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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.