2}{\beta}$, then $p_{woc}^{DC} = p_{wc}^{DC} = p^{C}$.
4. Also, total utility in the decentralized supply chains and centralized supply chain satisfy the following:
   $V_{woc}^{SC/DC} < V_{wc}^{SC/DC} = V^{C}$.
   That $V_{woc}^{SC/DC} = \pi_{R/woc}^{DC} + V_{M/woc}^{DC}$.
5. And finally for the consumer surplus in different models of the supply chain without government intervention we have:
   $CS_{woc}^{DC} < CS_{wc}^{DC} = CS^{C}$.

From Corollary 4.2, we find that cooperation and coordination between the manufacturer and retailer in the supply chain will increase the green degree of the product. As a result, always collaboration between the manufacturer and retailer make a cleaner environment.

As it is obvious from Corollary 4.3 the retail price in the centralized model or in the decentralized model with two-part tariff contract always is not less than the price of the product in the decentralized model without two-part tariff contract which this result contrasts with the result of 'double marginalization'. Based on double marginalization, the price of the product will decrease when an upstream firm cooperates with a downstream seller. But Corollary 4.3 shows that in the supply chains with considering a green degree of the product in the demand function result of 'double marginalization' may not be always true. This contradiction is due to the cost of per unit product. Actually, the green degree of the product and so on the cost of per unit product in cooperation models is higher than noncooperation models. Li et al. (2016) also achieved the same result in their study.

From Corollary 4.4 and Corollary 4.5, we find that total profit of the supply chain and consumer surplus in the centralized model or in the decentralized model with two-part tariff contract is always higher than the decentralized model without two-part tariff contract. we saw from Insight 1.3 that the retail price in the decentralized model without two-part tariff contract maybe greater than retail price in the cooperation models however consumer surplus in the cooperation models is always higher than the decentralized model without two-part tariff contract. This two results seem to have contrast with each other. But they are reasonable. The reason for them goes back to the green degree of the product and its related cost. In fact, when demand of the product is a function of other variables in addition to the price of the product it may occur. For example, consider consumer surplus in *Figure 2*, when the green degree of the product is equal to zero and the price of the product is p_1, consumer surplus will be equal to the area of triangle *abc*. Now if the green degree of the product is equal to θ^*, and the price of the product is p_2 which $p_2 > p_1$, then consumer surplus will be equal to the area of triangle *ABC* ($ABC > abc$). In this figure, we see that however the price of the product is increased but the green degree of the product and the demand of the product is also increased so consumer surplus is not decreased.

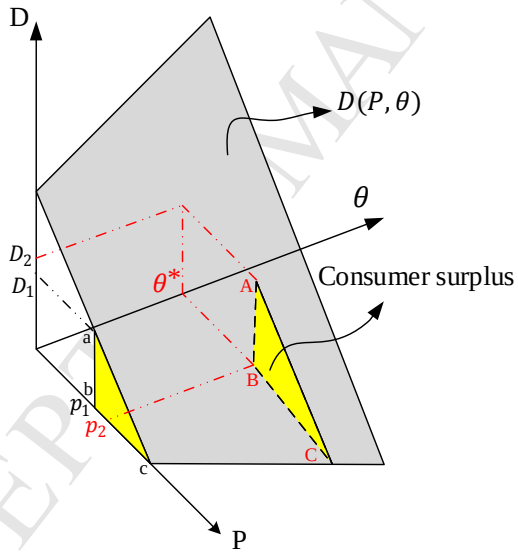


Figure 2. Effect of the green degree of the product on consumer surplus

In summary, for the models without government intervention, cooperation between the manufacturer and retailer always lead to produce a greener product, increase the profit of the entire supply chain and increase consumer surplus of customers. Therefore, coordinating the decentralized supply chain is necessary for all members of the supply chain.

4 Supply chain with government intervention: modeling and solutions

In this section, it is supposed that the government or policymakers, based on their policies, impose (pay) a tax (subsidy) on the final price of the product, and the demand function is as Equation (2).

4.1 Decentralized model

In decentralized decision-making, the channel members operate independently and maximize their individual profit functions. It is supposed that the manufacturer is the leader of the channel and the retailer is the follower, and at a higher level, the government is the leader of whole supply chain. The manufacturer and retailer make their decisions in sequence similar to that section 3.1. And finally, based on its policies, the government imposes (pays) taxes (subsidies) on the product. So the profit functions of the supply chain members will be as follows:

$$\pi_R^{DC} = (p - w)\, D(p, \tau, \theta) \tag{27}$$

$$\pi_M^{DC} = (w - c)\, D(p, \tau, \theta) - \frac{\eta\, \theta^2}{2} \tag{28}$$

$$V_M^{DC} = (w - c)\, D(p, \tau, \theta) - \frac{\eta\, \theta^2}{2} + \mu_1\, \mathrm{CS} \tag{29}$$

According to its policies, the government can have different objective functions. If the government decides to act in line with sustainability objectives and wants to consider social, economic and environmental aspects of sustainability in its own profit function, we can consider the utility function of government as:

$$\pi_G^{DC} = \gamma_1(\theta) + \gamma_2(\tau\, D(p, \tau, \theta)) + \gamma_3(\mu_2 \frac{D(p, \tau, \theta)^2}{2\beta}) \tag{30}$$

The first term is an environmental goal, the second an economic goal, and the last represents a fraction of consumer surplus as a social goal for the government.

For simplicity, if $\gamma_1 = \gamma_2 = \gamma_3 = 1$, then we will have:

Theorem 4. The optimal solutions for the manufacturer, retailer and government in a decentralized model will be as follows :

$$\theta^{DC} = \frac{\lambda(c\beta\eta - \alpha\eta - \lambda)}{\eta(2\lambda^2 + \beta\eta(-8 + 2\mu_1 + \mu_2))} \tag{31}$$

$$w^{DC} = \frac{\alpha\eta(-2 + \mu_1) + \lambda(-2 + \mu_1) + c(2\lambda^2 + \beta\eta(-6 + \mu_1 + \mu_2))}{2\lambda^2 + \beta\eta(-8 + 2\mu_1 + \mu_2)} \tag{32}$$

$$p^{DC} = \frac{\alpha\eta(-3 + \mu_1) + \lambda(-3 + \mu_1) + c(2\lambda^2 + \beta\eta(-5 + \mu_1 + \mu_2))}{2\lambda^2 + \beta\eta(-8 + 2\mu_1 + \mu_2)} \tag{33}$$

$$\tau^{DC} = \frac{(\alpha\eta - c\beta\eta - \lambda)(\lambda^2 + \beta\eta(-4 + \mu_1)) + \beta(\alpha - c\beta)\eta^2\mu_2}{\beta\eta(2\lambda^2 + \beta\eta(-8 + 2\mu_1 + \mu_2))} \tag{34}$$

So the manufacturer's maximum utility, the retailer's maximum profit and the government's maximum utility will be obtained from Theorem 4 and Equations (29), (27) and (30) as:

$$V_M^{DC*} = \frac{(\alpha\eta - c\beta\eta + \lambda)^2(-\lambda^2 - \beta\eta(-4 + \mu_1))}{2\eta(2\lambda^2 + \beta\eta(-8 + 2\mu_1 + \mu_2))^2} \tag{35}$$

$$\pi_R^{DC*} = \frac{\beta(\alpha\eta - c\beta\eta + \lambda)^2}{(2\lambda^2 + \beta\eta(-8 + 2\mu_1 + \mu_2))^2} \quad (36)$$

$$\pi_G^{DC*} = \frac{-(\alpha\eta - c\beta\eta + \lambda)^2}{2\eta(2\lambda^2 + \beta\eta(-8 + 2\mu_1 + \mu_2))} \quad (37)$$

Suppose that in a decentralized model with government intervention and under a two-part tariff contract, the manufacturer supplies the product to the retailer at a wholesale price w and charges a lump sum fee F. Then, the profit function of the retailer is:

$$\pi_R^{DC} = (p - w)\, D(p, \tau, \theta) - F \quad (38)$$

The pure profit function and utility function of the manufacturer will be:

$$\pi_M^{DC} = (w - c)\, D(p, \tau, \theta) + F - \frac{\eta\, \theta^2}{2} \quad (39)$$

$$V_M^{DC} = (w - c)\, D(p, \tau, \theta) + F - \frac{\eta\, \theta^2}{2} + \mu_1 \frac{D(p, \tau, \theta)^2}{2\, \beta} \quad (40)$$

The government utility function is considered as Equation. (30) and $\gamma_1 = \gamma_2 = \gamma_3 = 1$ so:

Theorem 5. The optimal solutions for the manufacturer, retailer and government in a decentralized model with government intervention and under a two-part tariff contract will be as follows:

$$\theta^{DC} = \frac{\lambda(c\beta\eta - \alpha\eta - \lambda)}{\eta(2\lambda^2 + \beta\eta(-4 + 2\mu_1 + \mu_2))} \quad (41)$$

$$w^{DC} = c + \frac{(\alpha\eta - c\beta\eta + \lambda)\mu_1}{2\lambda^2 + \beta\eta(-4 + 2\mu_1 + \mu_2)} \quad (42)$$

$$p^{DC} = \frac{\alpha\eta(-1 + \mu_1) + \lambda(-1 + \mu_1) + c(2\lambda^2 + \beta\eta(-3 + \mu_1 + \mu_2))}{2\lambda^2 + \beta\eta(-4 + 2\mu_1 + \mu_2)} \quad (43)$$

$$F = \frac{\beta^2\eta(\alpha\eta - c\beta\eta + \lambda)^2(2\lambda^2 + \beta\eta(-6 + \mu_1))(-2 - \mu_1)}{(-4\beta\eta + \lambda^2)^2(2\lambda^2 + \beta\eta(-4 + 2\mu_1 + \mu_2))^2} \quad (44)$$

$$\tau^{DC} = \frac{(\alpha\eta - c\beta\eta - \lambda)(\lambda^2 + \beta\eta(-2 + \mu_1)) + \beta(\alpha - c\beta)\eta^2\mu_2}{\beta\eta(2\lambda^2 + \beta\eta(-4 + 2\mu_1 + \mu_2))} \quad (45)$$

So the manufacturer's maximum utility, the retailer's maximum profit and the government's maximum utility in a decentralized model with government intervention and under a two-part tariff contract will be obtained from Theorem 5 and Equations (40), (38) and (30) as:

$$V_M^{DC*} = \frac{(\alpha\eta - c\beta\eta + \lambda)^2(-\lambda^2 - \beta\eta(-2 + \mu_1))(-6\beta\eta\lambda^2 + \lambda^4 + 2\beta^2\eta^2(6 + \mu_1))}{2\eta(-4\beta\eta + \lambda^2)^2(2\lambda^2 + \beta\eta(-4 + 2\mu_1 + \mu_2))^2} \quad (46)$$

$$\pi_R^{DC*} = \frac{\beta(\alpha\eta - c\beta\eta + \lambda)^2(\lambda^2 + \beta\eta(-2 + \mu_1))^2}{(-4\beta\eta + \lambda^2)^2(2\lambda^2 + \beta\eta(-4 + 2\mu_1 + \mu_2))^2} \quad (47)$$

$$\pi_G^{DC*} = \frac{-(\alpha\eta - c\beta\eta + \lambda)^2}{2\eta(2\lambda^2 + \beta\eta(-8 + 2\mu_1 + \mu_2))} \tag{48}$$

4.2 Centralized model

In the centralized model, only the manufacturer and retailer decide to work together and actually act as a centralized unit, and at a higher level, the government acts as a leader for the whole supply chain. In this case, the manufacturer and retailer determine the green level of the product and the final price together, and based on its own policies, the government imposes (pays) taxes (subsidies) on the final price of the product. So the pure profit function and utility function of the centralized supply chain will be:

$$\pi^C = (p - c)\, D(p, \tau, \theta) - \frac{\eta\, \theta^2}{2} \tag{49}$$

$$V^C = (p - c)\, D(p, \tau, \theta) - \frac{\eta\, \theta^2}{2} + \mu_1 \frac{D(p, \tau, \theta)^2}{2\, \beta} \tag{50}$$

In this mode, the following theorem and corollary will be achieved.

Theorem 6. The optimal solutions for the supply chain in a centralized model with government intervention will be as follows:

$$\theta^C = \frac{\lambda(c\beta\eta - \alpha\eta - \lambda)}{\eta(2\lambda^2 + \beta\eta(-4 + 2\mu_1 + \mu_2))} \tag{51}$$

$$p = \frac{\alpha\eta(-1 + \mu_1) + \lambda(-1 + \mu_1) + c(2\lambda^2 + \beta\eta(-3 + \mu_1 + \mu_2))}{2\lambda^2 + \beta\eta(-4 + 2\mu_1 + \mu_2)} \tag{52}$$

$$\tau = \frac{(\alpha\eta - c\beta\eta - \lambda)(\lambda^2 + \beta\eta(-2 + \mu_1)) + \beta(\alpha - c\beta)\eta^2\mu_2}{\beta\eta(2\lambda^2 + \beta\eta(-4 + 2\mu_1 + \mu_2))} \tag{53}$$

In this mode, the supply chain's maximum utility and the government's maximum utility will be obtained from Theorem 6 and Equation (50) and (30) as:

$$V^{C*} = \frac{(\alpha\eta - c\beta\eta + \lambda)^2(-\lambda^2 - \beta\eta(-2 + \mu_1))}{2\eta(2\lambda^2 + \beta\eta(-4 + 2\mu_1 + \mu_2))^2} \tag{54}$$

$$\pi_G^{C*} = \frac{-(\alpha\eta - c\beta\eta + \lambda)^2}{2\eta(2\lambda^2 + \beta\eta(-4 + 2\mu_1 + \mu_2))} \tag{55}$$

Corollary5. In the supply chain with government intervention, the following relationships exist between the solutions of the problem.

1. For the wholesale prices in the decentralized supply chain with and without two-part tariff contract we have:
   $w_{woc}^{DC} > w_{wc}^{DC}$.
2. For the green degrees of the products in the decentralized supply chains and centralized supply chain we have:

$\theta_{woc}^{DC} < \theta_{wc}^{DC} = \theta^{C}$.

3. For the prices that seller receives in different models of the supply chain with government intervention we have:

   If $\eta < \frac{2\lambda^2}{\beta(2-\mu_2)}$, then $p_{woc}^{DC} < p_{wc}^{DC} = p^{C}$;

   If $\eta > \frac{2\lambda^2}{\beta(2-\mu_2)}$, then $p_{woc}^{DC} > p_{wc}^{DC} = p^{C}$;

   and if we have $\eta = \frac{2\lambda^2}{\beta(2-\mu_2)}$, then $p_{woc}^{DC} = p_{wc}^{DC} = p^{C}$.

4. For the tax (subsidy) that government imposes (pays) on the price of the product in different models of the supply chain we have:

   $\tau_{woc}^{DC} > \tau_{wc}^{DC} = \tau^{C}$.

5. Also, total utility in the decentralized supply chains and centralized supply chain satisfy the following:

   $V_{woc}^{SC/DC} < V_{wc}^{SC/DC} = V^{C}$.

   That $V_{woc}^{SC/DC} = \pi_{R/woc}^{DC} + V_{M/woc}^{DC}$.

6. And finally for the consumer surplus in different models of the supply chain with government intervention we have:

   $CS_{woc}^{DC} < CS_{wc}^{DC} = CS^{C}$.

In summary, for the models with government intervention, cooperation between the manufacturer and retailer always lead to produce a greener product, increase the profit of the entire supply chain and increase consumer surplus of customers. Also in this mode, the government imposes (pays) a lower (greater) tax (subsidy) on the final price of the product.

In the next section, numerical examples will be presented.

5 Numerical example and sensitivity analysis

In this section, a numerical example is provided to demonstrate the feasibility of the mathematical models and analyze the effect of government policies on the profit of supply chain members and on the sustainable aspects of the supply chain. For all numerical examples, parameter values and change ranges are chosen in a way to satisfy the conditions of profit functions concavity and demand functions positivity (conditions of profit functions concavity and demand functions positivity are located in the appendix). So the related parameters are assumed to be

$\alpha = 400, \beta = 10, \lambda = 6, c = 6, \eta = 12, \mu_1 = 0.2, \mu_2 = 0.6, \gamma_1 = 1, \gamma_2 = 1, \gamma_3 = 1.$

5.1 Effect of a government tax (subsidy) on the supply chain

To investigate the effects of a government tax (subsidy) on the supply chain, first the government tax (subsidy) is considered as a parameter, and then the model is solved. The government is considered to want to see what happens to the profit of the supply chain members and what happens to the environment and social welfare when changes are made to the type (tax or subsidy) and amount of the tax or subsidy that is levied (paid) on the final price of the product. In this part, we have considered the manufacturer and retailer as a unit and called it the producer. In the figures, we don't show the cost of greening, but we consider this cost in related calculations.

Figures and calculations in this part of paper are based on the decentralized model with a manufacturer Stackelberg game under a two-part tariff contract between the manufacturer and retailer. If the government doesn't impose (pay) a tax (subsidy) on the final price of the product so the consumer surplus, the producer surplus and the green degree of the green product will be as in Figure. 3.

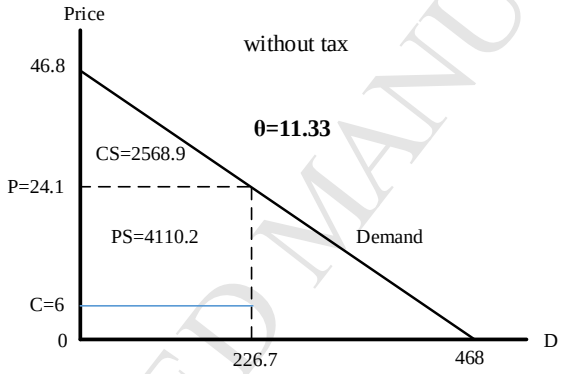


Figure. 3. The supply chain without government intervention

As is clear from Figure. 3, when the government doesn't impose (pay) a tax (subsidy) on the final price of the product, the optimal solutions will be:

Retail price=24.1, consumer surplus=2,568.9, producer surplus=4,110.2 and the green degree of the green product=11.33.

Now suppose that government levies $\tau = 10$ on the final price of the product. The effects of this imposed tax are depicted in Figure. 4.

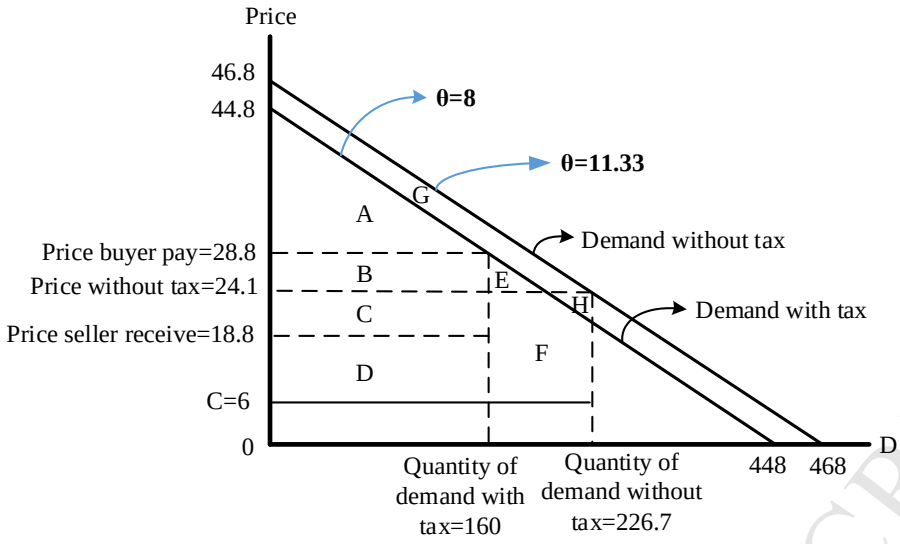


Figure. 4. The supply chain with government intervention

When the government levies tax $\tau = 10$ on the price of the product, a gap between the price that the buyer pays and the price that the seller receives is created. As previously mentioned, it does not matter whether a tax or subsidy on a product is levied on the seller or buyer of the product. In the end, the buyer and seller of the product share the burden or gain of the tax or subsidy, regardless of how it is levied. This point is clearly recognizable in Figure. 4, where the price of the final product without tax=24.1; when a tax is levied on the price of the product, then the price that the buyer pays for product=28.8, and the price that the seller receives for the product=18.8.

Table 1. effects of government tax on the supply chain

	WITHOUT TAX		**WITH TAX**		**CHANGE**	
Consumer Surplus	A+B+E+G	2568.9	A	1280	- (B+E+G)	-1288.9
Producer Surplus	C+D+F+H	4237.4	D	2048	- (C+F+H)	-2189
Tax Revenue	-		B+C	1600	+ (B+C)	+1600
Total Surplus	A+B+E+G+ C+D+F+H	6806.3	A+D +B+C	4928	- (E+G+F+H)	-1878.3

When the government levies a tax on the price of the product, the amounts of the consumer surplus and producer surplus will change as shown in Table 1. In addition, levied a tax on the price of the product causes a deadweight loss; in Figure. 4, that is equal to E+G+F+H. In the centralized model, the amount of this deadweight loss is equal to:

$$\frac{\beta^2\eta\tau(2\alpha\eta - 2c\beta\eta + \beta\eta\tau - \lambda^2\tau - 2(\alpha - c\beta)\eta\mu_1)}{2(-2\beta\eta + \lambda^2 + \beta\eta\mu_1)^2} \tag{56}$$

If the government pays a subsidy ($\tau < 0$) on the manufacturer's product instead of imposes a tax ($\tau > 0$) on the manufacturer's product, the opposite effect will occur for the supply chain members' profit. This means that the amount of profit that each member of the supply chain earns will increase. If the government pays a subsidy τ on the manufacturer's product, the government pays $\tau \times D$ to the supply chain members, including customers, but the supply chain members earn more than $\tau \times D$.

Paying a subsidy on the product has an effect opposite to deadweight loss. Therefore, a subsidy has a better effect on the supply chain in line with sustainability goals because it increases the profit of the supply chain members and also increases the social welfare of the customers and leads to a greater green degree of the green product. The results obtained in this section are consistent with the results in economic books, such as Lovell (2004) and Mankiw (2007).

The effects of different amounts of government taxes (subsidies) on the supply chain members is shown in Figure. 5.

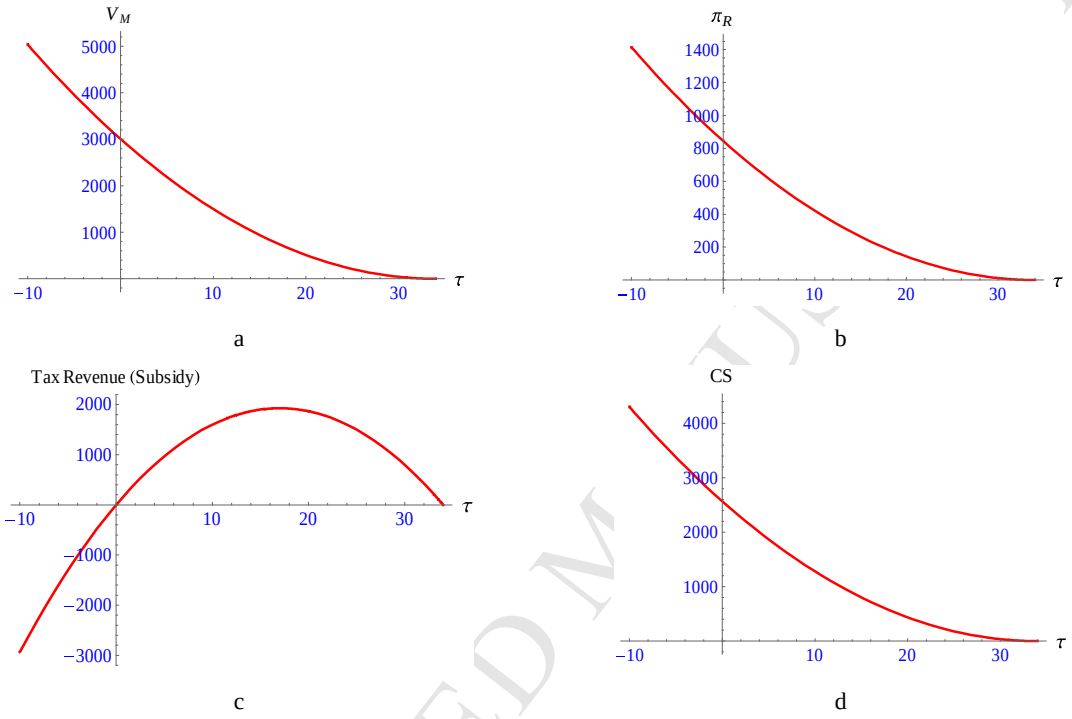


Figure. 5. Effect of government taxes (subsidies) on the supply chain member's profit

As shown in Figure. 5, the amount of the manufacturer's and retailer's profits and consumer surplus will decrease as the tax ($\tau > 0$) rises, and increase as the subsidy ($\tau < 0$) rises. Government tax revenue will increase as a result of raising the tax, but will decrease after a specified amount of tax because raising the tax rate means the retail price will increase. After a specified amount of tax, demand for the product will decrease, so government tax revenue will decrease. The results obtained in this section are consistent with the results in economic books, such as Lovell (2004) and Mankiw (2007).

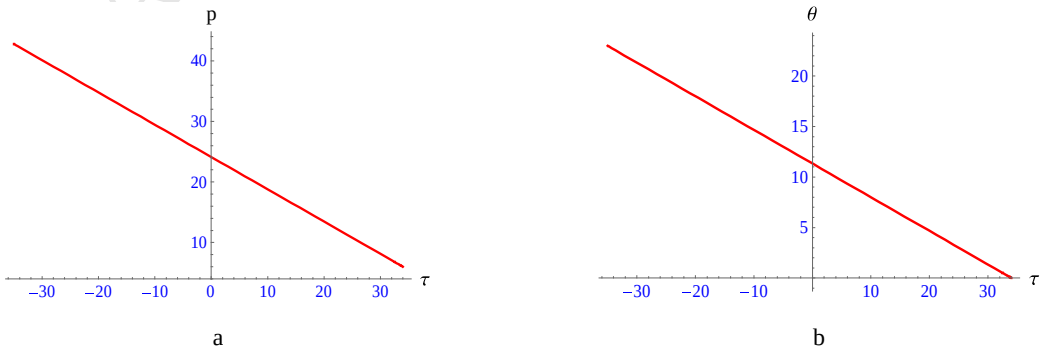


Figure 6.Effect of government taxes (subsidies) on the retail price and the green degree of the product

The effect of a government tax (subsidy) on the price that the retailer receives and the green degree of the product is shown in Figure 6. As is clear from Figure 6, the green degree of the product and the price that the retailer receives have a linear relationship with the tax (subsidy); the green degree of the product and the price that retailer receives will decrease as the tax ($\tau > 0$) rises, and increase as the subsidy ($\tau < 0$) rises.

Imposing a tax on a green product may seem unusual, but it can occur based on government policies. It may happen that the green degree of a manufacturer's product is lower than a specific amount, and other manufacturers produce greener products, so the government will impose a tax on the product to improve environmental conditions. The government may only have revenue-seeking policies, so the government will impose a tax on the product. In the above example, the government levies (pays) a tax (subsidy) on the final price of the product without any specific profit function or any specific policies, such as an environmental protection policy, a revenue-seeking policy, an increase in social welfare, or a combination of these policies. In the next section, different government policies, different profit functions considered for the government, and the effects of different government policies on the supply chain members are investigated.

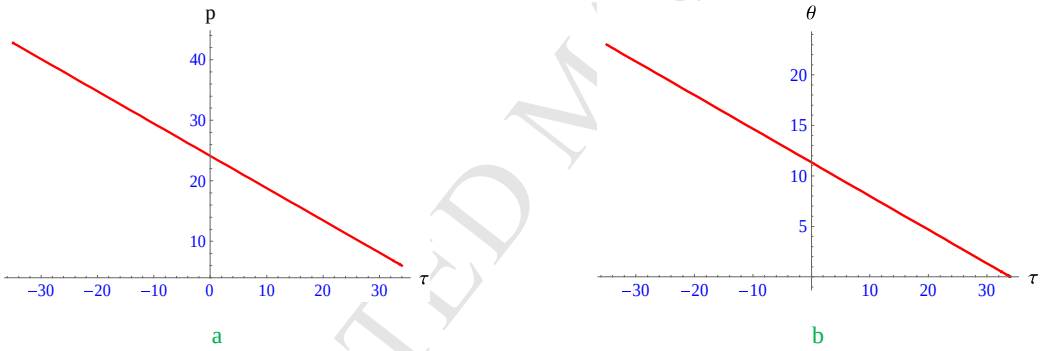


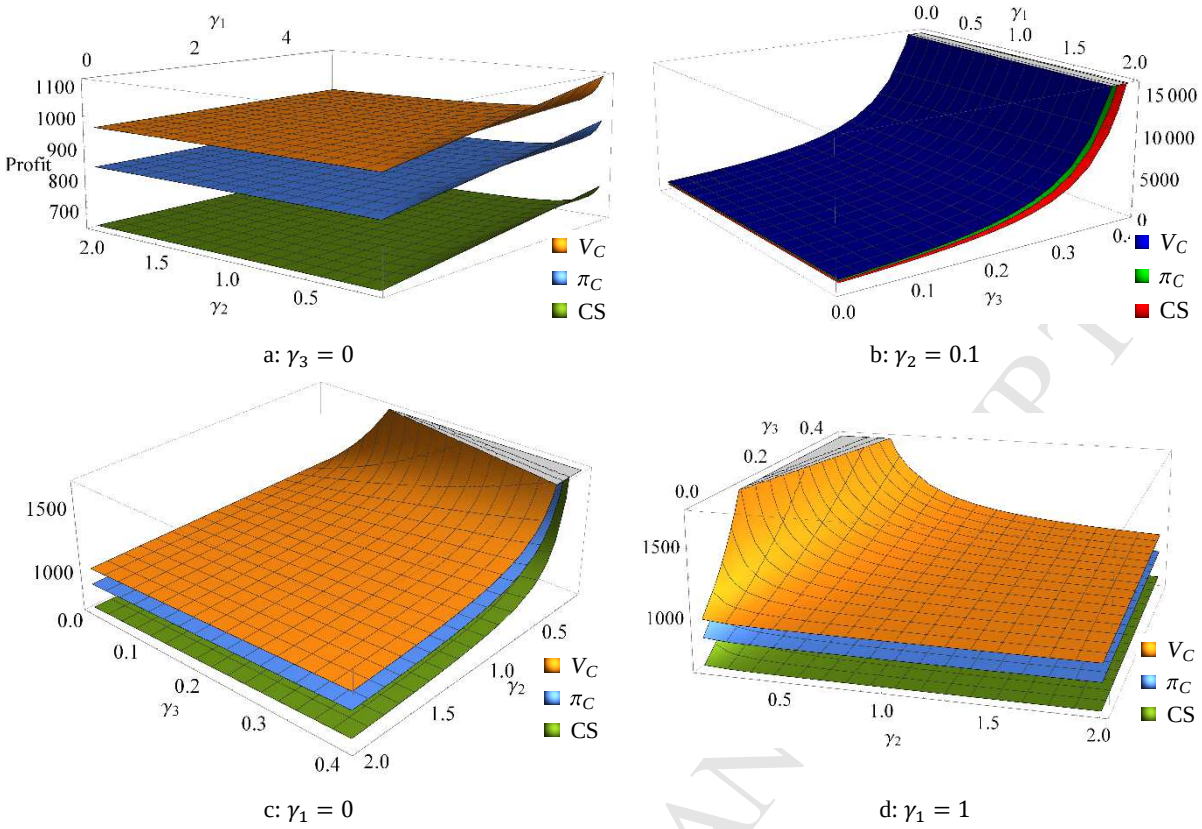
Figure 7.Effect of government taxes (subsidies) on the retail price and the green degree of the product

The effect of a government tax (subsidy) on the price that the retailer receives and the green degree of the product is shown in Figure 6. As is clear from Figure 6, the green degree of the product and the price that the retailer receives have a linear relationship with the tax (subsidy); the green degree of the product and the price that retailer receives will decrease as the tax ($\tau > 0$) rises, and increase as the subsidy ($\tau < 0$) rises.

5.2 Effect of different government policies on the supply chain

In this section, different profit functions is considered into account for different government policies and the effect of these policies on the social (consumer surplus), environmental (green degree of the product) and economic (supply chain member's profit) aspects of the supply chain is presented.

To investigate the simultaneous effects of different government policies on the supply chain, one of the coefficients of the government's goals in the government utility function is considered fixed, and the two other coefficients are changed.



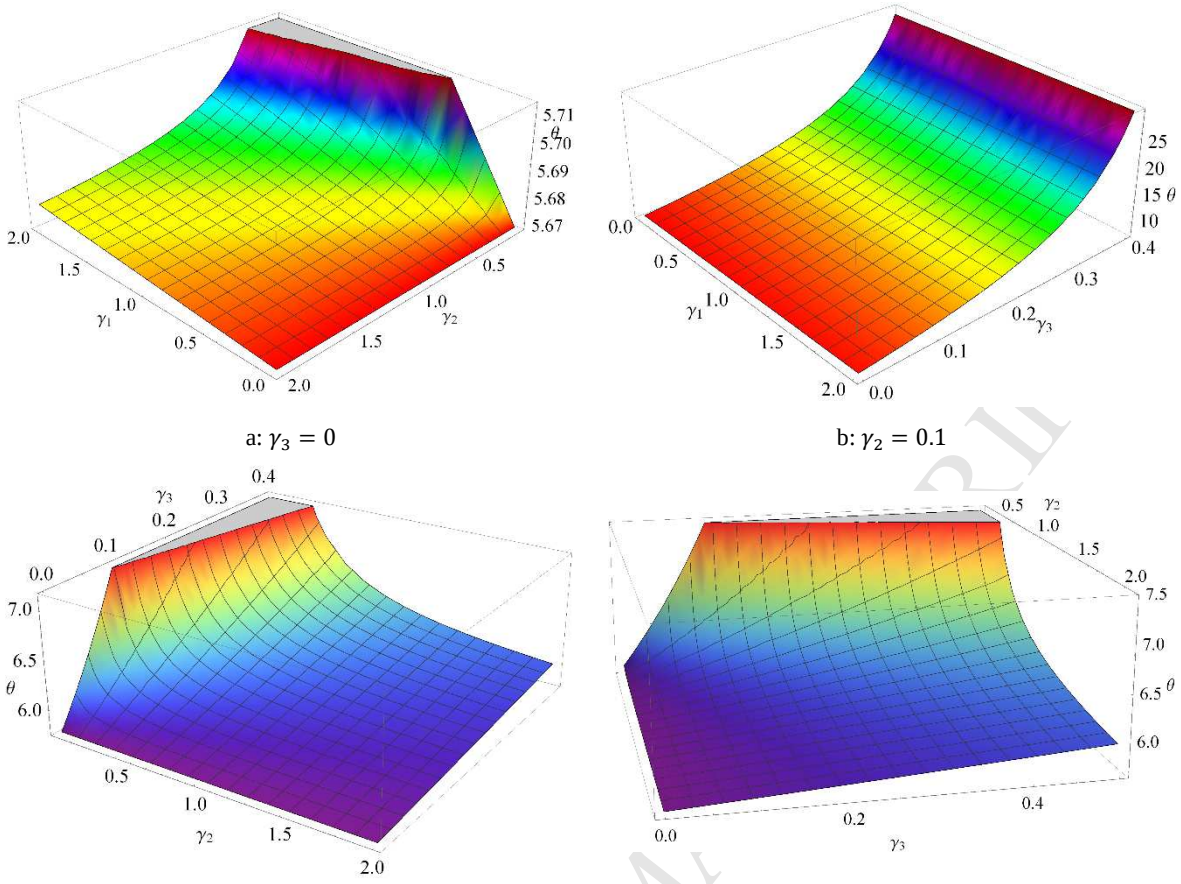
a: $\gamma_3 = 0$ b: $\gamma_2 = 0.1$

c: $\gamma_1 = 0$ d: $\gamma_1 = 1$

Figure 8. Effects of different government policies on the supply chain member's profit

It is very obvious that the profit function of the government has a linear relationship with each government goal coefficient. As these coefficients increase, the government profit function will increase, and as they decrease, the government profit function will decrease. So in the figures, only the profit of other supply chain members are depicted to avoid crowded figures.

As shown in Figure 8.a, if earned revenue has little value for the government (in this example $\gamma_2 < 0.5$), increasing the environmental dimension coefficient (γ_1) increases the profit of all supply chain members. But if earned revenue has great value for the government (in this example $\gamma_2 > 0.5$), increasing the environmental dimension coefficient (γ_1) does not significantly increase the profit of other supply chain members. In the comparison between the effect of the coefficients of the economic dimension and social dimension of the government utility function (Figure 8.b), we realize that increasing the social dimension coefficient of the government utility function has a very significant effect on the profit of supply chain members, while increasing the environmental dimension coefficient of the government utility function has a negligible impact on the profit of supply chain members. In the comparison between the effect of the coefficients of the economic dimension and social dimension on the government utility function (Figure 8.c and Figure 8.d), we realize that for small values of γ_2, the effect of increasing the social dimension coefficient of the government utility function on supply chain member profit is significant, and this effect gradually decreases with increasing values of γ_2.

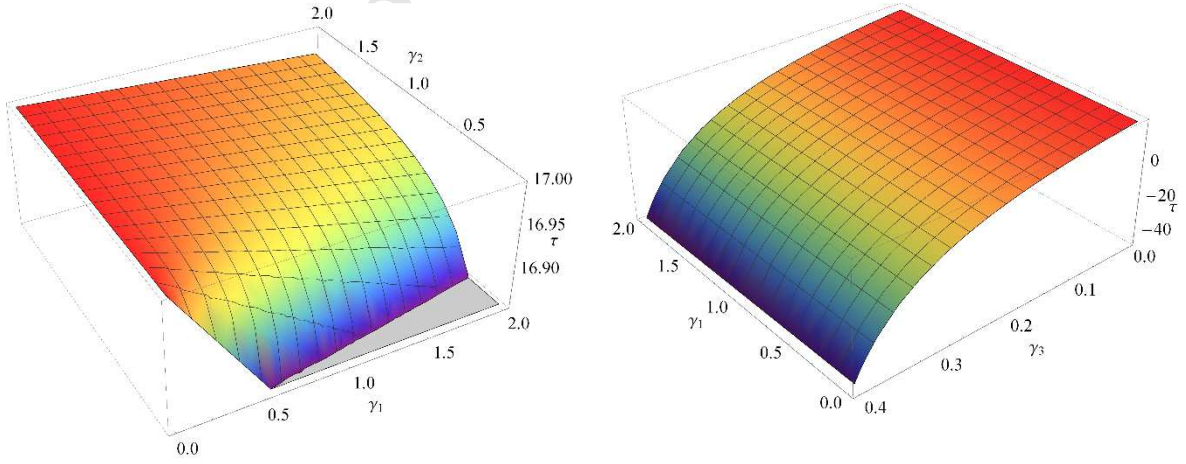


a: $\gamma_3 = 0$ b: $\gamma_2 = 0.1$

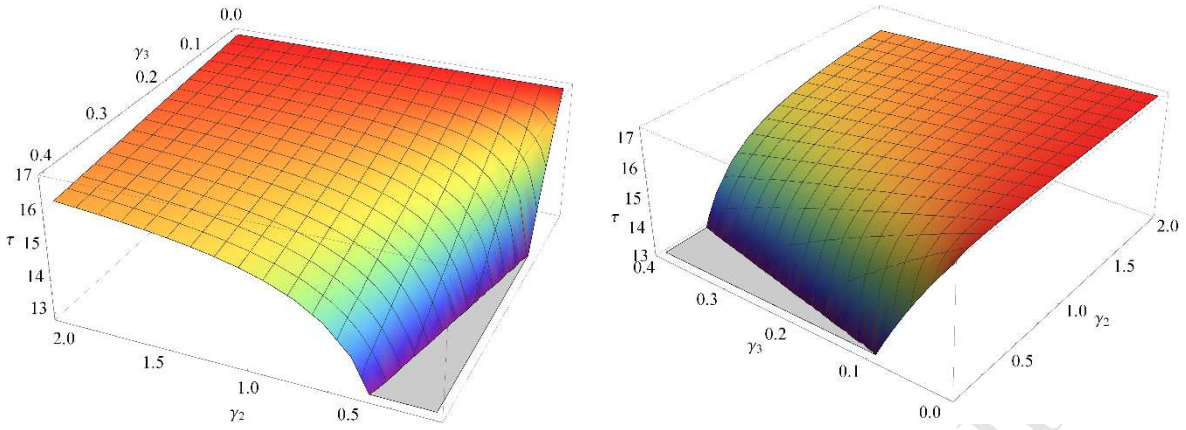
c: $\gamma_1 = 0$ c: $\gamma_1 = 1$

Figure 9. Effects of different government policies on the green degree of the product

Figure 9 shows that by increasing γ_2 the green degree of the product decreases and by increasing γ_1 or γ_3 the green degree of the product increases. We also realize from Figure 9 that increasing γ_3 has a much bigger effect on the green degree of the product than increasing γ_1. So improving social welfare also improves environmental conditions.



a: $\gamma_3 = 0$ b: $\gamma_2 = 0.1$



c: $\gamma_1 = 0$ c: $\gamma_1 = 1$

Figure 10. Effects of different government policies on the amount of government tax (subsidy)

Figure 10 shows that by increasing γ_2 the government tax (subsidy) will increase (decrease) and by increasing γ_1 or γ_3 the government tax (subsidy) will decrease (increase). We also realize from Figure 10 that increasing γ_3 has a much bigger effect on the government tax (subsidy) than increasing γ_1. Based on Figure 10.b, if improving social welfare has a high value for the government and earning revenue has a low value, the government will pay a high subsidy on the product.

5.3 Effects of the model parameters on the supply chain

The effect of the model's parameters on all supply chain members in the centralized model is depicted in Figure 11 and Figure 12. In the decentralized model, changing the parameters has the same effects on the supply chain members.

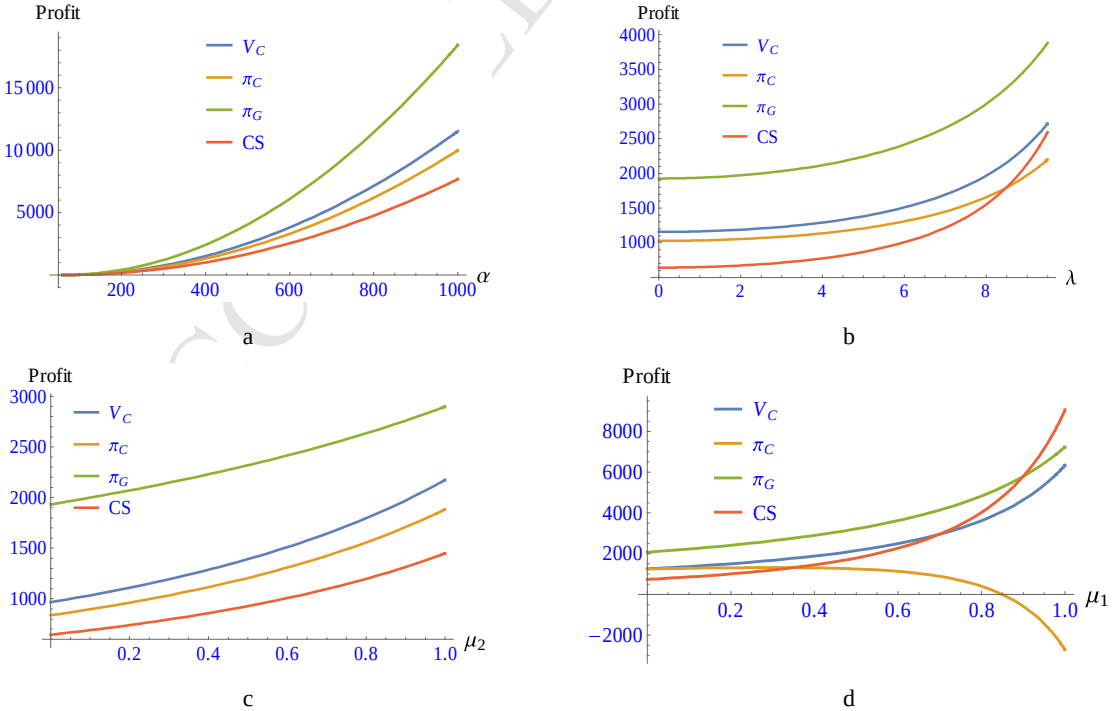


Figure 11. Effects of some model parameters on the supply chain

Figure 11 shows that by increasing α, λ, μ_1, and μ_2 the total profit (utility) of all the supply chain members will increase, and by increasing μ_1 the pure profit of the centralized supply chain will decrease, because increasing μ_1 leads the centralized supply chain to decrease the retail price, so the pure profit of the centralized supply chain will decrease. The results in this section are consistent with the results of some previous studies, such as the Panda (2014) and Panda et al. (2015).

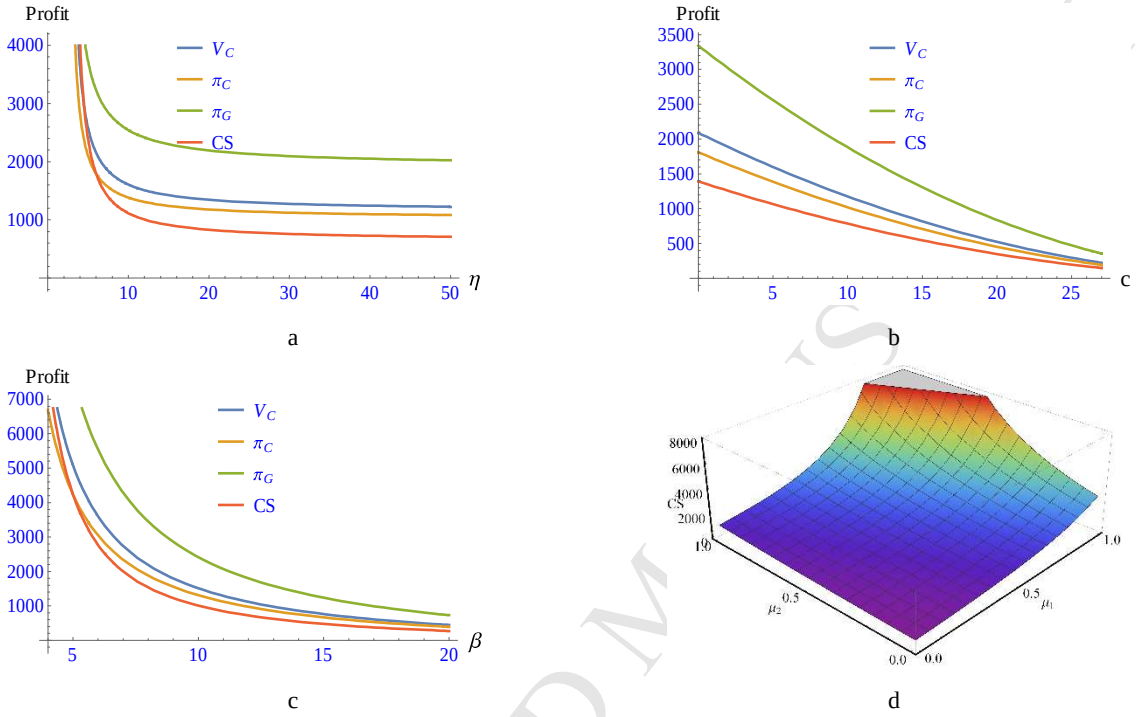
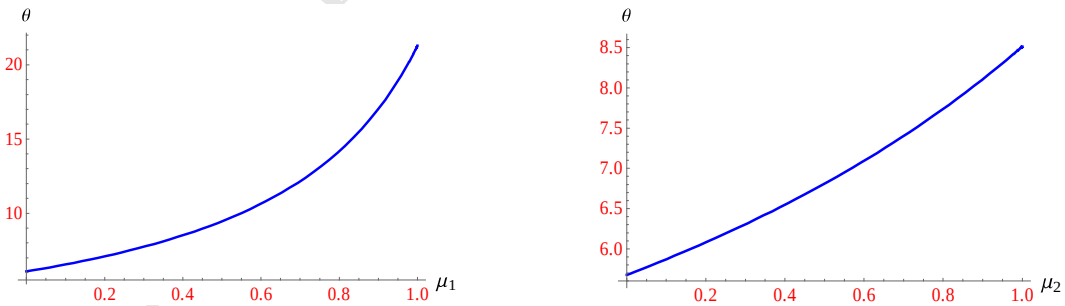
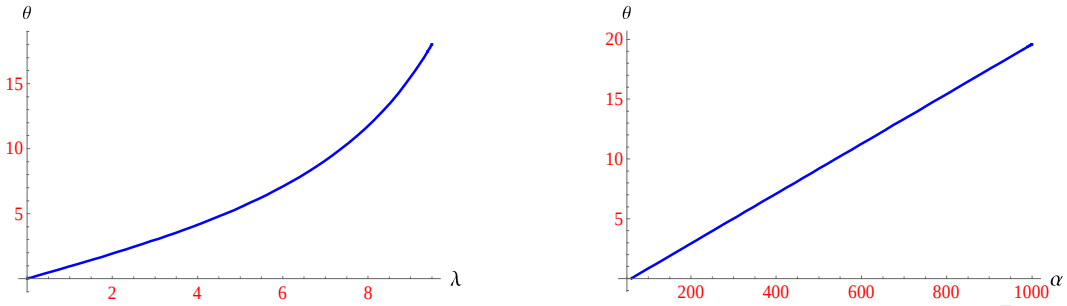


Figure 12. Effects of other parameters of the model on the supply chain

Figure 12 shows that by increasing η, c, β total profit (utility) of all the supply chain members will decrease. Also Figure 12.d shows by simultaneously increasing μ_1 and μ_2 consumer surplus will increase.

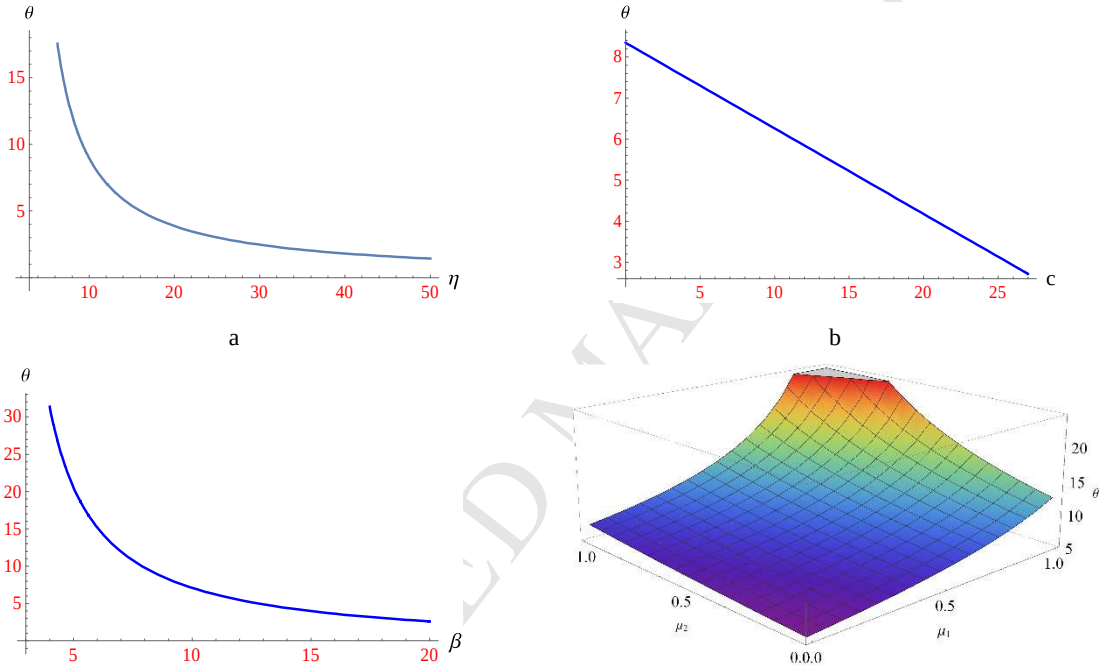




c d

Figure 13. Some parameters of the model that have a positive impact on the green degree of the product

Figure 13 shows that by increasing α, λ, μ_1, and μ_2 the green degree of the product will increase, and by decreasing them the green degree of the product will decrease.



a b

c d

Figure 14. Some parameter of the model that have a negative impact on the green degree of the product

Figure 14 shows that by increasing η, c, β the green degree of the product will decrease and by simultaneously increasing μ_1 and μ_2 the green degree of the product will increase.

6 Conclusions and suggestions for further research

This paper studied the pricing policies in a supply chain, factoring three dimensions of sustainability into the model formulation. We considered a supply chain that consists of one manufacturer and one retailer, and government at a higher level. The manufacturer produces a green product and supplies it to the final customers through the retailer. The government has a role as a leader for the supply chain, and in line with sustainability dimensions, acts to consider different aspects of sustainability in its utility function. In this paper, sustainability refers to the integration of

greening products (environment), consumer surplus (society) and supply chain members profits (economy). This paper leads to several interesting observations.

Observation 1. There are optimal green degrees of the green product and wholesale prices for the manufacturer in centralized and decentralized supply chains with and without government intervention. There are also optimal retail prices for the retailer in a decentralized supply chain with and without government intervention. In models with government intervention, there are also optimal government taxes (subsidies). Therefore, by deriving the optimal green degrees, wholesale prices, retail prices and optimal taxes (subsidies) in different supply chain settings, the manufacturer, retailer and government can develop appropriate pricing and policies based on our findings to maximize their benefits or to improve sustainability aspects in the supply chain.

Observation 2. Analytical analysis shows cooperation and coordination between the manufacturer and retailer in the supply chain will increase the green degree of the product. As a result, always collaboration between the manufacturer and retailer make a cleaner environment.

Observation 3. Analytical analysis also shows retail price in the centralized model or in the decentralized model with two-part tariff contract always is not lower than the price of the product in the decentralized model without two-part tariff contract which this result contrasts with the result of 'double marginalization'.

Observation 4. For the models with and without government intervention, cooperation between the manufacturer and retailer always lead to produce a greener product, increase the profit of the entire supply chain and increase consumer surplus of customers. Also in models with government intervention, the government imposes (pays) a lower (greater) tax (subsidy) on the final price of the product. Therefore, coordinating the decentralized supply chain is necessary for all members of the supply chain.

Observation 5. When the manufacturer incorporates a fraction of consumer surplus in its profit function, this causes the manufacturer to lower its wholesale price and as a result, the retailer benefits more than customers. So the manufacturer can set a two-part tariff contract with the retailer to ensure that gains from considering consumer surplus in its profit function are really given to the customers. The results show that incorporating a high fraction of consumer surplus in the manufacturer's profit function will increase the utility function of the manufacturer and may lead to a negative value for the manufacturer's pure profit function.

Observation 6. If the government imposes a tax on the price of the product, this causes customer demand for the product to decrease and also leads to a decrease in the supply chain members' profit. Another impact of levying a tax on the product is a deadweight loss. When the government levies a tax τ on the product, the government can earn $\tau \times D$ revenue, and the profit of other supply chain members decreases. The decrease of profit for other supply chain members is greater than the government revenue, and this difference between the two values is a deadweight loss. But if the

government, instead of levying a tax on the price of the product, provides a subsidy on the price of the product, supply chain members earn more than the paid government subsidy, and an effect opposite to a deadweight loss will occur.

Observation 7. Our findings also show that different government policies have significant impacts on the profit of the supply chain members and significant impacts on the environment and government-imposed (paid) taxes (subsidies). If the government has only a revenue-seeking policy, it will levy a tax on the price of the product, and the profit of other supply chain members and the green degree of the product will decrease. But if the environment or the social welfare have high value for the government, the government will provide a subsidy on the price of the product, and the profit of the supply chain members and the green degree of the product will increase.

Observation 8. Results show that incorporating a fraction of consumer surplus in the government utility function has a greater effect on the supply chain members' profit and on the green degree of the product than considering environmental concerns in the government utility function. This means that improving social welfare includes improving the environment. If social welfare has high value for the government, it will provide a high subsidy on the price of the product, so the manufacturer will set a high green degree for the product, and consumer surplus and producer surplus will also increase. So incorporating consumer surplus in the government utility function has double the effect on the sustainability of the supply chain as considering environmental concern in the government utility function.

The present paper is based on some assumptions that these assumptions simplifies the modeling. Our model considers a supply chain that consists of only one manufacturer and one retailer. However, in the real world there are numerous manufacturers and retailers, so one key research direction is to consider a supply chain that consists of multiple manufacturers and multiple retailers. Another important extension of this work would be considering goals of sustainability other than the green degree of the product or consumer surplus in the model. Furthermore, suppliers play an important role in the sustainable supply chain, so an interesting contribution would be developing a model that considers suppliers. In this paper we suppose the manufacturer incorporates consumer surplus in its profit function, another key research direction is to consider the retailer, or both retailer and manufacturer, act in line with their sustainability goals to incorporate the consumer surplus into their profit functions simultaneously. Demand functions in the present paper were assumed as the linear functions so consider demand functions as probability functions or uncertain functions is an interesting contribution to this paper.

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Article title:

A Game Theoretic Approach for Pricing, Greening, and Social Welfare Policies in a Supply Chain with Government Intervention

Highlights

- Simultaneously modeling three major dimensions of sustainability in a supply chain.
- Pricing, greening, and social welfare with and without government intervention.
- Modeling consumer surplus based on two variables
- Analyzing the effects of different government policies on profits and environment.
- Developing a contract to coordinate the decentralized supply chain.