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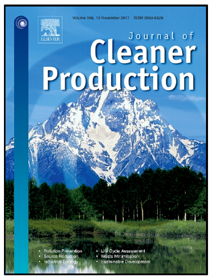

Direct and indirect intervention schemas of government in the competition between green and non-green supply chains

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Highlights:

Competition models between sets of green and regular supply chains are established

Direct tariff and tradable permits schemas are considered for government intervention

Leader-follower game model is used for interactions of the chains and government

The schemas affect environmental cost, government expenditure, and chains' profit

Case of competition between green and regular houses is studied under IEEO regulation

Direct and indirect intervention schemas of government in the competition between green and non-green supply chains

Abstract. This study investigates equilibrium between green and non-green product types under different government intervention schemas. To this end, we establish production competition models of a set of green and non-green supply chains (GSCs and NGSCs, respectively). GSCs and NGSCs are two-echelon supply chains (SCs) that present green and non-green types of a product to a market, respectively. We consider two schemas of governmental intervention: direct tariffs (DTs) and tradable permits (TPs), both with and without baselines. This research seeks to evaluate how the GSCs and NGSCs respond to the DT or TP schemas. To establish the best SC response strategies, we formulate three-level non-linear programming problems for four possible governmental intervention scenarios. We find that this problem is multidimensional with different system stakeholders including the government, SCs, consumers, and the environment. In fact, different schemas result in different satisfaction levels of stakeholders. Thus, an appropriate schema can be selected by considering corresponding effects on the stakeholders. The comprehensive evaluation of a case study on residential building construction SCs yields significant managerial insights.

Keywords: Intervention schemas; Governmental regulation; Direct tariff; Tradable permit; Supply chains competition; Green supply chain.

1. Introduction

The competition between green and non-green product types in various industries is evolving with respect to the development of new technologies and governmental interventions. In fact, many environmental innovations in product developments and production processes have occurred because of government regulations or consumer demand (Hafezalkotob, 2017a; Howes et al., 2013). For example, the widespread use and support of green technologies in residential construction are outcomes of resident behavior, governmental policies, and climate change (Si et al., 2016).

In response to the devastating effects of global warming, climate change, and pollution on humans, animals, and the environment (IEA, 2011), significant political and legislative initiatives have recently been undertaken. As a notable example, the Paris climate conference (December 2015) resulted in an important inter-governmental agreement that incorporated commitments on emissions, adaptation, finance, and transparency as well as practical steps to increase carbon trading[1]. The signatory governments (and governmental institutions) are obligated to provide legislative incentives (in terms of financial or legislative aid) or/and technical consultants to support and expand green products and technologies in different

[1] see ''Outcomes of the U.N. climate change conference in Paris'', at <http://www.c2es.org/international/negotiations/cop21-paris/summary>

industries. For instance, in response to the acute environmental concerns of the Swedish population, Swedish policy makers passed legislation on road transportation to support eco (e.g., hybrid or electric) vehicles (Huse and Lucinda, 2014). In fact, the Swedish government established a green car rebate policy that offers approximately $1500 to all private individuals purchasing an eco-automobile (Huse and Lucinda, 2014). The US and Canadian governments have implemented similar policies to support hybrid or electric automobiles (Beresteanu and Li, 2011; Chandra et al., 2010).

To pursue financial, social and environmental objectives, the governments often devise different policy instruments which are generally categorized as price-based (e.g., tax and subsidy schemas) and quantity-based instruments (e.g., cap-and-trade and tradable permit schemas) (Hepburn, 2006). In the price-based schemas, the governments financially intervene in the market to pursue specific policy objectives. For example, taxing tobacco results in increased cigarette prices and hence reduced consumption. 'Direct Tariff (DT) schema' is a tax levied or subsidy provided by a government for products that are available in the market. DT schema is the most important price-based instrument to expand green product. The quantity-based schemas are indeed command-and-control regulations on quantities such as placing an upper limit on the hazardous waste or pollutant of the products (Hepburn, 2006). 'Tradable permits (TP) schema' is a hybrid instrument in which polluters must legally purchase the permits from the permit owners, usually the green producers. In fact, TPs are tradable certificates granted to the green producers to compensate for the additional costs of the green production. Non-green producers are obligated to purchase TPs in a secondary market.

Both DT and TP schemas have some advantages and disadvantages. In DT schema, the government directly intervenes in a competitive market by imposing financial incentives and disincentives. DT can be a successful schema for supporting green products because it may considerably change the market equilibriums. However, direct intervention may not be preferred in some societies having economic liberalization approach. On the other hand, the government's tax and subsidy often alter the final prices of the products; thus, they affect social welfare of consumers. Due to the government's budget is limited, when the government levies subsidy on one product, it should collect money from the remainder of the economy which may affect other industries. Consequently, a comprehensive system approach to the entire economic, environment, and consumer welfare should be adopted by the government in DT schema. The government's intervention in the competitive market is lower in the TP schema because the government only establishes a regulatory framework for trading permits between the green and non-green products. Under TP schema, the non-green producers bear the cost of government's environmental policy, a contrast to the DT schema. A common shortcoming of the market-based permit schemas is that fluctuations in the TP price pose a risk to the green producers which is opposite to DT schema where the tariff price is often fixed (Klessmann et al., 2008).

DT schema is widely used by policy makers to support green products in industries such as eco-automobile industry (Beresteanu and Li, 2011; Chandra et al., 2010; Hafezalkotob, 2015; Huse and Lucinda, 2014), and energy-saving technology of brick production (Hafezalkotob, 2017a). There are various types of TP based on different concepts such as cap-and-trade, carbon allowances, and tradable green certificates which are implemented in various industries. For example, Tamás et al. (2010) proposed a tradable green certificates schema between green and black energy producers in the UK and compared the results with the tariff (feed-in-tariff) schema. In addition, cap-and-trade schema determines carbon emission allowance which can be traded between high-carbon and low-carbon products in many industries (Wang et al. (2016)).

In this study, we model TP schema in a general form in which permits are traded between green supply chains (GSCs) and non-green supply chains (NGSCs) according to the governmental regulatory framework. We evaluate the DP and TP schemas with and without baselines as different government regulatory approaches. A baseline implies the threshold for the implementation of governmental intervention schema. The baseline means that the intervention schema (TP or DT) should only be considered for the production quantity which is higher than the threshold.

Considering the competitive market between GSCs and NGSCs under government regulation, we investigate how a three-player game among GSCs, NGSCs and government can be formulated. Other research questions are summarized as follows:

- What are the best response strategies of NGSCs and GSCs to various governmental intervention schemas? (In particular, how might the different governmental intervention schemas change the equilibrium between green and non-green product types in a competitive market?)
- What are the effects of different intervention schemas on the environment, the government's budget, and SC satisfaction?

To the best of author's knowledge, the analytical comparison of direct (e.g., DTs) and indirect intervention (e.g., TPs) schemas of government in competition of SCs are not considered. Regarding the authority of government, we model its intervention schemas as multi-level programming problems. These three-player game models (among GSCs, NGSCs, and government) can be used for investigating the social, environmental, and economic effects of each schema.

This paper is organized as follows. Section 2 briefly describes the related literature. Section 3 presents prerequisites and assumptions. Regarding intervention schemas, Section 4 develops the competition models between NGSCs and GSCs as well as the government models. Section 5 incorporates a case study and yields some managerial insights. Eventually, Section 6 summarizes the main findings and directions for future research.

2. Literature review

This work delineates the competition between GSCs, governmental intervention on competitions, the tradable permits and cap-and-trade. These concepts are discussed in detail in the following subsections.

2.1. Survey on GSC, NGSC, and sustainability

Recently, sustainability analysis of GSCs and NGSCs has become an important subject for researchers and practitioners (Brandenburg et al., 2014). The triple-bottom-line (TBL) dimensions of organizational sustainability including environmental, social aspects, and economic considerations should be regarded in the management level of total SC. Rahdari and Anvary Rostamy (2015) proposed corporate governance, corporate social responsibility, and sustainability normative frameworks, management systems, guidelines, and rating systems as the indicators for TBL dimensions of the organizational sustainability. Ülkü and Hsuan (2017) established a pricing game model to investigate the effect of modularity and consumer sensitivity on sustainability based on the decisions of two rival companies. They concluded that modularity is an important factor that positively affecting sustainable production and consumption. Madani and Rasti-Bozorki (2017) developed a game theoretical model for competition of two sustainable SCs which studied the effects of tariff regulations on profits of the government and SCs.

2.2. Survey on the competition of GSCs

Different studies have implied that the competitive environment of various industries is evolving from the competition among independent companies towards the competition among SCs (Hafezalkotob, 2017a, 2015; Xiao and Yang, 2008). Several researches have used game theory methods to investigate the competition of two or more SCs (Bernstein and Federgruen, 2005; Masoumi et al., 2012; Nagurney, 2010; Nagurney et al., 2014; Rezapour et al., 2014; Rezapour and Farahani, 2010; Xiao and Yang, 2008; Zhang, 2006).

Competition between green and non-green types of products of SC(s) has also been discussed by some researchers. Basiri and Heydari (2017) studied the effects of manufacturing and selling a green product type in a SC that traditionally manufactures and sells a non-green product type. The interaction of these two substitutable products was evaluated under competitive and collaborative scenarios. Zhang et al. (2015) developed a multi-product newsvendor model for a two stage SC which manufactures green (environmental) and non-green (traditional) products. The model was investigated under competitive and cooperative situations and a return contract mechanism was proposed for coordination of the SC.

Some researchers have also studied the competition among GSCs from various aspects (Hafezalkotob, 2017a, 2015; Li and Li, 2014; Nagurney et al., 2006; Nagurney and Yu, 2012; Sheu, 2011; Sheu and Chen, 2012). Nagurney et al. (2006) applied variational inequality theory to analyze the electric power supply chain networks. Under different carbon taxation environmental policies, the algorithm presented optimal carbon taxes and equilibrium electric power transaction flows. Similarly, Nagurney and Yu (2012) utilized variational inequality theory to investigate the equilibrium in the oligopolistic competition among sustainable fashion SCs. In the proposed model, each fashion firm manages a SC with the aim to obtain maximum profit with least emission. Li and Li (2014) established a game theoretic model to formulate the competition between two sustainable SCs. They also considered the cooperative scenario between the manufacturer and supplier of a SC with the aim of maximizing the profit of the total SC. It is noteworthy that Hafezalkotob (2015), Hafezalkotob (2017a), Sheu (2011), and Sheu and Chen (2012) considered competition between GSCs under government intervention, which will be reviewed in the next section.

2.3. Survey on the government intervention in GSCs competition

Governments often impose regulations on different kinds of business to address national and global environmental problems. Game theory models are appropriate for analyzing the interaction between the government and companies. Zhao et al. (2013) provided a simulation-based method for two-person non-cooperative games between the manufacturers and the government. They indicated that if financial intervention of government to support cleaner production is insufficient, then the manufacturer's dominant strategy is not to alter the regular production processes. Hafezalkotob (2017b) utilized game theory to study the intervention of a government, with sustainable development objectives, in competition and cooperation of a domestic manufacturer with a foreign (international) SC. He showed that specific limitations for governmental tariffs exist that yield a stable competitive or monopolistic market.

By incorporating environmental concerns in the decision-making models, some studies adopted game theory to investigate interactions between government and GSC(s). Zhao et al. (2012) applied game theory to evaluate the effects of carbon emission policies of the government (e.g., penalties and incentives) upon strategies selected by the GSCs. Sheu (2011) adopted Nash bargaining game approach to study a negotiation problem among GSCs under government intervention. He showed that the relative bargaining power of GSC's participants in negotiations is considerably influenced by government's financial intervention. Using the Stackelberg game model, Hafezalkotob (2015) investigated the effects of government's tariff on competition between one NGSC and one GSC. Sheu and Chen (2012) developed a three-stage game-theoretic model to investigate the impact of the tax and subsidy levied by government on the competition of GSCs. The results indicated that financial intervention of government may significantly increase social welfare and chain based profits. Heydari et al. (2017) considered quantity discount and increasing fee contracts to coordinate closed loop and reverse SCs. They also investigated the role of tax exemption and subsidy of government in improving the SC efficiency.

Moreover, another line of research exists that addresses government intervention in energy saving efforts of SC(s). Xie (2015) established a game-theoretic model for the energy-saving and pricing decisions of a GSC with decentralized and centralized structures. He showed that the energy-saving efforts and profit of a GSC are significantly affected by the government regulations. Hafezalkotob (2017a) further developed the model introduced by Xie (2015) for competition, coopetition, and cooperation of two GSCs under government intervention. He found that cooperation of GSCs in energy saving efforts increases if the government pursues an energy-saving policy.

The government intervention schemas and their impacts on emission abatement are important topics. Determining the environmental effects of businesses, several researches have focused on the role of different regulations and policy instruments of government (Benjaafar et al., 2013). DT and TP schemas are two environmental policy instruments which are often devised by governments. Guo et al., (2016) used game theory approach to study the effects of different subsidy policies of government on two echelon SC and social welfare.

In literature, there is an important stream that incorporates cap-and-trade and tradable permits in the decision making problems of companies. Zheng et al. (2016) considered cap-and-trade policy in transportation mode selection and obtained optimum pricing and order quantities under demand uncertainty. Benjaafar et al. (2013) incorporated carbon emission concerns in operation management of classical lot-sizing models for single and multiple firms. They evaluated several regulatory policies such as mandatory caps on carbon emissions, taxes on firms based on emission, cap-and-trade, as well as cap-and-offset policies. Toptal et al. (2014) examined the effects of different emission regulations (e.g., carbon cap, tax and cap-and-trade policies) on inventory replenishment and emission reduction investment decisions. Sabzevar et al. (2017) formulated a game-theoretical model for Cournot competition between two firms under cap-and-trade emissions constraints.

There are some researches that have considered cap-and-trade and TP in interaction of a single or multiple SCs. Du et al. (2011) studied emission permit effects on an emission-dependent SC by game-theory analysis. Xia and Zhi (2014) established a Stackelberg game model through a two-echelon SC to analyze promotion level and emission reduction decisions under cap-and-trade system. Xu et al. (2017) considered the impacts of cap-and-trade regulation on make-to-order SC. They showed that optimal price and production decisions of the manufacturer and retailer of SC are highly affected by the price of emission permits. Xu et al. (2016) evaluated the effects of cap-and-trade regulation on a two-echelon sustainable SC and also compared the decentralized and centralized structures of the SC under emission trading price. Dong et al. (2016) analyzed the impact of cap-and-trade regulation on sustainability investment in sustainable products. They considered order and sustainability investment as decision variables in decentralized and centralized SCs and proposed revenue sharing and buyback contracts for SC coordination. Wang et al. (2016) investigated cost sharing and the wholesale price premium contracts in a SC under low-carbon environment regulations. They considered free carbon emission allowance and permit prices in the competition of high-carbon and low-carbon products. Zhang and Yang (2016) examined competition between two SCs under cap-and-trade schema in which the competition on the product greening level and price was considered.

In electicity sector, feed-in tariff (FIT, which is a price-based instrument) and tradable green certificate (TGC, which is a quantity-based instrument) are two important schemas to control non-renewable (black) energy generation and expand renewable (green) energy supply. Tamás et al. (2010) found that the outcomes of FIT and TGC schemas may be different. Indeed, the supplies of both black and green energy under FIT are higher than TGC due to subsidies (obviously). Currier and Sun (2014) and Currier (2013) evaluated the effect of TGC system on social welfare in electricity market. In the context of SC, Guo et al. (2016), Sheu and Chen (2012), Sheu (2011), Hafezalkotob (2015), Hafzalkotob (2017a), Zhao et al. (2012), and Mitra and Webster (2008) have considered price-based instruments of government in SCs interactions.

2.4. Research gap

This study is closely related to Hafezalkotob (2015), in which a model based on game theory is developed for a competitive market between a GSC and an NGSC under the intervention of a government with revenue-seeking and/or environmental protection policies. Hafezalkotob only considered the impact of a government-levied tariff on the centralized and decentralized structures of SCs. To the best of author's knowledge, no researcher has studied the effect of a governmental TP schema on competition between a GSC and an NGSC. Therefore, the three main contributions of this research that bridge the research gap are as follows: (i). We comprehensively compare the DT and TP schemas in a competition between a set of NGSCs and a set of GSCs. Considering that baselines may (or may not) exist for the schemas, the problem is investigated using four scenarios. (ii). We use a Stackelberg game approach and a multi-level programming problem to model government authority in the SCs competition. Therefore, four mathematical modeling problems are presented for the four schemas of governmental intervention in which the government, as the leader player, may seek to minimize expenditure and exhibit an environmental protection tendency. (iii). We present a case study on competition between construction SCs that build green and non-green houses in Iran. We also evaluate the competition between GSCs and NGSCs in the context of the residential construction industry in Iran under the intervention of the Iran Energy Efficiency Organization (IEEO).

3. Prerequisites and assumptions

At first, the notation and assumptions adopted in the models are introduced. Then, the models for the SCs and the government are presented. In the models, we assume that a green (non-green) SC that includes a green (non-green) manufacturer and a green (non-green) supplier offers a green (non-green) type of a product in a competitive market. Hence, the subscript index i $(i = g, ng)$ indicates green and non-green types of product or SCs.

Decision variables (players' strategies):

q_i the production quantity of type i product produced by the corresponding manufacturer;

Q_i the production quantity of type i product offered by all the corresponding SCs;

w_i the wholesale price per unit of type i product offered by the corresponding supplier;

t_i the DT imposed by the government on each unit of type i product;

p_p the price of each unit of tradable permit in the secondary market;

α the green quota determined by the government;

γ_i the baseline for type i product in the government intervention schema which indicates exemption quantity determined by the government.

Parameters:

p_i the retail price of type i product presented by the corresponding SC, (we assume that $w_i \geq c_i > 0$ as well as $p_i \geq w_i$);

a_i the baseline retail price for type i product, $a_i \geq 0$;

b_i the retail price sensitivity coefficient of product type i to production quantity, $b_i \geq 0$;

n_i the number of type i SC;

λ the substitutability coefficient of green and non-green types of product, $0 \leq d \leq 1$;

C_i the variable procurement and production cost per unit of type i product incurred by corresponding supplier, $C_i \geq 0$;

c_i the variable production cost per unit of type i product incurred by corresponding manufacturer, $c_i \geq 0$;

F_i the fixed production cost incurred by corresponding supplier, $F_i \geq 0$;

f_i the fixed production cost incurred by corresponding manufacturer, $f_i \geq 0$;

θ_i the coefficient indicates distribution of tariff between members of SC i ($0 \leq \theta_i \leq 1$);

β_i the coefficient indicates distribution of permit price between members of SC i ($0 \leq \theta_i \leq 1$);

e_i the environmental impact per unit of product type i, $e_i \geq 0$;

ϕ the cost factor associated with environmental pollution of products, $\phi \geq 0$;

D the minimum value for the total market demand, $D \geq 0$;

L_{S_i} the reservation profit of supplier i, $L_{S_i} \geq 0$;

L_{M_i} the reservation profit of manufacturer i, $L_{M_i} \geq 0$;

GNR the total government net revenue to tax and subsidy on SCs' products;

EC the total environmental cost of SCs' products.

For simplicity of formulations, let us assume the vectors $\boldsymbol{t} = (t_g, t_{ng})$, $\boldsymbol{q} = (q_g, q_{ng})$, $\boldsymbol{w} = (w_g, w_{ng})$, and $\boldsymbol{\gamma} = (\gamma_g, \gamma_{ng})$ as the decision variables of the GSCs and NGSCs. The vectors $\boldsymbol{q}$, $\boldsymbol{w}$, $\boldsymbol{t}$ and $\boldsymbol{\gamma}$ denote respectively the production quantities, wholesale prices, tariffs, and baselines. In order to establish the framework for mathematical modelling the problem, the following assumptions are considered.

Assumption 1. All the parameters are per-known and deterministic. In addition, we assume that all the parameters are considered as common knowledge of all the players. Thus, the game is evaluated under a symmetric information situation. In many developed countries, financial auditing systems monitor the sales, assets, and profits of firms. If convincing evidence exists that proves misstatements or errors in the statement of financial accounts, the firms may face prosecution. Thus in many industries, firms prefer to reveal actual information on their business. Symmetric information will, therefore, be a valid assumption.

Assumption 2. In a competitive market, there are n_g GSCs and n_{ng} NGSCs. Therefore, $Q_g = \sum_{k=1}^{n_g} q_{g_k}$ and $Q_{ng} = \sum_{k=1}^{n_{ng}} q_{ng_k}$ represent the total production quantities of GSCs and NGSCs, respectively. GSCs (and NGSCs) are assumed to be similar; thus, we have $Q_g = n_g q_g$ (and $Q_{ng} = n_{ng} q_{ng}$ for NGSCs).

Assumption 3. The environmental effects of non-green and green type of products are represented by e_{ng} and e_g, respectively. With the aim of generalizing the models, we do not limit the environmental effects of products to a particular feature. In fact, the environmental effects may include air, soil, or water pollution. Different criteria can be measured to gauge pollution intensity, e.g., annual production of CO_2 or NO_x, energy efficiency, and the recycling index of products.

Assumption 4. According to Cournot's model of production competition (see Chapter 2 of Kogan and Tapiero (2007)), the market is considered to be oligopolistic. In the oligopolistic competition between SCs in the market, the products of GSCs and NGSCs are partially substitutable. Thus, it is assumed that product price is a function of the production quantities of SCs.

$$p_i(Q_i, Q_j) = a_i - b_i(Q_i + \lambda Q_j) = a_i - b_i(n_i q_i + \lambda n_j q_j), \quad i = g, ng, \quad i \neq j. \tag{1}$$

This linear price function is very common in SC games (Bischi et al., 2009; Boonman et al., 2015; Hafezalkotob, 2017b; Kogan and Tapiero, 2007; Sheu, 2011; Sheu and Chen, 2012; Tamás et al., 2010; Xiao and Chen, 2009).

Assumption 5. The government is assumed to be a Stackelberg leader that directly or indirectly intervenes in the industry to reduce the environmental impact of products. Therefore, SC members devise the best response strategy regarding government's actions. Additionally, all SCs have decentralized decision-making structures, i.e., the supplier and manufacturer are independent profit-seeking companies. In each SC, the manufacturer, as a Stackelberg leader, determines the production quantity, and the supplier, as a Stackelberg follower, sets the wholesale price. We employ the backward induction procedure to evaluate the hierarchical game structure among players.

Assumption 6. DT and TP systems are two important schemas considered in this study. In the DT schema, special tariffs are directly levied by the government (i.e., the regulator) on the products of GSCs and NGSCs. A DT may act as a subsidy to incentivize GSCs and compensate for the higher cost of green production, and it may act as a tax to penalize NGSCs in an effort to change their production behavior. In fact, DTs are assumed to be free decision variables whose positive values represent a subsidy and whose negative values represent a tax (such as a feed-in tariff in the energy market). By contrast, a green permit is a market-based, government-mandated schema, often termed as a carbon credit. In a TP schema, GSCs are granted permits in proportion to their production quantity. However, NGSCs must purchase permits from GSCs in a secondary market (i.e., independent of the product market). In both schemas, a minimum baseline can be considered, which is mandatory in most developed countries. This implies that a production lower than the baseline is allowed. However, a production that exceeds a baseline incurs a tariff or requires the purchase of permits.

4. The model formulation

We consider a competitive market between green and non-green types of a product which are partially sustainable. n_g GSCs and n_{ng} NGSCs produce green and non-green product types, respectively. The market is assumed to be oligopolistic, whereby the GSCs and NGSCs compete in terms of the product quantity. Each SC consists of one supplier and one retailer. We assume that the SCs are decentralized, i.e., the supplier and manufacturer of each SC make decisions independently to maximize their profit. As the leader player, the government has the authority to orchestrate the competition between GSCs and NGSCs. We aim to evaluate how the GSCs and NGSCs respond to the DT or TP scheme of the government. Figure 1 is a schematic diagram of the competition between the SCs under governmental intervention.

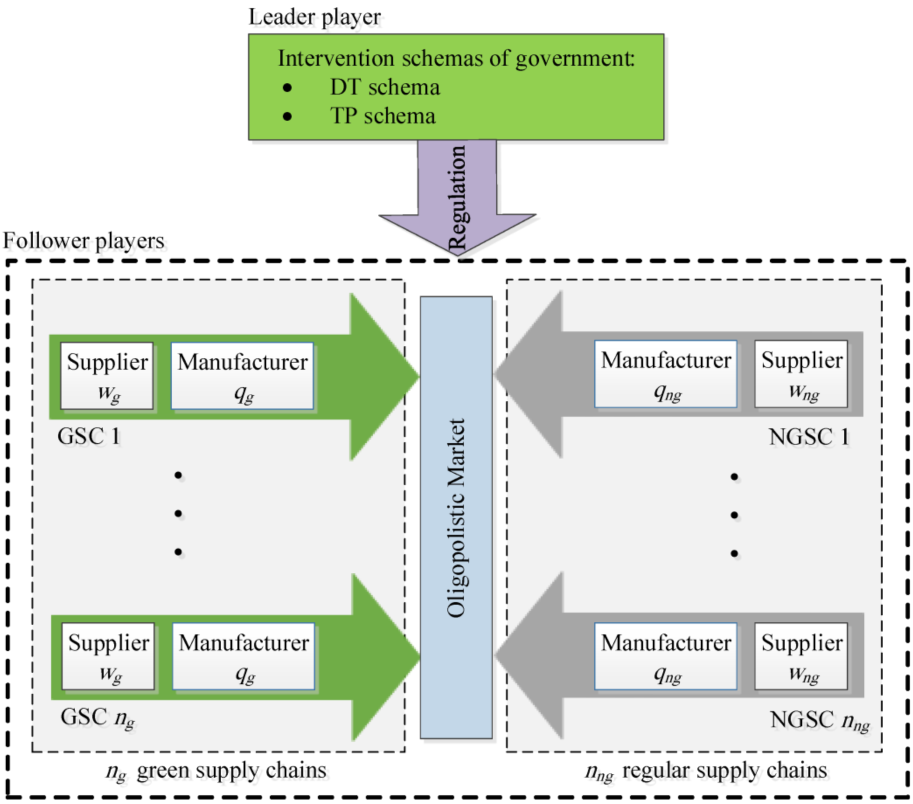

Fig. 1. Schematic representation of government intervention in the competition between GSCs and NGSCs.

The government may devise DT or TP schemas based on SC performance characteristics. In addition, the government may or may not consider baseline for intervention schemas. Figure 2 illustrates four scenarios obtained from the contrast between the DT and TP schemas of the government, with and without baselines. Governmental intervention in the form of a DT schema is more decisive than in the form of a TP schema. Additionally, the government directly intervenes in a competitive market when it determines a baseline for schemas.

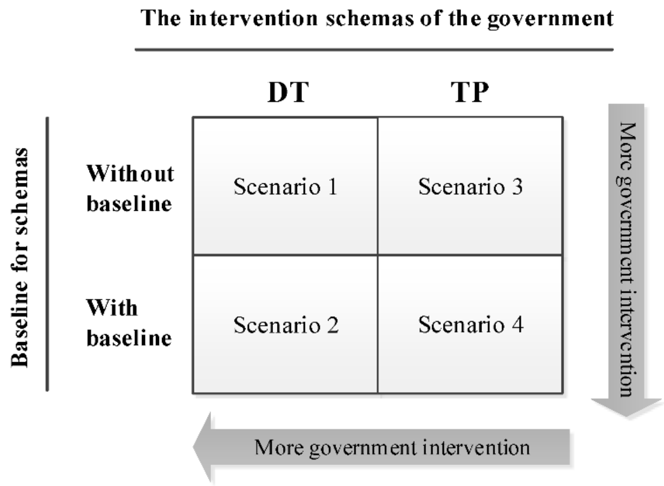

Fig. 2. The scenarios for government intervention.

In a DT schema, the tariffs levied by the government affect the primary market for products (i.e., the competitive market between GSCs and NGSCs). However, in a TP schema, permits can be traded in a secondary market between GSCs (i.e., TP suppliers) and NGSCs (TP demanders). Therefore, as illustrated in Fig. 1, the government indirectly supervises both the markets with TP schemas. However, it can only intervene in the primary market for products using a DT schema.

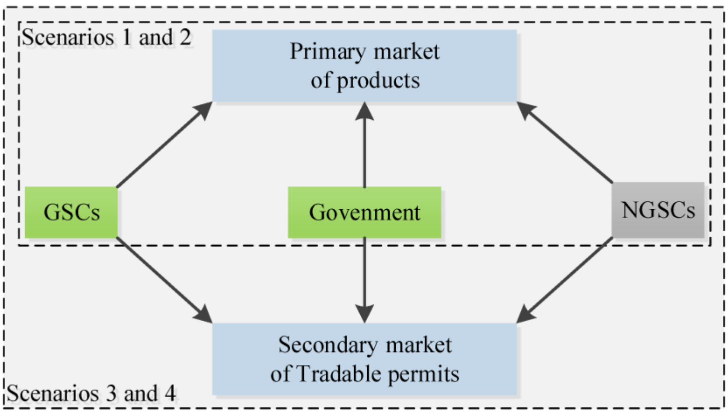

Fig 3. Primary and secondary markets in four scenarios.

Regarding the hierarchical decision-making structure of the agents shown in Fig. 3, we use backward induction as a solution concept to evaluate the game between the government and SCs. Thus, the production quantity of manufacturers is evaluated based on the wholesale price of suppliers and the government's intervention schema. Subsequently, the wholesale price of suppliers is investigated based on the governmental schema. Eventually, the optimum parameters of the governmental schema are examined. Figure 4 demonstrates the main steps of backward induction method and decision variables in each scenario.

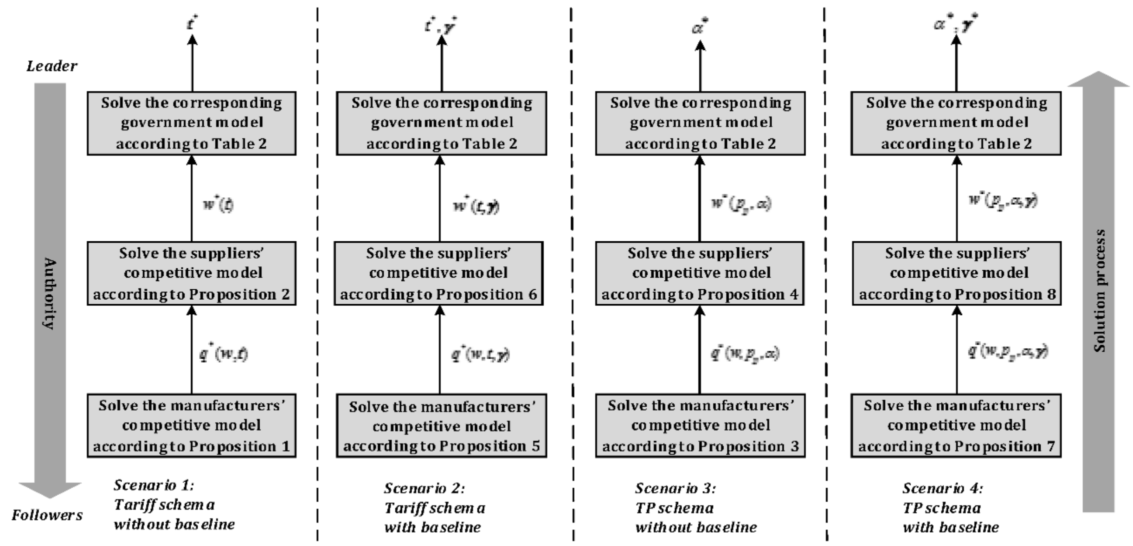

Fig. 4. The sequences of decision making in backward induction method in all the scenarios

4.1. The SCs interaction models

We develop four models for SCs interactions with regard to Fig. 2. For lucidity and convenience, we use the superscripts ''(1)'', "(2)", "(3)" and "(4)" to show Scenarios 1-4, respectively.

4.1.1. DT schema without baseline (Scenario 1)

In a competitive market, green and non-green manufacturers determine production quantities q_g and q_{ng} to maximize their profits. Thus, with regard to price function (1), manufacturer i determines quantity q_i to maximize its profit function as follows:

$$\begin{aligned}\pi_{M_i}(\boldsymbol{q},\boldsymbol{w},\boldsymbol{t}) &= (p_i - w_i)q_i + \theta_i t_i - c_i q_i - f_i \\ &= \left[a_i - b_i(n_i q_i + \lambda n_j q_j) + \theta_i t_i - w_i - c_i\right]q_i - f_i,\ \ i = ng, g,\ \ i \neq j.\end{aligned} \tag{2}$$

In profit function (2), we assume SC i pays (or receives depending on inherent tax or DT subsidy) a tariff t_i, whereby the shares of the manufacturer and the supplier are $\theta_i t_i$ and $(1-\theta_i)t_i$, respectively. According to Fig. 3, given the government's tariffs and the suppliers' wholesale prices, Theorem 1 presents the optimal production quantities.

Theorem 1. *In a competition between NGSCs and GSCs under a DT schema without a baseline, the optimal production quantities* $q_i^{(1)}(\boldsymbol{w},\boldsymbol{t}) = q_i^{(1)}$ *are as follows:*

$$q_i^{(1)}(\boldsymbol{w},\boldsymbol{t}) = \frac{A_i - 2b_j(w_i - \theta_i t_i) + \lambda b_i(w_j - \theta_j t_j)}{n_i E}, \tag{3}$$

in which $A_i = 2b_j(a_i - c_i) - \lambda b_i(a_j - c_j)$, $E = b_g b_{ng}(4-\lambda^2)$, $i, j = ng, g$ and $i \neq j$.

Appendix A presents the proof of all theorems. $q_i^{(1)}(\boldsymbol{w},\boldsymbol{t})$ represents the best response strategy of the manufacturer with respect to wholesale prices and tariffs. Obviously, negative production quantities are not allowed. Thus, throughout the paper, we should have $q_i^{(1)}(\boldsymbol{w},\boldsymbol{t})>0$. Substituting $q_i^{(1)}(\boldsymbol{w},\boldsymbol{t})$ into manufacturer's profit function (3), after mathematical simplifications, we have $\pi_{M_g}^{(1)}=n_g b_g\left(q_g^{(1)}\right)^2-f_g$ and $\pi_{M_{ng}}^{(1)}=n_{ng} b_{ng}\left(q_{ng}^{(1)}\right)^2-f_{ng}$.

Now, we study the suppliers' problem. In response to the government's tariffs, supplier i determines optimal wholesale price w_i to maximize

$$\pi_{s_i}(\boldsymbol{q},\boldsymbol{w},\boldsymbol{t})=\left[w_i+(1-\theta_i)t_i-C_i\right]q_i-F_i,\ i=ng,g,\ i\neq j, \tag{4}$$

in which $q_i=q_i^{(1)}$ is obtained based on Theorem 1. The suppliers' optimal wholesale prices are provided by Theorem 2.

Theorem 2. *In a competition between NGSCs and GSCs under a DT schema without a baseline, the optimal wholesale prices* $w_i^{(1)}(\boldsymbol{t})=w_i^{(1)}$ *of the suppliers are as follows:*

$$w_i^{(1)}(\boldsymbol{t})=\frac{\left\{\begin{array}{l}\lambda\left[A_j+2b_iC_j+2b_i(2\theta_j-1)t_j-\lambda b_j\theta_i t_i\right]\\ +4\left[A_i+2b_jC_i+2b_j(2\theta_i-1)t_i-\lambda b_i\theta_j t_j\right]\end{array}\right\}}{b_j(16-\lambda^2)},\ i=ng,g,\ i\neq j. \tag{5}$$

$w_i^{(1)}(\boldsymbol{t})$ represents the best response strategy of supplier i with respect to governmental tariffs. By substituting $w_{ng}^{(1)}$ and $w_g^{(1)}$ into the production quantity $q_i^{(1)}(\boldsymbol{w},\boldsymbol{t})$, after mathematical manipulation, we have the following:

$$q_i^{(1)}(\boldsymbol{t})=\frac{8A_i+2\lambda A_j-2b_j(8-\lambda^2)(C_i-t_i)+4b_i\lambda(C_j-t_j)}{n_iE(16-\lambda^2)},\ i=ng,g,\ i\neq j. \tag{6}$$

Moreover, the optimal price of product i can be obtained by substituting production quantity (6) into price function (1) which results in

$$p_i^{(1)}(\boldsymbol{t})=a_i-\frac{2b_i\left\{\begin{array}{l}(4+\lambda^2)A_i+5A_j-b_j(8-3\lambda^2)(C_i-t_i)\\ -b_i\lambda(6-\lambda^2)(C_j-t_j)\end{array}\right\}}{E(16-\lambda^2)},\ i=g,ng,\ i\neq j. \tag{7}$$

Table 1 summarizes the effects of the tariffs and number of SCs on the optimal production quantities, production quantities, and profits of manufacturers in a competitive market. Table 1 illustrates that an increase in tariff t_i (i.e., more government support) increases optimal production quantity $q_i^{(1)}$ and optimal manufacturer profit $\pi_{M_i}^{(1)}$.

However, this increase in the tariff adversely affects rival SCs. Because high-level of government support increases the profit of manufacturers, it may incline new SCs to enter the market. Table 1 denotes that $q_i^{(1)}$ and $\pi_{M_i}^{(1)}$ are decreasing functions of n_i. Thus, expanding the number of one type of SC decreases the production quantity of each SC and the corresponding manufacturer profit.

Table 1. Sensitivity analyses on the quantity, prices, and profit ($i = ng, g$ and $i \neq j$).

	$q_i^{(1)}$	$w_i^{(1)}$	$p_i^{(1)}$	$\pi_{M_i}^{(1)}$
$\frac{\partial}{\partial t_i}$	$\frac{2b_j(8-\lambda^2)}{n_i E(16-\lambda^2)} \geq 0$	$\theta_i - \frac{8}{16-\lambda^2} (\pm)$	$\frac{-2b_i b_j(8-3\lambda^2)}{E(16-\lambda^2)} \leq 0$	$\frac{2b_j(8-\lambda^2)q_i^{(1)}}{E(16-\lambda^2)} \geq 0$
$\frac{\partial}{\partial t_j}$	$\frac{-4b_i\lambda}{n_i E(16-\lambda^2)} \leq 0$	$\frac{-\lambda b_i}{b_j(16-\lambda^2)} \leq 0$	$\frac{-2b_i^2(6-\lambda^2)}{E(16-\lambda^2)} \leq 0$	$\frac{-4b_i\lambda q_i^{(1)}}{E(16-\lambda^2)} \leq 0$
$\frac{\partial}{\partial n_i}$	$\frac{-q_i^{(1)}}{n_i} < 0$	0	0	$-(q_i^{(1)})^2 \leq 0$
$\frac{\partial}{\partial n_j}$	0	0	0	0

Corollary 1. *The government is able to directly orchestrate the equilibrium production quantities of GSCs and NGSCs by levying an appropriate tariff in the competitive market. Additionally, because the profit of producers is directly affected by the DT schema, the business attractiveness of GSCs and NGSCs is changed by tariffs imposed by the government.*

Government involvement increases if the government uses a DT schema that may not be preferred in societies in which the government faces limitations regarding direct market intervention. In fact, the DT schema suffers from two drawbacks. First, in a DT schema, the government financially intervenes in a market in a direct manner because it directly pumps money to GSCs. If this money is not collected from the NGSCs of that sector, the government must obtain the budget from the remainder of the economy. Consequently, a DT schema should be carefully implemented using a holistic approach to the overall economy. Second, the market price of a product increases when a tax is imposed by the government (see Table 1); therefore, a portion of the government penalties is directly transferred to the consumer. This effect may offset the impact of a tariff on changing the behavior of RGSs; thus, a tariff should be carefully imposed by the government with regard to its effects on market prices and pollution reduction.

4.1.2. DT schema with baseline (Scenario 2)

In this section, we investigate the effects of baselines on the government DT schema (i.e., Scenario 1). The direct intervention of the government through a DT schema in Scenario 1 increases if the government applies baselines γ_g and γ_{ng} for tariffs. A baseline for a tariff is a threshold for tariff exemption. That is, γ_i refers to a production quantity threshold for product type i that provides complete relief from the tariff. Thus, the tariff is only considered for the $q_i - \gamma_i$ quantity. We note that the DT schema becomes ineffective and government's decisive role is eliminated if $q_i \le \gamma_i$. Hence, the government should note that $q_i > \gamma_i$ in this schema. Considering tariff exemptions $\boldsymbol{\gamma} = (\gamma_g, \gamma_{ng})$, profit function (2) for manufacturer i is transformed as follows:

$$\begin{aligned}\pi_{M_i}(\boldsymbol{q},\boldsymbol{w},\boldsymbol{t},\boldsymbol{\gamma}) &= (p_i - w_i)q_i + \theta_i t_i (q_i - \gamma_i) - c_i q_i - f_i \\ &= \left[a_i - b_i(n_i q_i + \lambda n_j q_j) + \theta_i t_i - w_i - c_i\right] q_i - \theta_i t_i \gamma_i - f_i,\ i = ng, g,\ i \ne j.\end{aligned} \tag{8}$$

According to Fig. 3, for given $\boldsymbol{w}$, $\boldsymbol{t}$, and $\boldsymbol{\gamma}$, Theorem 3 demonstrates the equilibrium production quantity of the manufacturers in this scenario.

Theorem 3. *In a competition between NGSCs and GSCs, the optimal production quantity under a DT schema with a baseline equals the optimal production quantity under a DT schema without a baseline,* i.e.,

$$q_i^{(2)}(\boldsymbol{w},\boldsymbol{t},\boldsymbol{\gamma}) = q_i^{(1)}(\boldsymbol{w},\boldsymbol{t}),\ i = ng, g,\ i \ne j. \tag{9}$$

Similar to Scenario 1, substituting $q_i^{(2)}(\boldsymbol{w},\boldsymbol{t},\boldsymbol{\gamma})$ in the manufacturer's profit function (8) yields (after mathematical simplifications) $\pi_{M_i}^{(2)} = n_i b_i \left(q_i^{(2)}\right)^2 - \theta_i t_i \gamma_i - f_i$. Now, we evaluate the supplier problem. In response to $\boldsymbol{t}$ and $\boldsymbol{\gamma}$ imposed by the government, supplier i sets the optimal wholesale price w_i to maximize

$$\pi_{s_i}(\boldsymbol{q},\boldsymbol{w},\boldsymbol{t}) = \left[w_i + (1-\theta_i)t_i - C_i\right] q_i - (1-\theta_i) t_i \gamma_i - F_i,\ i = ng, g,\ i \ne j, \tag{10}$$

in which $q_i = q_i^{(1)} = q_i^{(2)}$ is obtained from Theorem 3. Theorem 4 provides the suppliers' optimal wholesale prices.

Theorem 4. *In a competition between NGSCs and GSCs, the optimal wholesale price under a DT schema with a baseline equals to the optimal wholesale price under a DT schema without a baseline,* i.e.,

$$w_i^{(2)}(\boldsymbol{t},\boldsymbol{\gamma}) = w_i^{(1)}(\boldsymbol{t}),\ i = ng, g,\ i \ne j. \tag{11}$$

Since the wholesale prices and production quantities in the DT schema are not affected from exemption $\boldsymbol{\gamma}$, it is concluded (in a similar way as Scenario 1) that

$$q_i^{(2)}(\boldsymbol{t},\boldsymbol{\gamma}) = q_i^{(1)}(\boldsymbol{t}) = \frac{8A_i + 2\lambda A_j - 2b_j(8-\lambda^2)(C_i - t_i) + 4b_i\lambda(C_j - t_j)}{n_i E(16-\lambda^2)},\ i = ng, g,\ i \ne j, \tag{12}$$

$$p_i^{(2)}(\boldsymbol{t},\boldsymbol{\gamma}) = p_i^{(1)}(\boldsymbol{t}) = a_i - \frac{2b_i \begin{Bmatrix} (4+\lambda^2)A_i + 5A_j - b_j(8-3\lambda^2)(C_i - t_i) \\ -b_i\lambda(6-\lambda^2)(C_j - t_j) \end{Bmatrix}}{E(16-\lambda^2)}, \; i = g, ng, \; i \neq j. \quad (13)$$

Corollary 2 draws a comparison between the results of Scenarios 1 and 2.

Corollary 2. *Although the tariff exemptions do not affect the equilibrium production quantity and wholesale price of GSCs and NGSCs, they directly affect the profit of manufacturers and suppliers. Therefore, the government can levy a financial penalty or offer an incentive for SC participants without affecting the market equilibrium of production quantities.*

4.1.3. TP schema without baseline (Scenario 3)

This section focuses on modeling the competition between NGSCs and GSCs under a TP schema. A TP schema involves the assignment of permits to GSCs proportional to their output, the trade of permits independent of the product (e.g., in a secondary market) and the fulfillment of a quota by submitting TPs. In this schema, the NGSCs bear the cost of the green production of the GSCs. In fact, for each unit of the non-green product manufactured by an NGSC, the GSC should surrender α permit units, each of which has value a p_p. Therefore, the manufacturer in NGSC sets the production quantity which maximizes the following profit function:

$$\begin{aligned} \pi_{M_{ng}}(\boldsymbol{q},\boldsymbol{w},p_p,\alpha) &= (p_{ng} - w_{ng})q_{ng} - c_{ng}q_{ng} - \alpha\beta_{ng}p_p q_{ng} - f_{ng} \\ &= \left[a_{ng} - b_{ng}(n_{ng}q_{ng} + \lambda n_g q_g) - w_{ng} - c_{ng} - \alpha\beta_{ng}p_p\right]q_{ng} - f_{ng}. \end{aligned} \quad (14)$$

For each product unit, the GSC can now earn p_p in addition to its profit margin. However, under the quota requirement, the GSC must also surrender a unit of permit when it vends a green product. Thus, the manufacturer in a GSC determines the production quantity that maximizes the following profit function:

$$\begin{aligned} \pi_{M_g}(\boldsymbol{q},\boldsymbol{w},p_c,\alpha) &= (p_g - w_g + \beta_g p_p)q_g - c_g q_g - \alpha\beta_g p_p q_g - f_g \\ &= \left[a_g - b_g(n_g q_g + \lambda n_{ng}q_{ng}) - w_g - c_g + (1-\alpha)\beta_g p_p\right]q_g - f_g. \end{aligned} \quad (15)$$

In profit functions (14) and (15), it is assumed that the cost and profit of the TP schema can be shared between members of the NGSCs and GSCs in proportions β_{ng} and β_g, respectively. According to Fig. 3, given the government's quota and the suppliers' wholesale prices, Theorem 5 provides the manufacturers' optimal quantities.

Theorem 5. *In a competition between the NGSCs and GSCs under a TP schema without a baseline, the optimal production quantities* $q_i^{(3)}(\boldsymbol{w},p_p,\alpha) = q_i^{(3)}$ *where* $i = ng, g$, *are as follows:*

$$q_g^{(3)}(\boldsymbol{w}, p_p, \alpha) = \frac{A_g - 2b_{ng}(w_g - (1-\alpha)\beta_g p_p) + \lambda b_g(w_{ng} + \alpha\beta_{ng} p_p)}{n_g E}, \tag{16}$$

$$q_r^{(3)}(\boldsymbol{w}, p_p, \alpha) = \frac{A_{ng} - 2b_g(w_{ng} + \alpha\beta_{ng} p_p) + \lambda b_{ng}(w_g - (1-\alpha)\beta_g p_p)}{n_{ng} E}. \tag{17}$$

$q_i^{(3)}(\boldsymbol{w}, p_p, \alpha)$ denotes the best response strategy of the manufacturer regarding the wholesale prices, permit price, and quota. We assume $q_i^{(3)}(\boldsymbol{w}, p_p, \alpha) > 0$ throughout the study. Substituting $q_i^{(3)}(\boldsymbol{w}, p_p, \alpha)$ into manufacturer's profit functions (14) and (15), after some mathematical simplifications, yields $\pi_{M_g}^{(3)} = n_g b_g \left(q_g^{(3)}\right)^2 - f_g$ and $\pi_{M_{ng}}^{(3)} = n_{ng} b_{ng} \left(q_{ng}^{(3)}\right)^2 - f_{ng}$.

We now evaluate the suppliers' problem. Given the government's quota, suppliers set the wholesale price to maximize the corresponding profits as follows:

$$\pi_{s_{ng}}(\boldsymbol{w}, p_p, \alpha) = \left[w_{ng} - C_{ng} - \alpha(1-\beta_{ng}) p_p\right] q_{ng} - F_{ng}, \tag{18}$$

$$\pi_{s_g}(\boldsymbol{w}, p_p, \alpha) = \left[w_g - C_g + (1-\alpha)(1-\beta_g) p_p\right] q_g - F_g, \tag{19}$$

in which $q_g = q_g^{(3)}$ and $q_{ng} = q_{ng}^{(3)}$ are achieved from Theorem 5. The suppliers' optimal wholesale prices are provided by Theorem 6.

Theorem 6. *In a competition between the NGSCs and GSCs under a TP schema without a baseline, the optimal wholesale prices of green and non-green suppliers are as follows:*

$$w_g^{(3)}(p_p, \alpha) = \frac{\lambda A'_{ng} + 4A'_g + \left(\lambda B_{ng} + 4B_g\right) p_p}{b_{ng}(16 - \lambda^2)}, \tag{20}$$

$$w_{ng}^{(3)}(p_p, \alpha) = \frac{\lambda A'_g + 4A'_{ng} + \left(\lambda B_g + 4B_{ng}\right) p_p}{b_g(16 - \lambda^2)}, \tag{21}$$

in which $A'_{ng} = A_{ng} + 2b_g C_{ng}$, $A'_g = A_g + 2b_{ng} C_g$, $B_{ng} = 2\alpha(1-2\beta_{ng}) b_g - \lambda(1-\alpha)\beta_g b_{ng}$, and $B_g = 2(1-\alpha)(2\beta_g - 1) b_{ng} + \lambda\alpha\beta_{ng} b_g$.

Substituting $w_{ng}^{(3)}$ and $w_g^{(3)}$ into the production quantities $q_g^{(3)}(\boldsymbol{w}, p_p, \alpha)$ and $q_{ng}^{(3)}(\boldsymbol{w}, p_p, \alpha)$, Eqs. (16) and (17), after some mathematical manipulations, we have:

$$q_g^{(3)}(p_p, \alpha) = \frac{A_g + \left[2(1-\alpha)\beta_g b_{ng} + \lambda\alpha\beta_{ng} b_g\right] p_p}{n_g E} + \frac{2\lambda(A'_{ng} + B_{ng} p_p) - (8 - \lambda^2)(A'_g + B_g p_p)}{n_g(16 - \lambda^2)}, \tag{22}$$

$$q_{ng}^{(3)}(p_p, \alpha) = \frac{A_{ng} + \left[2\alpha\beta_{ng} b_g - \lambda(1-\alpha)\beta_g b_{ng}\right] p_p}{n_{ng} E} + \frac{2\lambda(A'_g + B_g p_p) - (8 - \lambda^2)(A'_{ng} + B_{ng} p_p)}{n_{ng}(16 - \lambda^2)}. \tag{23}$$

The green quota condition is an important environmental policy of the government. It states that the proportion of a green product in a competitive market (i.e., its market share) should not be less than α. Thus, the green quota condition can be mathematically expressed as follows:

$$\sum_{i=1}^{n_g} q_g^i \ge \alpha Q. \tag{24}$$

We note that the market equilibrium condition for the TP satisfies green quota condition (24) at the equilibrium status. In fact, the total TP quantity supply of GSCs is $n_g(1-\alpha)q_g$, and the total TP quantity demand of NGSCs is $n_{ng}\alpha q_{ng}$. Therefore, the TP market equilibrium can be expressed as $n_g(1-\alpha)q_g = n_{ng}\alpha q_{ng}$, which can be transformed into $n_g q_g = \alpha(n_g q_g + n_{ng}q_{ng}) \Rightarrow \sum_{i=1}^{n_g} q_g^i = \alpha Q$. For the secondary TP market, Corollary 3 states that the permit price in competition between the GSCs and NGSCs can be identified such that the green quota condition determined by the government is satisfied at the equilibrium condition.

Theorem 7. *In the TP market equilibrium, the equilibrium permit price for a given* α *is as follows:*

$$p_p^{(3)} = \frac{A'_{ng}\left[2\lambda(1-\alpha)+\alpha(8-\lambda^2)\right] - A'_g\left[(1-\alpha)(8-\lambda^2)+2\lambda\alpha\right] + \left[(1-\alpha)A_g - \alpha A_{ng}\right](16-\lambda^2)}{B_g\left[(1-\alpha)(8-\lambda^2)+2\lambda\alpha\right] - B_{ng}\left[2\lambda(1-\alpha)+\alpha(8-\lambda^2)\right] - \left[(1-\alpha)\beta_g b_{ng}\left[2(1-\alpha)+\lambda\alpha\right] + \alpha\beta_{ng}b_g\left[\lambda(1-\alpha)-2\alpha\right]\right](16-\lambda^2)}. \tag{25}$$

From Theorem 7, we find that in the TP schema, the government can only set a quota for the green and non-green products and that the permit price is determined by the supply and demand equilibrium.

Corollary 3. *In the TP schema, government involvement in the market becomes minimal. However, the government still has the authority to indirectly orchestrate the production quantities by the quota condition. Contrary to the DT schema, the TP schema can be appropriate in societies in which direct financial intervention by the government is not preferred.*

4.1.4. TP schema with baseline (Scenarios 4)

The government intervention in the competition of GSCs and NGSCs increases as the government establishes a baseline for the TP schema. Now, we study the TP schema explained in Scenario 3 with the exemption quantity thresholds for the competition between GSCs and NGSCs. In this schema, the government sets baselines γ_g and γ_{ng} for trading permits. Thus, production quantities that exceed these baselines require trading permits. In fact, the TP schema defined in Scenario 3 is only applied to the SCs production quantities $q_g - \gamma_g$ and $q_{ng} - \gamma_{ng}$. In this schema, the baselines become ineffective if $q_i \le \gamma_i$. Therefore, the government should consider $q_i > \gamma_i$. Regarding baselines $\boldsymbol{\gamma} = (\gamma_g, \gamma_{ng})$ for a TP, profit function (14) for a non-green manufacturer is transformed into the following:

$$\begin{aligned}\pi_{M_{ng}}(\boldsymbol{q},\boldsymbol{w},p_p,\alpha) &= (p_{ng} - w_{ng})q_{ng} - c_{ng}q_{ng} - \alpha\gamma_{ng}p_p(q_{ng} - \gamma_{ng}) - f_{ng} \\ &= \left[a_{ng} - b_{ng}(n_{ng}q_{ng} + \lambda n_g q_g) - w_{ng} - c_{ng} - \alpha\beta_{ng}p_p\right]q_{ng} - \alpha\gamma_{ng}p_p\gamma_{ng} - f_{ng}.\end{aligned} \tag{26}$$

Profit function (26) states that the green manufacturer should purchase a TP for $q_{ng} - \gamma_{ng}$ production quantity. Considering an exemption quantity threshold of γ_g, the procedure of the TP schema (similar to Scenario 3) should be performed for the quantity $q_g - \gamma_g$ of the GSC products. Therefore, profit function (15) for a green manufacturer is changed as follows:

$$\begin{aligned}\pi_{M_g}(\boldsymbol{q},\boldsymbol{w},p_p,\alpha) &= (p_g - w_g) + \beta_g p_p(q_g - \gamma_g) - c_g q_g - \alpha\beta_g p_p(q_g - \gamma_g) - f_g \\ &= \left[a_g - b_g(n_g q_g + \lambda n_{ng}q_{ng}) - w_g - c_g + (1-\alpha)\beta_g p_p\right]q_g - (1-\alpha)\beta_g p_p \gamma_g - f_g.\end{aligned} \tag{27}$$

Theorem 8 provides the manufacturers' equilibrium production quantity for a given $\boldsymbol{w}$, p_p, and $\boldsymbol{\gamma}$.

Theorem 8. *In a competition between the NGSCs and GSCs under a TP schema with a baseline, the optimal production quantities of the manufacturers are as follows:*

$$q_g^{(4)}(\boldsymbol{w},p_p,\alpha,\boldsymbol{\gamma}) = \frac{A_g - 2b_{ng}(w_g - (1-\alpha)\beta_g p_p) + \lambda b_g(w_{ng} + \alpha\beta_{ng}p_p)}{n_g E}, \tag{28}$$

$$q_{ng}^{(4)}(\boldsymbol{w},p_p,\alpha,\boldsymbol{\gamma}) = \frac{A_{ng} - 2b_g(w_{ng} + \alpha\beta_{ng}p_p) + \lambda b_{ng}(w_g - (1-\alpha)\beta_g p_p)}{n_{ng}E}. \tag{29}$$

The suppliers' problem for a TP schema with a baseline can be developed based on suppliers' profit functions (18) and (19) as follows:

$$\pi_{s_{ng}}(\boldsymbol{w},p_p,\alpha,\boldsymbol{\gamma}) = \left[w_{ng} - C_{ng} - \alpha(1-\beta_{ng})p_p\right]q_{ng} - \alpha\beta_{ng}p_p\gamma_{ng} - F_{ng}, \tag{30}$$

$$\pi_{s_g}(\boldsymbol{w},p_p,\alpha,\boldsymbol{\gamma}) = \left[w_g - C_g + (1-\alpha)(1-\beta_g)p_p\right]q_g - (1-\alpha)(1-\beta_g)p_p\gamma_g - F_g. \tag{31}$$

in which $q_g = q_g^{(4)}$ and $q_{ng} = q_{ng}^{(4)}$ are obtained from Theorem 7. Theorem 9 gives the suppliers' optimal wholesale prices.

Theorem 9. *In a competition between the NGSCs and GSCs under a TP schema with a baseline, the optimal wholesale prices of green and non-green suppliers are as follows:*

$$w_g^{(4)}(p_p,\alpha,\boldsymbol{\gamma}) = \frac{\lambda A'_{ng} + 4A'_g + \left(\lambda B_{ng} + 4B_g\right)p_p}{b_{ng}(16-\lambda^2)}, \tag{32}$$

$$w_{ng}^{(4)}(p_p,\alpha,\boldsymbol{\gamma}) = \frac{\lambda A'_g + 4A'_{ng} + \left(\lambda B_g + 4B_{ng}\right)p_p}{b_g(16-\lambda^2)}. \tag{33}$$

Similar to Eqs. (22) and (23), the optimal production quantities $q_g^{(4)}(\boldsymbol{w}, p_p, \alpha, \boldsymbol{\gamma})$ and $q_{ng}^{(4)}(\boldsymbol{w}, p_p, \alpha, \boldsymbol{\gamma})$ can be rewritten in the forms of $q_g^{(4)}(p_p, \alpha, \boldsymbol{\gamma})$ and $q_{ng}^{(4)}(p_p, \alpha, \boldsymbol{\gamma})$ by substituting $w_{ng}^{(4)}$ and $w_g^{(4)}$. Because the total supply and demand for TPs in the secondary market are $n_g(1-\alpha)(q_g^{(4)} - \gamma_g)$ and $n_{ng}\alpha(q_{ng}^{(4)} - \gamma_{ng})$, respectively, the equilibrium price of permits can be found through Theorem 10.

Theorem 10. *In the market equilibrium of a TP with a baseline, the equilibrium permit price for a given* α *is as follows:*

$$p_p^{(4)} = \frac{A'_{ng}\left[2\lambda(1-\alpha)+\alpha(8-\lambda^2)\right] - A'_g\left[(1-\alpha)(8-\lambda^2)+2\lambda\alpha\right] + \left[\left[(1-\alpha)A_g - \alpha A_{ng}\right] + E\left[\alpha n_{ng}\gamma_{ng} - (1-\alpha)n_g\gamma_g\right]\right](16-\lambda^2)}{B_g\left[(1-\alpha)(8-\lambda^2)+2\lambda\alpha\right] - B_{ng}\left[2\lambda(1-\alpha)+\alpha(8-\lambda^2)\right] - \left[(1-\alpha)\beta_g b_{ng}\left[2(1-\alpha)+\lambda\alpha\right] + \alpha\beta_{ng}b_g\left[\lambda(1-\alpha)-2\alpha\right]\right](16-\lambda^2)}. \tag{34}$$

From Theorem 10, we find that the permit prices in Scenarios 3 and 4 may differ, i.e., $p_p^{(4)} \neq p_p^{(3)}$. Although the formulations of production quantity and wholesale price in Scenarios 3 and 4 are similar, we have $q_i^{(4)}(\boldsymbol{w}, p_p, \alpha, \boldsymbol{\gamma}) \neq q_i^{(3)}(\boldsymbol{w}, p_p, \alpha)$ and $w_i^{(4)}(\boldsymbol{w}, p_p, \alpha, \boldsymbol{\gamma}) \neq w_i^{(3)}(\boldsymbol{w}, p_p, \alpha)$ because $p_p^{(4)} \neq p_p^{(3)}$. Corollary 4 explicates this finding.

Corollary 4. *In contrast to a DT schema in which exemption does not alter the best response strategies of SCs, exemption* $\boldsymbol{\gamma}$ *changes the best response strategies of SCs* (i.e., $\boldsymbol{q}$ *and* $\boldsymbol{w}$) *in a TP schema. Therefore, by determining the appropriate baselines for a TP schema, the government can indirectly orchestrate SC production quantities.*

Table 1 summarizes the optimal wholesale (market) prices, production quantities, and profits of the manufacturers and retailers in different scenarios.

Table 1. Production quantities, wholesale price and market prices, and SC's member profits under different scenarios.

	Scenarios for government intervention			
	DT without baseline	DT with baseline	TP without baseline	TP with baseline
q_g	$\frac{\left\{\begin{matrix}8A_g+2\lambda A_{ng}-2b_{ng}(8-\lambda^2)(C_g-t_g)\\ +4b_g\lambda(C_{ng}-t_{ng})\end{matrix}\right\}}{n_gE(16-\lambda^2)}$	$\frac{\left\{\begin{matrix}8A_g+2\lambda A_{ng}-2b_{ng}(8-\lambda^2)(C_g-t_g)\\ +4b_g\lambda(C_{ng}-t_{ng})\end{matrix}\right\}}{n_gE(16-\lambda^2)}$	$\frac{A_g+\left[2(1-\alpha)\beta_g b_{ng}+\lambda\alpha\beta_{ng}b_g\right]p_p}{n_gE}+$ $\frac{2\lambda(A'_{ng}+B_{ng}p_p)(2b_g^2-b_{rng}^2)+(A'_g+B_gp_p)(\lambda^2b_g^2-8b_{ng}^2)}{n_gb_{ng}b_g(16-\lambda^2)}$	$\frac{A_g+\left[2(1-\alpha)\beta_g b_{ng}+\lambda\alpha\beta_{ng}b_g\right]p_p}{n_gE}+$ $\frac{2\lambda(A'_{ng}+B_{ng}p_p)(2b_g^2-b_{ng}^2)+(A'_g+B_gp_p)(\lambda^2b_g^2-8b_{ng}^2)}{n_gb_{ng}b_g(16-\lambda^2)}$
q_{ng}	$\frac{\left\{\begin{matrix}8A_{ng}+2\lambda A_g-2b_g(8-\lambda^2)(C_{ng}-t_{ng})\\ +4b_{ng}\lambda(C_g-t_g)\end{matrix}\right\}}{n_{ng}E(16-\lambda^2)}$	$\frac{\left\{\begin{matrix}8A_{ng}+2\lambda A_g-2b_g(8-\lambda^2)(C_{ng}-t_{ng})\\ +4b_{ng}\lambda(C_g-t_g)\end{matrix}\right\}}{n_{ng}E(16-\lambda^2)}$	$\frac{A_{ng}+\left[2\alpha\beta_{ng}b_g-\lambda(1-\alpha)\beta_g b_{ng}\right]p_p}{n_{ng}E}+$ $\frac{2\lambda(A'_g+B_gp_p)(2b_{ng}^2-b_g^2)+(A'_{ng}+B_{ng}p_p)(\lambda^2b_{ng}^2-8b_g^2)}{n_{ng}b_{ng}b_g(16-\lambda^2)}$	$\frac{A_{ng}+\left[2\alpha\beta_{ng}b_g-\lambda(1-\alpha)\beta_g b_{ng}\right]p_p}{n_{ng}E}+$ $\frac{2\lambda(A'_g+B_gp_p)(2b_{ng}^2-b_g^2)+(A'_{ng}+B_{ng}p_p)(\lambda^2b_{ng}^2-8b_g^2)}{n_{ng}b_{ng}b_g(16-\lambda^2)}$
w_g	$\frac{\left\{\begin{matrix}\lambda\left[A_{ng}+2b_gC_{ng}+2b_g(2\theta_{ng}-1)t_{ng}-\lambda b_{ng}\theta_gt_g\right]\\ +4\left[A_g+2b_{ng}C_g+2b_{ng}(2\theta_g-1)t_g-\lambda b_g\theta_{ng}t_{ng}\right]\end{matrix}\right\}}{b_{ng}(16-\lambda^2)}$	$\frac{\left\{\begin{matrix}\lambda\left[A_{ng}+2b_gC_{ng}+2b_g(2\theta_{ng}-1)t_{ng}-\lambda b_{ng}\theta_gt_g\right]\\ +4\left[A_g+2b_{ng}C_g+2b_{ng}(2\theta_g-1)t_g-\lambda b_g\theta_{ng}t_{ng}\right]\end{matrix}\right\}}{b_{ng}(16-\lambda^2)}$	$\frac{\lambda A'_{ng}+4A'_g+\left(\lambda B_{ng}+4B_g\right)p_p}{b_{ng}(16-\lambda^2)}$	$\frac{\lambda A'_{ng}+4A'_g+\left(\lambda B_{ng}+4B_g\right)p_p}{b_{ng}(16-\lambda^2)}$
w_{ng}	$\frac{\left\{\begin{matrix}\lambda\left[A_g+2b_{ng}C_g+2b_{ng}(2\theta_g-1)t_g-\lambda b_g\theta_{ng}t_{ng}\right]\\ +4\left[A_{ng}+2b_gC_{ng}+2b_g(2\theta_{ng}-1)t_{ng}-\lambda b_{ng}\theta_gt_g\right]\end{matrix}\right\}}{b_g(16-\lambda^2)}$	$\frac{\left\{\begin{matrix}\lambda\left[A_g+2b_{ng}C_g+2b_{ng}(2\theta_g-1)t_g-\lambda b_g\theta_{ng}t_{ng}\right]\\ +4\left[A_{ng}+2b_gC_{ng}+2b_g(2\theta_{ng}-1)t_{ng}-\lambda b_{ng}\theta_gt_g\right]\end{matrix}\right\}}{b_g(16-\lambda^2)}$	$\frac{\lambda A'_g+4A'_{ng}+\left(\lambda B_g+4B_{ng}\right)p_p}{b_g(16-\lambda^2)}$	$\frac{\lambda A'_g+4A'_{ng}+\left(\lambda B_g+4B_{ng}\right)p_p}{b_g(16-\lambda^2)}$
p_g	$a_g-\frac{2b_g\left\{\begin{matrix}(4+\lambda^2)A_g+5A_{ng}-b_r(8-3\lambda^2)(C_g-t_g)\\ -b_g\lambda(6-\lambda^2)(C_{ng}-t_{ng})\end{matrix}\right\}}{E(16-\lambda^2)}$	$a_g-\frac{2b_g\left\{\begin{matrix}(4+\lambda^2)A_g+5A_{ng}-b_{ng}(8-3\lambda^2)(C_g-t_g)\\ -b_g\lambda(6-\lambda^2)(C_{ng}-t_{ng})\end{matrix}\right\}}{E(16-\lambda^2)}$	$a_g-b_g(n_gq_g^{(3)}+\lambda n_{ng}q_{ng}^{(3)})$	$a_g-b_g(n_gq_g^{(4)}+\lambda n_{ng}q_{ng}^{(4)})$
p_{ng}	$a_{ng}-\frac{2b_{ng}\left\{\begin{matrix}(4+\lambda^2)A_{ng}+5A_g-b_g(8-3\lambda^2)(C_{ng}-t_{ng})\\ -b_{ng}\lambda(6-\lambda^2)(C_g-t_g)\end{matrix}\right\}}{E(16-\lambda^2)}$	$a_{ng}-\frac{2b_{ng}\left\{\begin{matrix}(4+\lambda^2)A_{ng}+5A_g-b_g(8-3\lambda^2)(C_{ng}-t_{ng})\\ -b_{ng}\lambda(6-\lambda^2)(C_g-t_g)\end{matrix}\right\}}{E(16-\lambda^2)}$	$a_{ng}-b_{ng}(n_{ng}q_{ng}^{(3)}+\lambda n_gq_g^{(3)})$	$a_{ng}-b_{ng}(n_{ng}q_{ng}^{(4)}+\lambda n_gq_g^{(4)})$
π_{M_g}	$n_gb_g\left(q_g^{(1)}\right)^2-f_g$	$n_gb_g\left(q_g^{(2)}\right)^2-\theta_gt_g\gamma_g-f_g$	$\left[p_g^{(3)}-w_g^{(3)}-c_g+(1-\alpha)\beta_gp_p^{(3)}\right]q_g^{(3)}-f_g$	$\left[p_g^{(4)}-w_g-c_g+(1-\alpha)\beta_gp_p^{(4)}\right]q_g^{(4)}-(1-\alpha)\beta_gp_p^{(4)}\gamma_g-f_g$
$\pi_{M_{ng}}$	$n_{ng}b_{ng}\left(q_{ng}^{(1)}\right)^2-f_{ng}$	$n_{ng}b_{ng}\left(q_{ng}^{(2)}\right)^2-\theta_{ng}t_{ng}\gamma_{ng}-f_{ng}$	$\left[p_{ng}^{(3)}-w_{ng}^{(3)}-c_{ng}-\alpha\beta_{ng}p_p^{(3)}\right]q_{ng}^{(3)}-f_{ng}$	$\left[p_{ng}^{(4)}-w_{ng}-c_{ng}-\alpha\beta_{ng}p_p^{(4)}\right]q_{ng}^{(4)}-\alpha\gamma_{ng}p_p^{(4)}\gamma_{ng}-f_{ng}$
π_{S_g}	$\left[w_g^{(1)}+(1-\theta_g)t_g-C_g\right]q_g^{(1)}-F_g$	$\left[w_g^{(2)}+(1-\theta_g)t_g-C_g\right]q_g^{(2)}-(1-\theta_g)t_g\gamma_g-F_g$	$\left[w_g^{(3)}-C_g+(1-\alpha)(1-\beta_g)p_p^{(3)}\right]q_g^{(3)}-F_g$	$\left[w_g^{(4)}-C_g+(1-\alpha)(1-\beta_g)p_p^{(4)}\right]q_g^{(4)}-(1-\alpha)(1-\beta_g)p_p^{(4)}\gamma_g-F_g$
$\pi_{S_{ng}}$	$\left[w_{ng}^{(1)}+(1-\theta_{ng})t_{ng}-C_{ng}\right]q_{ng}^{(1)}-F_{ng}$	$\left[w_{ng}^{(2)}+(1-\theta_{ng})t_{ng}-C_{ng}\right]q_{ng}^{(2)}-(1-\theta_{ng})t_{ng}\gamma_{ng}-F_{ng}$	$\left[w_{ng}^{(3)}-C_{ng}-\alpha(1-\beta_{ng})p_p^{(3)}\right]q_{ng}^{(3)}-F_{ng}$	$\left[w_{ng}^{(4)}-C_{ng}-\alpha(1-\beta_{ng})p_p^{(4)}\right]q_{ng}^{(4)}-\alpha(1-\beta_{ng})p_p^{(4)}\gamma_{ng}-F_{ng}$

Note that $A_i, A'_i, B_i,$ and E are defined in Theorems 1-8.

4.2. The government models

Section 4.1 dealt with the computation of the best response strategies of the NGSCs and GSCs in a competitive market (Table 1) with regard to a given governmental schema DT or TP. In this section, we focus on formulating the government problem to determine the government's optimal strategy in each scenario shown in Fig. 2. Governments often use financial or nonfinancial instruments to reduce the negative environmental effects of the products. For instance, a primary objective of the European Union's energy policy is to decrease the energy consumption by buildings (Motuziene et al., 2016). Thus, the European Council implemented important legislative measures (e.g., Directive 2010/31/EU and Directive on energy efficiency 2012/27/EU) to enhance energy efficiency and decrease operational energy consumption and greenhouse gas (GHG) emissions by the buildings.

Appropriate measures for the evaluation of any green policy are its environmental cost (*EC*) and government net expenditure (Hafezalkotob, 2017a, 2017b, 2015). Sheu (2011), Sheu and Chen (2012), Hafezalkotob (2015), and Hafezalkotob (2017a) demonstrated that *EC* and *GNE* are important criteria for intervention in the SCs competition which should be considered as government's objective functions. Green and non-green products have different environmental impacts, denoted by e_g and e_{ng}, respectively, and ϕ is the cost factor associated with the environmental pollution caused by the products. *EC* represents the total environmental pollution cost of GSC and NGSC products, which can be expressed as follows:

$$EC = \sum_{k=1}^{n_g} \phi e_g q_{g_k} + \sum_{k=1}^{n_{ng}} \phi e_{ng} q_{ng_k} = n_g \phi e_g q_g + n_{ng} \phi e_{ng} q_{ng}\,. \tag{35}$$

GNE refers to the financial expenditure of the government as a result of a schema (i.e., the economic influence of green taxation and subsidization, see Sheu (2011), Sheu and Chen (2012), Hafezalkotob (2015), Hafezalkotob (2017a), and Hafezalkotob (2017b)). Therefore, *GNE* in Scenario 1 is defined as follows:

$$GNE = \sum_{k=1}^{n_g} t_g q_{g_k} + \sum_{k=1}^{n_{ng}} t_{ng} q_{ng_k} = n_g t_g q_g + n_{ng} t_{ng} q_{ng}\,. \tag{36}$$

Notably, we have $GNE = n_g t_g \left(q_g - \gamma_g\right) + n_{ng} t_{ng} \left(q_{ng} - \gamma_{ng}\right)$ in Scenario 2. However, the government in Scenarios 3 and 4 has no expenditure, i.e., $GNE = 0$. We assume that the government tries to minimize the environmental impact and policy-related expenditure, i.e., $\min Z = GNE + \varepsilon \cdot EC$, in which a larger value of the coefficient ε represents a more committed government behavior towards environmental protection. In fact, $\varepsilon > 1$ indicates the government's commitment to reducing the environmental cost rather than maximizing government net expenditure. However, $1 > \varepsilon \geq 0$ indicates that the minimization of net expenditure has an overwhelming importance for the government.

Regarding the government's leadership role in a competitive market, we now present a general form of a three-level nonlinear programming problem to determine the government's optimum strategies. A three-level programming problem can be interpreted as a three-person, non-zero-sum game with perfect information such that players sequentially choose the strategies from the top to the bottom level (Lee and Shih, 2001). The Stackelberg game model (37)−(43) is established according to the authority levels presented in Fig. 3. Governments regularly take the initiative in real decision-making problems. Thus, it is assumed that the government is a Stackelberg leader (i.e., the first-level decision-maker) and that the manufacturers and suppliers are Stackelberg followers (i.e., the second- and third-level decision-makers). In the Stackelberg equilibrium, the leader player declares its strategy first. Subsequently, the follower player(s) devise the best response strategies (Sherali et al., 1983).

$$\min Z = GNE + \varepsilon \cdot EC \tag{37}$$

Subject to

$$\pi_{S_i} \geq L_{S_i}, \quad i = \{ng, g\}, \tag{38}$$

$$\pi_{M_i} \geq L_{M_i}, \quad i = \{ng, g\}, \tag{39}$$

$$Q_g + Q_{ng} \geq D, \tag{40}$$

$$\text{Max } \pi_{S_g}, \tag{41}$$

$$\text{Max } \pi_{S_{ng}}, \tag{42}$$

Subject to:

$$\text{Max } \pi_{M_g}, \tag{43}$$

$$\text{Max } \pi_{M_{ng}}. \tag{44}$$

Inequalities (38) and (39) represent individual rationality (IR) constraints. They state that each SC manufacturer and supplier should earn an acceptable profit. Otherwise, these entities withdraw from the business, and the market demand is not satisfied. In fact, the IR constraints guarantee that the NGSC and GSC are apt to be present in the market and to maintain long-term relationships with the government. Constraint (40) states that the total demand of the market should be satisfied. Because the SC members are profit-seeking companies, the supplier's and manufacturer's profits are maximized at the second and third levels of the three-level non-linear programing (TLNLP).

According to the transformation method (Lee and Shih, 2001), a multi-level programming problem can be transformed into a one-level programming problem by considering the optimal values for decision variables of the lower-level problems as the conditions for the upper-level problem. Thus, regarding the optimal strategies of manufacturers and suppliers computed in Section 4.1, TLNLP (37)-(44) can be transformed into a one-level optimization problem. For intervention schema k of the government, Table 1 presents the best response strategy of SCs' members including $q_g^{(k)}$, $q_{ng}^{(k)}$, $w_g^{(k)}$, and $w_{ng}^{(k)}$ as well as the optimal profits $\pi_{M_g}^{(k)}$, $\pi_{M_{ng}}^{(k)}$, $\pi_{S_g}^{(k)}$, and $\pi_{S_{ng}}^{(k)}$. Considering these values in TLNLP (37)-(44), a one-level optimization problem for each government schema is obtained (Table 2). In Table 2, the conditions $n_g(1-\alpha)q_g^{(3)} = n_{ng}\alpha q_{ng}^{(3)}$ in Scenario 3 and $n_g(1-\alpha)\left(q_g^{(4)} - \gamma_g\right) = n_{ng}\alpha\left(q_{ng}^{(4)} - \gamma_{ng}\right)$ in Scenario 4 ensure the TP equilibrium prices according to Corollaries 3 and 4, respectively.

Table 2. Government's mathematical models regarding its intervention schemas (Fig. 1).

Baseline	The intervention schemas of the government	
	DT	TP
Without baseline	Min $Z(\boldsymbol{t}) = GNE(\boldsymbol{t}) + \varepsilon \cdot EC(\boldsymbol{t})$, Subject to: $GNE(\boldsymbol{t}) = n_g t_g q_g^{(1)} + n_{ng} t_{ng} q_{ng}^{(1)}$, $EC(\boldsymbol{t}) = n_g \phi e_g q_g^{(1)} + n_{ng} \phi e_{ng} q_{ng}^{(1)}$, $n_g q_g^{(1)} + n_{ng} q_{ng}^{(1)} \geq D$, $\pi_{S_g}^{(1)} \geq L_{S_g}$, $\pi_{S_{ng}}^{(1)} \geq L_{S_{ng}}$, $\pi_{M_g}^{(1)} \geq L_{M_g}$, $\pi_{M_{ng}}^{(1)} \geq L_{M_{ng}}$.	Min $Z(p_p,\alpha) = GNE(p_p,\alpha) + \varepsilon \cdot EC(p_p,\alpha)$ $\overset{GNE(p_p,\alpha)=0}{\Rightarrow}$ Min $Z(p_p,\alpha) = EC(p_p,\alpha)$ Subject to: $EC(p_p,\alpha) = n_g \phi e_g q_g^{(3)} + n_r \phi e_{ng} q_{ng}^{(3)}$ $n_g q_g^{(3)} + n_{ng} q_{ng}^{(3)} \geq D$, $n_g(1-\alpha)q_g^{(3)} = n_{ng}\alpha q_{ng}^{(3)}$. $\pi_{S_g}^{(3)}(p_p,\alpha) \geq L_{S_g}$, $\pi_{S_{ng}}^{(3)}(p_p,\alpha) \geq L_{S_{ng}}$, $\pi_{M_g}^{(3)}(p_p,\alpha) \geq L_{M_g}$, $\pi_{M_{ng}}^{(3)}(p_p,\alpha) \geq L_{M_{ng}}$, $n_g(1-\alpha)q_g^{(3)} = n_{ng}\alpha q_{ng}^{(3)}$.
With baseline	Min $Z(\boldsymbol{t},\boldsymbol{\gamma}) = GNE(\boldsymbol{t},\boldsymbol{\gamma}) + \varepsilon \cdot EC(\boldsymbol{t},\boldsymbol{\gamma})$, Subject to: $GNE(\boldsymbol{t},\boldsymbol{\gamma}) = n_g t_g\left(q_g^{(2)} - \gamma_g\right) + n_{ng} t_{ng}\left(q_{ng}^{(2)} - \gamma_{ng}\right)$, $EC(\boldsymbol{t},\boldsymbol{\gamma}) = n_g \phi e_g q_g^{(2)} + n_{ng} \phi e_{ng} q_{ng}^{(2)}$, $n_g q_g^{(2)} + n_{ng} q_{ng}^{(2)} \geq D$, $\pi_{S_g}^{(2)}(\boldsymbol{t},\boldsymbol{\gamma}) \geq L_{S_g}$, $\pi_{S_{ng}}^{(2)}(\boldsymbol{t},\boldsymbol{\gamma}) \geq L_{S_{ng}}$, $\pi_{M_g}^{(2)}(\boldsymbol{t},\boldsymbol{\gamma}) \geq L_{M_g}$, $\pi_{M_{ng}}^{(2)}(\boldsymbol{t},\boldsymbol{\gamma}) \geq L_{M_{ng}}$, $q_g^{(2)} \geq \gamma_g$, $q_{ng}^{(2)} \geq \gamma_{ng}$.	Min $Z(p_p,\alpha,\boldsymbol{\gamma}) = GNE(p_p,\alpha,\boldsymbol{\gamma}) + \varepsilon \cdot EC(p_p,\alpha,\boldsymbol{\gamma})$, $\overset{GNE(p_p,\alpha)=0}{\Rightarrow}$ Min $Z(p_p,\alpha,\boldsymbol{\gamma}) = EI(p_p,\alpha,\boldsymbol{\gamma})$, Subject to: $EC(p_p,\alpha,\boldsymbol{\gamma}) = n_g \phi e_g q_g^{(4)} + n_{ng} \phi e_{ng} q_{ng}^{(4)}$, $n_g q_g^{(4)} + n_{ng} q_{ng}^{(4)} \geq D$, $\pi_{S_g}^{(4)}(p_p,\alpha,\boldsymbol{\gamma}) \geq L_{S_g}$, $\pi_{S_{ng}}^{(4)}(p_p,\alpha,\boldsymbol{\gamma}) \geq L_{S_{ng}}$, $\pi_{M_g}^{(4)}(p_p,\alpha,\boldsymbol{\gamma}) \geq L_{M_g}$, $\pi_{M_{ng}}^{(4)}(p_p,\alpha,\boldsymbol{\gamma}) \geq L_{M_{ng}}$, $q_g^{(4)} \geq \gamma_g$, $q_{ng}^{(4)} \geq \gamma_{ng}$, $n_g(1-\alpha)\left(q_g^{(4)} - \gamma_g\right) = n_{ng}\alpha\left(q_{ng}^{(4)} - \gamma_{ng}\right)$.

From Table 1, we find that all the response strategies of SCs in each scenario are linear functions of the government's decisions, e.g., $q_i^{(1)}$ and $w_i^{(1)}$ in Scenario 1 are linear functions of the government's tariffs. Therefore, objectives in Table 2 are quadratic functions of the government's decision variables, e.g., the objective function of the first scenario can be rewritten in the quadratic function form as $\boldsymbol{e}^t\boldsymbol{t} + (1/2)\,\boldsymbol{t}^t\boldsymbol{H}\boldsymbol{t}$, such that $\boldsymbol{H}$ is a 2×2

symmetric matrix of parameters and $\boldsymbol{e}$ is a 2-vector parameter, and $\boldsymbol{t} = \begin{bmatrix} t_{ng} & t_g \end{bmatrix}$ is a two-vector of the government's tariffs. Consequently, all four mathematical models of Table 2 are quadratically constrained quadratic problems (QCQPs). There are diverse methods that can be used for solving QCQPs such as interior point, active set, trust region, gradient projection, generalized reduced gradient, and barrier penalty function methods (Bazaraa et al., 2013; Dostál, 2009).

5. Numerical example: A case study on housing production

In this section, a case study about housing production in Iran is presented to illustrate the government intervention schemas in the SCs competition. In all countries, the construction sector is responsible for the substantial proportion (one third) of the energy consumption and for GHGs emissions such that the energy efficiency of buildings and resources utilized in the construction processes significantly affect the energy consumption, climate change, and the environment (Liang et al., 2016; Menassa and Baer, 2014; Motuziene et al., 2016). For instance, buildings in the US (with approximately 50% of the total energy consumption) have a considerable energy-saving potential (International Energy Agency, 2013). Moreover, in the European Union, residential building sector is an important energy-intensive sector (approximately 40% of the total energy consumption) with one of the most cost-effective energy-saving potentials (Commission of the European Communities, 2006).

In each country, the effect of seasonal and annual temperature variations on the consumption of energy for heating and cooling is contingent on the regional climate, technical building characteristics (e.g., the energy efficiency of heating and cooling systems and thermal insulation) and resident habits, such as the level of thermal comfort required inside buildings (Roshan et al., 2012). In fact, GHG emissions are generated by many building components, such as the energy use of building systems (like lightning, heating, and cooling systems), construction materials, and land coverage changes. Building location and transportation systems are also significant contributors toward energy consumption and GHG emissions in the residential building sector.

Among the ten countries with the highest GHG emissions, Iran has recorded the highest increase in the last four decades (Nejat et al., 2015). However, it is noteworthy that the other nine countries were either developed countries or on the way to becoming such countries Considering the devastating effects of GHG emissions on humans, animals, and plants, politicians, environmentalists, and researchers have specifically focused on pollution in the residential building sector. In Iran, the construction industry is an important industrial sector that plays a significant role in sustainable development (Hafezalkotob, 2017a; Sattari and Avami, 2007). However, the dramatic increase in GHG emissions in the residential building sector (from 40 Mt in 1991 to 105 Mt in 2011, i.e., a 278% rise) implies a substantial waste of energy and emissions generation in this sector. Iran possesses abundant natural gas reserves which form the prevalent energy resource in the residential sector (Nejat et al., 2015). However, the prevalence of traditional construction methods, lack of public awareness of the cost advantages of green houses, low rate of old building renovations, and insufficient attention towards the use of renewable energy sources constitute the major obstacles in reducing the extent of GHG emissions (Nejat et al., 2015).

A proper regulation and guidance by policy makers, both at the local and state levels, is required to control the worrying trend of energy consumption and GHG emissions by the residential building sector in Iran. For example, the government has planned to increase the energy prices by reducing energy subsidies. On the other hand, it offers incentives for energy efficient systems such as solar water heaters, and efficient heating and cooling systems (Nejat et al., 2015). The Iran energy efficiency organization (IEEO) was founded in 1996 as a government regulatory agency with the mission to increase the energy efficiency and energy consumption rationalization in all energy-intensive sectors, such as the residential building sector (Hafezalkotob, 2017a). The main activities of the IEEO include economic and technical support activities, training and execution management, research and development, and increasing capabilities, particularly in the private sector[2].

The primary participants of a construction SC are supplier(s) of material and equipment and house producer(s) (combination of subcontractor(s) and prime contractor) (Benton and McHenry, 2009). In this section, we investigate the competition of construction SCs under different intervention schemas of IEEO. In the residential building sector, two types of GSCs and NGSCs are mass construction organizations that produce green and non-green types of houses, respectively. A constructed house is identified as a green house with energy label rate A if the R index (=index of building energy consumption/climate index) is lower than 1[3]. The production cost of the green houses is often more than that of the non-green houses; however, they involve lower energy costs. In this research, the cost-related parameters of the developed models are extracted from data achieved from authentic documentations, interview surveys of managers in residential building sectors and experts from the IEEO. The resultant values of the parameters in this case are $\alpha_g = 150$, $\alpha_{ng} = 100$, $b_g = b_{ng} = 0.0002$, $c_g = 80$, $c_{ng} = 40$, $C_g = 50$, $C_{ng} = 20$, $\beta_g = \beta_{ng} = \theta_g = \theta_{ng} = 0.5$, $n_g = 20$, $n_{ng} = 100$, $e_g = 14$, $e_{ng} = 36$ (tons of carbon), $\phi = 0.037$, and $L_{S_g} = L_{M_g} = L_{S_{ng}} = L_{M_{ng}} = f_g = f_{ng} = F_g = F_{ng} = 0$. The unit for cost parameter is \$ 1000 and a unit for production quantity is an 85 square meter apartment house.

Table 3 demonstrates the best strategies of NGSCs and GSCs with regard to different strategies of the government in the four intervention scenarios (according to Theorems 1-10).

[2] http://en.saba.org.ir/en/aboutus/history
[3] http://en.saba.org.ir/en/energyefficiencyprojects/building/labelinginhome

From Table 3, we find that the tariffs levied by IEEO in Scenario 1 affect the optimal production quantities and prices of houses as well as profits of SCs' members because the tariffs directly influence the profit function of producers and suppliers. Therefore, while making decision on tariffs, IEEO should seriously consider the responses of GSCs and NGSCs to the tariffs (for example, see Corollary 1). In Table 3, it is shown that when the IEEO provides financial support to green houses, the equilibrium production quantity of green houses and the producers' profits increase while their market price decreases. However, this support adversely influences the NGSCs. In Scenario 2, the effects of tariff exceptions are evaluated. As expected, tariff exemptions do not alter the strategies of producers and suppliers, but they change the profit of SCs' members. In addition, it is observed that the effects of tariff exemptions on profits are not considerable (particularly, compared with tariff effects in Scenario 1).

Table 3 also illustrates the impacts of quota in the TP schema (Scenario 3). When the quota approaches 1, the power of GSCs increases, particularly, the profits of producers and suppliers in GSCs grow; however, the market and wholesale prices remain approximately constant. Similarly, in Scenario 4, the exemption policy does not considerably alter the wholesale and market prices. On the other hand, the exemption in TP schema boosts the profits of GSCs' members while it reduces profits of NGSCs' members.

Table 4 illustrates the optimal strategies of government and the corresponding best response strategies of SCs in all the 4 Scenarios of intervention schema. The optimal values are computed by solving the problems of Table 2 via Maple nonlinear solver for QCQPs. When ε grows, the importance of environmental cost increases relative to government's expenditure. Therefore, the IEEO can make a tradeoff between *GNE* and *EC* objectives by changing the value of ε. We know from Table 4 that an increase in ε causes higher subsidy on green houses and higher tax on non-green houses; consequently, it increases the production quantity of green houses. However, the variation in ε does not meaningfully change the wholesale and market prices. In Scenarios 3 and 4, the trade-off between *GNE* and *EC* is not possible because $GNE = 0$; thus, the optimal values for corresponding problems of Table 2 are only reported.

Table 3. Sensitivity analysis of optimal quantities, prices, and profits of SCs and their members according to given strategies of government.

	Government strategies						SCs' best responses											
	t_g	t_{ng}	α	p_p	γ_g	γ_{ng}	q_g	q_{ng}	w_g	w_{ng}	p_g	p_{ng}	π_{M_g}	π_{S_g}	π_{SC_g}	$\pi_{M_{ng}}$	$\pi_{S_{ng}}$	$\pi_{SC_{ng}}$
DT without baseline Scenario (1)	-5	-5	–	–	–	–	527.03	452.63	56.04	37.71	140.65	89.26	1111.06	1866.58	2977.64	4097.46	6883.73	10981.19
	-5	0	–	–	–	–	449.53	523.93	55.52	37.60	139.82	88.08	808.30	1357.95	2166.26	5490.13	9223.41	14713.54
	-5	5	–	–	–	–	372.02	595.24	55.00	37.50	138.99	86.90	553.61	930.06	1483.67	7086.17	11904.76	18990.93
	0	-5	–	–	–	–	883.56	437.13	55.94	37.19	139.47	88.43	3122.69	5246.12	8368.81	3821.62	6420.32	10241.93
	0	0	–	–	–	–	806.05	508.43	55.42	37.08	138.64	87.25	2598.88	4366.11	6964.99	5170.07	8685.72	13855.80
	0	5	–	–	–	–	728.55	579.74	54.90	36.98	137.81	86.07	2123.12	3566.84	5689.96	6721.90	11292.80	18014.70
	5	-5	–	–	–	–	1240.08	421.63	55.83	36.67	138.29	87.60	6151.19	10333.99	16485.18	3555.39	5973.05	9528.44
	5	0	–	–	–	–	1162.57	492.93	55.31	36.56	137.46	86.42	5406.32	9082.61	14488.93	4859.63	8164.18	13023.81
	5	5	–	–	–	–	1085.07	564.24	54.79	36.46	136.63	85.24	4709.50	7911.96	12621.47	6367.25	10696.98	17064.22
DT with baseline Scenario (2)	5	-5	–	–	140	140	1240.08	421.63	55.83	36.67	138.29	87.60	5801.19	9983.99	15785.18	3905.39	6323.05	10228.44
	5	-5	–	–	140	280	1240.08	421.63	55.83	36.67	138.29	87.60	5801.19	9983.99	15785.18	4255.39	6673.05	10928.44
	5	-5	–	–	140	420	1240.08	421.63	55.83	36.67	138.29	87.60	5801.19	9983.99	15785.18	4605.39	7023.05	11628.44
	5	-5	–	–	280	140	1240.08	421.63	55.83	36.67	138.29	87.60	5451.19	9633.99	15085.18	3905.39	6323.05	10228.44
	5	-5	–	–	280	280	1240.08	421.63	55.83	36.67	138.29	87.60	5451.19	9633.99	15085.18	4255.39	6673.05	10928.44
	5	-5	–	–	280	420	1240.08	421.63	55.83	36.67	138.29	87.60	5451.19	9633.99	15085.18	4605.39	7023.05	11628.44
	5	-5	–	–	420	140	1240.08	421.63	55.83	36.67	138.29	87.60	5101.19	9283.99	14385.18	3905.39	6323.05	10228.44
	5	-5	–	–	420	280	1240.08	421.63	55.83	36.67	138.29	87.60	5101.19	9283.99	14385.18	4255.39	6673.05	10928.44
	5	-5	–	–	420	420	1240.08	421.63	55.83	36.67	138.29	87.60	5101.19	9283.99	14385.18	4605.39	7023.05	11628.44
TP without baseline Scenario (3)	–	–	0.1	0	–	–	806.05	508.43	55.42	37.08	138.64	87.25	2598.88	4366.11	6964.99	5170.07	8685.72	13855.80
	–	–	0.2	0	–	–	806.05	508.43	55.42	37.08	138.64	87.25	2598.88	4366.11	6964.99	5170.07	8685.72	13855.80
	–	–	0.3	4.1451	–	–	870.30	449.32	55.85	37.17	139.33	88.23	3029.72	5089.93	8119.65	4037.77	6783.45	10821.22
	–	–	0.4	11.978	–	–	991.72	337.62	56.66	37.33	140.63	90.07	3934.02	6609.15	10543.17	2279.74	3829.96	6109.69
	–	–	0.5	20	–	–	1116.07	223.21	57.50	37.50	141.96	91.96	4982.46	8370.54	13353.00	996.49	1674.11	2670.60
	–	–	0.6	27.019	–	–	1224.88	123.11	58.23	37.65	143.13	93.62	6001.33	10082.23	16083.56	303.12	509.24	812.36
	–	–	0.7	32.124	–	–	1304.01	50.31	58.76	37.75	143.98	94.82	6801.78	11426.99	18228.76	50.62	85.04	135.67
	–	–	0.8	35.035	–	–	1349.13	8.80	59.07	37.81	144.46	95.51	7280.56	12231.34	19511.90	1.55	2.60	4.15
	–	–	0.9	36.032	–	–	1364.59	0	59.17	37.83	144.63	95.74	7448.42	12513.34	19961.76	0.59	0.99	1.58
TP with baseline Scenario (4)	–	–	0.5	20.576	300	50	1699.11	329.82	56.27	36.23	137.93	87.97	6918.26	17857.21	27861.87	1918.44	3397.88	5316.32
	–	–	0.5	17.696	300	100	1574.11	354.82	56.15	36.35	138.03	87.87	5929.65	15323.71	23907.76	2075.56	3787.78	5863.35
	–	–	0.5	14.816	300	150	1449.11	379.82	56.03	36.47	138.13	87.77	5066.05	13000.21	20288.65	2329.69	4291.68	6621.37
	–	–	0.5	24.032	600	50	1849.11	299.82	56.42	36.08	137.81	88.09	8269.59	19372.21	29444.19	1497.46	2720.00	4217.46
	–	–	0.5	21.152	600	100	1724.11	324.82	56.30	36.20	137.91	87.99	7130.98	16802.71	25520.09	1581.38	3016.30	4597.68
	–	–	0.5	18.272	600	150	1599.11	349.82	56.18	36.32	138.01	87.89	6117.37	14443.21	21930.98	1762.30	3426.60	5188.90
	–	–	0.5	27.488	900	50	1999.11	269.82	56.56	35.94	137.69	88.21	9800.92	20671.21	30472.12	1112.47	2102.60	3215.07
	–	–	0.5	24.608	900	100	1874.11	294.82	56.44	36.06	137.79	88.11	8512.31	18065.71	26578.02	1123.19	2305.30	3428.49
	–	–	0.5	21.728	900	150	1749.11	319.82	56.32	36.18	137.89	88.01	7348.70	15670.21	23018.91	1230.91	2622.00	3852.92

Table 4. Optimal strategies of government and SCs' members in different intervention scenarios.

	Government optimal strategies							SCs' best responses									
	ε	t_g	t_{ng}	α	p_p	γ_g	γ_{ng}	q_g	q_{ng}	w_g	w_{ng}	p_g	p_{ng}	π_{M_g}	π_{S_g}	$\pi_{M_{ng}}$	$\pi_{S_{ng}}$
DT without baseline Scenario (1)	0	1.88	-8.12	–	–	–	–	1065.97	386.81	56.22	37.06	139.55	88.85	4545.19	7635.91	2992.37	5027.18
	5	2.90	-9.14	–	–	–	–	1154.30	369.14	56.31	36.97	139.48	88.92	5329.61	8953.74	2725.30	4578.50
	10	3.91	-10.16	–	–	–	–	1242.62	351.48	56.39	36.89	139.41	88.99	6176.43	10376.41	2470.70	4150.78
	15	4.93	-11.17	–	–	–	–	1330.95	333.81	56.48	36.80	139.34	89.06	7085.67	11903.93	2228.59	3744.04
	20	5.95	-12.19	–	–	–	–	1419.27	316.15	56.56	36.72	139.26	89.14	8057.32	13536.30	1998.96	3358.26
	25	6.97	-13.21	–	–	–	–	1507.60	298.48	56.65	36.63	139.19	89.21	9091.38	15273.51	1781.82	2993.45
	30	7.98	-14.23	–	–	–	–	1595.92	280.82	56.73	36.55	139.12	89.28	10187.84	17115.58	1577.15	2649.62
	35	9.00	-15.24	–	–	–	–	1684.24	263.15	56.82	36.46	139.05	89.35	11346.72	19062.49	1384.97	2326.75
	40	10.02	-16.26	–	–	–	–	1772.57	245.49	56.90	36.38	138.98	89.42	12568.01	21114.26	1205.27	2024.85
	45	11.04	-17.28	–	–	–	–	1860.89	227.82	56.99	36.29	138.91	89.49	13851.71	23270.87	1038.05	1743.92
	50	12.05	-18.30	–	–	–	–	1949.22	210.16	57.07	36.21	138.84	89.56	15197.81	25532.33	883.31	1483.97
DT with baseline Scenario (2)	0	8.96	-15.20	–	–	1680.56	–	1680.56	263.89	56.18	36.47	139.06	89.34	3768.18	11450.19	1392.75	2339.75
	5	10.99	-17.24	–	–	1857.20	–	1857.20	228.56	56.98	36.30	138.91	89.49	3586.86	12968.71	1044.78	1755.24
	10	13.03	-19.27	–	–	2033.85	–	2033.85	193.23	57.15	36.13	138.77	89.63	3295.69	14547.14	746.75	1254.54
	15	15.06	-21.31	–	–	2210.50	–	2210.50	157.90	57.32	35.96	138.63	89.77	2894.69	16185.49	498.64	837.72
	20	17.10	-23.34	–	–	2387.15	–	2387.15	122.57	57.49	35.79	138.49	89.91	2383.84	17883.75	300.47	504.78
	25	19.13	-25.38	–	–	2563.80	–	2563.80	87.24	57.66	35.62	138.35	90.05	1763.15	19641.93	152.21	255.72
	30	21.17	-27.41	–	–	2740.45	–	2740.45	51.91	57.83	35.45	138.21	90.19	1032.62	21460.02	53.89	90.54
	35	23.20	-29.45	–	–	2917.10	–	2917.10	16.58	58.00	35.28	138.07	90.33	192.25	23338.02	5.50	9.24
	40	23.64	-29.88	–	–	2954.55	–	2954.55	9.09	58.04	35.24	138.04	90.36	0.00	23743.80	1.65	2.78
	45	23.64	-29.88	–	–	2954.55	–	2954.55	9.09	58.04	35.24	138.04	90.36	0.00	23743.80	1.65	2.78
	50	24.00	-30.24	–	–	2972.24	–	2986.04	2.79	58.07	35.21	138.01	90.39	0.00	24252.66	0.16	0.26
TP without baseline Scenario (3)	–	12.05	-18.30	0.61	27.77	–	–	1837.09	232.58	56.96	36.32	138.93	89.47	13499.67	22679.45	1081.88	1817.56
TP with baseline Scenario (4)	–	–	–	0.56	54.29	2973.63	0.00	2988.33	2.29	58.07	35.21	138.01	90.39	0	24289.94	0.1	0.18

Figure 5 illustrates how the market share of green houses (i.e., $Q_g/(Q_{ng}+Q_g)$) depends on the environment protection tendency of the government. We observe from the figure, when ε increases (i.e., when the government has higher environment protection tendency), the market share of green houses increases in Scenarios 1 and 2. It is known that the baselines in DT and TP schemas result in higher market share of green houses relative to no baseline cases. The figure also shows that TP schema is more effective compared to DT schema regarding to the market share of green product; however, this priority decreases as ε rises.

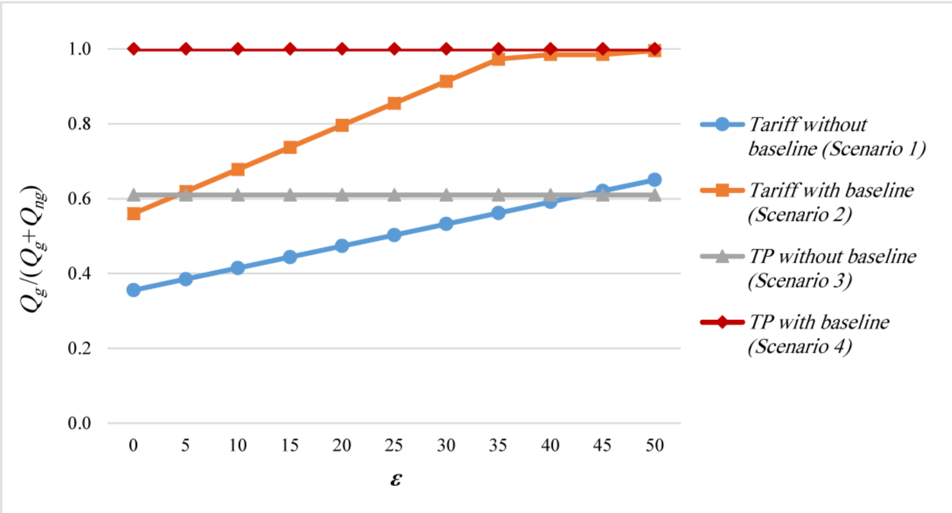

Fig 5. The effect of ε on market share of green product type in different scenarios

Figures 6 and 7 demonstrate the effect of environment protection tendency of the government on profits of GSC and NGSC, respectively. From the figures, we find that profit of GSC increases in Scenarios 1 and 2 when the government reflects high environment protection tendency; however, the profit of NGSC reduces with an increase in ε. This means that when the IEEO reinforces environment protection tendency, GSCs derive more satisfaction and they have more incentives to increase the green house production. Furthermore, Figure 6 shows that the GSCs' profit in TP schema is often more than in the DT schema; however, this preference decreases when ε rises. On the contrary, Fig. 7 illustrates that DT schema results in higher profit for the NGSCs relative to TP schema.

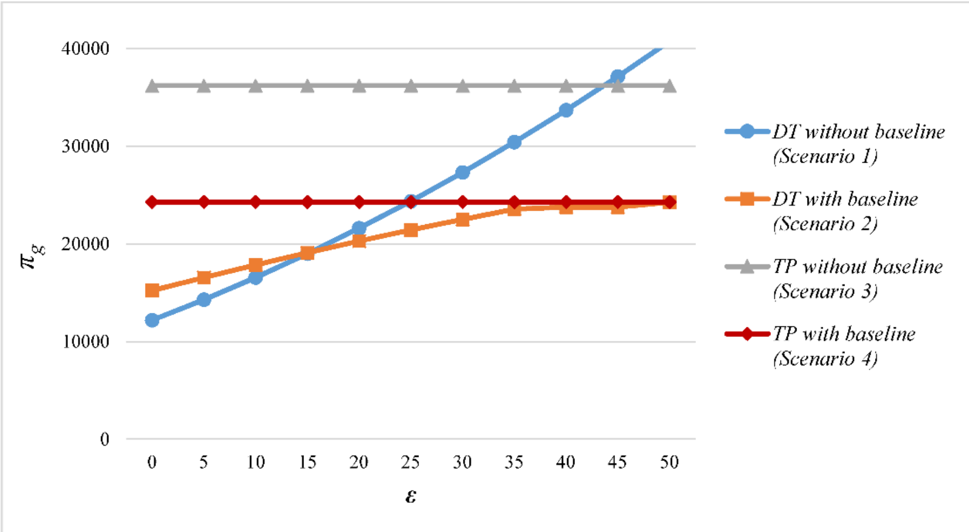

Fig 6. The effect of ε on profit of GSCs (i.e., $\pi_g = \pi_{M_g} + \pi_{S_g}$) in different scenarios.

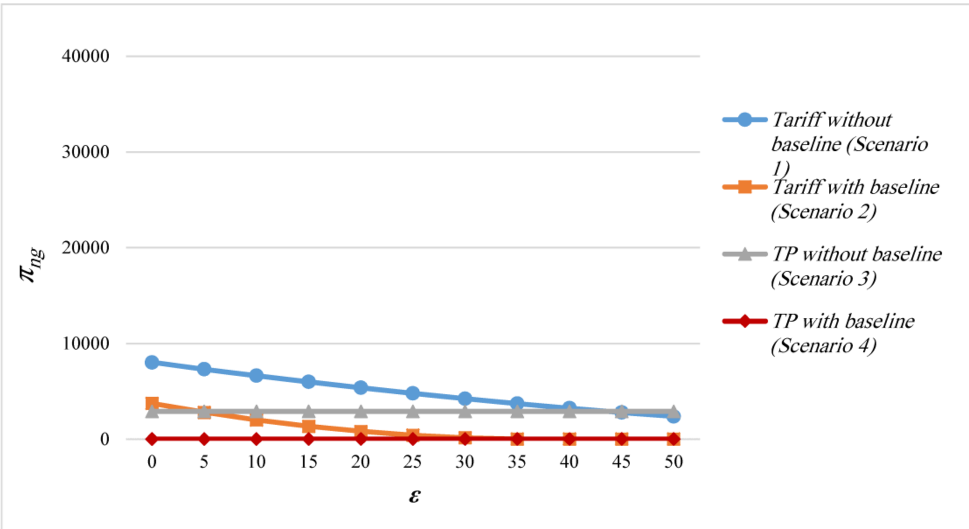

Fig 7. The effect of ε on profit of NGSCs (i.e., $\pi_{ng} = \pi_{M_{ng}} + \pi_{S_{ng}}$) in different scenarios

The effects of government's environmental protection tendency on its net expenditure and environmental cost are illustrated in Figs. 8 and 9, respectively. As expected, the GNE in Scenarios 1 and 2 grows when the government's environmental protection tendency increases. Moreover, the GNE in DT with baseline schema is often lower than that related to no baseline situation. From Fig. 9, we find that environmental costs in Scenarios 1 and 2 reduce when the government's environmental protection tendency rises. Additionally, the DT with baseline schema has lower environmental cost relative to the DT no baseline situation.

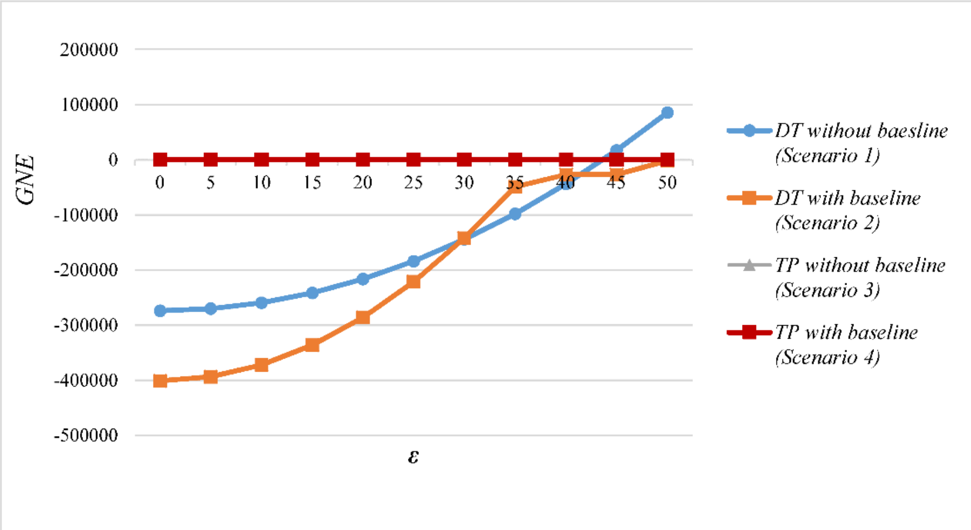

Fig 8. The effect of ε on government net expenditure in different scenarios

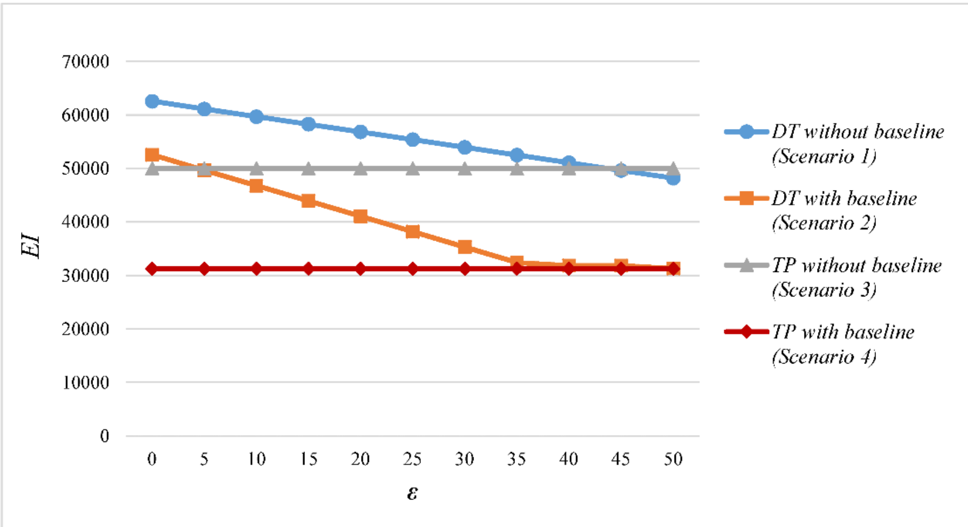

Fig 9. The effect of ε on environmental impact of SCs in different scenarios

6. Managerial implications

The findings of the developed models can be employed by both managers of SCs and policy makers to enrich their managerial insights into the decisions consequences. The key managerial implications of the research include:

- Realizing the best response strategies of SCs in different intervention schemas, the government can select an appropriate schema to effectively orchestrate the equilibrium between green and non-green products in the market (i.e., market share of products).
- The exemption policy (i.e., baselines) does not affect the strategies of SCs in the DT schema whereas it alters the SCs' strategies in the TP schema. Therefore, using TP schema with baselines, the government can orchestrate the production quantities of SCs without direct financial intervention.

- Satisfaction levels of GSCs and NGSCs are different under TP and DT schemas. Indeed, in the case study presented, DT schema is preferred by NGSCs but TP is preferred by GSCs.
- Environmental cost and government expenditure of the presented intervention schemas are different. Thus, the appropriate schema depends on government's inclination towards financial intervention and available budget as well as government's tendency to protect the environment.

In addition, the case study particularly presents the following managerial insights:

- Regarding the considerable impacts of tariffs levied by government on the supply and demand in the market, IEEO can effectively orchestrate the production quantities and prices of non-green and green houses by an appropriate DT schema.
- The exemption DT schema lowers the financial intervention of IEEO. However, because the effects of exemption on profit of companies are lower than the effects of tariffs, the exemption schema may not change the long-term behavior of companies.
- A comparison of the TP and DT schemas shows that market share of green houses in TP schema is often more than that in DT schemas. Moreover, TP schema yields higher satisfaction for GSCs but NGSCs are more satisfied from DT schema. The environment cost of DT schema is higher than the TP schema; however, DT schema results in a lower environmental cost if the IEEO has very high environmental protection tendency.
- It is better for IEEO to conduct TP schema if it is apt to support green houses in residential building sector and does not like to directly (financially) intervene in the market. On the other hand, the DT schema outweighs TP schema if IEEO is able to allocate sufficient financial resources to support green houses.

7. Conclusion

This study evaluates the competition between GSCs and NGSCs under different intervention schemas of the government including DT and TP. Each NGSC or GSC comprises one supplier who sets the wholesale price of components as well as one manufacturer who decides the number of products to be produced and supplied to the market. We established a Stackelberg game theory framework in which the government and SCs are considered as leader and follower players, respectively. We presented four mathematical models regarding DT and TP schemas with and without baselines. Although the mechanisms of both DT and TP schemas are different, the equilibrium production quantities, wholesale and market prices of SCs can be computed for a given strategy of the government (Theorems 1-10). From this study, we found that DT or TP policy making is a multidimensional problem with different system stakeholders, including the government, SCs, consumers, and the environment. Although both TP and DT schemas can change market equilibrium between green and non-green products, the government's intervention is lesser in TP schema. Moreover, different schemas result in different satisfaction levels for stakeholders. Thus, an appropriate schema can be selected by considering the corresponding effects on the stakeholders.

There exist several possible directions of future research for the work presented here. First, we assume that the GSCs (and NGSCs) are homogeneous; therefore, developing the models for heterogeneous SCs is interesting. Second, the models can be extended for more than two echelons of SCs or SCs with more complicated structures. Third, consideration of SCs competition under demand uncertainty can be an important extension.

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Appendix A

Proof of Theorem 1. The first order conditions for manufacturers in GSC and NGSCs are as follows:

$$\partial\pi_{M_i}\big/\partial q_i=(a_i+t_i\theta_i-w_i-c_i)-2b_in_iq_i-\lambda b_in_jq_j=0,\ i,j=g,ng,\ j\neq i. \quad \text{(A.1)}$$

Owing to $\partial^2\pi_{M_i}\big/\partial q_i^2=-2b_jn_i<0$, the profit function is concave and the optimal production quantities can be obtained from Eq. (A.1). Consequently, solving $\partial\pi_{M_g}\big/\partial q_g=0$ and $\partial\pi_{M_{ng}}\big/\partial q_{ng}=0$ results in

$$q_i^{(1)}(\boldsymbol{w},\boldsymbol{t})=\frac{A_i-2b_j(w_i-\theta_it_i)+\lambda b_i(w_j-\theta_jt_j)}{n_iE}, \quad \text{(A.2)}$$

in which $A_i=2b_j(a_i-c_i)-\lambda b_i(a_j-c_j)$, $E=b_gb_{ng}(4-\lambda^2)$, $i,j=ng,g$, $i\neq j$. □

Proof of Theorem 2. Substituting $q_i^{(1)}(\boldsymbol{w},\boldsymbol{t})$ (i.e., Eq. (A.2.)) into supplier's profit function (4), we conclude that

$$\pi_{s_i}(\boldsymbol{q},\boldsymbol{w},\boldsymbol{t})=\left[w_i+(1-\theta_i)t_i-C_i\right]q_i^{(1)}-F_i,\ i=ng,g,\ i\neq j. \quad \text{(A.3)}$$

Hence, the first order condition for supplier i can be stated as

$$\frac{\partial\pi_{S_i}}{\partial w_i}=\frac{A_i+2b_jC_i+2b_j(2\theta_i-1)t_i-\lambda b_i\theta_jt_j-4b_jw_i+\lambda b_iw_j}{n_iE}=0,\ i,j=ng,g,\ j\neq i. \quad \text{(A.4)}$$

Owning to $\partial^2\pi_{S_i}\big/\partial w_i^2=-4b_j\big/n_iE<0$, the profit function is concave and the optimal wholesale prices can be achieved from Eq. (A.4). Therefore, solving $\partial\pi_{S_g}\big/\partial w_g=0$ *and* $\partial\pi_{S_{ng}}\big/\partial w_{ng}=0$ yields

$$w_i^{(1)}(\boldsymbol{t}) = \frac{\begin{Bmatrix} \lambda\left[A_j + 2b_iC_j + 2b_i(2\theta_j - 1)t_j - \lambda b_j\theta_i t_i\right] \\ +4\left[A_i + 2b_jC_i + 2b_j(2\theta_i - 1)t_i - \lambda b_i\theta_j t_j\right] \end{Bmatrix}}{b_j(16-\lambda^2)}, \quad i = ng, g \ \ and \ \ i \neq j. \ \square \qquad \text{(A.5)}$$

Proof of Theorem 3. The manufacturer profit function (8) only differs from manufacturer profit function (2) in the term $\theta_i t_i \gamma_i$. Hence, the first order condition $\partial\pi_{M_i}(\boldsymbol{q},\boldsymbol{w},\boldsymbol{t},\boldsymbol{\gamma})/\partial q_i = 0$ is similar to Eq. (A.1) and we conclude that $q_g^{(2)}(\boldsymbol{w},\boldsymbol{t},\boldsymbol{\gamma}) = q_g^{(1)}(\boldsymbol{w},\boldsymbol{t})$ and $q_{ng}^{(2)}(\boldsymbol{w},\boldsymbol{t},\boldsymbol{\gamma}) = q_{ng}^{(1)}(\boldsymbol{w},\boldsymbol{t})$. □

Proof of Theorem 4. From Theorem 3, we know that $q_i^{(2)}(\boldsymbol{w},\boldsymbol{t},\boldsymbol{\gamma}) = q_i^{(1)}(\boldsymbol{w},\boldsymbol{t})$, on the other hand, the supplier profit function (10) only differs from manufacturer profit function (4) in the term $(1-\theta_i)t_i\gamma_i$. Thus, the first order condition $\partial\pi_{S_i}(\boldsymbol{w},\boldsymbol{t},\boldsymbol{\gamma})/\partial q_i = 0$ is similar to Eq. (A.4) and we have $w_g^{(2)}(\boldsymbol{t},\boldsymbol{\gamma}) = w_g^{(1)}(\boldsymbol{t})$ and $w_{ng}^{(2)}(\boldsymbol{t},\boldsymbol{\gamma}) = w_{ng}^{(1)}(\boldsymbol{t})$. □

Proof of Theorem 5. The first order conditions for manufacturers profit in NGSC and GSC (i.e., objective function (14)) are as follows:

$$\partial\pi_{M_{ng}}/\partial q_{ng} = (a_{ng} - \alpha\beta_{ng}p_c - w_{ng} - c_{ng}) - 2b_{ng}n_{ng}q_{ng} - \lambda b_{ng}n_g q_g = 0, \qquad \text{(A.6)}$$

$$\partial\pi_{M_g}/\partial q_g = (a_g + (1-\alpha)\beta_g p_c - w_g - c_g) - 2b_g n_g q_g - \lambda b_g n_{ng} q_{ng} = 0. \qquad \text{(A.7)}$$

It is straightforward that functions $\pi_{M_{ng}}$ and π_{M_g} are concave functions on q_{ng} and q_g, respectively. Hence, the equilibrium production quantities are obtained by solving Eqs. (A.6) and (A.7) which results in

$$q_{ng}^{(3)}(\boldsymbol{w}, p_p, \alpha) = \left[A_{ng} - 2b_g(w_{ng} + \alpha\beta_{ng}p_p) + \lambda b_{ng}(w_g - (1-\alpha)\beta_g p_p)\right]/n_{ng}E, \qquad \text{(A.8)}$$

$$q_g^{(3)}(\boldsymbol{w}, p_p, \alpha) = \left[A_g - 2b_{ng}(w_g - (1-\alpha)\beta_g p_p) + \lambda b_g(w_{ng} + \alpha\beta_{ng}p_p)\right]/n_g E. \quad \square \qquad \text{(A.9)}$$

Proof of Theorem 6. Substituting $q_g^{(3)}$ and $q_{ng}^{(3)}$ (i.e., Eqs. (16) and (17)) into the suppliers' profit function, we have

$$\pi_{s_{ng}}(\boldsymbol{w}, p_p, \alpha) = \left[w_{ng} - C_{ng} - \alpha(1-\beta_{ng})p_p\right]q_g^{(3)} - F_{ng}, \qquad \text{(A.10)}$$

$$\pi_{s_g}(\boldsymbol{w}, p_p, \alpha) = \left[w_g - C_g + (1-\alpha)(1-\beta_g)p_p\right]q_g^{(3)} - F_g. \qquad \text{(A.11)}$$

The first order conditions for profit functions (A.10) and (A.11) are as follows:

$$\partial\pi_{S_{ng}}/\partial w_{ng} = \left[A'_{ng} + \left[2\alpha(1-2\beta_{ng})b_g - \lambda(1-\alpha)\beta_g b_{ng}\right]p_p - 4b_g w_{ng} + \lambda b_{ng} w_g\right]/n_{ng}E = 0, \qquad \text{(A.12)}$$

$$\partial\pi_{S_g}/\partial w_g = \left[A'_g + \left[2(1-\alpha)(2\beta_g - 1)b_{ng} + \lambda\alpha\beta_{ng}b_g\right]p_p - 4b_{ng}w_g + \lambda b_g w_{ng}\right]/n_g E = 0, \qquad \text{(A.13)}$$

in which $A'_{ng} = A_{ng} + 2b_g C_{ng}$ and $A'_g = A_g + 2b_r C_g$. It is straightforward that functions $\pi_{S_{ng}}$ and π_{S_g} are concave functions on w_{ng} and w_g, respectively. Thus, solving $\partial\pi_{S_g}/\partial w_g = 0$ and $\partial\pi_{S_{ng}}/\partial w_{ng} = 0$ yields

$$w_g^{(3)}(p_p,\alpha)=\left[\lambda A'_{ng}+4A'_g+\left(\lambda B_{ng}+4B_g\right)p_p\right]\Big/b_{ng}(16-\lambda^2), \tag{A.14}$$

$$w_{ng}^{(3)}(p_p,\alpha)=\left[\lambda A'_g+4A'_{ng}+\left(\lambda B_g+4B_{ng}\right)p_p\right]\Big/b_g(16-\lambda^2), \tag{A.15}$$

in which $B_{ng}=2\alpha(1-2\beta_{ng})b_g-\lambda(1-\alpha)\beta_g b_{ng}$ and $B_g=2(1-\alpha)(2\beta_g-1)b_{ng}+\lambda\alpha\beta_{ng}b_g$. □

Proof of Theorem 7. In the market equilibrium of TP, the equilibrium permit price $p_p^{(3)}$ for a given α can be obtained by a unique p_p that satisfies the equilibrium between supply and demand of permits. Regarding $q_g^{(3)}(p_p,\alpha)$ and $q_{ng}^{(3)}(p_p,\alpha)$ previously computed in Eqs. (22) and (23), we can solve $n_g(1-\alpha)q_g^{(3)}(p_p,\alpha)=n_{ng}\alpha q_{ng}^{(3)}(p_p,\alpha)$ for p_p which results in

$$p_p^{(3)}=\frac{A'_{ng}\left[2\lambda(1-\alpha)+\alpha(8-\lambda^2)\right]-A'_g\left[(1-\alpha)(8-\lambda^2)+2\lambda\alpha\right]+\left[(1-\alpha)A_g-\alpha A_{ng}\right](16-\lambda^2)}{B_g\left[(1-\alpha)(8-\lambda^2)+2\lambda\alpha\right]-B_{ng}\left[2\lambda(1-\alpha)+\alpha(8-\lambda^2)\right]-\left[(1-\alpha)\beta_g b_{ng}\left[2(1-\alpha)+\lambda\alpha\right]+\alpha\beta_{ng}b_g\left[\lambda(1-\alpha)-2\alpha\right]\right](16-\lambda^2)}. \tag{A.16}$$

□

Proof of Theorem 8. We note that the first order conditions $\partial\pi_{M_{ng}}(\boldsymbol{q},\boldsymbol{w},p_p,\alpha)\big/\partial q_{ng}=0$ and $\partial\pi_{M_g}(\boldsymbol{q},\boldsymbol{w},p_p,\alpha)\big/\partial q_g=0$ are identical to Eqs. (A.6) and (A.7), respectively. Therefore, solving these conditions leads to similar equilibrium production quantities (i.e., Eqs. (16) and (17)). □

Proof of Theorem 9. It is straightforward that the first order conditions for the suppliers' profit functions (30) and (31) are identical to Eqs. (A.12) and (A.13), respectively. Thus, solving these conditions yields similar equilibrium wholesale prices (i.e., Eqs. (20) and (21)). □

Proof of Theorem 10. In the market equilibrium of TP with baseline, the equilibrium permit price $p_p^{(4)}$ for a given α and $\boldsymbol{\gamma}$ can be obtained by a unique p_p that satisfies equilibrium between demand and supply of permits. With regard to the $q_g^{(3)}(p_p,\alpha)$ and $q_{ng}^{(3)}(p_p,\alpha)$ presented by Eqs. (22) and (23), we solve $n_g(1-\alpha)(q_g^{(4)}-\gamma_g)=n_{ng}\alpha(q_{ng}^{(4)}-\gamma_{ng})$ to obtain p_p as follows

$$p_p^{(4)}=\frac{A'_{ng}\left[2\lambda(1-\alpha)+\alpha(8-\lambda^2)\right]-A'_g\left[(1-\alpha)(8-\lambda^2)+2\lambda\alpha\right]+\left[\left[(1-\alpha)A_g-\alpha A_{ng}\right]+E\left[\alpha n_{ng}\gamma_{ng}-(1-\alpha)n_g\gamma_g\right]\right](16-\lambda^2)}{B_g\left[(1-\alpha)(8-\lambda^2)+2\lambda\alpha\right]-B_{ng}\left[2\lambda(1-\alpha)+\alpha(8-\lambda^2)\right]-\left[(1-\alpha)\beta_g b_{ng}\left[2(1-\alpha)+\lambda\alpha\right]+\alpha\beta_{ng}b_g\left[\lambda(1-\alpha)-2\alpha\right]\right](16-\lambda^2)}. \tag{A.17}$$

Consequently, the exemption values $\boldsymbol{\gamma}=(\gamma_g,\gamma_{ng})$ affect supply and demand of TP in the secondary market; thus, they can change equilibrium price of permit. □

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