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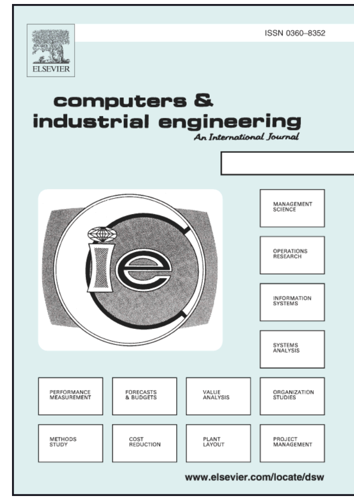

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Sustainable supply chain management with pricing, greening and governmental tariffs determining strategies: A game-theoretic approach

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Abstract

Despite the considerable influence of the governmental regulations on the green supply chain, in the most of the studies in the literature of green supply chain, almost the role of the government and interactions between the government and supply chains members' decisions are disregarded. In this study, a competitive mathematical model of government as the leader and two competitive green and non-green supply chains as the followers is developed and for the first time in this paper, pricing policies, greening strategies and governance tariffs determining in supply chains competition under government financial intervals are discussed. In the presented framework, the government seeks social benefits and determines subsidy and tax rates for green and non-green products respectively. The sale prices of products and the green degree of the green product are supply chains' decision variables. In centralized and decentralized models, the optimal values of decision variables are gained and some important sensitivity analyses of governance decisions are done. In the governmental decisions area, it is observed that the impact of raising subsidy rate is significantly more than tax rate and it leads to increase in profits of government and supply chains and sustainability of products. Also among the competition of supply chains, cooperating between members makes more profit for them and leads to produce more eco-friendly products.

Keywords**:** Pricing, Green supply chain management, Competitive supply chains, Sustainable governance policies, Subsidy and tax rate, Game theory.

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1 Introduction

Due to rapid depletion of natural resources and exacerbation of environmental pollution, especially greenhouse gases, environmental issues have attracted more and more attention from regions, countries and governments around the world (Gibbs & Deutz, 2005). According to this worry, shifting to a sustainable world through producing green products has become a popular trend in academic and practical research. Many studies have provided various approaches for sustainable environmental development (Jafari et al., In press). Navinchandra (1990) proposed the idea of green product design, whose aim was to increase product compatibility with the environment without compromising function or quality. Porter and Linde (1995) and Pujari (2006) then suggested that innovations with green products not only can improve greening and sustainability but also increase manufacturers' competitive advantage. As well, green supply chain (GSC) management can improve the environmental and economic performance of organizations, which can motivate organizations to continue greening (Jr et al., 2013; Q. Zhu et al., 2007).

Governments which have the most important and powerful roles in markets, can influence strategies and situations so that they lead to reduce pollution and increase sustainability in products. Growing awareness of the adverse effect of pollution on the environment has led governments and NGOs to put pressure on core producers in supply chains (SC) to develop and introduce sustainable products (Seuring, 2013; Seuring & Müller, 2008).

Unless policy makers introduce eco-friendly regulations, producers are more likely to choose the latter method (old-fashioned production methods and higher profit margins) in most cases. As a consequence, regulations mandating energy savings and low carbon production are being implemented by policy makers in many countries (Calantone, 1992; Hitchens, 1999; Steele, 1974).

Some European, North American and the Japanese governments use legislation and financial instructions to increase knowledge among people and producers of environmental pollution damage (Robeson, 1994; Sheu & Chen, 2012). Generally, there are two most important and appropriate clusters of governmental long-term risk-based approaches to tackle the pollution problem which are utilized by governments world widely, cap-and-trade and pollution taxation mechanisms; cap-and-trade strategy is a direct approach to reduce total amount of carbon emission, according to this mechanism, government gives the emission credits for each firm (named "cap") which could be traded between firms. Each firm couldn't impose pollution more than their credit. In the other hand, by the pollution taxation which is an indirect strategy, government charges firms for producing each unit of product that imposes pollution on environment more than a standard level (Pizer, 2002). For such products, government imposes a rate of tax (and in some cases to give support to green producers pays a rate of subsidy) which increase (decreases) the price of the non-green (green) product to discourage (encourage) consumers to purchase that product (Luke, 2005). Many countries all over the world are using one of these strategies for example Europe has applied cap-and-trade strategy by establishing European Union Emissions Trading Scheme (EU ETS) (Hintermann, 2010). Australia is an example for deploying pollution taxation strategy; as well British Columbia could reduce carbon emission by 9.9% with imposing pollution taxation approach in 2008 (Brown et al., 2012).

Xiaoyan Xu et al. (2016) investigated these two strategies and discovered that the social welfare under carbon tax regulation is not less than that under cap-and-trade regulation, so in this paper second strategy has been investigated and the effects of such regulations on the decisions which are made by different firms and interactions between government and SCs are studied.

In order to generalize the investigation, the coexistence of two competitive green and non-green supply chains (NGSC) is assumed. Also cooperation between SC's members can influence whole SC and government decisions, thus the impact of the structures of SCs is analyzed in this study.

This study wants to answer the following questions:

- How do the structures of SCs affect profits of producers, retailers and governments and the green degree of green products?
- What governance tariff boundaries guarantee minimum profits for all members in SCs?
- How can sustainable SCs be effectively governed in order to increase sustainability and public gains?
- Which strategies lead to more profit for governments and which lead to less environmental damage?
- How does producing greener products affect the final price of green and non-green products?

In this paper, the main aim is to establish a framework to control the relationship between government and SCs in a way that more sustainable products would be produced and all SCs' members gain a minimum level of profit. In the SCs' point of view, the optimal actions that lead to more profit will be determined which include making decisions about product prices, the green degree of green product and integration and cooperation or dependent working, in the other hand in the government's point of view, social affairs are more preferable than monetary issues.

Government not only tries to encourage firms to produce greener products, but also is about to guaranties the minimum level of profit for all members or in other word, make a competitive market. Investigating the government's role in green degree of green product in a competitive market has not been done, so discussing government strategies and their effects of various variables in market would be worthwhile.

The remainder of this paper is organized as follows: Previous studies and the literature are briefly reviewed in Section 2. Profit functions for SCs are modeled in section 3 and optimal decisions for each player are obtained and some parametric analyses are done. In Section 4, the role of government is discussed and profit functions, boundaries of decision variables and optimal decisions are presented. Some analytical results and managerial insights are discussed in Section 5 and finally concluding remarks and some directions for future research are provided in Section 6.

2 Literature review

The literature related to this study can be divided into two sections: competition among SCs and the relation between government and SCs. As GSC management has a wide literature, a brief literature is provided in follows.

2.1 Competition among SCs

In competition among SCs it could be observed that the competition level in markets is shifting from the competition between firms to competition among SCs (Nagurney & Yu, 2012). Studies of GSC management mainly focus on two aspects of greening: product recycling and reverse logistics in one hand and making green products with low amount of emission in the other hand, Chen and Sheu (2009) studied ways to improve recyclability of products by using a game model framework for a system which includes two competitive manufacturer, then Sheu (2011) investigated greening reverse logistics by using the Nash bargaining game to model competition of reverse-logistics suppliers and producers to maximize members' profits and social gains. Sheu and Chen (2012) found that in a GSC which includes supplier, manufacturer and retailer, opting low-wholesale-price strategy could be suggested to recycled-component suppliers under green subsidization to encourage manufacturers' intention of green product production under green taxation. Also as SCs' structures have an important effect on financial and environmental aspects of GSC management, many studies have studies coordination and structures among SCs' members. Barari et al. (2012)

investigated the Coordination between a producer that produces green products and a retailer that sells them and showed that this coordination led to more profit for them and more social and environmental gains, then Ghosh and Shah (2012) extended it by investigating different structures of a GSC that contains a manufacturer and a retailer. The manufacturer determines the green degree of green products and the retailer is responsible for sales. They also showed that coordination led to more innovations in greening. Zhang and Liu (2013) studied a three-level GSC consisting of a supplier, a manufacturer and a retailer with fixed value for green degree that market demand correlates with product green degree and found that cooperation leads to more profit for members. Zhang et al. (2014) considered a GSC in which the manufacturer produces green and non-green products simultaneously and a retailer sells them, they concluded that manufacturing costs influence whole-system performance and production modes and system performance in cooperative game is apparently better than that in non-cooperative game. Li et al. (2015) extended cooperation in dual-channel GSC and discussed pricing and greening strategies in a dual-channel GSC in centralized model (CM) and decentralized model (DM) which green degree of green product was a decision variable of manufacturer. Xie (2016) studied cooperative strategies for sustainability in a decentralized SC with competing suppliers and found that cooperation leads to more profit, more sustainability and more customer surplus. W. Zhu and He (2016) studied the impact of supply chain centralized/decentralized, structures, the green development-intensive/marginal-cost intensive product types, and the competition/greenness competition on supply chains' decision variables.

2.2 Relation between government and SCs

As it discussed in introduction, governmental legislations for environmental issues has attracted considerable attention of governments and researchers; so many agreements between governments on environmental legislations and responsibilities are gained, a list of environmental agreements are available in (https://en.wikipedia.org/wiki/List_of_international_environmental_agreements). Also many researchers recently have focused on optimal governmental decisions related to GSC management. In order to encourage green product manufacturers and fine non-green producers, governments use incentive and deterrent policies (Sheu, 2011; Sheu & Chen, 2012). By considering different combinations of two main important governmental legislative strategies, various structures of SCs and competition or cooperation strategies among SCs' members, many studies are done in recent years, a brief literature review related to the relation between government and GSCs are provided in follows. Q.-h. ZHU and DOU (2007) investigated the games between governments and core enterprises in GSC management; they found that subsidies and penalties from governments directly affect the game results, as well to gain long-term benefits, governments should enact and enforce increasingly strict environmental regulations, and increase relevant subsidies and penalties. Mitra and Webster (2008) considered recycling aspect in greening and studied governmental subsidies effect on promoting recycling and remanufacturing and concluded that imposing subsidies increase remanufacturers activities. Under cap-and-trade strategy Du et al. (2011) presented a newsvendor-based game model for analyzing the impact of emission cap-and-trade mechanisms on emission-dependent SCs under legislation imposed by governments. They studied the behavior and decision-making of each member in the emission-dependent supply chain and found that policy maker in cap-and-trade strategy can influence most of SC's variables such as bargaining power, profits and etc. Tsireme et al. (2012) explored the reasons that affect the decisions of managers of firms under the context of environmental policy to adopt management practices. They investigated the effects of governmental policies on GSC performance and their enthusiasm about making greener products. Jin and Mei (2012) focused on suppliers' role and studied strategies utilized by government and suppliers in a GSC using a game-theoretical model and found optimal strategies for government and suppliers which guarantee suppliers' profits beside social concerns. Sheu and Chen (2012) considered the co-existence of multi GSCs in market and discussed the impact of governmental policies on competition among GSCs; their study revealed that government participation in the game leads to more profit for integrated SCs. Zhao et al. (2012) investigated strategies used by manufacturer in GSC to decrease life-cycle environmental risks of materials and carbon emissions under governmental penalties or incentives and their results showed that imposing governmental penalties or incentives significantly influence manufacturers' strategies. Hafezalkotob (2015) proposed a game-theoretical model for governmental financial interventions in competition between green and non-green two-level SCs and solved numerical models for different situations created by government, then Hafezalkotob et al. (2015) investigated how the budgetary constraints of the government affect the efficiency of its decisions to reduce the pollution of the products in the presented model. Y. Xiao et al. (2016) considered a two-echelon sustainable supply chain with price-sensitive demand that impose emission on environment and government by carbon taxation wants to reduce the emission amount. They investigated the coordination between the supplier and retailer and proposed a tax sharing contract between them. Xiaoping Xu et al. (2016) studied a GSC which includes a manufacturer and a retailer to investigate production, coordination mechanism and emission abatement strategies in a Make-To-Order system and under cap-and-trade regulation. Xiaoyan Xu et al. (2016) investigated production and pricing problem of a manufacturing firm with multiple products. They compared results of cap-and-trade and green taxation strategies in environmental, monetary and social welfare aspects. Hafezalkotob (2017) studied the competition and cooperation of two manufacturers that one pursues an in-house production strategy, and the other outsources production to a foreign supplier and investigated the leadership role of government in the such situation and they found that specific boundaries for tariffs determined by the government lead to more sustainability and a competitive market. Ji et al. (2017) considered an online channel (dual-channel) beside the retail channel and developed the proposed framework in (Li et al., 2015) by selecting cap-and-trade strategy for governmental legislation.

However, to the best of the authors' knowledge, none of the above research considered governmental financial interventions beside the green degree of green product and analyzing governmental legislations effect on green degree of green product hasn't investigated yet. Thus, the most important contribution of this paper is its investigation of the impact of government policies on the green degree and sustainability of green products. This paper also discusses the profits and prices changes according to governmental tariffs' changes and finally effects of the structures of SCs in profits and greening is the other research aspect in this paper.

3 Competition among SCs

As shown in Figure 1, a competition between a GSC and a NGSC is considered that each consists of a producer and a retailer in a competitive market in which the GSC distributes green products and the NGSC distributes non-green products. Customers select each SC's products according to their loyalty and interest. Government, because of its greater power in the market, plays the leader's role and SC's members play follower's roles. Governmental tariffs are fixed parameters for SC's members and optimal decisions for SC's members are the functions of governmental tariffs, which will be discussed in more detail in the next section.

Figure 1 Two competitive SCs

3.1 Problem description and modeling

To establish the profit function of each player in SCs, each part of them are described in the following subsections:

Demand function: The demand for a product is the amount of that product consumers are willing or able to buy at a certain price; the relationship between price and quantity demanded is known as the demand function; the demand quantity could be affected by some factors such as: good's own price; price of related goods; personal disposable income; tastes or preferences; consumer expectations about future prices, income and availability; population; nature of the good and etc.

There are two most applicable scenarios for modelling the relationship between demand and price to calculate the revenue of each players:

- Direct demand function: The demand function is the mathematical expression of the relationship between the quantity of a product demanded and those factors that affect the willingness and ability of a people to buy the good that could be expressed as: $d = f(p)$, where d represents the demand and p is the price of that products.(for example these studies has utilized this method: X. Chen & Wang, 2015; Guan et al., 2015; Khan et al., 2016; Mohammadzadeh & Zegordi, 2016; Y. Xie et al., 2016; Yi et al., 2016; Zhou et al., 2017)
- Inverse demand function: The inverse demand function, or the price function, treats price as a function of quantity demanded: $p = f(d)$,. To compute the inverse demand function, simply solve for p from the demand function d (for example these studies has utilized this method: (Abada, Briat, et al., 2013; Abada, Gabriel, et al., 2013; Berry et al., 2013; Madaeni & Sioshansi, 2013; Mrázová & Neary, 2014; Papavasiliou & Oren, 2014)).

The inverse demand function was originally designed when economies were based primarily on agriculture. Farmers grew as much crop as possible, and the market price was determined by how much crop was produced. This is why quantity is the independent variable on the inverse demand function. Today, production is driven more by price. Businesses get an idea of the price of their product and this sets their production goals. For businesses, it may make more sense to use the direct demand curve, as this is a more realistic relationship for today.

As many researches today are based on direct demand function, this study has utilized the direct demand function, but investigating the result of employing the inverse demand function and replacing profit functions of players and solving the equations in a similar way will be interesting and comparing the result will be worthwhile.

Demand faced by each SC is a linear function of final prices of green and non-green products, governmental tariffs, the green degree of green products and the degree of customer’s loyalty to

GSCs. To formulate demand functions, the assumptions used in (Ghosh & Shah, 2012; Tsay & Agrawal, 2000; T. Xiao & Yang, 2008) are considered and the demand functions in each SC are as follows:

$$D_g = \rho\alpha - b_1(P_g - t_s\theta) + b_2(P_n + t_t) + \beta\theta \tag{1}$$

$$D_n = (1-\rho)\alpha - b_1(P_n + t_t) + b_2(P_g - t_s\theta) \tag{2}$$

In equations (1) and (2) D_g and D_n are the demands of GSC and NGSC, respectively; α is the market-based demand and ρ indicates the degree of customer's loyalty to GSC ($0 \leq \rho \leq 1$).

P_g and P_n denote net prices of green and non-green products, respectively; θ represents the green degree of green product, b_1 is the marginal SC demand per respective SC's final price, and b_2 is the cross price sensitivity and $b_1 \geq b_2$ indicates that the impact of SC's self-price is greater than the other price.

t_s is the subsidy rate for the green degree for a unit of green product, and t_t is the tax rate for non-green products. β is the expansion effectiveness coefficient of the green degree per unit of green product for GSC demand.

If the green degree would be considered to be as a parameter, it could be merged with α and the resulted demand functions would be equal to the suggested functions in (Hafezalkotob, 2015). Also if the governance rates would be equal to zero or in other word, if the role of government would be disregarded, the consequent model would be as same as the presented model in (Ghosh & Shah, 2012).

Cost of greening: In order to produce green products, only the green product manufacturer has to invest some extra money to attain new green innovations based on the original production process, and producing green products does not affect the manufacturer's traditional marginal costs (Ghosh & Shah, 2012; Swami & Shah, 2012). Thus, the cost of greening is assumed to be a quadratic function of green degree:

$$C(\theta) = \eta\theta^2 \quad (3)$$

In equation (3) η is the cost coefficient of the green degree per green product unit.

Governance financial interference: As mentioned before, governments are responsible for propelling SCs to produce green and sustainable products. They usually support GSCs by providing subsidies and reducing the final price for their products in order to encourage customers to prefer green goods. As well, governments penalize NGSCs by imposing taxes on non-green products to reduce incentives for customers to buy non-green products and compensate for environmental damage. The first effort to valuation of environmental damages with cost-benefit analysis was done in London third airport locating. In that analysis the noise pollution damages are financially valuated (Commission, 1971). Despite the various problems reported about this procedure, the cost-benefit analysis is one of the most important methods which is used to financially valuate environmental damages (Bonnieux & Rainelli, 1999). According to the definition which was presented in (Barbier et al., 1997), damage environmental resources or produce natural contamination is assumed as financial loss and improve the quality of them is assumed as making financial profit. Thus, to encourage green goods producers, the government pays $t_s\theta$ per green product unit as the subsidy rate and customers have to pay only $(P_g - t_s\theta)$ to purchase a green product. Also, in order to compensate for financial and social costs of non-green product production, the government adds a penalty rate of t_t to the non-green product as a tax, and customers have to pay $(P_n + t_t)$ to purchase this type of product. It should be noticed that the government's income from imposing taxes would be devoted to recompense non-green products damages to nature and the government seeks social welfare and customers' surplus.

Two assumptions that should be considered: first, demand in each SC should be non-negative; and second, each player should gain at least a predetermined minimum profit.

The profit function for each SC is summarized as follows:

$$\pi_{rg} = (P_g - W_g)D_g \quad (4)$$

$$\pi_{rn} = (P_n - W_n)D_n \quad (5)$$

$$\pi_{mg} = \left(W_g - c_g\right)D_g - \eta\theta^2 \tag{6}$$

$$\pi_{mn} = (W_n - c_n)D_n \tag{7}$$

Where in equations (4-7) π_{rg}, π_{rn}, π_{mg} and π_{mn} are the profit functions of the GSC retailer, NGSC retailer, GSC manufacturer and NGSC manufacturer, respectively. Here c_i is the per-unit manufacturing cost of traditional product *i*, and W_g is the per-unit wholesale price of product *i* decided by the manufacturer.

3.2 Solutions

In order to obtain the optimal decisions for players in the centralized and decentralized structures for SCs, the concavity of the profit functions should first be proven; the joint concavity of each profit function on decision variables is proven in the appendix. In practice, the government determines the subsidy and tax rate firstly, secondly according to their values, SCs' members make their decisions. In Stackelberg game, the follower makes his best response functions for his decision variables which are expressed with leader's decision variables. Then leader after replacing followers' decision variables by these response functions in his profit function, calculates optimum values for his decision variables. Here optimal decisions for players in the centralized and decentralized structures for SCs will be derived.

3.2.1 Centralized model

In the centralized model, manufacturer and retailer are vertically integrated; they are considered as a whole system and make their decisions cooperatively and simultaneously to maximize total profit of the SC. Thus, the total profits of GSC (π_g) and NGSC (π_n) are as in equations (8) and (9):

$$\pi_g = \pi_{mg} + \pi_{rg} = \left(P_g - c_g\right)D_g - \eta\theta^2 \tag{8}$$

$$\pi_n = \pi_{mn} + \pi_{rn} = (P_n - c_n)D_n \tag{9}$$

Theorem 1. *The optimal decision variables for the centralized model are:*

$$P_g = -\left(\begin{array}{c} c_g(b_1 t_s + \beta)\left(-2{b_1}^2 t_s + {b_2}^2 t_s - 2b_1\beta\right) + \\ 2\eta\left(b_1\left(2b_1 c_g + b_2(c_n + t_t)\right) + a(b_2 + 2b_1\rho - b_2\rho)\right)\end{array}\right)\Big/\varphi$$

$$P_n = \left(\begin{array}{c} (b_1{}^3 t_s{}^2 (c_n - t_t) + b_1 (b_2{}^2 t_s{}^2 t_t + (c_n - t_t)\beta^2 + b_2 c_g (t_s\beta - 2\eta)) + \\ b_2 (c_g \beta^2 + b_2 t_t (t_s\beta - 2\eta)) + 2b_1{}^2 (c_n - t_t)(t_s\beta - 2\eta) + a(\beta^2 - b_1{}^2 t_s{}^2 (-1+\rho) + \\ b_2 t_s \beta\rho - \beta^2\rho - 2b_2\eta\rho + b_1(-2t_s\beta(-1+\rho) + 4\eta(-1+\rho) + b_2 t_s{}^2 \rho))) \end{array} \right) \Big/ \varphi$$

$$\theta = \left(-(b_1 t_s + \beta)(-2b_1{}^2 c_g + b_2{}^2 c_g + b_1 b_2 (c_n + t_t) + a(b_2 + 2b_1\rho - b_2\rho))\right)/\varphi$$

in where

$$\varphi = (2b_1{}^3 t_s{}^2 + b_1(-b_2{}^2 t_s{}^2 + 2\beta^2) + \left(4b_1{}^2 - b_2{}^2\right)(t_s\beta - 2\eta)).$$

Proof: According to the joint concavity of each profit function in the centralized model (reported in appendix A), the optimal decision variables are derived by solving the equations $\partial\pi_g/\partial P_g = 0$, $\partial\pi_n/\partial P_n = 0$ and $\partial\pi_g/\partial\theta = 0$ simultaneously. □

3.2.2 Decentralized model

In the decentralized model, manufacturer and retailer make their own decisions independently to maximize their own profit. Thus in this model, Stackelberg game framework is used with the manufacturer as the leader and the retailer as the follower. First, the manufacturers determine the wholesale price and in GSC, the green degree also; then the retailers accordingly select the best price for products to maximize their own profit. So first we formulate the best response functions for retailers, which are expressed by wholesale prices and the green degree of green products.

Theorem 2. *The best response functions for net prices are:*

$$P_g = -b_2{}^2 t_s\theta + 2b_1{}^2(w_g + t_s\theta) + b_1(b_2(t_t + w_n) + 2\beta\theta) + a(b_2 + 2b_1\rho - b_2\rho)/4b_1{}^2 - b_2{}^2$$

$$P_n = -2b_1{}^2(t_t - w_n) + b_1 b_2(w_g - t_s\theta) + b_2(b_2 t_t + \beta\theta) + a(-2b_1(-1+\rho) + b_2\rho)/4b_1{}^2 - b_2{}^2$$

Proof: According to the joint concavity of each profit function in the decentralized model (reported in appendix A), the best response functions for net prices are derived by solving the equations

$\partial\pi_{rg}/\partial P_g = 0$ and $\partial\pi_{rn}/\partial P_n = 0$ simultaneously. □

Then, the optimal values of manufacturers' decision variables will be obtained by replacing net prices with these functions in manufacturers' profit functions and solving the equations $\partial\pi_{mg}/\partial W_g = 0$, $\partial\pi_{mg}/\partial\theta = 0$ and $\partial\pi_{mn}/\partial W_n = 0$, then the optimal values of the net prices will be calculated by replacing these optimal values in the best response functions of retailers. The optimal values are reported in the appendix.

3.3 Effects of changes in ρ and θ on SCs

ρ and θ are two important non-governmental factors in SC's profits and net prices. Thus, in Table 1, the effects of changes in these factors on SCs are indicated. The first column is the item for which we want to trace the changes, and in the second and third columns there are condition(s) that cause the change of that item to be positive in the centralized and decentralized models, respectively. Specified boundaries for some parameters are indicated as capital letters that are shown in the appendix.

Table 1 Effects of changes in the customers' loyalty degree and the green degree on SC

	DM	***CM***
$\partial P_g/\partial\rho$	$\eta > A$	$\eta > C$
$\partial P_n/\partial\rho$	($t_s < B$ & $A < \eta < C$) or ($t_s > B$ & $C < \eta < A$)	($t_s < \beta/b_1$ & $C < \eta < D$) or ($t_s > \beta/b_1$ & $D < \eta < C$)
$\partial\theta/\partial\rho$	$\eta > A$	$\eta > C$
$\partial(d_g + d_n)/\partial\rho$	$\eta > A$	$\eta > C$
$\partial(P_g - P_n)/\partial\rho$	$C < \eta < A$	$D < \eta < C$
$\partial\pi_g/\partial\theta$	$\theta < E$	$\theta < F$
$\partial\pi_n/\partial\theta$	$never$	$never$

4 Government role

4.1 Modelling government function

θ_s is the standard degree of greening that for a unit of a product with green degree (θ) lower than it, government has to pay $\lambda(\theta_s - \theta)$ to recompense environmental and social damage caused by that product, where λ is the cost/income coefficient of the difference between θ and θ_s for a product unit. For goods that are produced by the NGSC manufacturer, because their green degree equals 0, the government has to pay $\theta_s\lambda D_n$ for compensation environmental loss. Also, for green products with green degree that exceeds θ_s, not only the government does not have to pay any cost to recompense environmental and social damage, but it will also gain $\lambda(\theta - \theta_s)$ per each green product because of producing more sustainable goods and keeping natural resources safe and unused (Barbier et al., 1997).

The government's profit (π_{gov}) function is formulated as equation (18):

$$\pi_{gov} = (-\lambda(\theta_s - \theta) - t_s\theta)D_g + (-\theta_s\lambda + t_t)D_n \tag{10}$$

In this section a Stackelberg game framework is used to solve the models and calculate optimal values for decision variables. After replacing the best response functions of the SCs' members in π_{gov} and considering the mentioned constraints, the optimal values for t_s and t_t for different parameters of the model are derived in the centralized and decentralized models. Because these models are solved numerically by replacing numerical values for parameters, proving joint concavity is straightforward and those proofs have been omitted.

4.2 The centralized model

In order to maximize government's profit, it should be considered to guarantee that all members participate in the game must gain a minimum profit. So t_s and t_t boundaries will be determined firstly and secondly, the models will be solved and optimal values for t_s and t_t will be obtained. Finally, if this values are in the acceptable region, those are the optimal solutions; otherwise, border points should be checked.

Thus, using the reported parameters, first the acceptable region for t_s and t_t is shown in Figure 2. In Table 3, in each row the model is solved with specific parameters; in the first row, the optimal solutions for default values of parameters are calculated, but in the other rows, all parameters are the same as the default, except one and that one is reported in the first column of that row; and the new optimal values with these parameters are calculated and reported. In the centralized model, the minimum profit for each SC is considered to be equal to 10,000.

$$\alpha = 1200;\ b_1 = 7;\ b_2 = 2;\ \beta = 6;\ c_g = 30;\ c_n = 15;\ \eta = 5;\ \rho = 0.5;\ \lambda = 10;\ \theta_s = 150;$$

Figure 2 Acceptable region for the subsidy and tax rates in the CM

Figure 3 Government's profit in the acceptable region of the tariffs in the CM

Table 2 Optimal solutions for different parameters in the CM

	t_s^*	t_t^*	π_{gov}^*	π_g^*	π_n^*	P_g^*	P_n^*	θ^*
Default	0.68	20.68	730705	59518	10000	251.68	52.79	238.53
$\alpha = 2400$	0.43	129.72	421831	156082	10000	260.37	52.79	207.56
$b_1 = 5$	0.49	88.78	423633	52461	10000	240.96	52.79	227.62
$b_1 = 4$	0.59	65.30	749182	99471	10000	260.68	52.79	233.68
$\beta = 4$	0.97	0.88	605141	54499	10000	249.93	52.79	238.37
$c_g = 25$	0.68	20.35	1036780	67368	10000	260.84	52.79	253.77
$c_n = 20$	0.70	15.86	1507410	68124	10000	283.57	52.79	276.39
$\eta = 10$	1.34	1.69	-349200	57294	10000	259.65	52.79	179.60
$\rho = 0.6$	0.66	6.27	880038	72487	10000	260.80	52.79	245.11
$\lambda = 15$	0.68	20.69	1219170	59518	10000	251.68	52.79	238.53
$\theta_s = 200$	0.68	20.69	-177471	5918	10000	251.68	52.79	238.53
t_s=0	-	18.31	−820837	13601	10081	81.14	52.94	30.68
$t_t = 0$	0.72	-	443737	54876	15995	242.863	62.80	229.04
$t_s = 0 \& t_t = 0$	-	-	−906275	12672	15262	79.36	61.70	29.62

As shown in Figure 4 and Table 3, the government's profit will increase as t_s and t_t rise, and the maximum is reached in t_s and t_t boundaries. If these limitations are violated, the profit of the NGSC will be less than the level considered to be minimum profit; thus, the manufacturer and retailer of the NGSC will no longer be eager to participate in the game.

Last three rows in the table are presenting the results of variables where one or both of the governance variables are ignored. As it's clear, ignoring the government's role (especially the subsidy rate) and his legislations in GSC management leads to dramatic decrease in sustainability and social welfare.

4.3 The decentralized model

The acceptable region for t_s and t_t for the decentralized model are displayed in Figure 5; the default parameters are the same as in the previous section. In each row of Table 4, the model is solved with different parameters and the optimal solutions are obtained. Also, in the decentralized model, in order to assure a competitive market, it is considered that every SC must gain minimum profit of 10,000.

Figure 4 Acceptable region for the subsidy and tax rates in the DM

Figure 5 Government's profit in acceptable region of tariffs in the DM

Table 3 Optimal solutions for different parameters in the DM

	t_s^*	t_t^*	π_{gov}^*	π_g^*	π_n^*	P_g^*	P_n^*	θ^*
default	1.30	27.14	-153490	133719	10000	390.80	80.92	174.06
$\alpha = 2400$	0.96	139.71	-271265	189712	10000	399.26	80.92	157.48
$b_1 = 5$	1.15	108.04	-148461	159038	10000	467.85	93.57	227.62
$b_1 = 4$	1.06	111.38	-160488	166365	10000	410.65	82.56	173.82
$\beta = 8$	1.00	43.82	-77035	139436	10000	397.99	80.92	185.54
$c_g = 25$	1.30	27.84	-65466	150262	10000	407.47	80.92	193.03
$c_n = 20$	1.32	23.76	3976	157350	10000	425.91	85.92	201.63
$\eta = 2.5$	0.65	46.58	494161	132410	10000	386.90	80.92	253.50
$\rho = 0.55$	1.29	20.65	-109913	144722	10000	403.26	80.92	187.52
$\lambda = 15$	1.30	27.14	-134040	133719	10000	390.80	80.92	182.09
$\theta_s = 200$	1.30	27.14	-644386	133719	10000	390.80	80.92	182.09
t_s=0	-	12.00	-448220	10651	10020	101.40	81.00	14.70
$t_t = 0$	1.30	-	-258736	127301	16900	382.04	100.71	177.67
$t_s = 0\&t_t = 0$	-	-	-478473	10421	12893	100.62	89.86	14.52

In figure 5 the government's profit in the decentralized model will increase as t_t rise. For small values of t_s, government profit will decrease as t_s rise, but after passing a certain threshold, it will increase as t_s rise.

Last three rows in the table are presenting the results of variables where one or both of governance variables are ignored. Similar to the previous subsection, ignoring government's financial interventions leads to less greener products and less profit for GSC.

5 *Managerial insights and Sensitivity analyses*

5.1 Subsidy rate

In this section the effects of changes in the subsidy rate on profits, prices, demands and greening and sustainability of products will be discussed. All parameters are the same as in the previous section, and the tax rate (t_t) is set equal to 10.

In the figures below, limitations for t_s in the centralized and decentralized models are not equal;

thus, each plot is drawn in its acceptable region. c and d superscripts indicate the centralized and decentralized models, respectively.

- ***Insight 1.*** Profits changes according to the subsidy rate variations

Figure 6 Profits changes in the GSC according to the subsidy rate rising

Figure 7 Profits changes in the NGSC according to the subsidy rate rising

Figures 6 and 7 show the total profit in the centralized model and the total profit and the profits of manufacturer and retailer in the decentralized model for the GSC and the NGSC, respectively. For both, all profits increase by t_s and the maximum rise in profit is for total profit of the GSC in the centralized model. In each model, the manufacturers' profit is also more than the retailer's. In addition, in both figures, total profit of the SCs in the centralized model are higher than in the decentralized model. It could be observed that raising subsidy rate would encourage all members in SCs to produce greener and also opt cooperation.

- ***Insight 2.*** Changes of the social costs according to the subsidy rate variations

Figure 8 Changes in the costs of SCs to government according to the subsidy rate rising

Figure 9 Changes in the costs of tariffs and pollution to government according to the subsidy rate rising

Incomes/costs for government from the GSC and the NGSC in the centralized and the decentralized models, are represented in figures 8 and 9. Generally, by increasing t_s at first, costs from the GSC will increase, but once a certain threshold is passed in the centralized and the decentralized models, these costs will diminish. And if it keeps raising in t_s, the costs will even become a profit for government, but costs for the NGSC will increase.

In Figure 9, costs of pollution and tariffs in the centralized and decentralized models are separated. Increasing t_s increases what the government has to pay for tariffs. On the other hand, with decreasing pollution's costs, total costs for government decrease, and after a certain threshold in the centralized and decentralized models, costs are converted to income for government.

As for comparison of government's costs in the centralized and decentralized models, for small values of t_s, choosing the centralized structure leads to more costs for government, but for greater values of t_s, choosing the centralized structure for supply chains leads to lower costs in comparison with a decentralized structure.

As a result for policy makers, increasing t_s is more related to GSC and more support of GSC leads to less pollution.

- ***Insight 3.*** Changes in the prices according to the subsidy rate variation

Figure 10 Changes in the net prices according to the subsidy rate rising

Figure 11 Changes in the wholesale prices according to the subsidy rate rising

Figure 12 Changes in the final prices according to the subsidy rate rising

Net prices of green and non-green products change with variations of t_s, as illustrated in Figure 10, green product's net prices in the centralized and decentralized models rise at a steeper rate in comparison with non-green products. Also, for each value of t_s, non-green product has higher net prices in the decentralized model than in the centralized model. For small values of t_s, net prices of green product in the decentralized model are more than in the centralized model, but for greater values of t_s, net prices in the centralized model are more than in the decentralized model.

Non-green product wholesale price and difference between it and non-green product's net price are almost stable, but as displayed in Figure 11, green product wholesale price, the difference between green product's wholesale price and net price and the difference in wholesale prices between green products and non-green products rise rapidly. Thus, as the rate of subsidy raises, the value of green product in comparison with the value of non-green product raises.

The final prices that customers have to pay to purchase products are shown in Figure 12. Even though as t_s increases and the net price of green products rises rapidly, after subtracting governmental subsidies, the final price of green products (FPOGP) rises slowly and the final price of non-green products (FPONP) is almost indifferent to variations in t_s. The difference between net prices by increasing t_s rises rapidly, but for same value of t_s, this amount is more in the centralized model than in the decentralized model.

- ***Insight 4.*** Market size and sustainability changes according to subsidy rate variations

Figure 13 Changes in the green degree of green product according to the subsidy rate rising

Figure 14 Changes in the demands according to the subsidy rate rising

The green degree of green product will be increased by raising t_s in the centralized and decentralized models, and in both models, if a certain threshold of $t_s$is exceeded, the green degree will be higher than θ_s. It's clear in Figure 13 that not only the threshold for the centralized model is less than for the decentralized model, but also, for each value of t_s, the green degree in the centralized model is higher than in the decentralized model.

Demand variations are displayed in Figure 14. Non-green product demand is almost indifferent to increases in t_s, but green product's demand rises rapidly in the centralized and decentralized models.

It could be concluded that by raising the subsidy rate, government could improve sustainability and enlarge market size for green product while the market size for non-green products is fixed. Also as mentioned before, according to figure 13, selecting the centralized structure for SCs leads to more sustainability.

5.2 Tax rate

In this section, in order to analyze the effects of tax rate changes on SCs and government, the default parameter settings will be used and the subsidy rate will be equal to 0.6.

- ***Insight 5.*** Profits changes according to the tax rate variations

Figure 15 Profits changes in the GSC according to the tax rate rising

Figure 16 Changes in the demands according to the subsidy rate rising

Figures 15 and 16 show that by increasing t_t, profit of GSC's members and total profit of the GSC increases smoothly, but in NGSCs, profit of all members decrease rapidly. And for both the GSC and NGSC, the profit of total SCs in the centralized model is more than in the decentralized model; and the profit of manufacturers is more than the retailers.

- ***Insight 6.*** Social costs changes according to the tax rate variations

Figure 17 Changes in the costs of the SCs for the government according to the tax rate rising

Figure 18 Changes in costs of the tariffs and pollution for the government according to the tax rate rising

The costs that government has to pay because of GSC production is almost indifferent to changes in t_t for the decentralized model, but decreases in the centralized model, and as shown in Figure 17, NGSC production costs for government decrease with increasing in t_t; thus, total government's costs decreases in the both of centralized and the decentralized structures. Also, for all acceptable values of t_t in the centralized model, the government's costs are more than in the decentralized model.

Figure 18 shows that by increasing t_t, tariff's costs are stable, but pollution's costs diminish, especially in the centralized model. Also, tariff's costs in the centralized model are more than in the decentralized model, but for most values of t_t, pollution's costs in the centralized model are less than in the decentralized model.

- ***Insight 7.*** Changes in the prices according to the subsidy rate variation

Figure 19 Changes in the net prices according to the tax rate rising

Figure 20 Changes in the final prices according to the tax rate rising

Figure 21 Changes in the wholesale prices according to the tax rate rising

As the government raises the tax rate, NGSC has to decrease the non-green product's net price to make it competitive in the market; figure 19 shows that green product's net price rises slowly and non-green product's net price decreases slowly, and in this fixed value of t_s, for all values of t_t, the net price of green product in the centralized model is higher than in the decentralized model, but for non-green product, the net price in the decentralized model is higher than in the centralized model. The final prices that customers have to pay to purchase green product are nearly fixed with regard to increasing values of t_t, whereas for non-green product, the final price rise smoothly. As shown in Figure 20, differences between green and non-green products' net prices increase in both the centralized and decentralized models.

According to the figures 19 and 21, the net price and the difference between it and the wholesale price of green product are nearly fixed, but these items for non-green products are decreasing, and the only thing that is increasing is the difference between green and non-green product wholesale-prices.

- ***Insight 8.*** Market size and sustainability changes according to the tax rate variations

Figure 22 Changes in the green degree of green product according to the tax rate rising

Figure 23 Changes in the demands according to the tax rate rising

Figure 22 shows that changing t_t doesn't significantly influence the green degree of green products in the decentralized model, but it causes a little growth in the green degree of green products in the centralized model.

Figure 23 shows that the demand in the GSC in the centralized and decentralized models increases slowly, but the demand in the NGSC decreases at a steeper rate; thus, the resulting total demand decreases gradually. Also, total demand in the centralized model is significantly higher than in the decentralized model, and that's particularly because of the difference in the demand for green products in the centralized and decentralized structures.

It could be observed that changing tax rate is not a proper strategy to improve sustainability and it leads to reduce the market size.

6 Conclusions

This paper focused on governance policies in the markets that lead to the production of greener and more sustainable products. Profit functions of SCs' members were formulated considering governmental financial intervention and the greening degree of green product; then, by solving them, the optimal solutions for SCs' members in the centralized and decentralized models were obtained. Government's profit functions with different parameters in the centralized and decentralized models were formulated and solved. And finally, using numerical sensitivity analyses, the effects of governance tariff changes on the profits of players and government and environmental pollution and sustainability were investigated.

It was observed that raising subsidy rates to a certain threshold leads to increases in the demands, the green degree of green products, and profits of all SCs' members and government, and decreases in pollution costs for government. For the other tariff determined by government, tax rate, increasing this rate leads to increase in the profits of government and GSC and green product's prices, but decreases in the profit of the NGSC and pollution costs; and finally the green degree of green products was indifferent to tax rate variations.

Although this study has contributed to the literature of GSC management, its models are restricted to a duopoly of two SCs in which each SC can produce only one type of products; it would be interesting to generalize the models to more than two supply chains or more than one product. In this study, only CM-CM and DM-DM structures for the GSC and NGSC were discussed; this study could be improved by including CM-DM and DM-CM structures for supply chains in analyses or by formulating competition of two GSCs under governmental financial intervention. It was considered also that all information is available to all members; one could extend this study by solving models with asymmetric information settings. A final suggestion for further research is considering reverse demand function instead of direct demand function and comparing the results with the obtained funding in this paper.

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Appendices

A. In this section, the before mentioned conditions that cause the profit functions to be concave will be determined.

Table 5 Parameters boundaries for concavity of profit functions

CM	GSC	$\eta > (b_1 t_s + \beta)^2 / 4b_1$
	NGSC	$allways$
DM	GSC retailer	$allways$
	GSC manufacturer	$allways$
	NGSC retailer	$\eta > \dfrac{b_1((2{b_1}^2 - {b_2}^2)t_s + 2b_1\beta)^2}{4(8{b_1}^4 - 6{b_1}^2{b_2}^2 + {b_2}^4)}$
	NGSC manufacturer	$allways$

B. After solving models in the decentralized model in Section 3, to determine the optimal solutions for supply chain members, the following results are obtained.

$$\theta = \begin{pmatrix} (b_1(2{b_1}^2 t_s - {b_2}^2 t_s + 2b_1\beta)(8{b_1}^4 c_g - 9{b_1}^2{b_2}^2 c_g + 2{b_2}^4 c_g - 2{b_1}^3 b_2(c_n + t_t) + \\ b_1{b_2}^3(c_n + t_t) + a(6{b_1}^2 b_2(-1+\rho) - 2{b_2}^3(-1+\rho) - 8{b_1}^3\rho + 3b_1{b_2}^2\rho))) \end{pmatrix} / \psi$$

$$w_g = \left(\begin{array}{c} (16b_1{}^7c_g t_s{}^2 + 32b_1{}^6 c_g(t_s\beta - 2\eta) + 16b_1{}^4 b_2\left(b_2c_g(-2t_s\beta + 5\eta) + 3a\eta(-1+\rho)\right) \\ -28a\eta(-1+\rho)) + 4b_2{}^5\eta(b_2c_g + a(-1+\rho)) + b_1{}^2b_2{}^3(b_2c_g(7t_s\beta - 32\eta) - \\ 2b_1b_2{}^4\left(b_2{}^2c_gt_s{}^2 + b_2(c_n+t_t)\eta + 3a\eta\rho\right) - 2b_1{}^5(13b_2{}^2c_gt_s{}^2 - 8c_g\beta^2 \\ +8b_2(c_n+t_t)\eta + 32a\eta\rho) + b_1{}^3b_2{}^2(13b_2{}^2c_gt_s{}^2 - 6c_g\beta^2 + 12b_2(c_n+t_t)\eta + 40a\eta\rho)) \end{array} \right) \Big/ \psi$$

$$w_n = \left(\begin{array}{c} b_1b_2{}^5(b_2t_s{}^2(-c_n+t_t) + c_g(t_s\beta - 2\eta)) + b_1{}^3b_2{}^2(b_2{}^2t_s{}^2(6c_n - 7t_t) \\ +2(-2c_n+t_t)\beta^2 - 6b_2c_g(t_s\beta - 2\eta)) + 2b_1{}^5(b_2{}^2t_s{}^2(-6c_n + 7t_t) + 4(c_n - t_t)\beta^2 \\ +4b_2c_g(t_s\beta - 2\eta)) + 16b_1{}^6(c_n - t_t)(t_s\beta - 4\eta) + 4b_2{}^6(c_n - t_t)\eta \\ +8b_1{}^4b_2\left(c_g\beta^2 + b_2(-2c_nt_s\beta + 2t_st_t\beta + 10c_n\eta - 11t_t\eta)\right) \\ +b_1{}^2b_2{}^3\left(-2c_g\beta^2 + b_2(4c_nt_s\beta - 3t_st_t\beta - 32c_n\eta + 34t_t\eta)\right) \\ -a(4b_1{}^2 - b_2{}^2)(b_1(-2b_1{}^3t_s{}^2 + b_1(b_2{}^2t_s{}^2 - 2\beta^2) + b_2{}^2(t_s\beta - 6\eta) \\ -4b_1{}^2(t_s\beta - 4\eta)) + (b_1(b_1t_s - b_2t_s + \beta)(2b_1{}^2t_s - b_2{}^2t_s + 2b_1\beta) \\ +2(-8b_1{}^3 + 6b_1{}^2b_2 + 3b_1b_2{}^2 - 2b_2{}^3)\eta)\rho) + 8b_1{}^7t_s{}^2(c_n - t_t) \end{array} \right) \Big/ \psi$$

$$P_g = \left(\begin{array}{c} (16b_1{}^7c_gt_s{}^2 + 32b_1{}^6c_g(t_s\beta - \eta) + b_1{}^2b_2{}^3(b_2c_g(7t_s\beta - 6\eta) \\ -48a\eta(-1+\rho)) + 4b_1{}^4b_2(b_2c_g(-8t_s\beta + 7\eta) + 18a\eta(-1+\rho)) \\ +8ab_2{}^5\eta(-1+\rho) - 2b_1b_2{}^4\left(b_2{}^2c_gt_s{}^2 + 2b_2(c_n+t_t)\eta + 6a\eta\rho\right) \\ -2b_1{}^5\left(13b_2{}^2c_gt_s{}^2 - 8c_g\beta^2 + 12b_2(c_n+t_t)\eta + 48a\eta\rho\right) \\ +b_1{}^3b_2{}^2(13b_2{}^2c_gt_s{}^2 - 6c_g\beta^2 + 20b_2(c_n+t_t)\eta + 68a\eta\rho)) \end{array} \right) \Big/ \psi$$

$$P_n = \left(\begin{array}{c} (4b_1{}^7t_s{}^2(c_n - 3t_t) + b_1{}^3b_2{}^2(b_2{}^2t_s{}^2(c_n - 12t_t) - 2(c_n - 2t_t)\beta^2 - 10b_2c_g(t_s\beta - 2\eta)) \\ +2b_1{}^5\left(b_2{}^2t_s{}^2(-2c_n + 11t_t) + 2(c_n - 3t_t)\beta^2 + 6b_2c_g(t_s\beta - 2\eta)\right) \\ +8b_1{}^6(c_n - 3t_t)(t_s\beta - 4\eta) - 8b_2{}^6t_t\eta + 2b_1b_2{}^5\left(b_2t_s{}^2t_t + c_gt_s\beta - 2c_g\eta\right) \\ +b_1{}^2b_2{}^3(\beta(b_2t_s(c_n - 6t_t) - 4c_g\beta) - 6b_2(c_n - 10t_t)\eta) + 2b_1{}^4b_2(\beta(b_2t_s(-3c_n + 13t_t) \\ +6c_g\beta) + 14b_2(c_n - 5t_t)\eta) - 2a(3b_1{}^2 - b_2{}^2)(b_1(-2b_1{}^3t_s{}^2 + b_1(b_2{}^2t_s{}^2 - 2\beta^2) \\ +b_2{}^2(t_s\beta - 6\eta) - 4b_1{}^2(t_s\beta - 4\eta)) + (b_1(b_1t_s - b_2t_s + \beta)(2b_1{}^2t_s - b_2{}^2t_s + 2b_1\beta) \\ +2(-8b_1{}^3 + 6b_1{}^2b_2 + 3b_1b_2{}^2 - 2b_2{}^3)\eta)\rho)) \end{array} \right) \Big/ \psi$$

in where

$$\psi = \left(\begin{array}{c} b_1\left(2b_1{}^2t_s - b_2{}^2t_s + 2b_1\beta\right)\left(8b_1{}^4t_s - 9b_1{}^2b_2{}^2t_s + 2b_2{}^4t_s + 8b_1{}^3\beta - 3b_1b_2{}^2\beta\right) \\ +2(-64b_1{}^6 + 84b_1{}^4b_2{}^2 - 33b_1{}^2b_2{}^4 + 4b_2{}^6)\eta \end{array} \right)$$

C. Abbreviations

$$A = \frac{b_1({2b_1}^2 t_s - {b_2}^2 t_s + 2b_1\beta)(8{b_1}^4 t_s - 9{b_1}^2{b_2}^2 t_s + 2{b_2}^4 t_s + 8{b_1}^3\beta - 3b_1{b_2}^2\beta}{2(64{b_1}^6 - 84{b_1}^4{b_2}^2 + 33{b_1}^2{b_2}^4 - 4{b_2}^6)}$$

$$B = \beta(6{b_1}^2 - 2{b_2}^2)/(2{b_1}^3 - b_1{b_2}^2)$$

$$C = (b_1 t_s + \beta)\left(2{b_1}^2 t_s - {b_2}^2 t_s + 2b_1\beta\right)/(8{b_1}^2 - 2{b_2}^2)$$

$$D = (b_1 t_s + \beta)(b_1 t_s - b_2 t_s + \beta)/(4b_1 - 2b_2)$$

$$E = (w_g - c_g)(b_1 t_s + \beta)/2\eta$$

$$F = (P_g - c_g)(b_1 t_s + \beta)/2\eta$$

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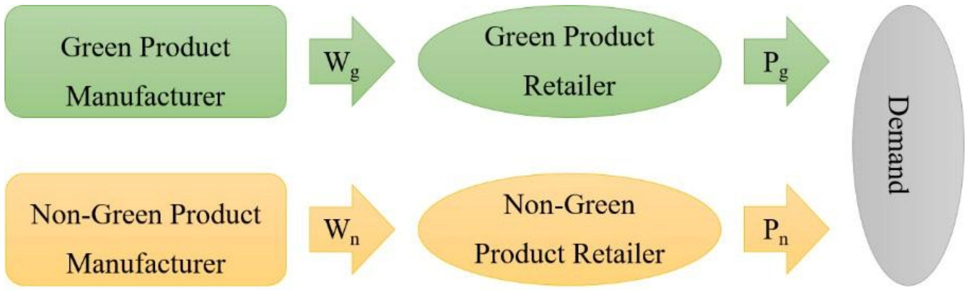

Figure 1 Two competitive SCs

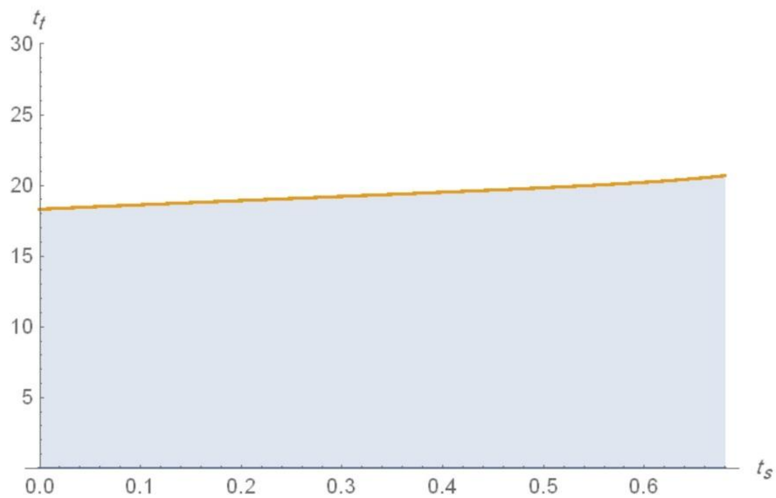

Figure 2 Acceptable region for the subsidy and tax rates in the CM

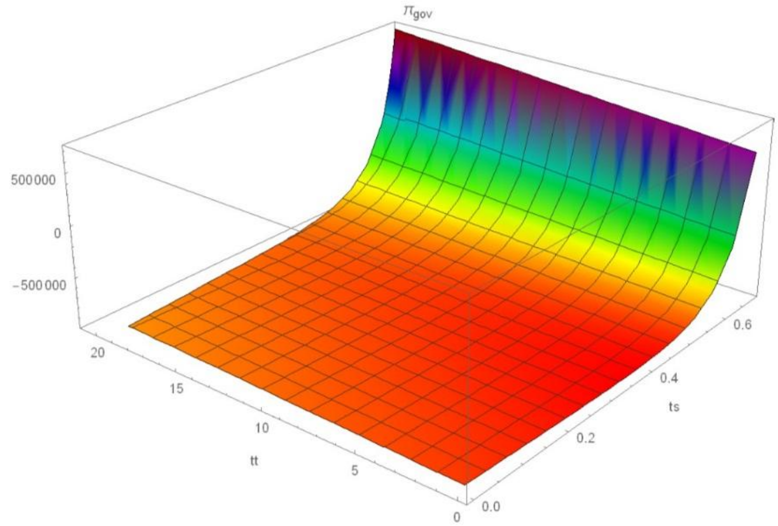

Figure 3 Government's profit in the acceptable region of the tariffs in the CM

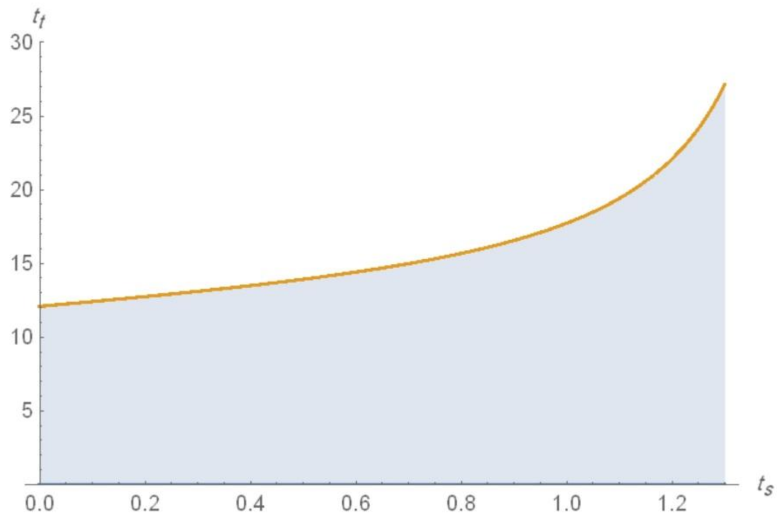

Figure 4 Acceptable region for the subsidy and tax rates in the DM

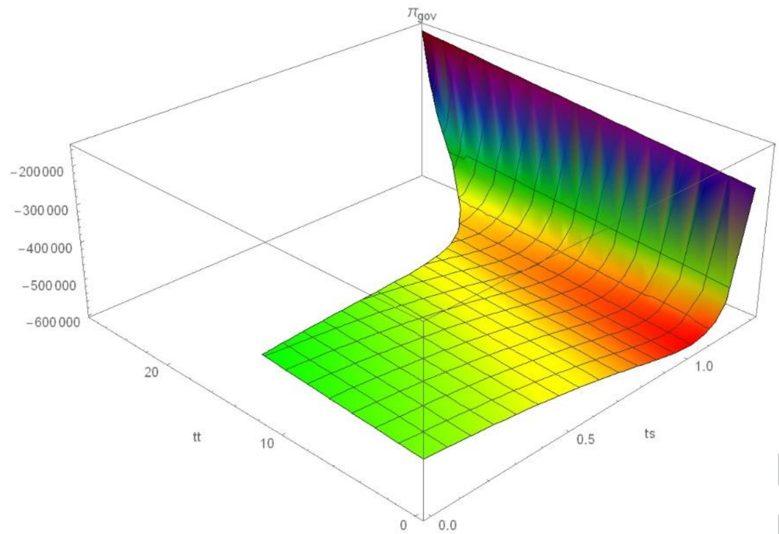

Figure 5 Government's profit in acceptable region of tariffs in the DM

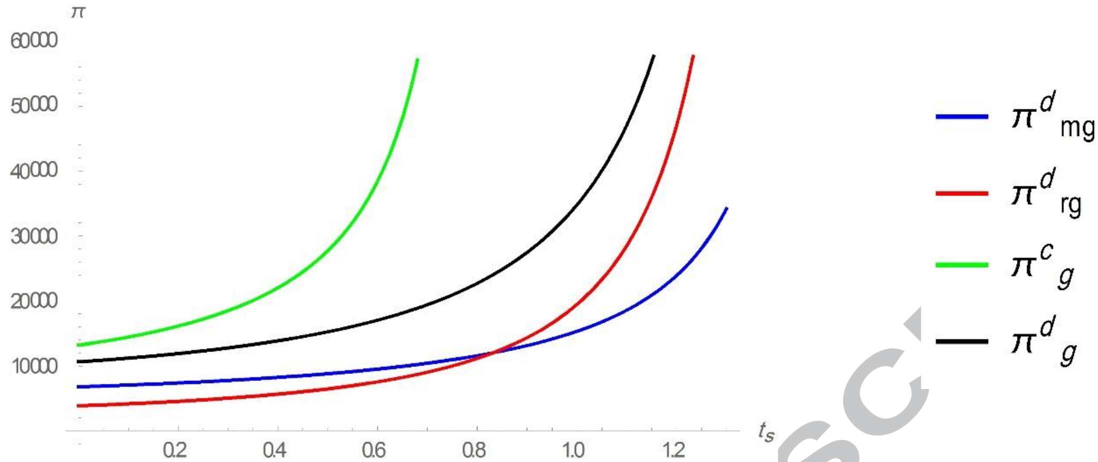

Figure 6 Profits changes in the GSC according to the subsidy rate rising

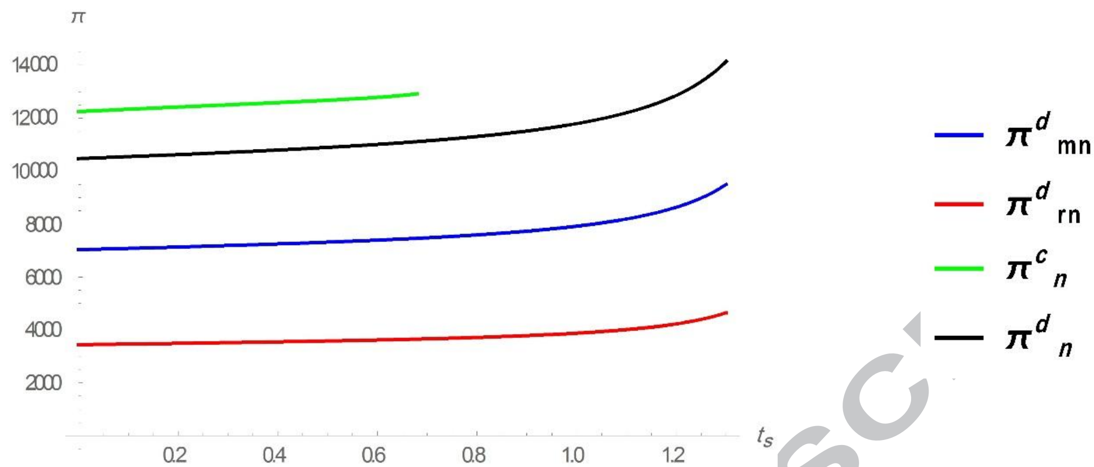

Figure 7 Profits changes in the NGSC according to the subsidy rate rising

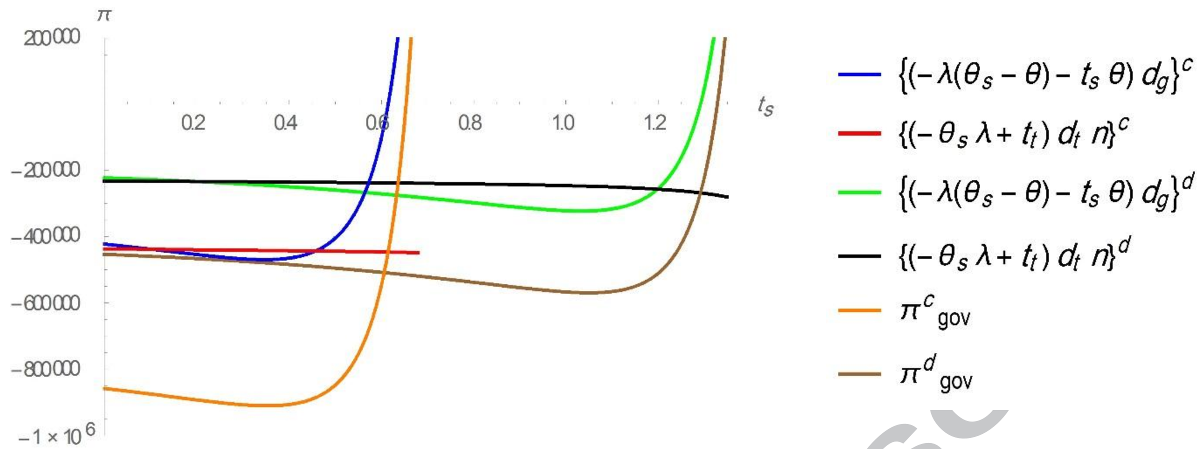

Figure 8 Changes in the costs of SCs to government according to the subsidy rate rising

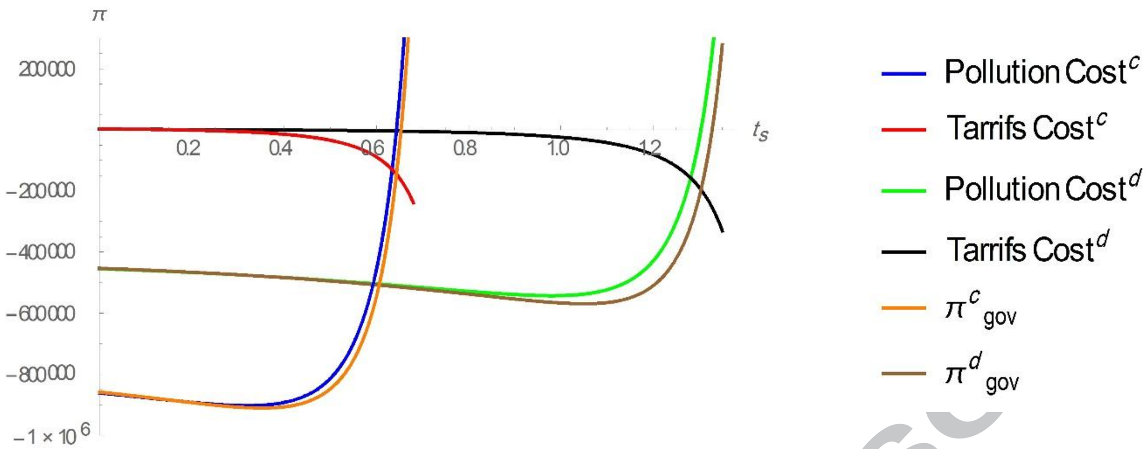

Figure 9 Changes in the costs of tariffs and pollution to government according to the subsidy rate rising

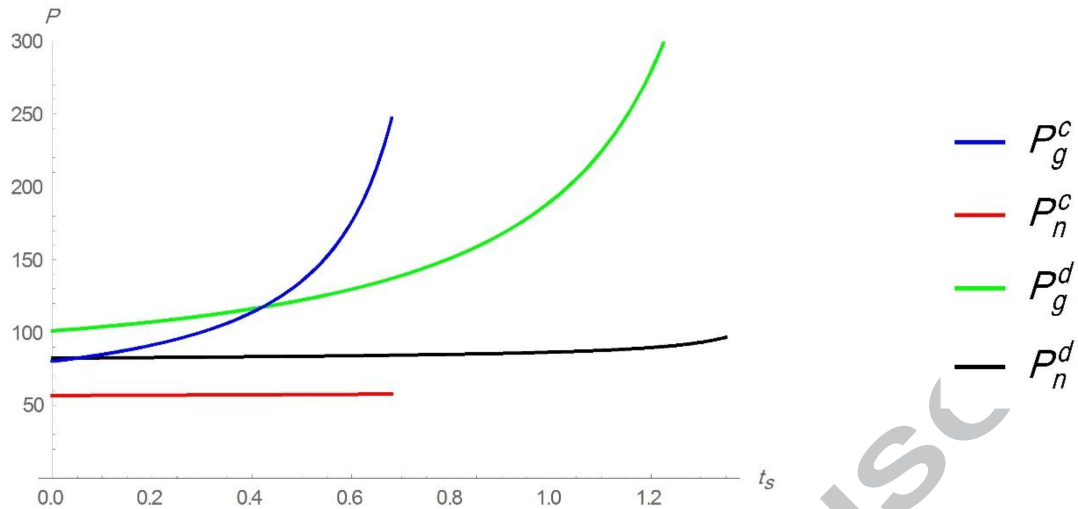

Figure 10 Changes in the net prices according to the subsidy rate rising

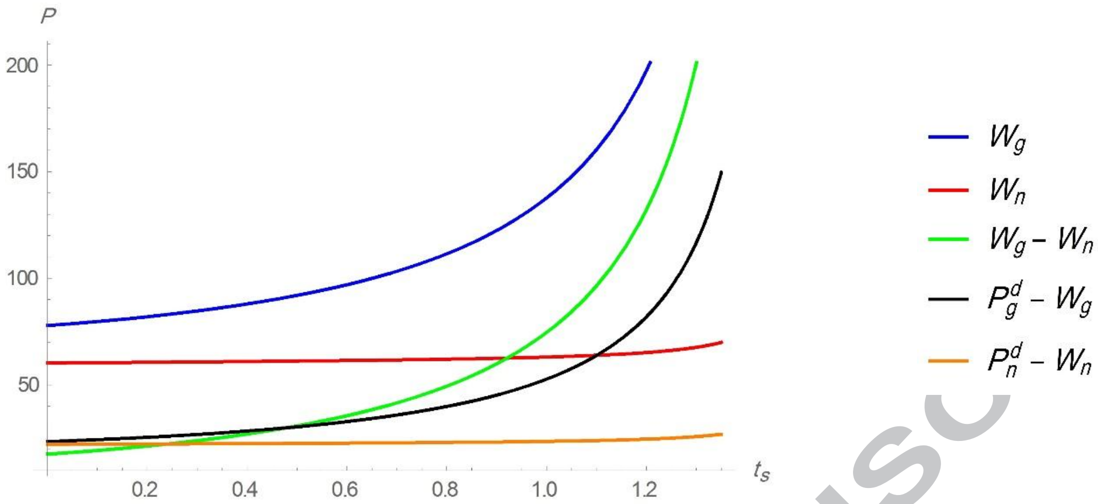

Figure 11 Changes in the wholesale prices according to the subsidy rate rising

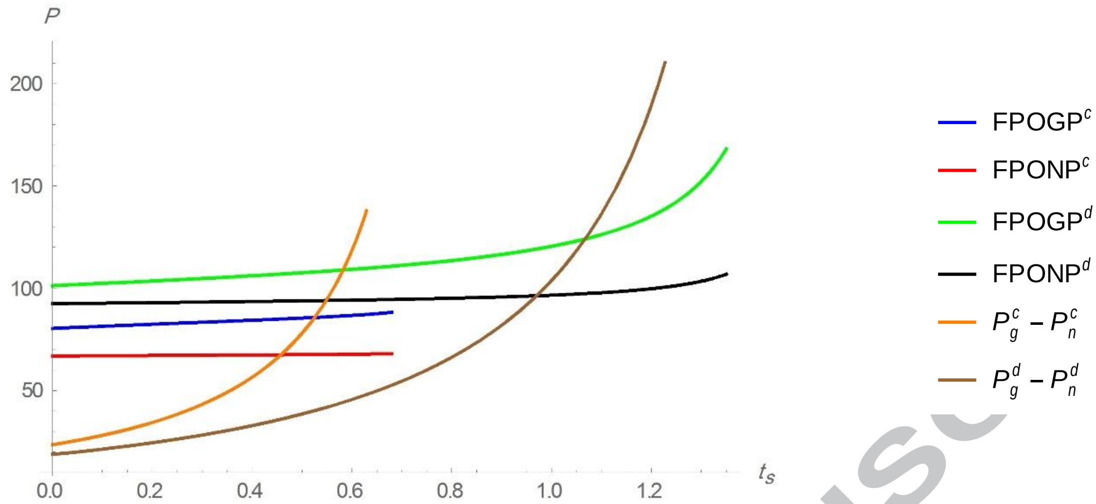

Figure 12 Changes in the final prices according to the subsidy rate rising

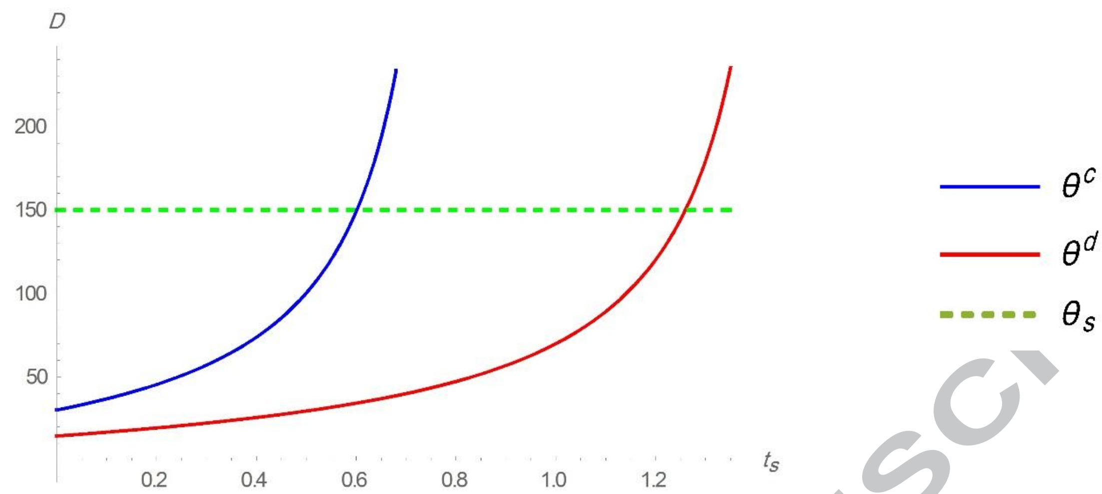

Figure 13 Changes in the green degree of green product according to the subsidy rate rising

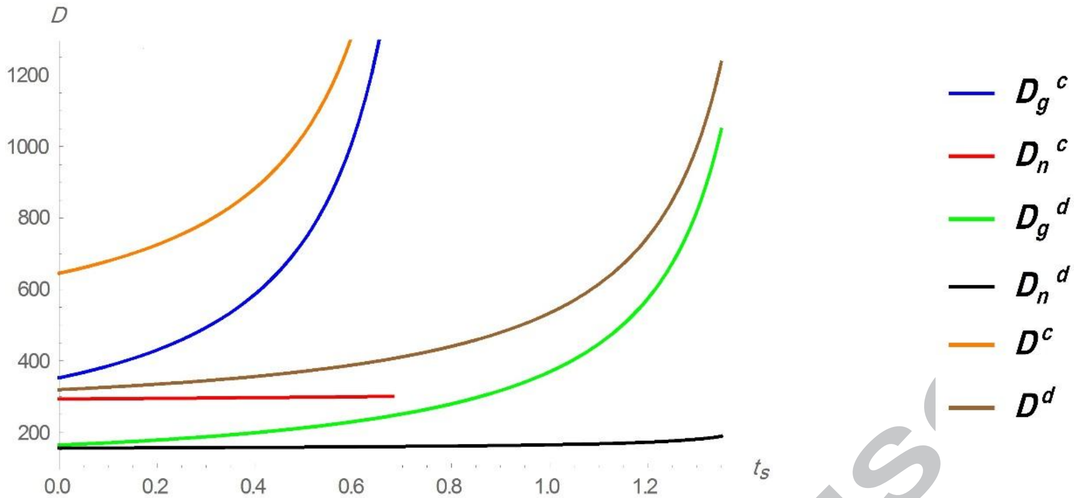

Figure 14 Changes in the demands according to the subsidy rate rising

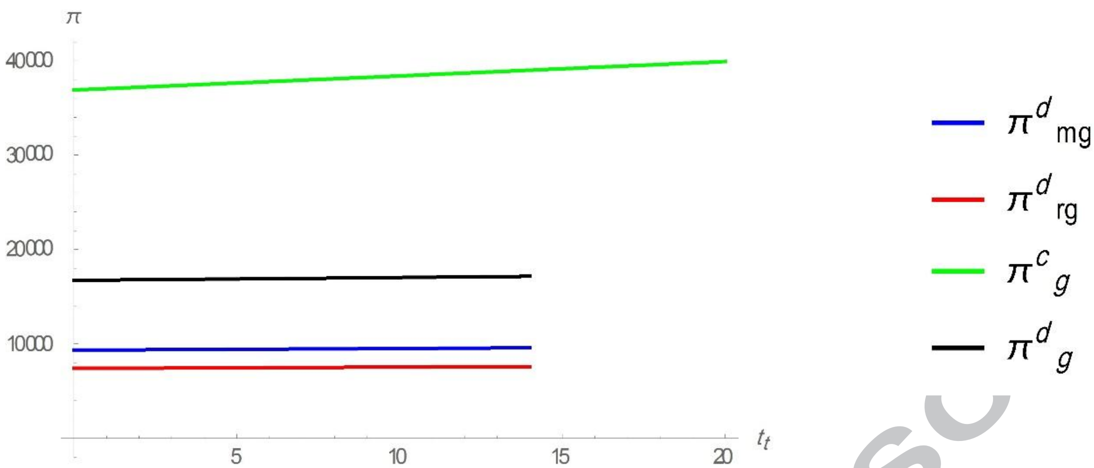

Figure 15 Profits changes in the GSC according to the tax rate rising

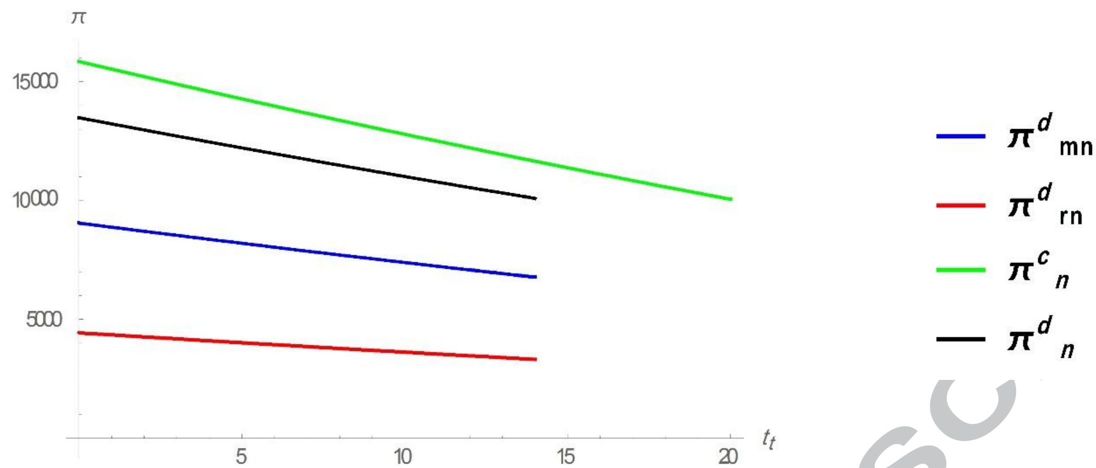

Figure 16 Changes in the demands according to the subsidy rate rising

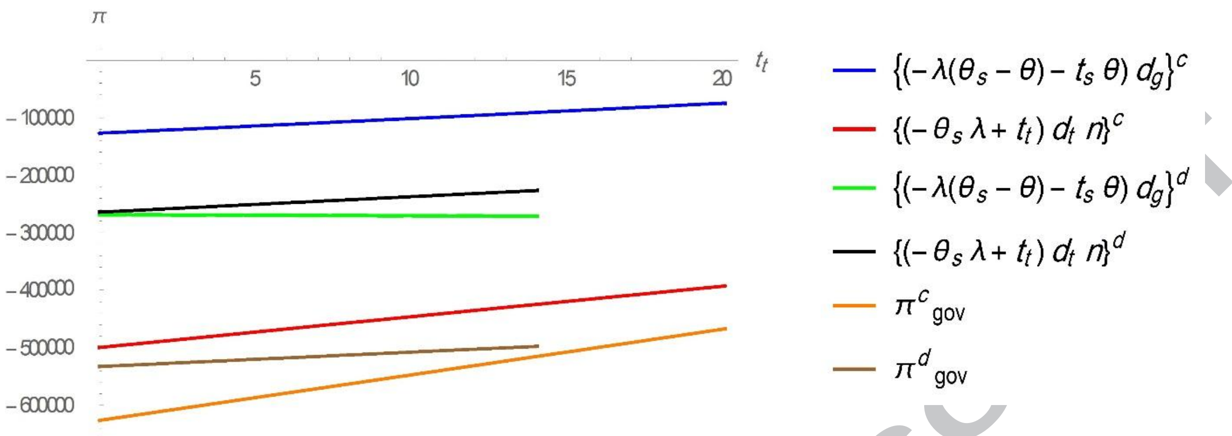

Figure 17 Changes in the costs of the SCs for the government according to the tax rate rising

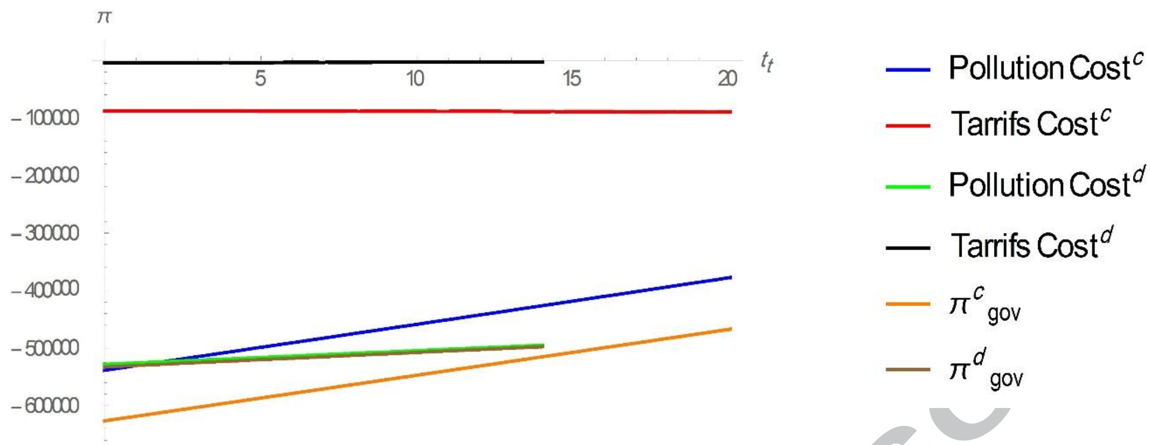

Figure 18 Changes in costs of the tariffs and pollution for the government according to the tax rate rising

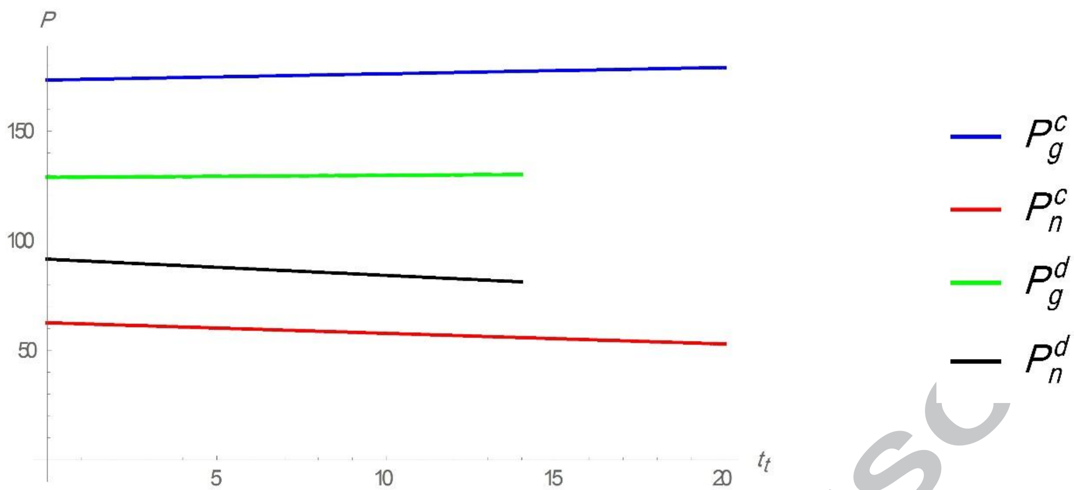

Figure 19 Changes in the net prices according to the tax rate rising

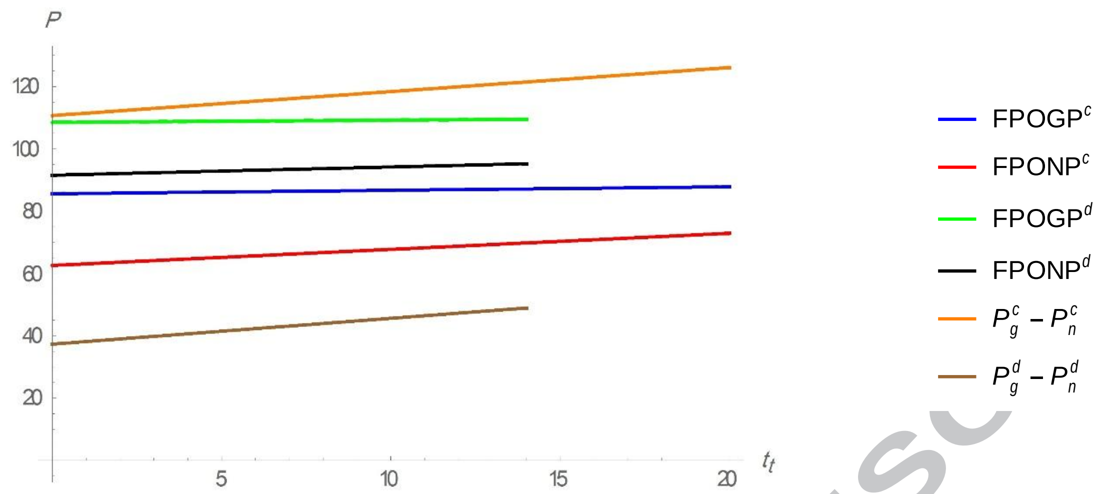

Figure 20 Changes in the final prices according to the tax rate rising

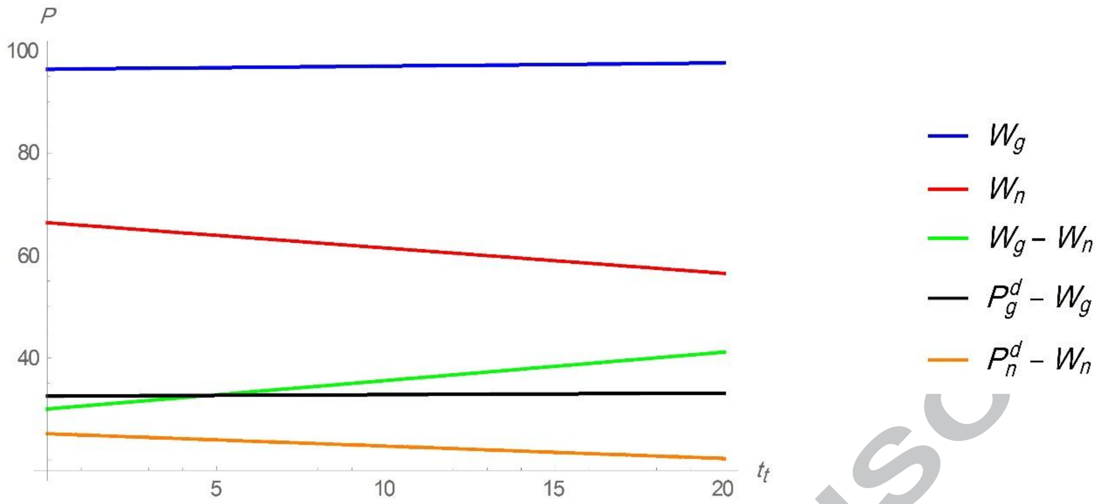

Figure 21 Changes in the wholesale prices according to the tax rate rising

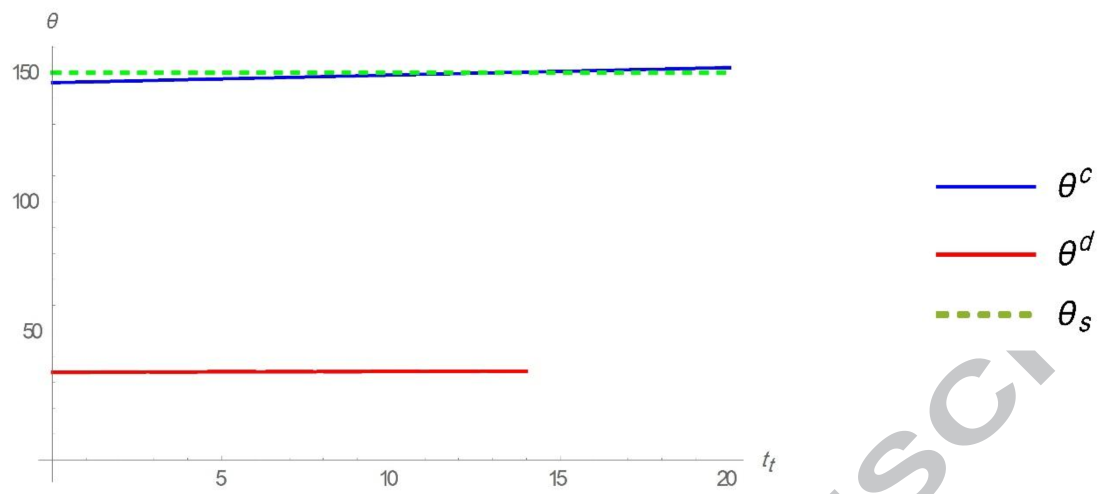

Figure 22 Changes in the green degree of green product according to the tax rate rising

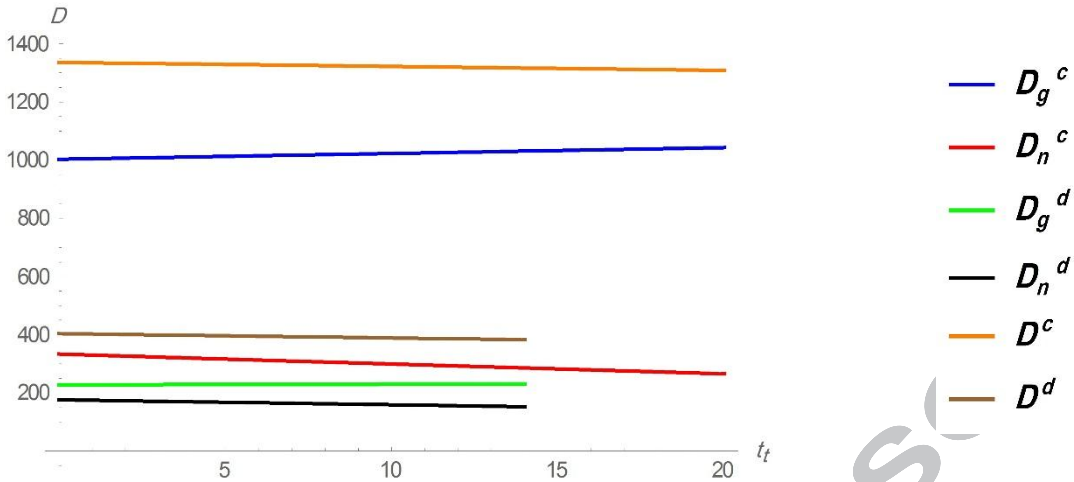

Figure 23 Changes in the demands according to the tax rate rising

Sustainable supply chain management with pricing, greening and governmental tariffs determining strategies: A game-theoretic approach

Highlights:

- We extended the green supply chain to the context of government intervention.
- Subsidies have significantly more impact than taxes on profits and sustainability.
- The green degree of green products is indifferent to tax rate variations.
- Raising tariffs to a certain threshold leads to make more profit for government.
- Choosing centralized structure for supply chains leads to produce greener products.