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Comparison of energy efficiency subsidies under market power

Pu-Yan Nie[a,1], Chan Wang[a,*], Yon-Cong Yang[b]

[a] Institute of Guangdong Economy & Social Development, School of Finance, Collaborative Innovation Center of Scientific Finance & industry, Guangdong University of Finance & Economics(GDUFE), Guangzhou 510320, PR China
[b] Guangdong University of Foreign Studies, Guangzhou 510420, PR China

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ABSTRACT

Energy efficiency subsidies are very popular all over the world for energy conservation and emission reduction. By using a game theory model, this article captures the differences of two important types of subsidies: fixed subsides and output subsidies. Some interesting conclusions are achieved, and some social phenomena are rationally explained. Firstly, increasing total subsidies increases the number of subsidized firms. Moreover, fiercer competition produces more firms to be subsidized. Thus, the number of subsidized firms depends on the competition in this industry. Secondly, output subsidies achieve a higher consumer surplus and a lower producer surplus than do fixed subsidies. Therefore, consumers like output subsidies, while firms like fixed subsidies. Finally, output subsidies achieve a more favorable environmental impact and subsidize more firms than do fixed subsidies. That is, the environmental effects of output subsidies dominate those of fixed subsidies. In summary, based on both the effects on the environment and the consumer surplus, this article supports output subsidies and explains the advantages of output subsidies.

1. Introduction

In general, energy efficiency is defined as “the ratio between the useful output and input of an energy conversion process” in physics. According to this definition, both technology and policies play exceedingly important roles in improving energy efficiency. This article focuses on policy factors in promoting energy efficiency, because the International Energy Agency (IEA) recommended the adoption of specific energy efficiency policy measures to the G-8 summits in 2006, 2007 and 2008.

Many countries worldwide subsidize either firms or consumers to improve energy efficiency (Proskuryakova and Kovalev, 2015; Avci et al., 2015; Kerr et al., 2017). These countries include India (Acharya and Sadath, 2017), Sweden (Backlund and Thollander, 2015), China (Nie et al., 2016a; Chen et al., 2017), Thailand (Suerkemper et al., 2016), and Mexico (Rosas-Flores et al., 2017). The Japanese government has adopted several subsidy schemes to promote energy efficiency in all sectors of the economy, including industry. For industry, the largest scheme, in terms of financial volume, promotes the installation of energy-efficient facilities. One third of the investment cost for a project can be subsidized, with an upper limit per project of ¥500 million (OECD/IEA, 2008). In Thailand, the implementation of the 20-year Energy Efficiency Action Plan (EEAP) aims to improve energy efficiency. The object of the EEAP is to reduce energy intensity by 25% in 2030 compared to 2010 (Suerkemper et al., 2016). The United Kingdom has also launched programs to improve energy efficiency (Rosenow et al., 2014). In 2006, Sweden launched the ESD (Energy Service Directive) to improve energy efficiency (Backlund and Thollander, 2015). Girod et al. (2017) introduced the energy efficiency policy in Europe and pointed out that 21 European countries have launched different energy efficiency subsidies.

As subsidies are extremely important for improving energy efficiency worldwide (Yao et al., 2014; Chen and Nie, 2016; Yang et al., 2016; Nie et al., 2016b; Yang and Nie, 2015; Tsai and Chen, 2017; Wang et al., 2017), energy efficiency subsidies have attracted considerable attention from many researchers (see Gillingham et al., 2009; Allcott and Greenstone, 2012; Yang and Nie, 2016). Some researchers compare the theoretical benefits of energy efficiency subsidies with other strategies, such as carbon tax (McKibbin et al., 2011; Chen and Nie, 2016), loans, and standards (Walls, 2014). Yang et al. (2016) and Nie et al. (2016b) focus on renewable energy subsidies and compare the efficiency of three types of subsidies in practice.

Other researchers try to design suitable measures to subsidize energy efficiency (Riccardi et al., 2015; Urban and Chiang, 2016; Nie and

* Corresponding author.
E-mail address: wangchan512@163.com (C. Wang).
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Yang, 2016). For example, in a theoretical approach, Abrardi and Cambini (2015) have developed energy efficiency under incomplete information in a competitive environment. Further, Arias and van Beers (2013) conclude that there is a positive relationship between subsidies to patents and energy efficiency and suggest that patents should be subsidized to improve energy efficiency. Allcott et al. (2015) have recently presented a new way ("tagging energy efficiency subsidies") to subsidize energy efficiency, and they argue that "tagging energy efficiency subsidies" will promote efficiency substantially. Subsidies differ for some special industries. By computational fluid dynamic (CFD) modeling, Niamsuwan et al. (2015) support a suggestion to improve energy efficiency for an air-conditioning plant.

Almost all existing papers on energy efficiency subsidies focus on the free competitive market. However, in developing countries, the markets are not freely competitive, and market power exists. Therefore, it is interesting and important to consider energy efficiency subsidies under market power. Moreover, different subsidies have different effects on firms' strategies (Yang, 2014; Sun and Nie, 2015; Nie, 2017). For example, Yang and Nie (2015) addressed the effects of innovation subsidy and argued that output subsidy is the most efficient of all types of subsidies. It is therefore to address the effects of the different types of subsidies on firms' energy efficiency strategies and the emission.

Actually, fixed subsidy and output subsidy exist simultaneously all over the world. For example, energy efficiency subsidy for large investment in Japan is subsidized ¥500 million (OECD/IEA, 2008) and this is a type of fixed subsidy. The Netherlands has launched a renewable energy efficiency subsidy based on outputs (Van Sark et al., 2014)

Under market power, this article addresses two types of energy efficiency subsidies: fixed subsidies and output subsidies. Given fixed total subsidies, we find that, in both cases, fiercer competition results in more firms undertaking subsidies. Moreover, both types of subsidies reduce total emissions. By comparing the two types of subsidies, we conclude that consumers benefit from output subsidies, while firms benefit from fixed subsidies. We also prove that output subsidies reduce total emissions, compared with fixed subsidies.

The contributions of this article lie in two aspects: On the one hand, this article captures the effects of market structure on energy efficiency subsidy. Specifically, fiercer competition causes more firms to undertake subsidies. This may help decision-makers in respect of energy efficiency subsidies. On the other hand, both the advantages and disadvantages of two types of subsidies are highlighted. An authority that is concerned with the environment or consumers prefers an output subsidy. A regulator that cares about producers prefers a fixed subsidy.

The rest of this article is organized as follows: The model is established in Section 2. In the model, the total subsidies are given and fixed, because of the financial budgets. The benchmark model is discussed in Section 3. Two types of subsidies are addressed and compared in Section 4. Conclusions are provided in the final section.

2. Model

Here, we establish the model of subsidies of energy efficiency. This article focuses on direct energy-efficiency subsidies to firms. Higher energy efficiency both saves energy and reduces emissions. Assume that N firms depend on the energy in this energy intensive industry. The firms produce identical products. For convenience, we denote the firm as $i \in \{1, 2, \dots, N\}$. To simplify the problem, given the price as p and the outputs of the firm i to be q_i, we assume the inverse demand function is

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

where $A > 0$ stands for the market size of final products. The production of these products depends on energy and other inputs. Assume that other inputs are fixed and that the production function is

$$q_i = \theta_i e_i, \tag{2}$$

where $e_i > 0$ stands for the energy inputs of firm i and $\theta_i \in \{\theta_L, \theta_H\}(\theta_L < \theta_H)$ represents the energy efficiency. When $\theta_i = \theta_L$, the energy efficiency of firm i is lower, while $\theta_i = \theta_H$ indicates that the energy efficiency of firm i is higher. To simplify, we assume that $\theta_L = 1$ and $\theta_H > 1$. Further, with energy inputs e_i, we assume that the emission level of firm i is $EM_i = \tau e_i$, where $\tau > 0$ is a constant.

Assume that the marginal costs of production of energies are c, where $1 > c > 0$ is a constant standing for the price of energies. The profits of the firm i are

$$\pi_i = p\theta_i e_i - ce_i - (\theta_i - 1)e_i + s_i, \tag{3}$$

where s_i denotes the governmental subsidies to improve energy efficiency. If $\theta_i = 1$, $s_i = 0$. That is, firms with lower energy efficiency receive no subsidies while higher efficiency firms are all subsidized, because of $\theta_L = 1$ and $\theta_H > 1$. In (3), the first term means the revenues, the second term manifests the costs with energy costs, and the third term is the costs of improving energy efficiency. The fourth term represents the governmental subsidies.

In the above model, linear demand function is employed for simplicity. Furthermore, we use linear production function, which is easy to extend to other complicated production functions.

3. Benchmark without subsidies under complete information

Here, we discuss the situation without subsidies, or $s_i = 0$ for all i. The equilibrium is addressed as follows. Assume that K firms have the technology to improve energy efficiency. Without loss of generality, we assume that firm i, $i = 1, 2, \dots, K$, employs the technology to improve energy efficiency. Namely, $\theta_1 = \theta_2 = \dots = \theta_K = \theta_H$ and $\theta_{K+1} = \theta_{K+2} = \cdots\theta_N = \theta_L = 1$. From (1)–(3), we have $\pi_i = (A - \sum_{i=1}^{N} \theta_i e_i)\theta_i e_i - ce_i - (\theta_i - 1)e_i$, which is concave, and the unique equilibrium is determined by the first order optimal conditions.

$$\frac{\partial \pi_i}{\partial e_i} = \theta_i(A - \sum_{j=1}^{N} \theta_j e_j - \theta_i e_i) - c - (\theta_i - 1) = 0. \tag{4}$$

The equilibrium demand of energy is

$$e_1^{*,1} = e_2^{*,1} = \dots = e_K^{*,1} = \frac{A - c - (N - K + 1)(1 - \frac{1}{\theta_H})(1 - c)}{(N + 1)\theta_H},$$
$$e_{K+1}^{*,1} = e_{K+2}^{*,1} = \dots = e_N^{*,1} = \frac{A - c + K(1 - \frac{1}{\theta_H})(1 - c)}{(N + 1)}. \tag{5}$$

The corresponding profits are

$$\pi_1^{*,1} = \pi_2^{*,1} = \dots = \pi_K^{*,1} = \pi^{*,1H} = \frac{[A - c - (N - K + 1)(1 - \frac{1}{\theta_H})(1 - c)]^2}{(N + 1)^2},$$
$$\pi_{K+1}^{*,1} = \pi_{K+2}^{*,1} = \dots = \pi_N^{*,1} = \pi^{*,1L} = \frac{[A - c + K(1 - \frac{1}{\theta_H})(1 - c)]^2}{(N + 1)^2}. \tag{6}$$

From (6), we have $\pi^{*,1H} < \pi^{*,1L}$. Therefore, the equilibrium number of firms to employ energy efficiency improving technology is $K^{*,1} = 0$. We immediately have the following conclusion:

Proposition 1. Without subsidies, no profit incentive firms have the intention of improving energy efficiency.

Remarks:. Without subsidies, on the one hand, adopting technology to improve energy efficiency increases the marginal production costs. On the other hand, marginal production is promoted. Under this trade-off, firms make decisions over whether to employ technology to improve their energy efficiency. Without subsidies, as the increasing costs are much higher than the increasing revenues, no firms are willing to employ technology to improve energy efficiency. Thus, it is very difficult to popularize the new technology to improve energy