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Top runner program in China: A theoretical analysis for potential subsidies

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ABSTRACT

This article focuses on energy efficiency subsidy to "top runners" (high energy efficiency firms) in China. By game theory approach, some interesting conclusions are achieved. Firstly, a subsidy stimulates subsidized firms' output and profits. Secondly, a subsidy to "top runners" will reduce total emission. Thirdly, both the environmental effects of market structure and the number of subsidized firms are captured. Finally, under asymmetric information condition, we give the values of subsidy budget to identify firms' energy efficiency. In summary, this article supports the theoretic analysis of potential subsidy for TOP RUNNER program in China.

1. Introduction

Energy efficiency[1] is exceedingly important in the whole society and attracts extensive attentions from the public, researchers and governments [1–4]. Further, International Energy Agency (IEA), a non-profit organization, launched 25 important recommendations to improve energy efficiency and to protect environment [5]. According to these significant recommendations, many governments all over the world try to improve energy efficiency by governmental policies and subsidies [6–11].

Different types of governmental policies to stimulate energy efficiency promotion all over the world. For example, German initially operated "BLUE ANGEL CERTIFICATION" in 1977 to improve energy efficiency and U.S launched ENERGY STAR program in 1992 [12]. Japan proposed "TOP RUNNER" program to improve energy efficiency in 1998 [13] and top runners represent those firms with high energy efficiency. In addition, China followed the Japanese pattern and also started to implement the top-runner policy system for energy efficiency to reduce the emission in 2014 [14]. Moreover, Vivoda [15] analyzed the regional institutions of natural gas to improve energy efficiency in Asian, and Siderius [16] discussed the MINIMUM EFFICIENCY PERFORMANCE STANDARDS (MEPS) criterion to improve the energy efficiency of electricity industry.

Subsidies, including direct subsidies [6,7], tax subsidies [8], and so on, play crucial role to promote energy efficiency. Moreover, some scholars compared different energy efficiency subsidies and designed new subsidy mechanism to improve energy efficiency [17–25]. Allcott, Knittel and Taubinsky [20] designed a tagging energy efficiency subsidy and their study showed that this type of policy improves energy efficiency efficiently. In addition, Nie, Yang, Chen and Wang [7] compared output subsidy with fixed subsidy and argued that output subsidy is better than fixed subsidy in reducing the emission, While Yang, Chen and Nie [21] addressed subsidy to renewable energy efficiency under asymmetric information recently. By a mathematical model, Riccardi, Bonenti, Allevi, Avanzi and Gnudi [22] discussed the effects of both environmental regulation and subsidies on the energy efficiency of steel industry with energy efficiency subsidy. In summary, various measures to improve energy efficiency are extensively discussed in recent years and different types of subsidies own both advantages and disadvantages [24,25]. China always subsidize to improve energy efficiency and China subsidized energy management center to improve energy efficiency and to reduce emission from 2009 [26].

Therefore, it is an important task to analyze the effects of energy efficiency policy. Note that China is the largest energy consumption country in the world and therefore it is of paramount importance to address the energy efficiency policy in China. So this article highlights the energy efficiency policy in China. We will introduce the current energy efficiency policy in China as follows.

At the end of 2014, Ministry of Industry and Information Technology of the People's Republic of China launched a policy to subsidize energy efficiency "top runners" in energy-intensive industry[2] [2] and this policy has three major purposes. Firstly, by establishing

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[1] Energy efficiency is defined by International Energy Agency as "something is more energy efficient if it delivers more services for the same energy inputs" (http://www.iea.org/aboutus/faqs/energyefficiency/).

[2] http://www.miit.gov.cn/n11293472/n11293832/n12843926/n13917012/16400095.html.

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Fig. 1. The symbol of "TOP RUNNER" (From http://www.miit.gov.cn/n11293472/n11293832/n12843926/n13917012/16400095.html.

example firms and enhancing policy incentives, the energy efficiency criterions are correspondingly improved. Secondly, TOP RUNNER promotes the energy efficiency in the long terms for some industries. Finally, this policy helps both to save energy and to reduce the emission. The scopes covered by this policy include: Final products depending on energy, energy-intensive industries, and public institutions. The government selects "top runners" based on firms' application, expert review and public declaration.

To operate "TOP RUNNER", on one hand, the final products are labeled "top runners" (See Fig. 1). On the other hand, firms with high energy efficiency are subsidized according to outputs in some industries. For example, the total subsidy to an air conditioner with high energy efficiency is about 500–1000 Yuan RMB in 2015.

Specially, compared with "TOP RUNNER" in Japan, China both labeled "top runners" for firms or productions and subsidized the corresponding firms or productions. Moreover, no special research on "top runners" exists and it is critical to fill in the theory about the subsidy to "top runners". Further, "TOP RUNNER" program is introduced in Ref. [14] and no deep analysis about the effects of "TOP RUNNER" program is launched. On the other hand, game theory methods in economics are employed in energy but we did not find any literature to adopt game theory to judge "TOP RUNNER" program. This article aims to fill in this gap and uses game theory to develop the theory of "TOP RUNNER" program.

Based on the reality above, this article highlights the output subsidy of energy efficiency to energy-intensive industries in China. We aim to capture the effects of energy efficiency subsidy on consumer surplus, producer surplus and emission. Under the condition of perfect information (firms' inputs, outputs and production efficiency and other information are known), we find that the subsidy has little effects on consumer surplus, but improves producer surplus and social welfare obviously. Environmental effects are also discussed. Under asymmetric information (firms' inputs, outputs and production efficiency and other information are not well known by the government), we give the scope of subsidy budget to identify the energy efficiency of all firms.

Contributions of this article are outlined in two parts. In applications, this article supports decision strategies to subsidize energy efficiency of "top runners" in China and other countries. We propose an incentive constraint to subsidize energy firms, which may be helpful for governmental subsidy decisions. In theory, we develop regulation theory for resource industries. This article introduces the method to evaluate the environmental effects of finance subsidy and this definition is useful to access the subsidy for energy intensive firms.

Recently, Abrardi and Cambini [27] also addressed the energy efficiency policy under both perfect information and asymmetric information. Compared with Abrardi and Cambini [27], this article focuses on the energy efficiency policy to improve firms' energy efficiency in energy-intensive industries, while Abrardi and Cambini [27] discussed the policy to promote the consumers' energy efficiency with final products depending on energy. Moreover, this article specially focuses on the "TOP RUNNER" program in energy-intensive industries in China.

The rest of this article is organized as follows: Basic model is established in Section 2. In this section, a benchmark model is established. The corresponding model is analyzed under perfect information in Section 3. We discuss the effects of subsidy on firms' outputs, profits and the total emission. Then the model is addressed under asymmetric information in Section 4. The subsidy budget is discussed to identify all firms' energy efficiency. Results are remarked in the final section and some further researching topics are discussed.

2. Model

Here we establish the basic model of energy efficiency subsidy to energy intensive industries. Because the energy intensive industries own market power, market structure is considered in the model and the subsidy refers to the interesting paper [6]. Assume that N firms exist in an energy-intensive industry and there is no difference for their final products. Under market structure, we assume that the outputs of the final products to be q_i for firm $i(i = 1,2, \cdots,N)$. The price of the final products (or the inverse demand function) is

$$p = A - \sum_{i=1}^{N} q_i, \tag{1}$$

where $A > 0$ means the market size. For N firms in the energy-intensive industry, K firms have energy efficiency advantages over the others ($N - K$ firms). Without loss of generality, the energy efficiency of firm $i(i = 1,2, \cdots,K)$ is θ_H and the others' energy efficiency is θ_L, where $\theta_H > \theta_L > 1$. Denote the energy inputs of firm $i(i = 1,2, \cdots,K)$ to be e_i and the energy price to be ω. Assume other inputs to be fixed and the production function of firm i $(i = 1,2, \cdots,N)$ is

$$q_i = \theta_i e^i, \tag{2}$$

where $\theta_i = \theta_H$ for $i = 1,2, \cdots,K$ and $\theta_i = \theta_L$ for $i = K + 1, K + 2, \cdots,N$. Moreover, we point out that (2) is a Cobb-Douglas production function with special formulation. The profit function is

$$\pi_i = p\theta_i e^i - \omega e_i - \tau\theta_i e_i + \gamma_i \theta_i e^i, \tag{3}$$

where $0 < \tau < 1$ represents the marginal costs. In (3), the first term means the revenues of firm i, the second term is the costs incurred by energy inputs and the third term stands for the costs incurred by production technology. The last term means the subsidy from government and $\gamma_i \geq 0$ is the subsidy intensity. In the third term, a firm with higher energy efficiency incurs higher marginal costs and vice versa. The corresponding total emissions of this energy-intensive industry are

$$EM = \varsigma \sum_{i=1}^{N} e_i. \tag{4}$$

Here $\varsigma > 0$ is a constant manifesting the marginal emission of energy consumption. The emission ςe is also called as anergy (deficiency of energy), which is proportional to energy inputs.

The timing of this game is given as follows: In the first stage, government claims the subsidy policy (including the subsidized firms and the amount of subsidy). Without loss of generality, we assume that the total budget to subsidize is $S_0 > 0$, which is the same as Nie et al. [7]. In the second stage, firms compete in quantity.

3. Results under perfect information

Here we address the above model under perfect information. Notice that the energy efficiency of all firms can be observed. In this case, $\gamma_i = \gamma > 0$ for $i = 1,2, \cdots,K$ and $\gamma_i = 0$ for $i = K + 1, K + 2, \cdots,N$. In other words, firms with high energy efficiency all receive the identical intensity subsidy. Here we analyze the model with backward induction strategy.