Economics Letters 154 (2017) 64–68

Contents lists available at ScienceDirect

Economics Letters

journal homepage: www.elsevier.com/locate/ecolet

Long-run welfare effect of energy conservation regulation

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HIGHLIGHTS

- We investigate the long-run effect of energy conservation regulation.
- We consider the cases in which Pigovian tax is imposed.
- Additional energy conservation regulation is always harmful under perfect competition.
- It may improve both social and consumer welfare under imperfect competition.

ARTICLE INFO

Article history:
Received 15 November 2016
Received in revised form 15 February 2017
Accepted 24 February 2017
Available online 27 February 2017

JEL classification:
D61
H54
L13

Keywords:
Energy-saving
Environmental tax
Free entry market
Consumer-benefiting regulation

ABSTRACT

We investigate the long-run effect of energy conservation regulation, which forces firms to raise energy-saving investment above the cost-minimizing level. If Pigovian tax is imposed, additional regulation always harms social welfare under perfect competition, while it can improve welfare under imperfect competition. Our result under imperfect competition holds regardless of whether strategies are strategic substitutes or complements in contrast to direct entry regulation.

1. Introduction

In many countries, environmental and/or energy consumption taxes are imposed to internalize the negative externality of energy consumption.[1] Nevertheless, additional regulations that aim to improve the efficiency of energy consumption exist globally. In Japan, following the Act of the Rational Use of Energy, which was originally enacted in 1979 and has been repeatedly amended, the Ministry of Economy, Trade, and Industry sets industry-specific targets for the improvement of energy efficiency and regulates energy efficiency levels. Moreover, the Ministry of the Environment imposes energy efficiency regulation on power plants in addition to regulating the emissions of pollutants. Similar regulations exist outside Japan, such as in the United States (Energy Policy and Conservation Act, 1975, National Appliance Energy Conservation Act, 1987, Energy Policy Act, 2005), Germany (EnEV, 1977), Singapore (Energy Conservation Act, 2012), and Thailand (The Ministerial Regulation B.E. 2547, 2004).

In this study, we investigate a model in which firms engage in energy-saving investment that improves energy consumption efficiency. A typical example of energy-saving investment is introducing exhaust heat recovery equipment, which increases the fixed cost (sunk cost) and reduces the variable cost.[2] The government controls the investment level by regulation. We consider the situation in which Pigovian tax is imposed, and thus, the negative externality has already been fully internalized. Pigovian tax is an effective tool for internalizing the negative externality of energy

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[1] Norway, Sweden, Denmark, France, and Portugal have introduced carbon taxes in addition to energy taxes and several other countries plan to follow suit. The United States, the United Kingdom, Germany, and Japan have energy taxes (Ministry of the Environment, Government of Japan, 2016).

[2] For examples of energy-saving investment and the empirical analysis of its policy effects, see de Groot et al. (2001) and the works cited therein.

http://dx.doi.org/10.1016/j.econlet.2017.02.030
0165-1765/

consumption.[3] However, we examine whether there is a rationale for energy conservation regulation even in the presence of Pigovian tax and make two main findings. On one hand, under perfect competition, additional energy conservation regulation harms consumer and social welfare in the long run. On the other hand, under imperfect competition, additional energy conservation regulation can improve both consumer and social welfare, even in the long run. Our result suggests that under imperfect competition, energy conservation regulation may be useful even when the government imposes Pigovian tax. However, our result may not hold if there is a significant spillover effect in energy-saving investment.[4]

Energy conservation regulation has two main advantages over direct entry regulation, as discussed by Mankiw and Whinston (1986) and Suzumura and Kiyono (1987).[5] First, energy conservation regulation increases both the total social surplus and consumer welfare, while direct entry regulation increases the total social surplus but reduces consumer welfare.[6] Second, energy conservation regulation increases both the total social surplus and consumer welfare regardless of whether the strategies in the quantity competition stage are substitutes or complements, while direct regulation increases the total social surplus only when strategies are strategic substitutes. Thus, the current paper complements the literature on direct entry regulation.

This study is related to the discussion on endogenous market structure with endogenous sunk costs in which firms compete in terms of R&D and/or advertising investment that consists of sunk costs. Pioneering work was carried out by Dasgupta and Stiglitz (1980). They considered a model in which firms choose cost-reducing R&D investment in a free entry market. Sutton (1991, 1998) discussed various activities, such as quality-improving investment and advertising activities and suggested the existence of a lower bound of market concentration in free entry markets, from both theoretical and empirical viewpoints. Etro (2014) presented rigorous analysis supporting his discussion. Our study lies between exogenous and endogenous sunk cost models. In our model, the sunk cost is exogenous for firms as long as the regulation is effective, while for the government, the sunk cost is controllable by the regulation. Our focus is on the welfare effect of regulation that is not discussed in the above works.

2. The model

There are infinitely many potential new entrants, each of which has an energy consumption function $y = g(x, I) : \mathbb{R}^2_+ \mapsto \mathbb{R}_+$, where $y \in \mathbb{R}_+$ is the energy consumption level, $x \in \mathbb{R}_+$ is the output level, and $I \in \mathbb{R}_+$ is the energy conservation investment level. Energy conservation investment is assumed to improve marginal energy consumption efficiency. We assume that $g(x, I)$ is twice continuously differentiable, $g_x > 0$, $g_{xx} > 0$, $g_I < 0$, $g_{xI} < 0$, and $g_{II} > 0\ \forall x > 0$ (the subscript denotes the derivative, for example, $g_x = \partial f/\partial x$ and $g_{xx} = \partial^2 f/\partial x^2$). The assumption $g_x > 0$ implies that higher production requires higher energy consumption. The assumptions $g_{xx} > 0$ and $g_{II} > 0$ are made to ensure that the profit function is concave. The assumption $g_{xI} < 0$ implies that energy conservation investment reduces marginal energy consumption and thus reduces the marginal production cost. This is the critical assumption in our analysis.

Let $n\,(\geq 1)$ be the number of entering firms and $X := \sum_{i=1}^n x_i$ be total output in the market. The (inverse) demand function is given by $p(X) : \mathbb{R}_+ \mapsto \mathbb{R}_+$. We assume that $p(X)$ is nonincreasing and twice differentiable. We also assume that $p'(X) < 0$ for all X as long as $p > 0$. One unit of energy consumption yields $d > 0$ units of the negative externality.[7] We assume that the government sets $t = d$. In other words, the negative externality of energy consumption is fully internalized.

Firm i's profit π_i is $p(X)x_i - (w + t)y_i - I_i$, where w is the exogenous energy price and t is energy consumption tax. We suppose $w = 0$ for notational simplicity. We also assume that demand is sufficiently large that $n \geq 1$ holds in all relevant subgames in free entry markets.

The total social surplus is given by

$$W = \int_0^X p(q)dq - d\sum_{i=1}^n y_i - \sum_{i=1}^n I_i. \tag{1}$$

The game runs as follows. Before the game, the government chooses the minimal level of investment I^* as its energy conservation regulation. In the first stage, by observing I^*, potential new entrants choose whether or not to enter the market. In the second stage, after observing the number of new entrants n, each new entrant i ($i = 1, \ldots, n$) independently chooses x_i and I_i under the constraint $I_i \geq I^*$. We restrict our attention to the symmetric equilibrium at which all firms entering the market choose the same x and I.

3. The results

3.1. Benchmark: perfect competition case

In this subsection, we consider the case in which all firms are price takers in the product market. Suppose that I^* is small and the constraint $I_i \geq I^*$ is not binding. In the second stage, n-symmetric firms choose x and I to maximize their profits. We assume $|g_{xx}g_{II}| > (g_{xI})^2$ to ensure that $\pi_i(x, I)$ is concave. The first-order conditions are

$$p = tg_x, \tag{2}$$

$$-tg_I = 1. \tag{3}$$

Let I^N be the investment level at which the constraint $I_i \geq I^*$ is not binding. If $I_i \leq I^N$, each firm chooses $I = I^N$; otherwise, each firm chooses $I = I^*$.

In the first stage, infinitely many potential new entrants decide whether to enter the market. The number of entrants n is given by the zero-profit condition:

$$px - ty - I = 0. \tag{4}$$

If the minimal investment regulation is effective (i.e., the constraint $I \geq I^*$ is binding), Eqs. (2) and (4) determine n and x given $I = I^*$. On the contrary, Eqs. (2)–(4) determine n, x, and I when no effective regulation exists. Henceforth, we restrict our attention to the case in which the regulation is effective.

We use the superscript T to denote the equilibrium outcome in the subgame, where superscript "T" denotes "price taker". We

[3] Under perfect competition, Pigovian tax is optimal both in the short-run case (in a market with a fixed number of firms) and in the long-run case (in a market where the number of firms is determined by the zero-profit condition). Katsoulacos and Xepapadeas (1995), Lee (1999), and Requate (1997) showed that Pigovian tax can be optimal even under long-run imperfect competition. For a discussion of the long-run optimal environmental tax rate under imperfect competition, see also Cato (2010) and Lahiri and Ono (2007).

[4] We thank the referee for drawing our attention to this important point.

[5] The long-run effects of various policies are intensively discussed by Cato and Matsumura (2013), Etro (2004, 2007), and Lahiri and Ono (1995, 1998).

[6] This property is shared by Lahiri and Ono (1988), who showed another version of excessive entry.

[7] Some readers might think that d should be increasing in total energy consumption $Y := \sum_{i=1}^n y_i$. We can show that our results hold even when d is increasing in Y at the cost of some notations.