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For the sustainable performance of the carbon reduction labeling policies under an evolutionary game simulation

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ABSTRACT

The study proposes an evolutionary game model to investigate the possible responses of enterprises to incentive policies related to the implementation of a carbon reduction labeling scheme, such as a direct subsidy and preferential taxation rates. System dynamics is applied to simulate the created game model and we analyze two scenarios, namely the individual and combined intervention of incentive policies. A case study of China's air conditioner enterprises is then examined, with the simulation results highlighting that both a direct subsidy and preferential taxation positively influence the implementation of the carbon reduction labeling scheme. In particular, the combination of these two incentive policies is efficient compared with individual policy making. Finally, the limitations of the game theoretical analysis are discussed and future research directions are provided.

1. Introduction

In recent decades, climate change has become an increasingly important environmental issue affecting sustainable development (Avci et al., 2014; Cachon, 2014). As such, the reduction of greenhouse gas emissions, a major contributor to climate change, has been paid greater attention (Higgins et al., 2011; Pan et al., 2013; Cachon, 2014; Avci et al., 2014). A possible mode of reducing emissions and saving energy is the implementation of a carbon reduction labeling scheme that measures carbon dioxide, or its equivalent greenhouse gas emissions, based on a full lifecycle assessment of a product or service (Carbon Trust, 2008). Such a scheme serves as an effective tool for encouraging individuals to change their consumption behavior in a way that will benefit the environment by providing carbon emissions information on products and services (Young et al., 2010; Liu et al., 2016). As carbon reduction labeling schemes are still in their infancy in various countries such as the United Kingdom, the Netherlands, and Japan (Tan et al., 2014; Liu et al., 2016), well-designed governmental policies are crucial to promote low-carbon development (Cohen and Vandenbergh, 2012; Kanada et al., 2013). However, previous studies have focused on carbon labeling scheme design to improve the transparency of current standards (Guenther et al., 2012; Zhao et al., 2012a; Garcia and Freire, 2014; Wu et al., 2014), enhance consumers' perceptions (Bleda and Valente, 2009; Upham et al., 2011; Sharp and Wheeler, 2013; Hartikainen et al., 2014), and eliminate a non-tariff barrier during international trade (Plassmann et al., 2010; Vranes, 2010; Cohen and Vandenbergh, 2012; Liu et al., 2016).

Enterprises are also significant stakeholders in reducing carbon emissions (Wang et al., 2011; Tian et al., 2014). Investigations of the sales of carbon-labeled products have indicated that consumers would like to pay more for green products (Zhao et al., 2014; Zhao et al., 2015). With green consumption gradually emerging in the market, demand for eco-friendly products may further promote organizational innovation and allow enterprises to capture market share (Cohen and Vandenbergh, 2012; Lin et al., 2013). For instance, Wal-Mart has spent $30 million on the development of "green" refrigerators and seen sales increase by 20% (Fetterman, 2006). However, the additional cost of low-carbon certification and technologies, market risk, and complexity of the external business environment may result in uncertainty regarding commercial success (Zhao et al., 2013; Shuai et al., 2014; Bi et al., 2015). In this context, governments play a leading role in developing well-designed policies to drive industrial innovation into product sustainability and thus promote sustainable performance (Kanada et al., 2013; Choi, 2015). Sustainable performance requires coordination among all participating agents to work together to create a win–win outcome (Choi, 2015). However, it is difficult to visualize the

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performance of these policies, due to the complexity of a sustainable operation for all the participants, e.g., trustworthy and loyal partnership (Myeong et al., 2014; Choi, 2014, 2015). Additionally, inflexible policymaking may be ineffective if enterprises do not respond actively (Kane, 2010).

This study proposes an evolutionary game theoretical approach that models the likely behavior of enterprises in response to a number of governmental policy instruments such as financial subsidies and taxation related to the implementation of a carbon reduction labeling scheme. System dynamics (SD) is applied to simulate the created game model followed by two major scenarios, in which enterprises' actions are determined according to individual and combined policy interventions. The application of game theory is expected to help enterprises take positive actions toward carbon emissions reduction by implementing a carbon reduction labeling scheme, thereby providing insight into the design of sustainability policies that promote low-carbon development.

2. Literature review

2.1. Application of game theory to green consumption

Game theory focuses on the interactions among conflicted players whose strategic behaviors are influenced by their payoffs (Wu et al., 2012; Zhao et al., 2015). For the past 50 years, it has been widely applied to a number of global issues such as technological innovation, power management, supply chain management, and resource allocation (Campos-Nañez et al., 2008; Leng and Parlar, 2009; Zhao et al., 2012b; Marden and Wierman, 2013; Daming et al., 2014).

However, the application of game theory to green consumption is in progress. For instance, Conrad (2005) built a duopoly game to determine how a consumer's environmental preference affects the prices, product characteristics, and market shares of competing firms. The result indicated that appropriate subsidy and taxation policies could incentivize firms to seek the optimal distribution of green products in the market. The same approach was taken by Rodríguez-Ibeas (2007), who divided consumers into two categories (green and brown) and developed a duopoly game to investigate how a consumer's environmental awareness affects environmental quality and social welfare. The author highlighted that environmental awareness is a key factor in reducing pollution as long as the marginal costs of environmentally friendly products are sufficiently low. Similarly, Liu et al. (2012) developed a two-stage Stackelberg game model to investigate the impact of consumers' environmental awareness on key supply chain stakeholders such as manufacturers and retailers. They found that environmental awareness was positively related to the profit of retailers and that superior eco-friendly operations could increase the profitability of manufacturers. In addition, Cohen et al. (2015) proposed a two-stage Stackelberg game to model the interaction between the government and suppliers of green technology, identifying that subsidies offered to consumers influence a supplier's decision making on pricing, which could raise consumer surplus.

Ibanez and Grolleau (2008) developed a three-stage game model and indicated that eco-labeling schemes were an environmentally effective policy as long as they set appropriate labeling costs. Indeed, Bleda and Valente (2009) indicated that when consumers were provided with appropriate information on the greenness of products via eco-labels, producers were driven to reduce the environmental impact of their products. Jamalpuria (2012) introduced a fiscal incentive in the form of a tax rebate to promote the application of eco-labels by using a duopoly game. However, the author found that an eco-labeling scheme alone was not sufficiently efficient to internalize all the negative externalities of green consumption. For instance, the higher priced green product may lead to greater market uncertainty (Windrum et al., 2009; Diaz-Rainey and Tzavara, 2012). Wing et al. (2011) argued that preferential taxation policy was important for promoting green consumption, while Hu (2012) also identified subsidy and green design as additional factors that support the survival of market competition. Lorek and Spangenberg (2014) confirmed that incentives were indispensable to drive green consumption. However, Hu et al. (2014) pointed out that the effectiveness of Pigouvian tax and subsidy policies depended on the product characteristics.

While these previous studies are useful for informing our approach, most assume that consumers' environmental preference or awareness is a constant or discrete function, which results in fixed market demand. Moreover, incentives to promote green consumption are mostly considered to be given to corporations rather than to consumers. This study thus adds to the literature by incorporating the dynamic change in market demand for carbon-labeled products as well as the direct subsidy given to consumers into the game theoretical analysis to investigate the possible influences on enterprises.

2.2. SD simulation for the game theoretical analysis

SD can help decision makers improve their understanding of the complex feedback structure of a system (Kreng and Wang, 2013; Yunna et al., 2015). A game makes a unique prediction from the possible strategic actions that each player may choose. However, this solution is ultimately indicated by an equilibrium state (i.e., the Nash equilibrium), and the involved dynamic and transient transformation is often neglected (Kim and Kim, 1997). SD bridges this gap by simulating the embodied game scenarios visually in terms of their non-linear feature (Suryani et al., 2010).

Yu and Zhu (2011) presented a Stackelberg game between the government and enterprises in the electrical market, in which SD was used to simulate their interaction. The simulation results identified that price, tax, and the impact of inflation were the most significant factors for maintaining market stability. Similar studies have been conducted by Miller et al. (2012) and Alishahi et al. (2012). The former designed an optimal price mechanism to reduce the peak loads of the smart grid, in which SD was embodied into a game model with incomplete information to simulate the decision interaction of the producer, distributor, and consumers. The latter designed a reliability-based incentive mechanism (feed-in tariff) to promote wind power generation, in which game theory was integrated with SD to model the strategic uncertainties in the power market. The study identified that incentives were efficient to promote wind power expansion with system reliability at a predetermined level.

These game models are based on a number of assumptions. One key assumption is that players are perfectly rational and have common knowledge of this rationality (Samuelson, 2002). This assumption indicates that players who strive to maximize their utilities are capable of thinking through all the possible solutions and choosing the appropriate course of action (Chen et al., 2012). However, Shubik (2002) and Szabó and Fath (2007) pointed out that such an assumption was inconsistent with the real world because individual rationality was restricted by the available information, cognitive limitations, and time available to make decisions.

To overcome the hypothesis of perfect rationality in a game model, evolutionary game theory is proposed. For instance, Wang et al. (2011) used SD to simulate an evolutionary game between the government and enterprises regarding the management of environmental pollution. A dynamic penalty was suggested as an efficient surveillance measure to reduce environmental contamination by enterprises. The same approach was improved by Tian et al. (2014) and Liu et al. (2015), who developed an SD model based on evolutionary game theory to design an optimal subsidy policy to incentivize green supply chain management and to investigate the stability of stakeholder interactions in China's coal mining safety inspection system, respectively. Liu et al. (2015) further indicated that a dynamic penalty-based incentive was effective at compelling enterprises to implement safety productions voluntarily.

While previous studies reflect that SD is a useful tool for the application of game theory, especially for the simulation of policy intervention, most take the policy instrument (e.g., subsidy, taxation) as an entity, regardless of the possible influences that result from the various options. By contrast, this study divides incentive mechanisms into different categories to predict the possible responses of enterprises to the implementation of a carbon reduction labeling scheme by using the evolutionary game approach. Further, the SD tool is specifically used to simulate the changing of the numbers of enterprises set by two policy intervention scenarios.

3. Game model

3.1. Evolutionary game model

Organizational behavior is driven by internal and external factors such as competition, policy instruments, and consumer demand (Tian et al., 2014), as shown in Fig. 1. The two players involved in the game (i.e., any enterprise in the market) are considered to have bounded rationality. Each enterprise proposed in this study has two strategic options. The first option is to implement the carbon reduction labeling scheme (hereinafter referred to as "Implement"), including the application of carbon labeling certification, use of low-carbon technologies, and so on (Shuai et al., 2014). The second is not to implement the carbon reduction labeling scheme (hereinafter referred to as "N-implement"). Table 1 shows the payoff matrix of the two players.

In Table 1, i represents the enterprises that are competitive in the marketplace, $i = 1, 2$; j represents the number of enterprises that have implemented the carbon reduction labeling scheme based on the different strategic choices selected, $j = 1, 2, 3, 4$; t represents the different types of subsidies, $t = 1, 2$; k represents the different types of tax rates, $k = 1, 2, 3, 4$; ξ_i^j represents the market share of the ith enterprise based on the jth market scenario; P_{ij} represents the unit price of the product provided by the ith enterprise based on the jth market scenario; C_{ij} represents the unit production cost of the ith enterprise based on the jth market scenario; S_t represents the t-th type of subsidy (i.e., whether it subsidizes the enterprise or consumer); Π_i^k represents the tax reduction for the ith enterprise from the kth type of rate; $D(\xi_i^j)$ represents the product demand of the ith enterprise based on the jth market scenario; and $D(S_t)$ represents the increasing product demand from the t-th type of subsidy for consumers.

To facilitate the model solution, three hypotheses are given as follows:

a. Each strategy is mutually exclusive (i.e., only one strategy can be selected at one time).
b. Each enterprise examines the payoffs of the related strategy with equal probability to decide whether to change the selected strategic choice.
c. In the game model, the total number of the enterprises is constant.

Let x_i represent the proportion of the enterprises that select the strategy "Implement" among all enterprises, while the proportion of the enterprises that select "N-implement" is $1 - x_i$. The expected payoff when the enterprises choose "Implement" is set as U_{Ei}, the average expected payoff of the enterprises is set as U, and the expected payoff of the enterprises choosing "N-implement" is U_{EN}. The replicator dynamic equations of the "Implement" and "N-Implement" strategies are given as follows:

$$\frac{dx_i}{dt} = x_i(U_{Ei} - \bar{U}) = x_i(1 - x_i)(U_{Ei} - U_{EN}) \quad (1)$$

$$\frac{d(1 - x_i)}{dt} = (1 - x_i)(U_{EN} - \bar{U}) = (1 - x_i)x_i(U_{EN} - U_{Ei}) \quad (2)$$

3.2. SD-based simulation

According to the different strategic choices that result from the interactions among the conflicted players, multiple scenarios are established. SD is used to construct a causal loop system for the scenario analysis (Yunna et al., 2015). The SD model used in this study is composed of two subsystems, namely the enterprises' subsystem and consumers' subsystem, as shown in Fig. 2. Consumers' preferences toward carbon-labeled products may have a strong influence on enterprises' income. Further, governmental policy is set as a moderator variable in both subsystems.

3.2.1. Enterprises' subsystem

Enterprises respond to the implementation of a carbon reduction labeling scheme by varying their quantities, as determined by the replicator dynamic equation in Eq. (1). In reality, because enterprises may need some time to carry out a new strategic action (Zhu and Sarkis, 2006), a delay function is introduced into the proposed model. In line with Dowlatshahi (2005), the delay function is set to three months in this study. In addition, the selected strategy is generally affected by enterprises' capabilities, resources, and market forces (Tian et al., 2014). Thus, we use γ to represent the success rate of the implementation of the carbon reduction labeling scheme. The maximum value is 1 and the mean is 0.7, since Koufteros et al. (2005) have

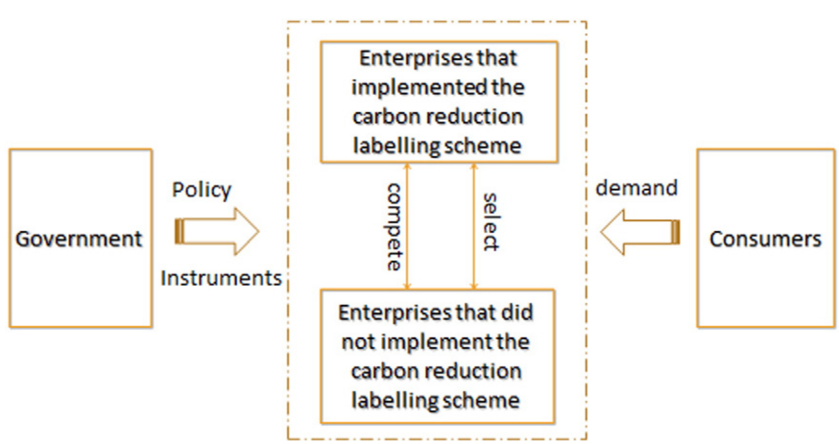

Fig. 1. Driving factors of enterprises' behavior.

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Table 1
Payoff matrix of the enterprises.

Enterprise 1	Enterprise 2	
	Implement	N-implement
Implement	$(P_{11}\text{-}C_{11}+S_t)\times[D(\xi_1^1)+D(S_t)]+\Pi_1^k$; $(P_{21}\text{-}C_{21}+S_t)\times[D(\xi_2^1)+D(S_t)]+\Pi_2^k$	$(P_{12}\text{-}C_{12}+S_t)\times[D(\xi_1^2)+D(S_t)]+\Pi_1^k$; $(P_{22}\text{-}C_{22})\times D(\xi_2^2)$
N-implement	$(P_{13}\text{-}C_{13})\times D(\xi_1^3)$; $(P_{23}\text{-}C_{23}+S_t)\times[D(\xi_2^3)+D(S_t)]+\Pi_2^k$	$(P_{14}\text{-}C_{14})\times D(\xi_1^4)$; $(P_{24}\text{-}C_{24})\times D(\xi_2^4)$

indicated that the success rate of new product development is approximately 60% to 80%.

The major equations of the subsystem are given as follows:

$$\mathrm{EEI} = \mathrm{INTEG}\ (\mathrm{RC}, \text{initial value}) \tag{3}$$

$$\mathrm{RC} = \mathrm{DBC} \times \mathrm{TNE} \times \gamma \tag{4}$$

$$\mathrm{DBC} = \mathrm{DELAY1}\ (\mathrm{BC}, 3) \tag{5}$$

$$\gamma = \mathrm{RANDOM\ NORMAL}\ (0, 1, 0.7, 0.1, 0) \tag{6}$$

$$\mathrm{BC} = \frac{dx_i}{dt} = x_i(U_{Ei} - \bar{U}) = x_i(1 - x_i)(U_{Ei} - U_{EN}) \tag{7}$$

$$U_{Ei} = [(\mathrm{GP} - \mathrm{GC} + \mathrm{ES}) \times \mathrm{GNU}/\mathrm{EEI}] + \mathrm{RT} \tag{8}$$

$$U_{EN} = (\mathrm{OP} - \mathrm{OC}) \times (\mathrm{TNC} - \mathrm{GNU})/\mathrm{EEN} \tag{9}$$

where EEI represents the number of the enterprises that have implemented the carbon reduction labeling scheme; RC the variation in the enterprises that have implemented the scheme; DBC the variation after the implementation period; TNE the total number of the enterprises; γ the success rate of the scheme's implementation; BC the initial variation in the enterprises that have implemented the scheme; GP the carbon-labeled product price; GC the carbon-labeled product cost; ES the direct subsidy for the enterprises that have implemented the carbon reduction labeling scheme; GNU sales of the carbon-labeled product; RT the tax rate; OP the price of the non-carbon-labeled product; OC the cost of the non-carbon-labeled product; TNC the total number of the investigated consumers; and EEN the number of the enterprises that have not implemented the carbon reduction labeling scheme.

3.2.2. Customers' subsystem

The customers' subsystem mainly contains demand for carbon-labeled products, which is shown in Fig. 2. Stock is controlled by the

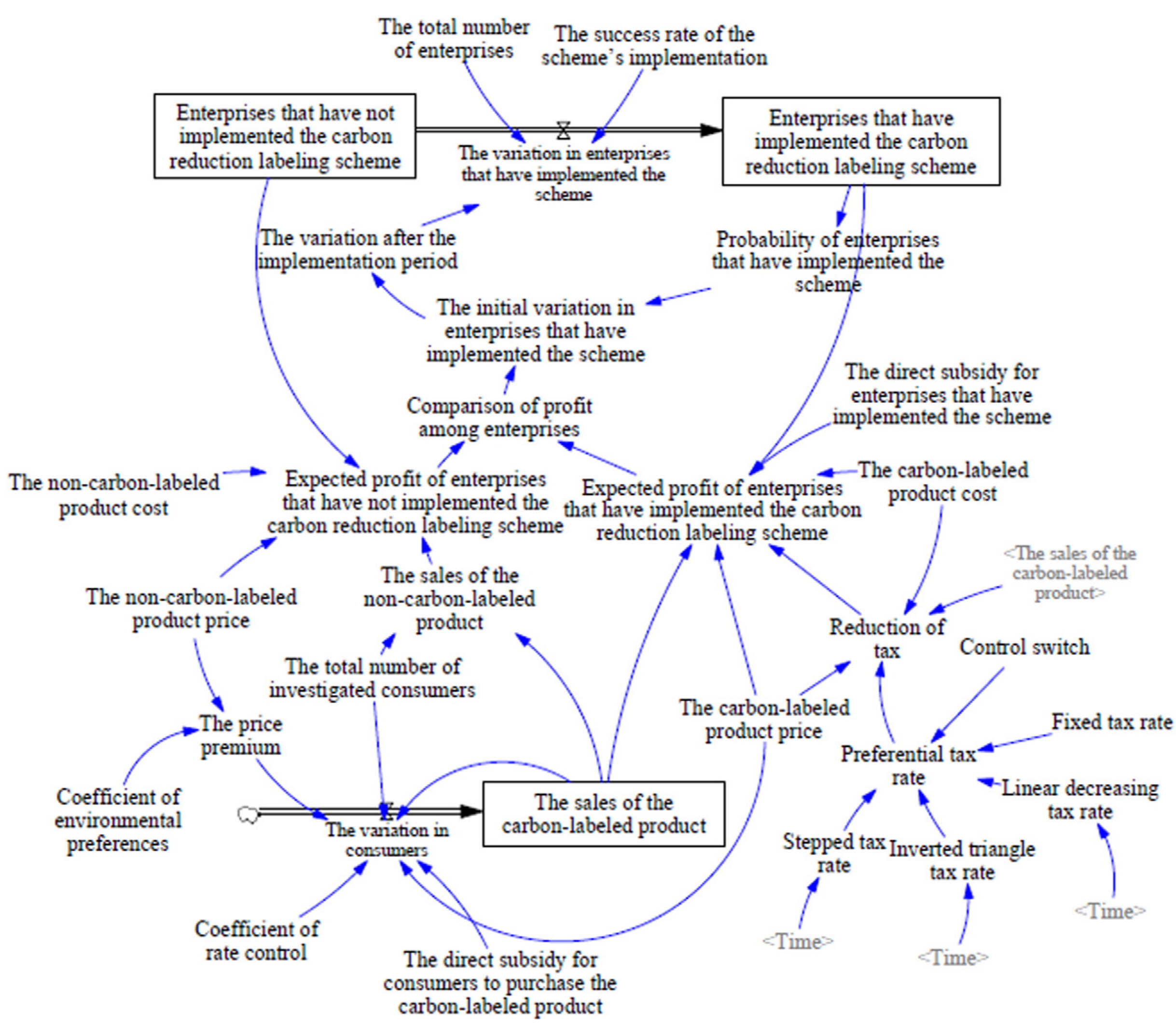


Fig. 2. SD model based on an evolutionary game.

rate of the variance of consumers, which is defined by using the Lyapunov function (Kelly et al., 1998), as shown in Eq. (10):

$$BR = \frac{d(GNU)}{dt} = \beta \times (PR + CS - GP \times GNU) \tag{10}$$

where BR represents the variation in consumers; CS the direct subsidy for consumers to purchase the carbon-labeled product; and GP the carbon-labeled product price.

Here, GNU is measured as the sales of the carbon-labeled product, given as follows:

$$GNU = INTEG\,(BR, \text{initial value}) \tag{11}$$

PR is the price premium, which can be deemed as a consumer's willingness to pay for the carbon-labeled product, given as follows:

$$PR = (1 + \theta) \times OP \tag{12}$$

where θ represents the coefficient of environmental preferences and OP the non-carbon-labeled product price. Whether the carbon-labeled product is welcomed by consumers may be based on their environmental preferences. Zhao and Zhong (2015) indicated that consumers with high environmental preferences were willing to buy green products.

4. Case study

Air conditioner enterprises in China are herein used as an illustrative case example to demonstrate the application of the proposed evolutionary game model. In China, air conditioners are indispensable for maintaining a comfortable and healthy interior environment in residential buildings. As a result, their use accounts for a major share of energy consumption in such buildings (Chua et al., 2013). Indeed, Kyle et al. (2010) identified a strong link between climate change and heating and cooling demand.

The rapid development in the country's building industry over the past few decades (Chen et al., 2015) has led to an increase in the sales of air conditioners (Fig. 3). However, to mitigate the impact of climate change, a series of countermeasures have been proposed to influence China's air conditioning industry. For example, GREE invests billions of Chinese yuan annually to promote the application of fluoride-free technology when designing air conditioners (China HVACR, 2015). Moreover, China's air conditioner enterprises can be certified to verify their energy efficiency (Lin and Rosenquist, 2008).

Labeling the energy efficiency of air conditioners, which is a type of carbon reduction labeling scheme, is divided into three grades (i.e., grades 1–3). The first grade represents the lowest energy consumption (i.e., a refrigerating coefficient of less than 3.4; Standardization Administration of the People's Republic of China, 2010). Similarly, we use the methodology proposed by Zhao et al. (2012a) to divide carbon reduction labeling into three grades, namely high, medium, and low, as shown in Fig. 4.

The data on the input parameters of the SD model are mainly derived from the China Household Electrical Appliances Association, National Bureau of Statistics of the People's Republic of China, and similar studies (Table 2). The number of the enterprises is set to 32, and air conditioner sales were 43.9 million units in 2014 (National Bureau of Statistics of the People's Republic of China, 2015). Since China has not yet launched an official carbon reduction labeling scheme, the pilot enterprises using carbon labeling are considered to be using the first grade of the energy efficiency label, which accounted for 9.7% of market share in 2014 (ZOL, 2015). Thus, we define the number of pilot enterprises as three. Similarly, the price of a carbon-labeled air conditioner is 16% higher than that of an ordinary one (ZOL, 2015).

The subsidy standard is based on the Ministry of Industry and Information Technology of the People's Republic of China (2012), which indicated that enterprises received a subsidy ranging from 300 RMB to 400 RMB for each product, according to its corresponding energy efficiency grade. Lin and Jiang (2011) indicated that subsidies to different stakeholders would result in varying degrees of the promotion of low-carbon consumption. In the same vein, consumers in this study are assumed to receive a subsidy when purchasing a carbon-labeled product. Consistent with the subsidy standard for enterprises, consumers' subsidies are given in three hierarchies: 300 RMB, 350 RMB, and 400 RMB per unit.

According to the Enterprise Income Tax Law of the People's Republic of China, the general tax rate on enterprise income is 25%. Preferential taxation policy aims to waive a certain percentage of the full corporate income tax rate (Huang, 2006). Furthermore, the central government implements preferential tax policies for SMEs and high-tech enterprises of 15% and 20%, respectively (The Central People's Government of the People's Republic of China, 2007). However, no specific preferential tax policy drives carbon reduction labeling schemes in China.

Elschner et al. (2011) and Ng et al. (2012) identified that tax reductions could serve as an incentive for green development. Hence, we define four categories of preferential taxation, namely a fixed tax rate, stepped tax rate, linear decreasing tax rate, and inverted triangle tax rate. The fixed tax rate is set as a constant of 20% throughout the simulation period. The stepped tax rate begins with 25% until the second time node of the simulation and then decreases to 20% between the second and fourth time nodes, before remaining at 15% until the end of the simulation. The linear decreasing tax rate is where the taxation

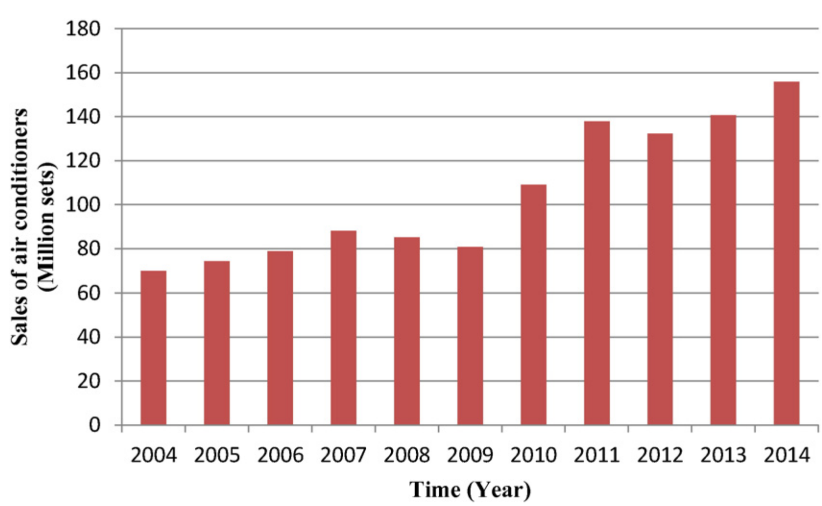


Fig. 3. Sales of air conditioners.

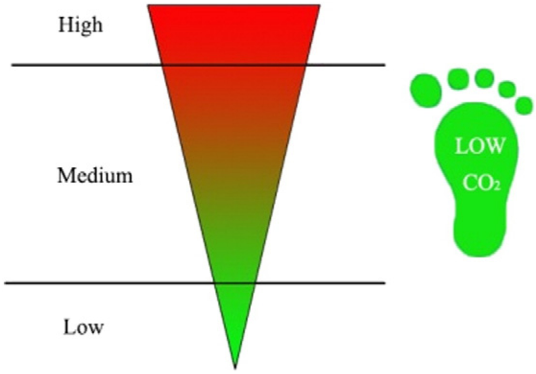


Fig. 4. The proposed carbon reduction labeling scheme.

decreases linearly from 25% to 15% from the start to the sixth time nodes and then remains at 15% until the end of the simulation. The inverted triangle tax rate decreases linearly from 25% to 15% from the start to the third time nodes and then increases to 20% until the sixth time node, before remaining at 20% for the rest of the simulation. Table 3 presents the diagrams of the four predefined tax rates and their corresponding functions.

5. Simulation results and discussion

The software package Vensim PLE for Windows Version 6.3 is used for the SD model simulation. Two scenarios were built to investigate how enterprises responded to different governmental policies when implementing the carbon reduction labeling scheme. Scenario 1 assessed enterprises' responses to a variation in subsidy and preferential taxation (as reflected by the variation in the number of enterprises), where the policy instruments are employed separately. Scenario 2 assessed enterprises' responses to a combined policy instrument (again, as reflected by the variation in the number of enterprises).

5.1. Simulation results of Scenario 1

In this scenario, the number of carbon labeled enterprises remains at a stable level (around eight), although there is a slight increase in the initial stage (Fig. 5). This variation trend line is set as the benchmark to enable comparison with Scenario 2.

The responses of enterprises are determined by the change in the number that implemented the carbon reduction labeling scheme. The initial number of the adopting enterprises might have increased because firms wanted to benefit from the development of low-carbon products in the sense of improving the green value of products, enhancing product competiveness, and raising corporate social image (Chen, 2008). However, market demand is a critical factor in business operations (Lin et al., 2013). Consumer behavior is a key driver of market demand, although the perceived value is diverse (Zhou et al., 2009). As the market for low-carbon products gradually becomes saturated, consumption is expected to decrease, which may result in a temporal fluctuation in the number of enterprises that implement the carbon reduction labeling scheme (Janssen and Jager, 2002). Further, not all enterprises are willing to incorporate green technologies into their product innovation because of unintended market risk, additional costs, and so on (Lin et al., 2013; Zhao et al., 2015). This fact might explain why the number of enterprises that implemented the carbon reduction labeling scheme ultimately remains around eight.

Table 2
Data on the input parameters.

	Parameter	Data	Unit
Level variables	EEI	3	/
	EEN	29	/
	GNU	11.5	Million set
Constant	OC	5000	RMB
	OP	5600	RMB
	GC	5900	RMB
	GP	6500	RMB
	θ	0.1	/
	TNE	32	/
	TNC	43.9	Million set

Fig. 6 shows that the direct subsidy affects enterprises' decision to implement the carbon reduction labeling scheme. As the subsidy rises, the stable values of enterprises increase compared with the benchmark to equilibrium values of 10, 11, and 12, respectively. When the same subsidies are given to consumers, the equilibrium values are 8, 9, and 10, respectively. Hence, a direct subsidy to enterprises is much better than that given to consumers, in line with the findings of Tian et al. (2014). One possible reason is that enterprises are more sensitive to incentive policies compared with consumers (Diamond, 2009). For instance, enterprises have absorbed the impact of allocation rules on carbon allowances (Zhang et al., 2015).

Fig. 7 shows the enterprises' responses to the four preferential taxation policies. Compared with the other three categories of preferential taxation, a fixed tax rate fosters rapid growth in the enterprises implementing the carbon reduction labeling scheme in the early stage. However, the equilibrium number of the enterprises is the least. The stepped tax and linear decreasing tax rates give rise to the same equilibrium, although the latter encourages the enterprises to implement the scheme more quickly. In this context, the effect of the linear decreasing tax rate seems better than that of the stepped one. The dynamic equilibrium imposed by the inverted triangle tax rate approaches that of the fixed tax rate when the preferential tax rate is 20%. However, it is below that imposed by the stepped and linear decreasing tax rates. The linear decreasing tax rate is thus suggested as the optimal form of taxation policy because of its predictability, which may enforce the enterprises to participate in carbon labeling more aggressively.

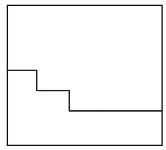
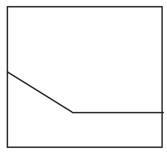
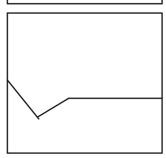
In summary, the analysis of Scenario 1 found that the linear decreasing tax rate and enterprise subsidy of 400 RMB are the optimum policy making tools. Moreover, the enterprise subsidy resulted in a faster rise in the enterprises implementing the carbon reduction labeling scheme in the early stage compared with the preferential taxation policy, as shown in Fig. 8. However, the equilibrium number of the enterprises is smaller for the former, which reflects that the linear decreasing tax rate may have long-term efficacy. This result verifies the findings of Ockwell et al. (2008), who demonstrated that preferential taxation could be more effective than a subsidy for the development of low-carbon products.

5.2. Simulation results of Scenario 2

In Scenario 2, the two incentive policies are combined to investigate the possible responses of the enterprises according to three combinations based on the subsidy amount. Fig. 9 shows that all the three policy combinations have a similar trend in terms of the number of enterprises that implement the carbon reduction labeling scheme. As the subsidy amount increases, the fixed tax rate triggers the largest growth in the enterprises implementing the scheme, followed by the linear decreasing tax and stepped tax rates. The inverted triangle tax and fixed tax rates trigger nearly the same equilibrium at a 20% rate, which has the weakest influence on the change in the enterprises.

By comparing Scenarios 1 and 2, we see that the equilibrium values are increased in the latter, as shown from Figs. 6 to 9. Hence, the combined policy has a greater influence on the implementation of the carbon reduction labeling scheme. The optimum combination is a direct subsidy of 400 RMB for each air conditioner with a linear decreasing tax rate, as shown in Fig. 10. This combination of policies gives rise to not only a faster growth in enterprises implementing the scheme in the early stage, but also a more stable market equilibrium. In particular,

Table 3
Determination of preferential taxation policy.

Policy variable	Category	Diagram	Function
Preferential tax rate	Fixed tax rate		20%
	Stepped tax rate		WITHLOOKUP (time, ([(0,0)–(50,0.5)],(0,0.25),(2,0.25),(2,0.2),(4,0.2),(4,0.15),(6,0.15),(50,0.15)))
	Linear decreasing tax rate		WITHLOOKUP (time, ([(0,0)–(50,0.5)],(0,0.25),(6,0.15),(50,0.15)))
	Inverted triangle tax rate		WITHLOOKUP (time, ([(0,0)–(50,0.5)],(0,0.25),(3,0.15),(6,0.2),(50,0.2)))

the equilibrium value is larger than that when choosing any policy individually.

5.3. Sensitivity analysis

A sensitivity analysis is next carried out to investigate whether the results of the SD model vary once the related parameters change and to assess which variable has the greatest impact on the model results (Blumberga et al., 2015; He and Zhang, 2015). Four variables are selected for the sensitivity analysis: a coefficient of environmental preferences, a coefficient of rate control, the initial number of the enterprises that implement the carbon reduction labeling scheme, and the total number of the consumers. The sensitivity is calculated by using the slope between −10% and 10% of the variance of the four variables to investigate the changes in the number of the enterprises that implement the carbon reduction labeling scheme. The results show that if the related parameters change from −10% to −10%, the change in the number of the enterprises that sell carbon-labeled products is within ±1%, as shown in Fig. 11. Since this sensitivity is in a reasonable range, the model is robust to be used for the game theoretical simulation.

5.4. Discussion

Over the past few years, managers have been encouraged to measure and report lifecycle-based carbon emissions (e.g., by using carbon reduction labeling schemes to incentivize emissions reductions and energy saving; Weidema et al., 2008). However, the complexities of lifecycle assessment and difficulties obtaining a globally recognized protocol for standardized carbon footprint methodologies limit the accuracy of the calculated values (Cohen and Vandenbergh, 2012; Hetherington et al., 2014). For example, the main standards related to

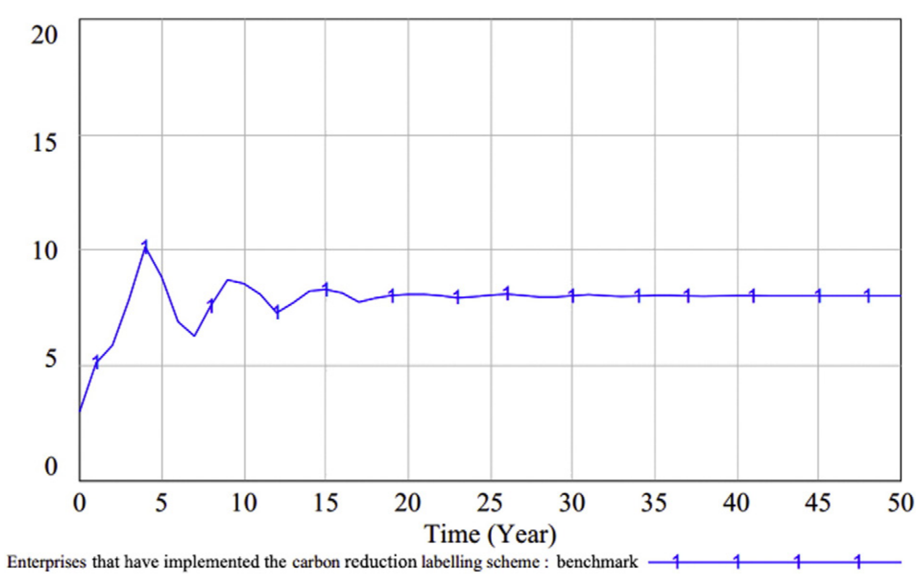
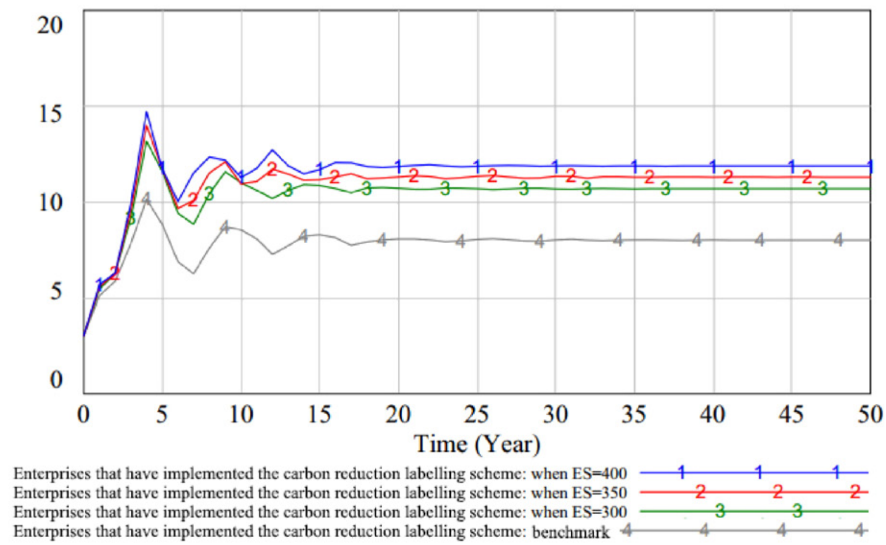
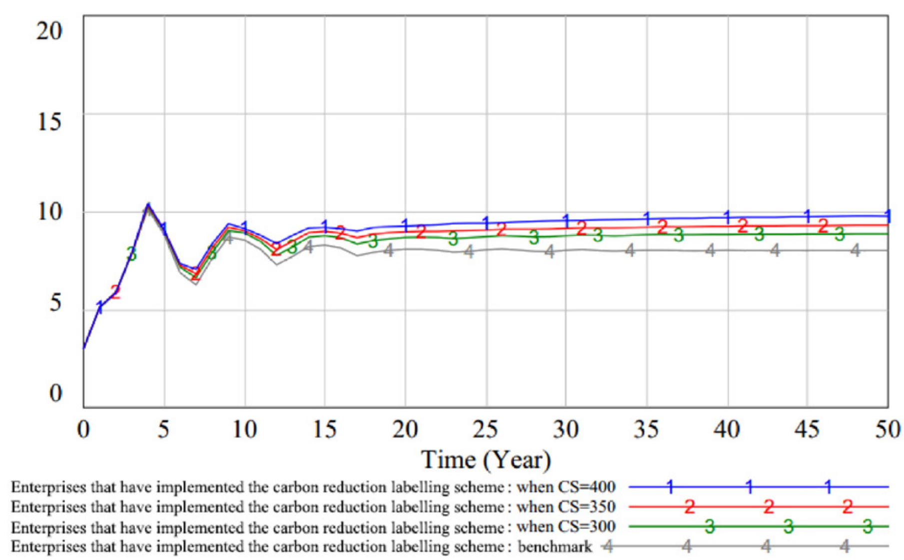


Fig. 5. Responses of the enterprises to the carbon reduction labeling scheme.



a. Subsidy for enterprises that have implemented the carbon reduction labeling scheme



b. Subsidy for consumers to buy carbon-labeled products

Fig. 6. Enterprises' responses to the direct subsidy.

carbon footprinting are PAS 2050, ISO 14067, and WRI/WBCSD, which have different system boundaries and thus may give rise to varied carbon footprint information (Wu et al., 2014). This may further complicate consumers' decision making, as the product shows the same level of quality but is labeled with different CO_2 values. In addition, how to improve transparency in carbon reduction labeling schemes to provide sufficient information to consumers affects consumption significantly (Harbaugh et al., 2011; Wu et al., 2014). For example, Berry et al. (2008) indicated that the public, while in favor of carbon reduction labeling schemes, found it difficult to perceive the emissions value shown on the label. Hence, such schemes must communicate a sufficiently meaningful message to consumers to promote low-carbon consumption. Although carbon reduction labeling schemes are in their infancy, their positive influence on energy saving and carbon emissions reductions is clear (Cohen and Vandenbergh, 2012). A number of adopting countries including the United Kingdom, the United States, Japan, France, and Switzerland pressure enterprises to improve their product sustainability by raising product quality or reducing carbon emissions (Liu et al., 2016). At present, China is under tremendous pressure because of its industrial effects in the context of the global climate crisis (Chen and Groenewold, 2015). Owing to the increasing awareness of climate change, the labeling scheme will drive enterprises to take action on product design and innovation to provide environmentally friendly products for consumers and thus gradually transform into green businesses (Dangelico and Pontrandolfo, 2010; Cohen and Vandenbergh, 2012; Zhao et al., 2012a).

The implementation of a carbon reduction labeling scheme involves the coordination of various stakeholders such as governments, enterprises, and consumers, which may take the form of a mandatory or a voluntary system (Tan et al., 2014). Although their involvement is often voluntary, enterprises usually respond to a range of signals (e.g., consumer demand, governmental policies). Hence, the proposed game provides an insight into how they carry out carbon reduction labeling in various game scenarios. In particular, game theoretical analysis allows the identification of alternative business strategies to help enterprises reduce their lifecycle-based carbon emissions without affecting their commercial sustainability.

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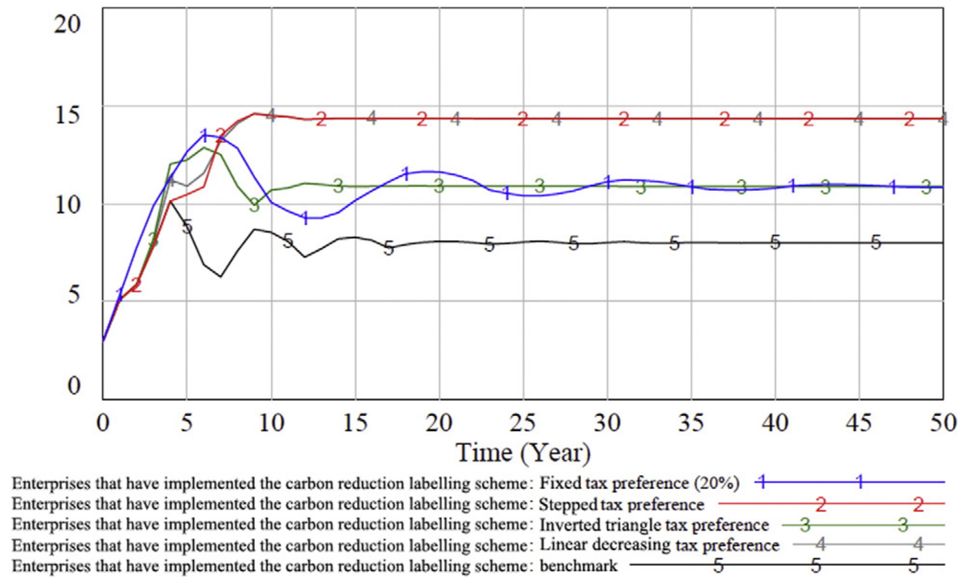

Fig. 7. Enterprises' responses to the four predefined preferential tax rates.

Governmental incentives such as subsidies, preferential tax rates, governmental procurement, and price mechanisms may play a key role in stimulating enterprises to pursue carbon labeling (Geng and Doberstein, 2008; Zhao et al., 2013). Nevertheless, a continuous incentive mechanism may result in a financial burden for the government. Olson (2013) verified that governmental incentives were insufficient to overcome tradeoff-related weak market demand. For long-term success in the implementation of the carbon reduction labeling scheme, governmental incentives must thus be of an appropriate intensity to drive enterprises toward becoming low-carbon companies.

6. Conclusions and implications

Carbon reduction labeling schemes are regarded as an effective measure to raise the environmental awareness of climate change and thus promote green consumption and reduce carbon emissions. The study presents an evolutionary game model to examine how enterprises respond to a range of governmental incentive policies related to the implementation of a carbon reduction labeling scheme, namely a direct subsidy and a series of preferential tax rates. SD is then employed to simulate the created game model by using scenario analysis based on two scenarios: an individual and a combined policy intervention.

Next, a case study of China's air conditioner enterprises is presented, which shows that subsidy and preferential taxation policy significantly influence the implementation of the carbon reduction labeling scheme. In particular, the simulation results show that a direct subsidy given to enterprises is better than one given to consumers. A combination of incentives (i.e. a direct subsidy and preferential taxation) is more efficient to drive the implementation of the carbon reduction labeling scheme. The presented simulation results offer insightful suggestions for enterprises to take actions on their lifecycle-associated carbon emissions to improve product quality as well as move toward low-carbon consumption.

Despite this study's findings, the limitations of this approach remain. China has been identified as one of the largest contributor of CO_2

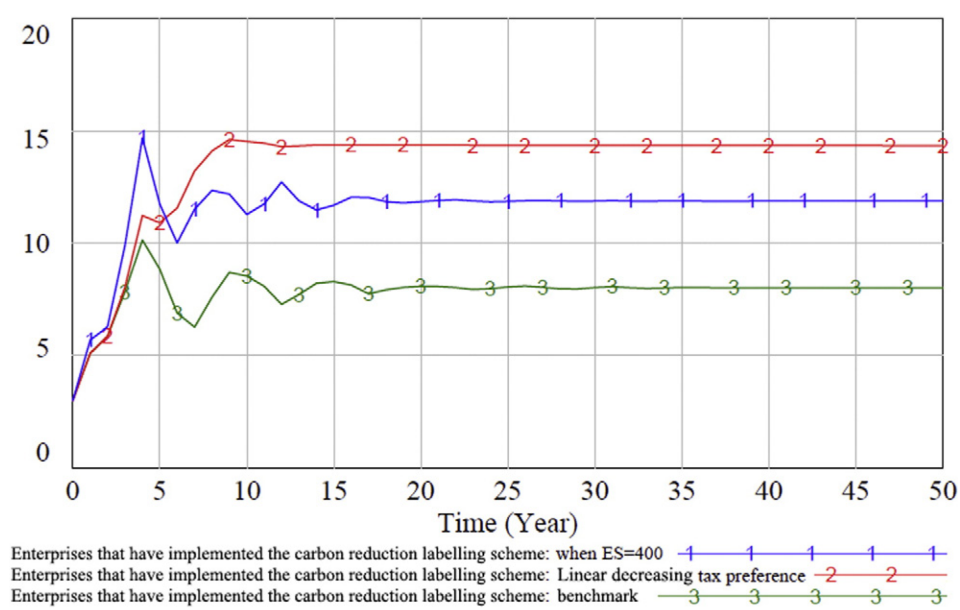

Fig. 8. Enterprises' responses to the two optimal incentive policies.

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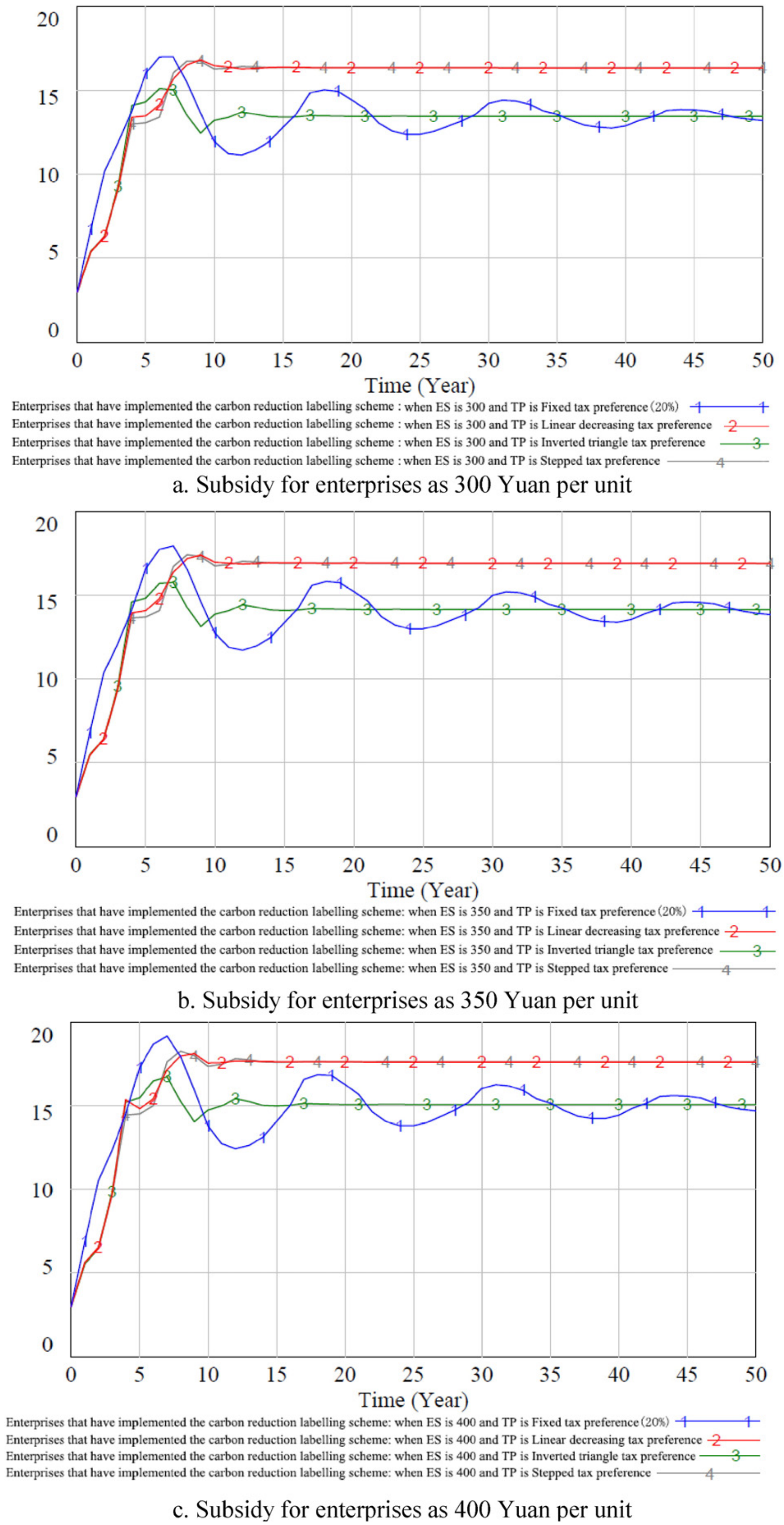

Fig. 9. Enterprises' responses to the combined policies.

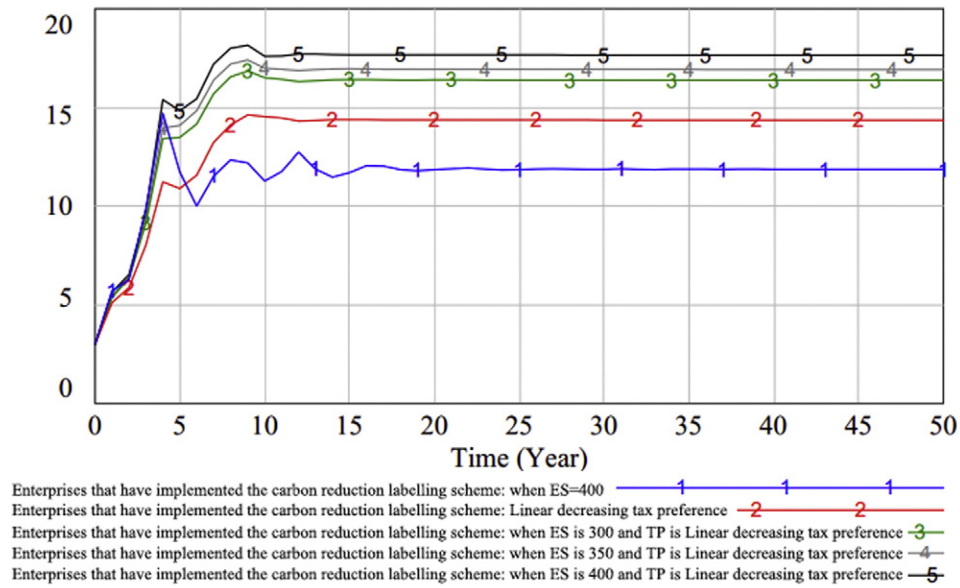

Fig. 10. Optimal combination of the policy intervention.

emissions in the world (Zhang and Choi, 2013; Lin and Xie, 2016). Within this national context, The Chinese government introduced a selective concentration policy to improve performance in terms of carbon emissions reduction (Zhang and Choi, 2013; Zhang et al., 2014; den Elzen et al., 2016). For instance, the carbon market mechanism has been proposed in the '12th Five-Year Plan', which indicates the establishment of carbon emissions trading markets based upon a unified low-carbon product standards (Mo et al., 2016). Aside from the two incentive programs examined in this study, it is important to investigate the impact of other carbon reduction policies, e.g., carbon pricing and government procurement, on the related stakeholders in future studies, thus to promote low carbon development.

The carbon emissions reduction has resulted in an aggregation effect of low carbon development in a region, and this is the case even for northeast Asia (Zhang and Choi, 2013; Huisingh et al., 2015). Korea, as a major contributor of carbon emissions, has shown the highest growth rate of carbon emissions since 1990s (Zhang et al., 2013; Shim and Hong, 2016). Similar to China, Korea has introduced a series of policy initiatives to improve energy utilization and reduce carbon emissions, e.g. a greenhouse gas emissions target management system (GHG-TMS) has been established in 2010, to determine the emissions reduction targets for seven sectors and 26 industries (Zhang and Choi, 2013; Zhang et al., 2013). Although these policies have common aims at carbon emissions reduction, Korea is featured on a market-system, while China mainly depends on governmental regulation (Zhang and Choi, 2013; Rietbergen et al., 2015). Thus, the further study will follow up with a comparatively intra- and inter-regional analysis, to discriminate their possible impacts on the performance of carbon emissions reduction.

Further, the interactions between consumer and industry were omitted herein. In addition, some of the parameters are derived from similar previous studies, which may not highlight all the features of the game. Further studies should thus aim to improve the game theoretical analysis to represent the complexity of all possible stakeholders. The validity of the model could also be tested by applying it to a wide variety of case studies.

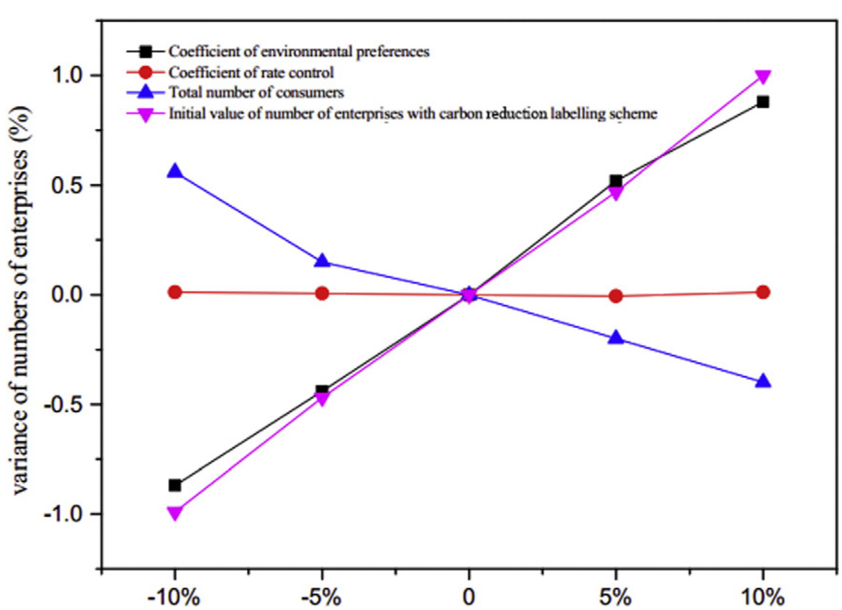

Fig. 11. Sensitivity analysis of the model.

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