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Communication

Subsidy modes, waste cooking oil and biofuel: Policy effectiveness and sustainable supply chains in China

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HIGHLIGHTS

- A dynamic game model is constructed to analyze the incentive effects of subsidy modes.
- Two types of subsidies increase the profits of both biofuel refiners and recyclers.
- Investment subsidies reduce the revenue of biofuel refiners.
- China's subsidy policies for converting waste oil into biofuel need modifications.

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ABSTRACT

Many countries are concerned with the waste-to-energy for economic development and societal welfare. This paper constructs a dynamic game model that, for the first time compares the incentive effects of four common subsidy modes on waste cooking oil supply for biofuel refining and sales of waste cooking oil refined products. The model considers the impact of preferential tax treatment, a raw material subsidy, a sales subsidy and an investment subsidy on the profits of biofuel enterprises and waste cooking oil recyclers. Results indicate that common approaches adopted in developed economies such as raw material price subsidies and finished products sales subsidies increase the profits of both biofuel enterprises and recyclers. On the contrary, investment subsidies, which are relatively common in some regions of China, increase the profits of recyclers, while reducing revenues achieved by biofuel enterprises. To promote the supply chain, policy should give priority to raw material price subsidies and finished products sales subsidies, and for investment subsidies, however, the government should be cautious.

1. Introduction

Many countries are concerned with waste cooking oil-to-biofuel industries, and use a range of subsidies to support sustainable supply chain. For example, the US, which was estimated to produce some 100 million gallons of waste cooking oil produced per day (Radich, 2006), implements a sales subsidy of 50 cents per gallon for waste oil (Yu and Gao, 2011). To divert waste cooking oil flows, Japan, which generates over 400,000 tons waste cooking oil each year (Japan for Sustainability, 2011), recycles waste disposals at high prices. This results in a price advantage of raw material relative to the illegal manufacturers. In Japan, car owners who use 100% biofuel need not pay gasoline transaction taxes (Iijima, 2012).

Reutilization of waste cooking oil in China needs urgent attention, especially when compared to the relatively successful record in developed countries. China is the large producer of waste cooking oil, with 500 million tons of waste cooking oil produced each year in the catering industry of large and medium cities (Bai, 2010). Moreover, current policies for producing biofuel with waste cooking oil focus on planning and regulation with little focus on supply chain subsidies or subsidy modes. The result of this is a severe shortage of raw material supply to a large number of biofuel enterprises. Therefore, improving subsidy policies, in particular, the modes of subsidy will have a significant effect in responding to this dilemma.

The use of waste cooking oil to produce biofuel has also drawn attention within academic circles. The research work concerns two aspects: (1) analysis of waste cooking oil processing and the

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development status of biofuel, with suggestions for strengthening policy incentives such as subsidies, but without further comparison of subsidy modes. For example, Song (2012) pointed out that the government should increase the fund subsidies to promote waste oil refining biofuel. Liang et al. (2013) analyzed the key factors of generating waste cooking oil, and concluded that government should develop financial subsidy policies to solve the bottleneck problem. Through an introduction of international experience among Brazil, Japan or the US and other developed countries, Araujo et al. (2010), Li (2011) and Qiao (2012) indicated that strengthening policy support, especially with the use of subsidies, is an important measure in promoting the converting of kitchen waste into a valuable resource. Other scholars such as Zhang et al. (2009) and Zhang (2012) have emphasized the necessity of supply chain or industry chain incentive policies. (2) Attach importance to the types of renewable energy subsidies. Although not involving the conversion of waste cooking oil to biofuel, this still has a certain referential significance. Taking the US evolution of energy strategy as the research object, Paul (2001) analyzed the US government's renewable modes of energy subsidy. Li et al. (2009) argued that, in order to promote the development of renewable energy, Chinese government could implement subsidy modes of renewable energy such as tax exemptions, investment subsidy increase and low-interest loans. Du et al. (2011) investigated preferential tax, financial subsidies and preferential buying patterns to put forward reform measures in renewable energy subsidies in China. Some scholars, by using panel data models and policy simulations, have compared the cost-effectiveness of feed-in tariffs and other subsidies such as renewable energy quota systems (Dong, 2012), capital subsidies (Hsu, 2012), permission market systems (Fagiani et al., 2013) and direct subsidies (Jonathan, 2013).

While valuable research has been carried out there remain gaps in the literature: (1) little attention is paid specifically to the modes of subsidy in the refinement of waste cooking oil; (2) the existing literature mainly employs methods of the qualitative analysis, panel data model and system dynamics simulation with little focus on the dynamic game between waste collectors and biofuel enterprises. Actually, there are multiple game players such as recyclers, small illegal oil producers, biofuel enterprises and government in the process of production. As government intervention is crucial to divert the waste cooking oil from recyclers to biofuel but not small oil mills and illegal food producers, it is both feasible and a new contribution to build a dynamic game model with two players – waste collectors and biofuel enterprises, and seek an equilibrium solution in the circumstance of government intervention.

2. Model analysis

That waste cooking oil refining biofuel is different from recycling of household appliances and other waste materials, which is specially embodied as follows: (1) recyclers rather than biofuel enterprises are the price leaders, because the former can sell waste cooking oil to a large number of small oil mills and illegal food producers rather than biofuel enterprises. Based on this, the waste collectors first choose recycling prices primarily according to their maximum profits, then the biofuel enterprises optimize the output; (2) in terms of theoretical research and policy practice, the subsidies for waste household appliances recycling are more likely related to recycling rate. However, according to the practice of the US, Japan and other countries, the subsidy policies for biofuel produced by waste cooking oil does not depend on recovery, but on the nature of project launched, the amount of investment, the price of raw material supply and the sales price of finished goods. Accordingly, the subsidy modes mainly classified as preferential tax, price subsidies for the raw materials supply, finished goods sales subsidies and investment subsidies. Of all the subsidy modes, investment subsidies are widely used in China. Incorporate the four subsidy modes into the reverse supply chain model composed by recyclers and biofuel enterprises. The two game players are risk-neutral, and the information is completely symmetrical. In this model, The recovery, the purchase price of raw material and the unit cost of waste collectors are τ, w and c, respectively. As the fixed investment I are needed mainly for recyling network construction, this paper refers to Savaskan et al. (2004) research on the recycling of waste household appliances and set $I=b\tau^2$, where b is the difficulty factor for recycling. Assume all the recycled products are used in the production of biofuel, the finished product rate is λ (see Fig. 1). Set the finished products price of biofuel enterprises as p, and the unit cost of finished products as c_r. Following Ferrer and Swaminathan's (2006) study, set the resource product demand function as $q=\phi-p$, in which $\phi>0$ is the market size.

2.1. Decision-making models in the case of no subsidy incentives

In the case of no subsidy incentives, the revenue function of biofuel is

$$\max \pi_w = q(\phi - q - w - c_r) \tag{1}$$

and accordingly, the revenue function of the waste collectors is

$$\max \pi_r = \frac{q}{\lambda}(w-c) - b\tau^2 \tag{2}$$

subject to

$$0 \le \lambda \le 1 \tag{3}$$

Obviously, $\partial^2\pi_w/\partial q^2 < 0$, $\partial^2\pi_r/\partial w^2 < 0$, i.e., π_w and π_r are concave functions of the variables q and w, respectively, indicating the existence of maximum for π_w and π_r. Moreover, backward induction will be adopted because the recycler is the leader of Stackelberg. The partial derivative of π_w with respect to q gives the quantities produced as

$$q^* = \frac{\phi - w - c_r}{2} \tag{4}$$

Inserting (4) into (2), and taking the partial derivative of π_r and w, the purchase prices of raw material are

$$w^* = \frac{\phi + c - c_r}{2} \tag{5}$$

Inserting (4) and (5) into (1) and (2) gives the equilibrium profits of biofuel enterprises and recyclers in the case of no subsidy support are obtained as Eqs. (6) and (7).

$$\pi_w = \frac{1}{16}(\phi - c - c_r)^2 \tag{6}$$

$$\pi_r = \frac{1}{8\lambda}(\phi - c - c_r)^2 - b\tau^2 \tag{7}$$

2.2. Decision-making models in the case of different subsidy modes

2.2.1. Preferential tax incentives

Assume that the government provides preferential tax for biofuel enterprises based on their income, then the profit is

$$\max \pi_w^t = (1+t)q(\phi - q - w - c_r) \tag{8}$$

where t indicates preferential tax rate. Taking partial derivatives of π_w^t on q, and inserting the obtained value q^t into (2), the equilibrium of w^t is obtained. When the q^t and w^t is substituted in the profit function of biofuel enterprises and recyclers, the