Long-Run Welfare Effect of Energy Conservation Regulation

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13 November 2016

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Abstract

We investigate the long-run effect of energy conservation regulation, which forces firms to raise energy-saving investment above the cost-minimising level (i.e. the business-as-usual level). If Pigovian tax is imposed, additional regulation always harms social welfare under perfect competition. However, under imperfect competition, additional regulation can improve welfare even if Pigovian tax is imposed. Thus, under imperfect competition, there is a rationale for additional energy conservation regulation even in the presence of Pigovian tax. Our result under imperfect competition holds regardless of whether strategies are strategic substitutes or complements in contrast to direct entry regulation.

JEL classification: D61, H54, L13

Keywords: energy-saving, environmental tax, free entry market, consumer-benefiting regulation

*The first author acknowledges the financial support from JSPS KAKENHI Grant Number 15K03347. Needless to say, we are responsible for any remaining errors.

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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.

1 Introduction

In many countries, environmental and/or energy consumption taxes are imposed to internalise 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 In Japan, following the Act of the Rational Use of Energy, which was originally enacted in 1979 and has been repeatedly amended, the Ministry of Economy, Trade, and Industry sets industry-specific targets for the improvement of energy efficiency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 consider the situation in which Pigovian tax is imposed and thus the negative externality has already been fully internalised. Pigovian tax is an effective tool for internalising the negative externality of energy consumption.[2] However, we examine

[1]For example, in Japan, gasoline tax is ¥ 53.8 per litre, coal tax is ¥ 1,370 per ton, and electric power consumption tax is ¥ 355 per MWh. Norway, Sweden, Denmark, France, and Portugal introduced carbon taxes in 1991, 1991, 1992, 2014, and 2015, respectively in addition to energy taxes. In France, carbon tax is €22 per ton, which will be raised to €100 by 2030. In Portugal, carbon tax is €6.67 per ton. South Africa and Chile plan to introduce carbon taxes in 2017. The United Kingdom and Germany have energy taxes. The tax rates of gasoline in all the European countries mentioned above are higher than those in Japan and the tax rates of coal consumption are also higher, except for Germany. The United States also has energy taxes; however, the tax rates of gasoline and coal are lower than those in Japan (Ministry of the Environment, Government of Japan, 2016).

[2]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 (e.g. demand is linear) 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).

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, 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. We also show that our result holds when the tax rate is below the Pigovian level unless the tax rate falls too low.

Energy conservation regulation has two main advantages over direct entry regulation, as discussed by Mankiw and Whinston (1986) and Suzumura and Kiyono (1987).[3] 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.[4] 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.

2 The Model

In the model presented herein, 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,

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

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

$g_x > 0$, $g_{xx} > 0, g_{xI} < 0$, 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 (≥ 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.[5]

Firm i's profit π_i is $p(X)x_i - (w + t)y_i - I_i$, where $w > 0$ is the energy price and t is energy consumption tax. We assume that w is given exogenously. 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

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

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 to enter the market. In the second stage, after observing the number of new entrants n, each new entrant i $(i = 1..., n)$ 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.

[5]Some readers might think that d should be increasing in total energy consumption $Y := \sum_{i=1}^{n} y_i$. We consider the case in which few other industries consume energy and thereby yield negative externalities. Further, the effect of the marginal damage to energy consumption by an industry is insignificant. We show that our results hold even when d is increasing in Y at the cost of some notations.

3 The Results

In this section, we discuss the case in which the government sets $t = d$. In other words, the negative externality of energy consumption is fully internalised.

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 maximise 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

$$p = (w + t)g_x, \tag{2}$$

$$-(w + t)g_I = 1. \tag{3}$$

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:

$$px - (w + t)y - I = 0. \tag{4}$$

If the minimal investment regulation is effective (i.e. the constraint $I \geq I^*$ is binding), equations (2) and (4) determine n and x given $I = I^*$. On the contrary, equations (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 TP to denote the equilibrium outcome in the subgame, where superscript 'T' denotes 'price taker' and 'P' denotes Pigovian tax. We present the results on the relationship between I^* and the equilibrium outcomes.

Lemma 1 *Suppose that the constraint $I \geq I^*$ is binding. Under perfect competition, (i) n^{TP} is strictly decreasing in I^*, (ii) x^{TP} is strictly increasing in I^*, (iii) p^{TP} is increasing in I^*, and (iv) W^{TP} is decreasing in I^*.*

Proof See the Appendix.

We now emphasise that (iii) does not hold in the short run (when the number of firms is given exogenously). A higher I^* lowers the marginal cost of firms and reduces the price, resulting in a gain for consumers. However, this beneficial price reduction for consumers is unsustainable. A higher I^* raises the costs of firms and induces their exits from the market, resulting in a higher price in the long run.

When the negative externality of energy consumption is fully internalised under perfect competition, additional regulation that requires a larger investment level than the cost-minimising one reduces production efficiency. Thus, it is harmful for both consumer welfare and social welfare from the long-run viewpoint. However, this is not true under imperfect competition.

3.2 Imperfect competition case

In this subsection, we consider the case in which firms are price makers 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_i to maximise their profits. We assume that

$$2p' + p''x - (w+t)g_{xx} < 0, \tag{5}$$

$$-(2p' + p''x - (w+t)g_{xx})g_{II} > (w+t)(g_{xI})^2 \tag{6}$$

to ensure that $\pi(x, I)$ is concave. A sufficient condition for (5) is $p' + p''x < 0$ (strategic substitutes). Another sufficient condition is g_{xx} is sufficiently large or $|p'|$ is sufficiently large relative to $|p''|$ and this is also a sufficient condition for (6). Thus, our analysis can apply to strategic complement cases as long as (5) and (6) are satisfied.

The first-order condition for x is

$$p + p'x = (w+t)g_x. \tag{7}$$

The first-order condition for I is identical to the case of perfect competition.

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 (4). The superscript MP denotes the equilibrium outcome in the game, where 'M' denotes 'price maker' in the product market and 'P' denotes Pigovian tax. We present our main result as follows.

Proposition 1 *Suppose that the constraint $I \geq I^*$ is binding. Under imperfect competition, a marginal rise in I^* from the non-binding level I^N increases W^{MP}.*

Proof

$$\begin{aligned} \left.\frac{dW}{dI^*}\right|_{I=I^N} &= \frac{dn}{dI}(px - (w+d)g - I) + n\frac{dx}{dI}(p - (w+d)g_x) - n((w+d)g_I + 1) && (8) \\ &= n\frac{dx}{dI}(p - (w+d)g_x) && (9) \end{aligned}$$

where we use $t = d$, equation (4) (the first term in (8) is zero), and equation (3) (the third term in (8) is zero). From (7), we obtain $p - (w+d)g_x > 0$. Under these conditions, (9) is positive if and only if $dx/dI > 0$.

By differentiating (7) and (4), we obtain

$$\begin{pmatrix} np' + nxp'' + p' - (w+t)g_{xx} & x(p' + xp'') \\ nxp' + p - (w+t)g_x & x^2p' \end{pmatrix} \begin{pmatrix} dx \\ dn \end{pmatrix} = \begin{pmatrix} (w+t)g_{xI} \\ (w+t)g_I + 1 \end{pmatrix} dI^*. \tag{10}$$

By using (7) we obtain

$$\begin{pmatrix} np' + nxp'' + p' - (w+t)g_{xx} & x(p' + xp'') \\ (n-1)xp' & x^2p' \end{pmatrix} \begin{pmatrix} dx \\ dn \end{pmatrix} = \begin{pmatrix} (w+t)g_{xI} \\ (w+t)g_I + 1 \end{pmatrix} dI^*. \tag{11}$$

By applying Cramer's rule to (11), we obtain

$$\frac{dx}{dI^*} = \frac{(w+t)g_{xI}x^2p' - ((w+t)g_I + 1)x(p' + xp'')}{x^2p'(2p' + xp'' - (w+t)g_{xx})}. \tag{12}$$

From (3), we obtain $(w+t)g_I + 1 = 0$ when $I = I^N$. Thus,

$$\left.\frac{dx}{dI^*}\right|_{I=I^N} = \frac{(w+t)g_{xI}x^2p'}{x^2p'(2p' + xp'' - (w+t)g_{xx})}. \tag{13}$$

From (5), we find that the denominator in (13) is positive. The numerator in (13) is positive because $g_{xI} < 0$ and $p' < 0$. These lead to Proposition 1. Q.E.D.

Proposition 1 states that under imperfect competition, additional regulation that induces further energy conservation investments can improve welfare, even when Pigovian tax is imposed. Thus, energy conservation regulation can be a reasonable policy tool in such a market. Note that because the profits of firms are zero and tax revenue is equal to the loss caused by the negative externality, the total social surplus is equal to the consumer surplus. Thus, Proposition 1 implies that a marginal rise in I^* increases the consumer surplus (i.e. it reduces p^{MP}), which is in stark contrast to the case of perfect competition (Lemma 1).

An increase in I^* has three effects. First, it increases the investment cost and raises the entry cost for each new entrant, which thus reduces the number of entering firms. However, since Pigovian tax fully internalises social costs, zero profit means that a marginal change in the number of firms is irrelevant for social welfare given the output of each firm, x. Therefore, the first term in (8) is zero. Second, a rise in I^* increases the output of each firm because it reduces the marginal production cost. Because the output of each firm is too small for social welfare under imperfect competition, it improves welfare (i.e. the second term in (8) is positive). Third, an increase in I^* raises the total cost (production cost plus investment cost) of each firm and reduces efficiency. However, this welfare-reducing effect of the marginal increase in the energy-saving investment from the cost-minimising level is second order (envelope theorem), and thus the third term in (8) is zero. Therefore, a marginal increase in I^* from the cost-minimising level always improves welfare.

Next, we briefly discuss what happens when the tax rate is below the Pigovian tax level.[6] Suppose that the tax rate is below the Pigovian tax level. Then, the first term in (8) is not zero. By applying Cramer's rule to (11), we obtain

$$\left.\frac{dn}{dI^*}\right|_{I=I^N} = -\frac{(n-1)xp'(w+t)g_{xI}}{x^2(p')^2 - (w+t)g_{xx}x^2p' + x^2p'(p'+xp'')} < 0. \tag{14}$$

Because $px - (w+d)g - I < px - (w+t)g - I = 0$, the first term in (8) is positive. In other words, when the tax rate is below the Pigovian tax level, an additional welfare-improving effect of an increase in I^* exists, because the decrease in the number of entering firms directly improves welfare. Thus, as long as $p - (w+d)g_x \geq 0$, Proposition 1 holds even when the tax rate is below the Pigovian tax level. However, if the tax rate is too low, the second term in (8) can be negative and thus the sign of (8) is ambiguous.[7]

Some readers might suspect that our analysis is simply a variant of the excess entry theorem shown by Mankiw and Whinston (1986) and Suzumura and Kiyono (1987), considering that an increase in fixed cost I is essential and that energy conservation regulation is not essential. They might guess that an increase in I directly reduces the number of entering firms and improves welfare. However, this is not correct. Suppose that $g(x,I) = g^a(x) + g^b(I)$ and $g^b(I)$ is decreasing. In this setting, all assumptions except for the assumption $g_{xI} < 0$ can be satisfied. In this case, $g_{xI} = 0$, and thus a marginal increase in I^* from I^N does not affect x and n. Therefore, Proposition 1 does not hold. Thus, the assumption $g_{xI} < 0$ (additional regulation increases investment costs but reduces marginal costs) is essential in our analysis.

[6]The environmental tax rate is often below the Pigovian tax level. See Sen *et al.* (2010) and Mizutani *et al.* (2011), who discussed gasoline taxes in India and Japan, respectively. In addition, in the short-run case, the government has an incentive to set a tax rate below the Pigovian tax level under imperfect competition, as long as firms are symmetric. See Levin (1985) and Requate (1993).

[7]Suppose that $p = a - X$, $g(x,I) = k(I)x^2$, $k' < 0$ and $k'' > 0$. We can show that (8) is in fact negative if d is large and t is small.

To further clarify the difference between our result and the excess entry theorem, we briefly discuss what happens if the government controls the number of entering firms directly. Suppose that Pigovian tax is imposed.

Let $x(n)$ and $I(n)$ be the output of each firm and investment level at the symmetric equilibrium. From (3) and (7), we obtain

$$\begin{pmatrix} (n+1)p' + p''x - (w+t)g_{xx} & -(w+t)g_{xI} \\ (w+t)g_{xI} & (w+t)g_{II} \end{pmatrix} \begin{pmatrix} dx \\ dI \end{pmatrix} = -\begin{pmatrix} x(p'+p''x) \\ 0 \end{pmatrix} dn. \tag{15}$$

By applying Cramer's rule to (15), we obtain

$$\frac{dx}{dn} = \frac{-x(p'+p''x)(w+t)g_{II}}{((n+1)p' + p''x - (w+t)g_{xx})(w+t)g_{II} + (w+t)^2(g_{xI})^2}, \tag{16}$$

$$\frac{dI}{dn} = \frac{x(p'+p''x)(w+t)g_{xI}}{((n+1)p' + p''x - (w+t)g_{xx})(w+t)g_{II} + (w+t)^2(g_{xI})^2}. \tag{17}$$

From (6), we find that the common denominator in (16) is negative. The numerators in (16) and (17) are positive if and only if $p' + p''x < 0$ (i.e. strategies are strategic substitutes).

Let $W(n)$ be the welfare function given by

$$W(n) = \int_0^{nx(n)} p - n((w+d)g + I(n)). \tag{18}$$

Let n^F be the number of entering firms at the free entry equilibrium:

$$\begin{aligned} \left.\frac{dW}{dn}\right|_{n=n^F} &= (x + nx')p - (w+d)g - I - n(w+d)g_x x' - I'(n)((w+d)g_I + 1) \\ &= nx'(p - (w+d)g_x), \end{aligned} \tag{19}$$

where we use $px - (w+d)g - I = 0$ when $n = n^F$ and $(w+d)g_I + 1 = 0$. Note that $d = t$. Therefore, (19) is negative, and thus the number of entering firms is excessive for social welfare if and only if $p' + p''x < 0$ (i.e. strategies are strategic substitutes), as shown by Mankiw and Whinston (1986) and Suzumura and Kiyono (1987). This finding implies that directly regulating the number of entering firms may also improve welfare.

However, we emphasise two important differences between direct entry regulation and energy conservation regulation. First, Mankiw and Whinston (1986) and Suzumura and Kiyono (1987) showed that reducing the number of firms may improve welfare but that it also reduces the consumer surplus. By contrast, additional energy-saving regulation increases both the total social surplus and the consumer surplus. Next, energy-saving regulation improves welfare even when strategies are strategic complements.[8]

4 Concluding remarks

In this study, we investigate regulation that induces larger energy-saving investment. Under perfect competition, when Pigovian tax is introduced, additional energy-saving regulation that forces firms to invest more in energy-saving activities than the cost-minimising level (i.e. the business-as-usual level) increases the total costs of firms and reduces both the total social surplus and the consumer surplus in the long run. However, larger energy-saving investment reduces energy consumption costs, accelerates competition, and yields additional welfare gains under imperfect competition, even in the long run. We thus show that even if Pigovian tax is imposed, additional energy consumption regulation increases both the total social surplus and the consumer surplus in the long run. However, if the emission tax is low and negative externality of emissions is significant, additional energy consumption regulation may reduce the total social surplus. In this sense, environmental tax policy and energy-saving regulation can be complements rather than substitutes.

[8]Another advantage of energy conservation regulation over direct entry regulation should be mentioned here. In this study as well as in the literature on the excess entry theorem, we assume that all potential new entrants are identical. This may be rationalised in free entry markets because inefficient potential entrants cannot enter the market because of their competitive disadvantage. However, direct entry regulation may allow less efficient entrants to enter the market. Moreover, the government knowing the equilibrium number of firms without regulation is more difficult than knowing the cost-minimising investment level. Suppose that demand is linear, given by $p = a - X$. To derive the equilibrium number in free entry markets, the government needs to know the value of the demand parameter a; moreover, to derive the cost-minimising investment level, the government need not know this information.

However, regulation targeting lower emissions without reducing energy consumption, such as that encouraging carbon dioxide capture and storage, may increase energy consumption and marginal costs; thus, our analysis does not apply to such regulation. Expanding the scope of our findings to cover both non-energy consumption and energy consumption environmental regulations would therefore be an interesting future research topic.

Appendix

Proof of Lemma 1(i)

By differentiating (2) and (3), we obtain

$$\begin{pmatrix} np' - (w+t)g_{xx} & xp' \\ nxp' + p - (w+t)g_x & x^2p' \end{pmatrix} \begin{pmatrix} dx \\ dn \end{pmatrix} = \begin{pmatrix} (w+t)g_{xI} \\ (w+t)g_I + 1 \end{pmatrix} dI^*. \tag{20}$$

From (2), this is rewritten as

$$\begin{pmatrix} np' - (w+t)g_{xx} & xp' \\ nxp' & x^2p' \end{pmatrix} \begin{pmatrix} dx \\ dn \end{pmatrix} = \begin{pmatrix} (w+t)g_{xI} \\ (w+t)g_I + 1 \end{pmatrix} dI^*. \tag{21}$$

Applying Cramer's rule to (21),

$$\frac{dn}{dI^*} = \frac{-np'(-(w+t)g_I - 1) + (w+t)g_{xx}(-(w+t)g_I - 1) - nx(w+t)p'g_{xI}}{-x^2p'(w+t)g_{xx}}. \tag{22}$$

Note that since $I^* \geq I^N$, $-(w+t)g_I - 1 \leq 0$. Therefore, the numerator of (15) is negative and the denominator of (15) is positive. Thus, $dn/dI^* < 0$. Q.E.D.

Proof of Lemma 1(ii)

Applying Cramer's rule to (21),

$$\frac{dx}{dI^*} = \frac{(w+t)x^2p'g_{xI} + xp'(-(w+t)g_I - 1)}{-x^2p'(w+t)g_{xx}}. \tag{23}$$

Because $-(w+t)g_I - 1 \leq 0$, both the denominator and the numerator of (16) are positive. Thus, $dx/dI^* > 0$. Q.E.D.

Proof of Lemma 1(iii)

$$\frac{dp}{dI^*} = (x\frac{dn}{dI^*} + n\frac{dx}{dI^*})p' \tag{24}$$

Substituting (15) and (16) into (17),

$$\frac{dp}{dI^*} = \frac{[(w+t)xg_{xx}(-(w+t)g_I - 1)]}{-x^2p'(w+t)g_{xx}}p' \geq 0 \tag{25}$$

since $-(w+t)g_I - 1 \leq 0$. Q.E.D.

Proof of Lemma 1(iv)

$$\begin{aligned}\frac{dW}{dI^*} &= \frac{dn}{dI^*}(px - (w+d)g - I^*) + n\frac{dx}{dI^*}(p - (w+d)g_x) - n((w+d)g_I + 1) \\ &= -n((w+d)g_I + 1) \leq 0 \end{aligned} \tag{26}$$

where the second equality comes from $d = t$, (2), and (3). The inequality follows because $-(w+t)g_I - 1 \leq 0$. Q.E.D.

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