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How to subsidize energy efficiency under duopoly efficiently?

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HIGHLIGHTS

- This article captures the effects of output subsidy.
- Firms without subsidy are not willing to improve energy efficiency.
- Subsidy stimulates the subsidized firms' outputs and deters the others' outputs.
- The subsidy intensity depends on firms' position.
- Overdue subsidy cannot reach the environmental object.

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ABSTRACT

Establishing a game theory model, this paper captures the effects of output subsidy on energy efficiency under Cournot competition and Stackelberg competition. Three types of subsidies are considered in the model, namely without subsidy, unilateral subsidy and bilateral subsidy. The findings indicate that firms without subsidy are not willing to improve energy efficiency. Also, subsidy stimulates the subsidized firms' outputs while deters the outputs of other firms. Meanwhile, the equilibrium subsidy intensity depends on firms' position. Furthermore, the minimal subsidy budgets under different situations are presented. Especially, given the fixed subsidy budget, the output of the subsidized firm is the highest if this firm plays the leading position. In addition, certain subsidy can reduce the total emission, while overdue subsidy cannot reach the environmental object.

1. Introduction

International Energy Agency (IEA) defined energy efficiency (EE) as "something is more energy efficient if it delivers more services for the same energy input" [1]. Furthermore, to promote energy efficiency, IEA recommended the adoption of energy efficiency subsidy policies by governments [2–6]. McKibbin, Morris and Wilcoxen [7] and Wall [8] showed the advantages of energy efficiency subsidy. Therefore, energy efficiency subsidy is attached extensive importance by many researchers, such as the interesting reviewing papers of Gillingham et al. [9] and Allcott and Greenstone [10].

Actually, as one of the most important energy efficiency policies, subsidy plays a key role in the process of transformation from 'industrial development' to 'green development' [11]. For this reason, many countries and regions subsidize firms or consumers to improve energy efficiency to cope with global climate change [12], like Japan [13], Thailand [14], United Kingdom (UK) [15], and Sweden [16,17]. Fais et al. [18] addressed the regional energy efficiency with subsidy in Europe.

There exist different types of energy efficiency subsidies all over the world, such as fixed subsidy and output subsidy. Craig and Allen [19] showed that demographic factors, attitudes, planned purchases, and energy efficiency initiatives of utility provider affect energy efficiency subsidy significantly. Furthermore, market structure also has significant impact on the effects of governmental subsidies on energy efficiency. Under monopoly, considering externalities and price-quality discrimination, Nauleau et al. [20] argued that social optimum could be achieved by different types of subsidies.

In practice, since energy efficiency subsidies reduce emission with the support of public finance, it is very important to design

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the suitable measures to subsidize energy efficiency [21]. Recently, Abardi and Cambini [22] developed energy efficiency strategies under incomplete information in competitive environment. Further, Arias and van Beers [23] suggested to subsidizing patents to improve energy efficiency, since they are positively related. Allcott et al. [24] recently gave a new way called as "tagging energy efficiency subsidies" to subsidize energy efficiency and argued that it would lead to large efficiency gain. Resorted to methods given by Sun and Nie [25], Nie [26] recently compared the effects of fixed subsidies with output subsidies and concluded that output subsidies improve environmental object and consumer surplus more than fixed subsidies.

Significantly, Nie [26] proved the output subsidies are more efficient to reach environmental object and suggested output subsidies to improve energy efficiency. Furthermore, it is important to identify how the government should subsidize firms under asymmetric efficiency. Therefore, we follow the idea of Nie [26] and focus on two firms under asymmetric situation.

Notice that besides energy efficiency, subsidies are commonly used in many other fields, such as R&D subsidies and investment subsidies. The impact of subsidies under duopoly, however, differs in various sectors and fields. For instance, R&D subsidies stimulate innovation investment effectively [27,28], while investment subsidy may crowd-out private expenditure in investment [29,30]. In related studies, regardless of subsidizing forms, the effects of subsidies are always discussed by game theory and the optimal subsidies could be obtained by backward induction. In this paper, we follow this method to analyze the effects of energy efficiency subsidies, while the results are different from the literature mentioned above because the major concerns are not the same.

Under different primary energy efficiency, this article aims to capture the optimal subsidizing strategies. We try to answer the following questions in this paper: What are the effects of subsidy on the subsidized firms and other firms? How are the effects of firms' position on firms' strategies? What is the minimal subsidy budget? How are the effects of subsidy on total emission?

Taking market structure into account, this paper relates to the studies of Nauleau et al. [20] and Nie [26]. Nauleau et al. [20] discussed the effects of subsidy on the energy efficiency under monopoly and argued that all types of subsidies can reach social optimum. While Nie [26] found that output subsidy is better than the fixed one under oligopoly. The findings of the two researches showed that the effects of energy efficiency depend on market structure. This article continues to capture the effects of market structure on energy efficiency under asymmetry and focus on the effects of firms' position on energy efficiency subsidy. Specifically, we take Cournot competition and Stackelberg competition into consideration since they are standard and fundamental economic theories in industrial analysis. Cournot competition refers to the situation that firms make production decisions independently at the same time in quantity competition. In the case of Stackelberg competition, the leader firm moves first and then the follower firms move sequentially. In both situations firms compete in quantity to maximize their profits. The equilibrium could be obtained by backward induction.

The contribution of this paper is to argue that total subsidy depends on the subsidized firms' position. The subsidy intensity reaches the lowest if the subsidized firm acts as the follower, while reaches the highest when the subsidized firm plays the leading position. The minimal budget under various types of firms' position is analyzed. The minimal budget is the lowest if the low energy efficiency firm acts as the follower and is solely subsidized. The minimal budget to subsidize both firms under the condition that the high energy efficiency firm acting as the leader is larger than that the low energy efficiency playing the leading position.

The rest of this article is organized as follows: The model is established in Section 2. In the model, the total subsidies are fixed and government employs output subsidy. The Cournot competition with output subsidies is discussed in Section 3. The Stackelberg competition is addressed in Section 4. In Section 5, Stackelberg case is compared with Cournot competition. Conclusions are remarked in the final section.

2. Model

We establish the model of the output subsidies of energy efficiency under duopoly situation. Namely, the energy-efficiency subsidies given to the firms are based on their outputs directly. Assume that there are two firms depending on energies in this industry. Moreover, firms produce the identical products. For convenience, we denote the two firms as $i \in \{1, 2\}$, respectively. To simplify the problem, given the price p and the outputs of firm i to be q_i, we assume the inverse demand function is

$$p = A - q_1 - q_2, \tag{1}$$

where $A > 0$ means the market size of final products. Similar to [26], the production of these products depends on energies and other inputs. Assume that other inputs are fixed and the initial production function is linear to the energy input. Assume the initial marginal production to be θ_1 and θ_2, which satisfy $1 = \theta_1 < \theta_2$. The two firms invest in energy efficiency that denoted as $\bar{\theta}_1$ and $\bar{\theta}_2$, where $\bar{\theta}_1 \geqslant \theta_1$ and $\bar{\theta}_2 \geqslant \theta_2$. Moreover,

$$\bar{\theta}_i = \begin{cases} \theta_i & \text{No EE investment}, \\ \theta_i + \Delta\theta & \text{With EE investment}. \end{cases} \tag{2}$$

We assume that $\Delta\theta > 0$ is a constant in (2). The corresponding production function is

$$q_i = \bar{\theta}_i e_i. \tag{3}$$

Further, with energy inputs e_i, we assume that the emission of firm i is $EM_i = \tau e_i$, where $\tau > 0$ is a constant.

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

$$\pi_i = p\bar{\theta}_i e_i - c e_i - \bar{\theta}_i(\bar{\theta}_i - \theta_i)e_i + s_i(\bar{\theta}_i e_i), \tag{4}$$

where $s_i(\bar{\theta}_i e_i) = \gamma\bar{\theta}_i e_i$ denotes governmental subsidies to improve energy efficiency, and $\gamma \geqslant 0$ is the intensity of the output subsidy. In (4), the first term means the revenues; the second term manifests the costs with energy costs and the third term is the costs to improve energy efficiency. The fourth term indicates the governmental subsidies.

The timing of this game is: In the first stage, given $1 = \theta_1 < \theta_2$, government declares the firm(s) to be subsided and the intensity of the output subsidy (γ). In the second stage, the two firms simultaneously determine whether to invest energy efficiency or not. In the third stage, the two firms compete in quantity.

In the above model, linear demand function is always employed to simplify the model. Furthermore, we use linear production function and it is easy to extend to other complicated production function. Moreover, this article assumes that the information is complete. That is, both firms and government know the costs and the energy efficiency. Moreover, following [26], we also assume that the budget of output subsidies is $S_0 > 0$. Moreover, if a firm is subsidized, we assume that this firm is required to improve energy efficiency.

Moreover, by (3) and (4), we assume that the two firms receive the identical increase of marginal production to invest EE, while the costs are different. The firm with higher marginal production