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Abstract

This study shows the equivalence of the emission intensity regulation with tradable emission permits and the combination of emission tax and refunding of the tax revenue to consumers. If firms are symmetric, the equivalence result holds even without tradable permits.

Keywords: carbon pricing, electrification, the second best

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1 Introduction

Decarbonization of the electric power source and electrification are key factors for creating a low carbon society.[1] The Japanese government plans to reduce carbon dioxide emissions by 80% by 2050 and has committed to the mid-term target of a 26% reduction in greenhouse gas emissions by 2030, compared with 2013 (Cabinet of Japan, 2018). To achieve these targets, reducing emissions in the electricity market is very important (Global Environment Committee, 2017).

Ministry of the Environment Japan plans to introduce carbon pricing through either carbon tax or tradable permits in the electric power supply market. However, such carbon pricing raises the electricity price, which can be an obstacle for electrification. In other words, a higher electricity price will delay the switch from coal, oil, and gas to electricity. Such a delay has already been observed in Japan. The Japanese government introduced a feed-in-tariff for renewable energy in 2010, and its costs are financed by a specific tax (surcharge) for electricity consumption. This has raised the price of electricity by ¥2.25 per KWh in 2016 (about 15%), and the surcharge rate is expected to become higher in the near future. This will substantially reduce the competitive advantage of electricity over fossil fuels (Advisory Committee for Natural Resources and Energy, 2018).

To strike a balance between lowering the emission intensity of the electric power supply market and promoting electrification, the Ministry of the Environment proposed using the revenue from carbon tax levied to electric power suppliers or from tradable permits for reducing specific tax on electricity consumption (reducing the surcharge for renewable energy). This will restrict the increase in electricity price but weaken the incentive to reduce electricity consumption, which may be suboptimal. Nevertheless, this policy may be a suitable option for promoting electrification.

Traditionally, the Japanese government regulates environmental efficiency based on output level rather than on the total amount of emission or energy consumption. Fol-

[1] See Global Environment Committee (2017). Examples of electrification include the switch from gasoline vehicles to electric vehicles and from boilers to electric heat pumps.

lowing the Act on the Rational Use of Energy, which was originally enacted in 1979 and has been amended repeatedly, the Ministry of Economy, Trade, and Industry set industry-specific per-output targets for the improvement of energy efficiency, and regulates energy efficiency levels (Matsumura and Yamagishi, 2017). Moreover, the Ministry of the Environment imposes energy efficiency regulation on power plants in addition to regulating pollutant emissions. Regarding carbon dioxide emission, the government encouraged firms in the electricity market to adopt voluntary targets of emission intensity, and firms have adopted the target emission level of 0.38 ton per kWh (Global Environment Committee, 2017). Emission intensity regulation also has a weaker effect on the restriction of consumption level than on the restriction of total emissions or carbon pricing. Thus, the regulation may have a similar effect as that of the combination of carbon pricing and refunding of the tax revenue to electricity consumers.[2]

In this study, we prove the equivalence of the emission intensity regulation and the combination of carbon pricing and refunding of tax revenue to consumers. Our result shows that emission intensity regulation is as reasonable as the above policy combination for striking a balance between lowering the emission intensity and promoting electrification.

2 The Model

We consider the following partial-equilibrium model wherein n firms choose output and abatement levels. The model consists of a perfectly competitive market, and the demand function is $D(\cdot)$. We assume that $D' < 0$, as long as both the price and quantity are positive. For $i = 1, \ldots, n$, q_i is firm i's output, a_i is the level of firm i's abatement activity, and $c_i(q_i, a_i)$ is firm i's cost function. We assume $\partial c_i/\partial q_i > 0$ and $\partial c_i/\partial a_i > 0$ and that the function is strictly convex. $e_i(q_i, a_i)$ is firm i's emission function. We assume $\partial e_i/\partial q_i > 0$ and $\partial e_i/\partial a_i < 0$ and that the function is convex. Each consumer faces the

[2]For examples and discussions on the emission intensity regulation and a comparison between emission tax and emission intensity regulation, refer to Helfand (1991), Farzin (2003), and Lahiri and Ono (2007). However, none discussed carbon pricing policies with refunds and compared these policies with the emission intensity regulation.

effective electricity price $p + f$, where p is the electricity price and f is the renewable energy surcharge. We assume the interior solution (i.e., $q_i > 0$, $a_i > 0$, and $e_i > 0$ at equilibrium).

2.1 Tax-Revenue Refund

In this subsection, we consider the carbon pricing (emission tax) with refunds to consumers. The government imposes emission tax with tax rate $t > 0$ and uses the tax revenue to reduce f. $f = F - s$, where F is the surcharge before refunding and s is the reduction of surcharge.[3] The government chooses s to meet the budget constraint $tE = sQ$, where E and Q are the expected total emission and total demand, respectively.

Firm i's profit is $\pi_i = pq_i - c_i - te_i$. Each firm maximizes π_i with respect to q_i and a_i, given p and t. Let $q_i^T(p;t)$ and $a_i^T(p;t)$ be the profit-maximizing outcome under carbon pricing given p and t, where the superscript "T" means "Tax." The supply function is given by $S(p;t) := \sum_{i=1}^{n} q_i^T(p;t)$. The supply-demand equilibrium is given by the market-clearing condition $S(p;t) = D(p + f)$. From these conditions, we obtain the equilibrium price p^T and refund s^T as well as obtain the equilibrium output $q_i^T = q_i^T(p^T;t)$ and abatement $a_i^T = a_i^T(p^T;t)$.

2.2 Emission Intensity Regulation

In this subsection, we consider the emission intensity regulation. The government imposes emission intensity $\theta > 0$. That is, the emission-to-output rate of each firm i needs to be $e_i/q_i \leq \theta$. If e_i is larger than θq_i, firm i must purchase the permit from a firm whose emission level is smaller than θq_i.[4] Let r be the price of this permit. Because there is no refunding, $f = F$.

[3] We assume F is exogenously given and sufficiently large so that $F - s$ is never negative. If the government adopts another type of carbon pricing—by introducing tradable permits of emission, selling them through auction, and refunding the revenue from them to consumers—we obtain the same result. However, if the government adopts grandfathering rather than auction, the equivalence does not hold, because the government's revenue from permits (and thus the amount of refunding) is smaller.

[4] In Japan, the government allows joint implementation by firms to meet the emission intensity regulation. This is equivalent to allowing tradable permits. Note that in contrast with the standard tradable permit policy with auction, the firm need not purchase the permit as long as the firm meets the emission intensity regulation.

Firm i's profit is $\pi_i = pq_i - c_i - r(e_i - \theta q_i)$. Each firm maximizes π_i with respect to q_i and a_i, given p and r. Let $q_i^I(p, r)$ and $a_i^I(p, r)$ be the profit-maximizing outcomes under the emission intensity regulation, given p and r, where the superscript "I" refers to "Intensity." The supply function of the electricity market is given by $S(p, r) := \sum_{i=1}^n q_i^I(p, r)$. The supply-demand equilibrium of the electricity market is given by $S(p, r) = D(p + F)$. The supply-demand equilibrium of the permit is given by

$$\sum_{i=1}^{n} e_i^I(p, r) = \sum_{i=1}^{n} \theta q_i^I(p, r), \tag{1}$$

where $e_i^I(p, r) = e_i(q_i^I(p, r), a_i^I(p, r))$. From these conditions, we obtain the equilibrium price p^I and equilibrium permit price r^I as well as obtain the equilibrium output $q_i^I = q_i^I(p^I, r^I)$ and abatement $a_i^I = a_i^I(p^I, r^I)$.

3 Equivalence of the Two Policies

We now present our result on the equivalence of the two policies.

Proposition 1 *For any t, there exists θ, and conversely, for any θ, there exists t such that the two policies yield the same outputs and abatements (i.e., $(q_i^T, a_i^T) = (q_i^I, a_i^I)$ for all i) and thus the same emission levels (i.e., $e_i(q_i^T, a_i^T) = e_i(q_i^I, a_i^I)$ for all i).*

Proof. First, we show that for any t, there exists θ such that the emission intensity regulation yields the same outcomes as those under the tax-revenue refund policy.

Consider the equilibrium outcomes under the tax-revenue refund policy. Regarding the supply side, from the first-order conditions for firm i, we obtain

$$p^T = \frac{\partial c_i}{\partial q}(q_i^T, a_i^T) + t\frac{\partial e_i}{\partial q}(q_i^T, a_i^T), \tag{2}$$

$$-t\frac{\partial e_i}{\partial a}(q_i^T, a_i^T) = \frac{\partial c_i}{\partial a}(q_i^T, a_i^T). \tag{3}$$

Regarding the demand side, the inverse demand function is obtained as

$$p + F - s = D^{-1}(Q) \ \therefore p = D^{-1}(Q) - F + s.$$

From the market-clearing condition, we obtain $Q = D(p + F - s) = S^T(p;t) = \sum_{i=1}^n q_i^T(p;t)$ when $p = p^T$ and $s = s^T$. Substituting this into (2), we can rewrite (2) as

$$D^{-1}\left(\sum_{i=1}^n q_i^T\right) - F + s^T = \frac{\partial c_i}{\partial q}(q_i^T, a_i^T) + t\frac{\partial e_i}{\partial q}(q_i^T, a_i^T). \tag{2'}$$

From the budget-balance condition, we obtain

$$t\sum_{i=1}^n e_i(q_i^T, a_i^T) = s^T \sum_{i=1}^n q_i^T. \tag{4}$$

Here, (2'), (3), and (4) yield the equilibrium output q_i^T and abatement a_i^T for $i = 1, \ldots, n$, along with s^T.

We now consider the equilibrium outcomes under the emission intensity regulation. Regarding the supply side, from the first-order conditions for firm i, we obtain

$$p^I + r^I\theta = \frac{\partial c_i}{\partial q}(q_i^I, a_i^I) + r^I\frac{\partial e_i}{\partial q}(q_i^I, a_i^I), \tag{5}$$

$$-r^I\frac{\partial e_i}{\partial a}(q_i^I, a_i^I) = \frac{\partial c_i}{\partial a}(q_i^I, a_i^I). \tag{6}$$

Regarding the demand side,

$$p + F = D^{-1}(Q) \ \therefore p = D^{-1}(Q) - F.$$

Using the market-clearing condition, we rewrite (5) as

$$D^{-1}\left(\sum_{i=1}^n q_i^I\right) - F + r^I\theta = \frac{\partial c_i}{\partial q}(q_i^I, a_i^I) + r^I\frac{\partial e_i}{\partial q}(q_i^I, a_i^I). \tag{5'}$$

We now show that under the emission-intensity regulation, the following $\theta = \theta^I$ yields the same equilibrium outcome as that under the tax-revenue refund policy:

$$\theta^I = \frac{\sum_{i=1}^n e_i(q_i^T, a_i^T)}{\sum_{i=1}^n q_i^T}. \tag{7}$$

From (4), we obtain $\theta^I = s^T/t$.

If $r^I = t$, the systems of equations (5') and (6) are same as that of equations (2') and (3). This implies that if $r^I = t$ in equilibrium under the emission intensity regulation, the market equilibrium outcomes are the same in both systems, that is, $q_i^I = q_i^T$ and $a_i^I = a_i^T$ for $i = 1, \ldots, n$.

Finally, we show that the market-clearing condition is satisfied when $r = t$. This condition (1) is satisfied because

$$\sum_{i=1}^{n} e_i(q_i^I, a_i^I) = \sum_{i=1}^{n} e_i(q_i^T, a_i^T) = \theta^I \sum_{i=1}^{n} q_i^T = \sum_{i=1}^{n} \theta^I q_i^I,$$

where the second equation stems from (7).

Next, we show that for any θ, there exists t such that the two policies yield the same outcomes. We show that under the tax-revenue refund policy, setting $t = r^I$ yields the same equilibrium outcome as that under the emission intensity regulation.

Under the tax-revenue refund policy, $t = r^I$, and (4) implies that

$$s^T = r^I \frac{\sum_{i=1}^{n} e_i(q_i^T, a_i^T)}{\sum_{i=1}^{n} q_i^T}.$$

On the other hand, since (1) is satisfied for (q_i^I, a_i^I) in the equilibrium under the emission intensity regulation, $\theta = \sum_{i=1}^{n} e_i(q_i^I, a_i^I)/\sum_{i=1}^{n} q_i^I$ holds. Substituting these into (2') and (5'), respectively, we find that the systems of (2')-(3) and (5')-(6) coincide. This implies that $q_i^T = q_i^I$ and $a_i^T = a_i^I$ for $i = 1, \ldots, n$. **Q.E.D.**

The intuition behind Proposition 1 is as follows. The tax-revenue refund policy enhances electricity consumption. Through the market mechanism, it stimulates the electricity supply. The emission intensity regulation stimulates electricity production because each firm i obtains permits equal to θq_i. Through the market mechanism, it stimulates electricity consumption. With keeping these positive effects on consumption, both the policies can adjust marginal costs of emission, t and r, at the same level. Therefore, both the policies are equivalent.

4 Conclusion

Our result suggests that the government need not formulate a new policy for striking the balance between lowering the emission intensity and promoting electrification. An old policy, emission intensity regulation, is sufficient for such a purpose. Moreover, the emission intensity, θ, would be the direct policy target for this purpose rather than the carbon price t. The current Japanese regulation may be too loose for ambitious targets, and stricter regulation may be required. However, emission intensity regulation is a reasonable policy tool for this purpose.

It is also worth noting that permit trading under the emission intensity regulation has a practical property different from the standard cap-and-trade fashion. In the cap-and-trade fashion, the government must consider how it initially distributes the permits. However, the emission intensity regulation resolves this problem: the government only needs to set a desired θ.

If we restrict our attention to symmetric firms, no firm trades permits in equilibrium. Thus, without such permits, the equivalence result holds. In other words, if firms are homogeneous, emission intensity regulation works as well as the tax-revenue refund policy, even without tradable permits (or, equivalently, without joint implementation across the firms). Moreover, we can show that this result does not depend on the assumption of perfect competition. If we consider Cournot competition among symmetric firms, our result holds as long as the government commits t and s or θ before firms choose their actions.[5]

Our equivalence result holds only when the government refunds the tax revenue to the consumers in the same market, proportional to the consumption level. For example, if the government refunds tax revenue for tax reduction in other markets or for reduction of payments that are independent of the electricity consumption level, carbon pricing restricts the electricity consumption more strongly than does emission intensity regulation.[6] Thus, the two policies yield different consequences for welfare and the environment.[7]

[5] The formal proof is available upon request. If the government chooses s after q_i and a_i are determined by the firms, each firm i strategically increases q_i for increasing s, and thus the equivalence result does not hold under imperfect competition. If we consider Cournot competition including asymmetric firms, the equivalence does not hold because firms have market power in the permit market. See von der Fehr (1993). However, for any level of t, the emission intensity regulation can yield the same outcomes as those under the tax-revenue refund policy if the permit price is fixed at the carbon tax rate t. This implies that firms' market power in the product market does not affect our conclusion.

[6] In this case, we can prove that to attain the same level of permit price as the carbon tax, emission intensity regulation yields a larger total output than carbon pricing (without refunding) does.

[7] Prior literature compared carbon pricing (without refunding) and emission intensity regulation, and

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discussed under which conditions is carbon pricing better for welfare. This implies that carbon pricing and emission intensity regulation are not equivalent without refunding. See Lahiri and Ono (2007).