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Impacts of regional governmental incentives on the straw power industry in China: A game-theoretic analysis

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A B S T R A C T

China's straw power industry has been suffering from feedstock deficiency since the very beginning. Some local governments propose to offer price incentives to farmers or brokers on straw transaction activities. This paper aims to evaluate the impacts of such incentives and explore feasible ways for maximizing the potential positive effects. Both non-cooperative and cooperative game models are constructed for the members in a typical straw supply chain of China. The equilibrium decisions, payoffs, and social benefits are derived and compared analytically, while numerical experiments are set up for testing the analytical results and extending potential discussions. It is found that the incentives could not only enhance the straw transaction volume, but also benefit the straw supply chain members and the society. Meanwhile, the incentive effects are equal regardless of whether brokers or farmers act as the recipients. However, brokers may have larger bargaining power and grab more subsidizing benefits from farmers in the non-cooperative case. When the straw power plant works cooperatively with brokers, the subsidies may be shared equally and induce higher social benefits. In addition, the subsidies may work better when farmers have higher monetary sensitivity. It is thus suggested that the local governments should offer price incentives to either farmers or brokers on straw transaction activities and facilitate the cooperation between straw power plants and brokers. In particular, the governments should exert more incentive effort in relatively poor regions where farmers tend to be more monetary sensitive.

1. Introduction

Renewable energy has gained great attention from all over the world in recent years due to several driving forces such as seeking alternatives to fossil fuels, guaranteeing national energy security, and reducing carbon emissions (Mafakheri and Nasiri, 2014). Being widely distributed on earth and regarded as sustainable and carbon neutral if with careful management, biomass has become an attractive type of renewable energy (Singh, 2017). Among the multiple ways of bio-energy utilization, power generation through biomass combustion has been the most prevalent due to its relatively mature technologies (Shafie, 2016). However, the economic performance of biomass power industry seems to be poor, mainly because of its high cost of feedstock (Beagle and Belmont, 2016). In order to facilitate the application of such technology, governments have released a variety of supporting policies including price incentives (e.g., NDRC, 2010). Meanwhile, practitioners and researchers have been focusing on better planning and management of the feedstock supply networks (Sharma et al., 2013).

In China, the abundant agricultural residues, namely straws, have been considered as the most promising biomass resource (Qiu et al., 2014). A series of supporting policies for straw power industry have been issued since the year 2006 (Zhang et al., 2014). Consequently, hundreds of straw power plants have emerged all over the country during the past decade. However, reports and researches have shown that most of those running straw power plants were under financial deficit due to the high cost and supply shortage of feedstock (Zhao and Yan, 2012; Zhang et al., 2013). Different from forestry biomass and energy crops in big farms (see, e.g., Krishnan and McCalley, 2016), the straw holders in China are thousands of small farmers that cultivating on dispersedly distributed small farmlands (Jiang et al., 2012). As such, the intermediate merchants or brokers play an important role in the feedstock supply chain of China's straw power industry. They connect the straw power plants

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with the small farmers and take charge of all the pre-procedures of feedstock supply, which include collecting, storing, processing, and shipping the straws from scattered fields to the straw power plants (Zhang et al., 2016). In addition, as Chinese farmers have been using straws for fire, fertilizing, and domestic animal feeding, their consciousness of selling straws for commercial purpose is not strong enough (Zhao et al., 2016). What's even worse, they tend to burn straws directly in fields during busy harvesting seasons for saving time and labor, which not only deteriorates local air condition, but also cuts down the available feedstock for the surrounding straw power plants (Wu et al., 2017). In order to break through the feedstock dilemma of local straw power industry, also to help alleviating local air pollution, some local governments propose to subsidize straw transaction activities on farmers or brokers, i.e., to offer price incentives on each unit of straws that being sold from farmers to brokers. Wang and Watanabe (2016a, 2016b) have shown that such incentives may be beneficial to the straw power industry, however, the implementing ways for maximizing the potential positive effects remain to be further explored.

The research stream has contributed to the improvement of feedstock supply efficiency for biomass power industry from various aspects. For instance, Sosa et al. (2015) develop a linear programming tool to optimize biomass supply chain logistics in Ireland. Zhang et al. (2016) introduce a new pattern of feedstock supply for China's biomass generation industry which involves a formal official organization of villagers' committees. Zhao and Li (2016) establish a multi-objective integer programming model for selecting optimal locations and designing corresponding feedstock supply chains of biomass power plants. Yazan et al. (2016) try to come up with the most effective second-generation biomass supply chain design in terms of economic and environmental sustainability performance. However, the effective design and potential effects of local governmental incentives on straw transaction activities have seldom been studied except in Wang and Watanabe (2016a, 2016b). This paper tries to analyze the impacts of such incentives, and further explore the feasible implementing ways for maximizing the potential positive effects. The analytical model in this paper is different from that in Wang and Watanabe (2016a, 2016b), especially in farmers' straw supply function. Moreover, the collaboration of the straw power plant and brokers, as well as farmers' monetary sensitivity are further studied in this paper. Consequently, additional insights on the incentive design could be derived.

The main methodology used in this study is game-theoretic analysis, which have been applied in studying biomass supply chains as an effective tool. Nasiri and Zaccour (2009) take the first shot to propose a sequential game model among farmer, electricity generator, and electric utility, which is abstracted from Canadian background. Sun et al. (2013) conduct game-theoretic analysis among one biomass supplier and two competing buyers with Chinese background. Wen and Zhang (2015) design a Mixed Acquisition Mode of straw feedstock for China's straw power plants through game analysis and supply chain coordination. Ye et al. (2017) apply game-theoretic approach to study the agricultural feedstock supply chain of biofuel industry under yield uncertainty. In addition, they further propose several contracts to overcome the double marginalization effect (Ye et al., 2018). This paper follows similar fashion with the above studies, but is different in the focusing problem and model settings. By applying game-theoretic analysis, the interactions among key players in China's straw power industry could be modeled, and the conductive effects of local governmental incentives could be studied.

This paper contributes to the literature by displaying a practical model of China's straw power supply chain with local governmental incentives on straw transactions, and offering additional insights on the implementation of such incentives through the model results. Both the non-cooperative and cooperative cases are considered for comparing the incentive effects under different scenarios, and the corresponding game models are constructed among key players. The equilibrium decisions, payoffs, and social benefits are derived and analyzed, and numerical experiments are set up for testing the analytical results and extending potential discussions. Through the study, several interesting results have been found and practical suggestions have been made accordingly. First, the incentives could not only enhance the straw transaction volume, but also benefit the straw supply chain members and have positive effects on social welfare. However, the optimal subsidy level may not be affordable by local governments when the straw supply chain members work separately. Second, the incentive effects are equal regardless of whether farmers or brokers act as the recipients. However, brokers may have larger bargaining power and grab more subsidizing benefits from farmers in the non-cooperative case. Third, when the straw power plant and brokers act cooperatively, the subsidies may be shared evenly, and induce higher benefits for both the straw supply chain members and the society. Lastly, the subsidies may work better when farmers have higher monetary sensitivity. According to the main findings, it is suggested that the local governments should offer price incentives to either farmers or brokers on straw transaction activities. However, the local governments may need to facilitate the cooperation between the straw power plant and brokers for maximizing the potential benefits and making the optimal subsidy level affordable. In addition, the local governments should exert more incentive effort to relatively poor regions where farmers tend to be more sensitive to the straw price.

The remaining content is organized as follows. Section 2 describes the settings and establishes the game models among Farmer, Broker, and SPP (straw power plant). In Section 3, the equilibrium results are derived, and the impacts of the local governmental incentives are discussed analytically. Section 4 validates the analytical results and extends the discussions through numerical experiments. Section 5 concludes the paper.

2. Model

2.1. Settings and assumptions

The model of this paper is constructed according to the practical situation faced by the straw power industry in China. A typical feedstock supply chain of China's straw power industry is considered, which consists of three main entities, i.e., Farmer, Broker, and SPP (straw power plant). Farmer here stands for the entire entity of all farmers in SPP's straw collecting area, so does Broker. Such setting is not unrealistic from economy of scale and stability points of view (Nasiri and Zaccour, 2009). By taking a second thought, it makes sense considering the main purpose of this paper that to analyze the incentive impacts on China's straw power industry, rather than on certain individuals. Horizontal competition between straw power plants is not considered, so SPP stands for the single straw power plant in the model hereafter. It is not hard to understand that the distribution of straw power plants should be scattered if with careful plan for avoiding fierce feedstock competition. Fig. 1 shows the straw supply chain structure considered in this paper, which integrates the exogenous factors from the State Grid Corporation of China (SGCC) and the Local Government.

Receiving raw straw price P_1 (CNY/ton) from Broker and unit selling reward P_f (CNY/ton) from Local Government, Farmer decides the selling quantity Q (ton) of raw straws in fields. After collecting, transporting, storing, and processing, Broker ships the combustible processed straws to SPP with a loss ratio k. The loss ratio captures