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# The dynamic analysis and simulation of government subsidy strategies in low-carbon diffusion considering the behavior of heterogeneous agents

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ABSTRACT

How to select subsidy strategy for government in low-carbon diffusion is discussed in this paper, considering heterogeneous agents' behavior. Firstly, four government subsidy strategies are given, and the evolutionary game models are constructed including enterprises and consumers. Then seven diffusion scenarios are analyzed according to different initial states, and discussed in two situations, that is, when there is no fluctuation and when there is fluctuation. And then the related simulation analysis is carried out through a case of new energy vehicles diffusion, and the result shows: (1) when the percents of enterprises and consumers with low-carbon strategy and low-carbon consumption are small, the measure only using government subsidy cannot lead to the success of low-carbon diffusion, only if combined with other measures. (2) when the percents of enterprises and consumers with low-carbon strategy and low-carbon consumption both increase to a certain degree, low-carbon diffusion can be realized successfully even without government subsidy, which is true even when there is periodic fluctuation. (3) as for low-carbon diffusion, it may be better to pull the low-carbon market through the demand side than to push the low-carbon market through the supplier side. Finally, the related policy recommendations are given.

## 1. Introduction

In recent years, environmental problems have become the growing concern of the world, and the focus topic of the academic community as well. Therefore it's necessary for enterprises to put environment protection and sustainable development into their growing process. But as for the corresponding large investment and technology, market uncertainty, and the risk of the un-recovered cost, enterprises always have to make a choice between their own benefits maximization and environment pollution. Meanwhile, consumers become more and more sensitive to environmental problems, leading to unprecedented pressure on society and government, and the high price of low-carbon products is an obstacle to consumers' choice. What's more, the government also faces a conundrum in dealing with pollution and promoting low-carbon diffusion.

Subsidy is one of the common instruments for Chinese government to promote low-carbon diffusion especially in the early stage. Effective policy can not only regulate, guide the behavior of agents in the market, but also promote social sustainable development. In practice, however, the intensity of government subsidy has not brought us the expected result in promoting low-carbon diffusion, that is, government subsidy have not been fully used, and the new energy vehicles diffusion is a convincing proof. Therefore, as for the government, the problems as (1) how to select the appropriate subsidy form according to the behavior of heterogeneous agents? and (2) as the main guiding mode, whether subsidy can really achieve the desired result? and (3) what's the effect of promoting low-carbon diffusion with different subsidy forms in different stages? All these questions are the topic and interests of this paper.

## 2. Literature review

At present, the related research on low-carbon subsidy mainly focuses on the following two areas: (1) one is the related research in which government subsidy is shown as a prerequisite, and this area includes two aspects: one is based on different decision-maker (Cheng et al., 2015; Zhang et al., 2013; Li and Zhao, 2014; Xu et al., 2016; Zuo et al., 2016; Ji, 2016; Zhu et al., 2014; Lu and Shao, 2016; Yu et al., 2016), and the other is based on the system optimization research with government subsidy (Liu, 2015; Cheng, 2015; Liu and Mu, 2016; Xiao, 2016; Jung et al., 2016; Aryanpur and Shafiei, 2015), which mainly focuses on supply chain field. (2) the second area is the related research in which government subsidy is considered as the research target, and this area includes two aspects as well: one is about the study on

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government subsidy strategy from different perspectives (Li et al., 2014; Hirte and Tscharaktschiew, 2013; Zhang et al., 2014a, 2014b; Jeon et al., 2015), and the other is about the empirical study on the effects of government subsidy (Qiao et al., 2016; Trappey et al., 2012; Simpson and Clifton, 2016; Lieven, 2015; Silvia and Krause, 2016; Langbroek et al., 2016; Zhang et al., 2014a, 2014b; Michalena and Hills, 2016; Liu et al., 2015; Nenadovic et al., 2016; Chen et al., 2016).

In the first area, the research mostly focuses on the strategy selection of different agents like enterprises, consumers and government, given that there is government subsidy. For example, Cheng et al. (2015) studied the optimal strategy of government subsidy based on the constructed cost-benefit model of enterprises' active carbon reduction and the cost-benefit model of industry, and obtained enterprises' optimal strategy and Pareto optimal. Zhang et al. (2013) analyzed the selection mechanism and the influencing factors of enterprises and government through signaling game model of government and enterprises based on the subsidy policy for energy saving and emission reduction. Li and Zhao (2014) discussed the influence to R&D costs of low-carbon supply chain on cost allocation coefficient and government subsidy, and concluded the strategies between low-carbon R&D cooperation and government subsidy under different game situations. Xu et al. (2016) compared different government subsidy and taxing acts, and analyzed the impact of government subsidy and taxation on the decision-making of carbon products and non-carbon products. Zuo et al. (2016), using dynamic game model, studied the influence of different factors on farmers scale pig raising considering farmers' low-carbon breeding behavior, such as carbon tax, low-carbon farming subsidy coefficient, low-carbon level of products, and consumer willingness to pay for low-carbon products. Ji (2016) discussed the pricing strategy of close-loop supply chain in the view of recycling subsidies and carbon tax. Zhu et al. (2014) compared two subsidy forms (subsidy given to enterprises and subsidy given to consumers), and analyzed the influence of government subsidy on the decision variables of low-carbon products manufactures, ordinary products manufactures and retailers. Lu and Shao (2016) proposed the problem of how the energy service company (ESCO) prices and choosing performance levels for EPC with government subsidy. Yu et al. (2016) focused on the decision-making problem faced by manufacturers to determine which levels of green products to produce and production quantities at each green level. Liu (2015) studied how to develop carbon taxes and subsidy macroeconomic regulation for government under carbon emissions targets, and the impact of government policy on manufactures production decision. Cheng (2015) discussed the efficiency and equity of the coordination of single-stage and multi-stage green supply chain with local government subsidy. Liu and Mu (2016) evaluated the influence of government low-carbon subsidy upon a two-stage supply chain including a dominant supplier and a subordinate distributor, and concluded that the supply chain would be coordinated under the condition of stochastic demand, if the government simultaneously gave the subsidies to both of the supplier and the distributor. Xiao (2016) built a two-stage supply chain system with a manufacture, a retailer and a single period product, from the perspective of supply chain, and studied the problem of how to make decisions and build low-carbon supply chain under carbon taxes and subsidy, in the method of game theory. Jung et al. (2016) proposed a data subsidy scheme where the regulator offered a spectrum price discount to mobile network operators in return for imposing the responsibility of providing a predefined data amount to users free of charge, and analyzed the subsidy effect. Aryanpur and Shafiei (2015) established an optimization model to assess the lowest cost technology options, and the impact of factors on the utilization of renewable resources was evaluated, such as fossil fuel prices, the carbon tax and government incentives. As can be seen from above research, the present research mainly studies individual behavior from the perspective of micro level, and are lack of macro level analysis and discussion.

The second area mainly focuses on how to formulate the government subsidy policy more effective and what about the effect in a specific field. For example, Li et al. (2014) established the game model under government subsidy policy in abatement cooperation in supply chain, and analyzed the government optimal subsidy policy and the enterprises optimal abatement inputs and profits respectively under the conditions of Nash equilibrium. Hirte and Tscharaktschiew (2013) studied the optimal subsidy on electric vehicles in German metropolitan areas with spatial urban model. Zhang et al. (2014a, 2014b) explored the choices and changes of the dependence of strategies between government and enterprises using signaling game theory. Jeon et al. (2015) proposed a method of optimizing financial subsidy and public research and development investments for renewable energy technologies, rather than optimizing financial subsidy alone. As for the empirical research, the present study mainly considers the assessment of the implementation effect of government subsidy. For example, Qiao et al. (2016) analyzed theoretically the impact system of the subsidy on low-carbon technology adoption, and tested the intervention effect of the subsidy on the low-carbon technology adoption based on the survey data in Shanxi and Hebei provinces. Trappey et al. (2012) took Taiwan's green transportation policy as a case to evaluate the corresponding low-carbon island policy. Simpson and Clifton (2016) studied the distributional, procedural and outcome justice of the subsidy for residential solar photovoltaic energy systems in Western Australia. References (Lieven, 2015; Silvia and Krause, 2016; Langbroek et al., 2016) analyzed the effect of government subsidy on the promotion of new energy vehicles including pure electric vehicles. Reference (Zhang et al., 2014a, 2014b; Michalena and Hills, 2016) studied the effect of government subsidy on the new energy industry implementation. Liu et al. (2015) studied the historical evolution and benefit-cost explanation of periodic fluctuation in coal mine safety supervision using evolutionary game analysis framework. Nenadovic et al. (2016) examined the relationship among adaptive capacity, subsidy programs, and fishers' participation in fisheries management, as a potentially important mediating factor affecting outcomes using a data set from two periods of a fishing community in Baja California Sur. Chen et al. (2016) constructed a theoretical framework development for the technological implementation of IHFO with Biogas project Subsidy, Fermented Bed Subsidy and Sewage Charge in the Government Policy design. As can be seen from above, the related empirical research is a static analysis of the implementation of government subsidy even at the macro level. But there is little reference concerning whether government subsidy is necessary and when is necessary from developing and dynamic perspective.

It is therefore of interest to study the selection of government subsidy strategies dynamically combined with micro and macro level. And the rest of this paper is organized as follows: in Section 3, theoretical basis about the influence of the amount of government subsidies on low-carbon diffusion is further discussed, as well as the research method theory. In Section 4, four different subsidy forms are given, and the evolutionary game model of low-carbon diffusion is established with heterogeneous agents, and the hybrid strategies solution of different forms are given as well. In Section 5, these strategies are divided into seven cases, based on which the effective low-carbon diffusion is analyzed. In Section 6, the simulation, analysis and verification are given through an empirical research. In Section 7, the paper is summarized, the related policy recommendations are given, and the future work is presented.

## 3. Theoretical basis

At present, most research agreed that government subsidy can promote low-carbon diffusion (Qiao et al., 2016; Zhang et al., 2014a, 2014b; Xu and Xu, 2015; Luo, 2014; Nicolini and Tavoni, 2017; Xu and Qi, 2016). For example, Xu and Xu (2015) explored effects of the interaction between innovation providers and potential adopters on macroscopic diffusion and found out that government subsidy had significant positive effect on low-carbon technological innovation