Emission Cap Commitment versus Emission Intensity Commitment as Self-Regulation

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Emission Cap Commitment versus Emission Intensity Commitment as Self-Regulation[*]

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Abstract

We compare emission cap commitment that restricts total emissions and emission intensity commitment that restricts emissions per unit of output as measures of self-regulation. The monopolist chooses either emission cap commitment or emission intensity commitment and sets the target level under the constraint that the resulting emissions do not exceed the upper limit. We find that profit-maximizing firms choose emission cap commitment, although emission intensity commitment always yields greater consumer surplus. It is ambiguous whether emission intensity commitment or emission cap commitment yields greater welfare. We present two cases in which emission intensity commitment yields greater welfare. One is the most stringent target case (the target emission level is close to zero), and the other is the weakest target case (the target emission level is close to business-as-usual). Our result suggests that the incentive for adopting emission cap commitment is too large for profit-maximizing firms, and thus, governments should encourage the adoption of emission intensity commitment, especially to achieve a zero-emission society efficiently.

JEL classification codes: Q52, L12, L51

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1 Introduction

Self-regulatory actions by an industry or firms have received considerable attention from economists and policymakers. In particular, self-regulation has been introduced in environmental policies as a tool to improve the environment, in addition to command-and-control regulation and/or economic incentives, such as emission taxes and tradable permits. Firms publicly initiate pledges to improve their environmental performance and undertake efforts to attain the goals by themselves.[1] A typical question regarding self-regulation is why firms voluntarily take certain actions even though they are costly. The literature on self-regulation suggests that polluting firms strategically act and self-regulate because of the threat of future regulation by regulatory authorities (e.g., Maxwell et al., 2000; Antweiler, 2003; Lyon and Maxwell, 2003; Fleckinger and Glachant 2011). Maxwell et al. (2000) formulated a theoretical model in which firms can choose their levels of voluntary pollution prior to political action by consumers leading to mandatory regulation and showed that self-regulation effectively preempts political entry. Antweiler (2003) empirically tested the effect of green regulatory threat. In addition, private politics, such as a boycott, have been used to explain the motivation of voluntary actions. Egorov and Harstad (2017) examined the interaction among public regulation, self-regulation, and boycott as private politics and showed the possibility of self-regulation. There is, however, another natural question to self-regulation: what measure should firms adopt as self-regulation?

There are several ways to commit to improve environmental performance.[2] Consider air pollution or carbon dioxide (CO2) emissions. A commitment to decrease the total

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[1] This form of self-regulation is called "unilateral commitments" in which the target is set by the industry or companies themselves. The OECD (1999) categorized voluntary environmental agreements into the three categories of unilateral commitments, public voluntary programs, and negotiated agreements.

[2] For example, major Japanese firms belonging to the Japan Business Federation, Japan Iron and Steel Federation, and Federation of Electric Power Companies of Japan have committed to either upper bound of emissions or emission intensity per unit of output. Moreover, an international survey by KPMG in 2015 showed that nearly 92% of Global Fortune 250 firms issued corporate social responsibility reports in 2015, up from 35% in 1999, and most are concerned with environmental problems.

emissions or to limit the upper bound of emissions per year is a direct measure (emission cap commitment). On the other hand, the emission intensity per unit of output is another popular measure (emission intensity commitment).[3] The choice of commitment device might affect the behavior of firms and resulting welfare.[4]

We formulate a self-regulation model in which the polluting firm self-regulates to preempt mandatory regulation or to avoid consumer activism, and then the firm determines its output and abatement. The model employs a general formulation of a monopoly setting to highlight the difference between emission intensity commitment and emission cap commitment as measures of self-regulation. Our central concerns are which of emission intensity commitment or emission cap commitment is chosen by the pollutant, and the ranking of consumer surplus and social welfare between these two measures of self-regulation. We compare the equilibrium outcomes at the environmental target, which is a common requirement regardless of the measure of self-regulation. Specifically, the environmental target is assumed the total amount of emissions.

We find that the equilibrium abatement investment and output are larger (and thus, consumer surplus is larger) under emission intensity commitment than under emission cap commitment. By contrast, emission cap commitment yields higher profit than does emission intensity commitment. Therefore, profit-maximizing firms choose emission cap commitment as a self-regulation tool. From a welfare perspective, however, it is ambiguous whether emission cap commitment or emission intensity commitment is better. We find that emission intensity commitment is unambiguously better than emission cap commitment in two im-

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[3] Japanese electric power companies have committed to CO2 emissions/kWh, not total emissions, as self-regulation. Japanese Ministry of the Environment has declared that it would introduce stricter regulation if this self-regulation were to turn out not to work effectively.

[4] A substantial body of literature on mandatory green regulations compares the different forms of mandatory regulation, including emission tax, emission cap regulation, and emission intensity regulation. Many studies have shown that different policy instruments yield different welfare and environmental consequences, because different policy instruments provide different incentives for firms (Besanko, 1987; Helfand, 1991; Lahiri and Ono, 2007; Kiyono and Ishikawa, 2013; Amir et al., 2017). The studies have mainly focused on the effects of regulations on welfare and emission levels, and have not discussed firms' incentives for adopting a regulation measure.

portant cases: in the case with the strictest target (when the emission target is close to zero emissions) and in the case with the loosest target (when the emission target is close to the business-as-usual level). Firms prefer emission cap commitment even when emission intensity commitment is desirable for welfare. Thus, our result suggests that the incentive to adopt emission cap commitment is too strong for profit-maximizing firms as a self-regulation measure and governments should encourage the adoption of emission intensity commitment rather than emission cap commitment, especially to achieve a zero-emission society efficiently.

However, emission cap commitment can yield greater welfare. We show that emission cap commitment can yield greater welfare, depending on the emission target level and the curvature of the abatement cost function. If the target level is far from both zero emission and business-as-usual levels, and the convexity of the abatement cost function is strong, emission cap commitment is better for welfare.

The rest of this study is organized as follows. Section 2 describes the model. Section 3 analyzes and compares the two self-regulation measures of emission intensity commitment and emission cap commitment. Section 4 concludes.

2 The Model

We consider the self-regulation model of a polluting monopoly.[5] The firm produces a single commodity for which the inverse demand function is given by $P(q) : \mathbb{R}_+ \mapsto \mathbb{R}_+$. We assume that $P(q)$ is twice continuously differentiable and $P'(q) < 0$ for all q as long as $P > 0$. Let $C(q) : \mathbb{R}_+ \mapsto \mathbb{R}_+$ be the cost function of the firm, where $q \in \mathbb{R}_+$ is the output of the firm. We suppose C is twice continuously differentiable, increasing, and convex for all q.[6] We assume that the marginal revenue is decreasing (i.e., $2P'(q) + P''(q)q < 0$). This condition

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[5] Our results hold in symmetric Cournot oligopolies under the standard conditions (e.g., stability conditions).

[6] We can relax this assumption. Our results hold if $C'' - P' > 0$ for all q as long as $P > 0$.

guarantees that the second-order condition is satisfied.

Some emissions are associated with production, which yields a negative externality. After emissions have been generated, they can be reduced by the polluting firm through investment in abatement technologies.[7] Thus, the firm's net emissions are $E := g(q) - x$, where $g : \mathbb{R}_+ \mapsto \mathbb{R}_+$ represents emissions associated with production and $x (\in \mathbb{R}_+)$ is the firm's abatement level. We assume that g is twice continuously differentiable, increasing, and convex for all q.

The firm's profit is

$$P(q)q - C(q) - K(x),$$

where the third term represents the abatement cost. We suppose that K is twice continuously differentiable, increasing, and strictly convex for $x > 0$. We further assume that $K(0) = K'(0) = 0$.[8] This assumption guarantees that the social optimal level of abatement is never zero and that the profit function is smooth.

Total social surplus (firm profits plus consumer surplus minus the loss caused by the externality) is given by

$$W = \pi + CS - \eta(E) = \int_0^q P(z)dz - C(q) - K(x) - \eta(E),$$

where $\eta : \mathbb{R}_+ \mapsto \mathbb{R}_+$ is the welfare loss of emissions.

The firm undertakes self-regulation through emission intensity commitment or emission cap commitment. One might consider that the regulator should impose an emission tax or mandatory regulation on the polluting firm in order to restrict emissions rather than relying on self-regulation. The situation this study considers is similar to that of Segerson and Miceli (1998), Lyon and Maxwell (2003), Glachant (2007), and Brau and Carraro (2011).

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[7] These are called end-of-pipe technologies. An alternative approach to reduce emissions is to change the production process. For a recent discussion of the relationship between mandatory regulation and this type of innovation, see Matsumura and Yamagishi (2017).

[8] The form of the abatement (R&D) cost function is a standard assumption in industrial organization and environmental economics (D'Aspremont and Jacquemin, 1998; Amir et al., 2017).

Self-regulation might be preferable to mandatory regulation, since the former reduces the administrative cost associated with serious mandatory regulation by law or avoids political resistance from regulated industry. Alternatively, if the government plans to impose an emission tax to reduce total emissions to $\bar{E}$ and firms expect the possible introduction of an emission tax following self-regulation, the firms would introduce self-regulation that yields $E = \bar{E}$ to prevent the introduction of such an emission tax.

An alternative interpretation of the environmental target that the polluting firm voluntary commits to is based on consumer activism. Unlike lobbying or political campaigns, consumers who have disutility from negative externalities organize activist groups and start a boycott if their requirements are not met (Egorov and Harstad, 2017). In this case, it is natural to consider that their concern is emission levels.

We assume that the environmental target is exogenously given. In other words, we do not model the regulator and the activist group as players. As discussed earlier in this section, we can describe $\bar{E}$ depending on the administrative cost, political pressure, or the opportunity cost of the consumer boycott. There are, however, several ways to formulate such regimes so that we simply treat the target as an exogenous variable and examine how the firm undertakes self-regulation at each level, $\bar{E}$. We assume that $\bar{E} \in (0, E^B)$ where E^B is the profit-maximizing emission level without a binding emission target (business-as-usual level). Let q^B be the profit-maximizing output without a binding emission target.

The timing of the game is as follows. Given the environmental target, $\bar{E}$, the firm decides whether to use emission intensity commitment or emission cap commitment in the first stage. In the second stage, the firm chooses its output and abatement level to maximize the profit under the self-regulation it committed to in the first stage.

3 Analysis

We compare the effects on equilibrium outcomes of the two instruments used in this research.

3.1 Emission Intensity Commitment

First, we consider the case in which the firm adopts emission intensity commitment as self-regulation. Let α be the committed upper bound of the emission per unit of output. In the second stage, the firm chooses its output, q, and abatement level, x, to maximize its profit subject to

$$\alpha \geq \frac{E}{q} = \frac{g(q) - x}{q}. \tag{1}$$

When the constraint is binding[9], the firm's optimization problem is

$$\max_{q} P(q)q - C(q) - K(g(q) - \alpha q). \tag{2}$$

Let the superscript EI denote the equilibrium outcomes under emission intensity commitment. Define $\pi^{EI}(q;\alpha) := P(q)q - C(q) - K(g(q) - \alpha q)$. The equilibrium output, $q^{EI}(\alpha)$, is characterized by the following first-order condition:

$$\frac{\partial \pi^{EI}}{\partial q} = P'q + P - C' - K'(g' - \alpha) = 0. \tag{3}$$

The second-order condition is satisfied. We obtain $x^{EI}(\alpha) = g(q^{EI}(\alpha)) - \alpha q^{EI}(\alpha)$ and $E^{EI}(\alpha) = g(q^{EI}(\alpha)) - x^{EI}(\alpha) = \alpha q^{EI}(\alpha)$.

Differentiating (3) leads to

$$\frac{dq^{EI}}{d\alpha} = -\frac{\partial^2 \pi / \partial q \partial \alpha}{\partial^2 \pi / \partial q^2} > 0, \tag{4}$$

where we use $\partial^2 \pi / \partial q \partial \alpha = K' + (g' - \alpha)K''q > 0$ and $\partial^2 \pi / \partial q^2 = 2P' + P''q - C'' - g''K' - (g' - \alpha)^2 K'' < 0$. An increase in α relaxes the emission restriction and reduces the marginal cost of production, which increases q.

In the first stage, the firm sets the emission intensity $\alpha = \bar{\alpha}$ such that $E^{EI}(\bar{\alpha}) = \bar{E}$. Let $(q^{EI}(\bar{E}), x^{EI}(\bar{E}))$ be the pair of equilibrium output and abatement and $W^{EI}(\bar{E})$ be the equilibrium welfare under emission intensity commitment when $\alpha = \bar{\alpha}$.

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[9] In this game, the constraint is always binding because $\bar{E} < E^B$.

3.2 Emission Cap Commitment

Next, we consider the case in which the firm adopts emission cap commitment. The profit function of the firm is $P(q)q - C(q) - K(g(q) - \bar{E})$. Let the superscript EC denote the equilibrium outcomes under emission cap commitment. Then, the profit function of the firm under emission cap commitment is defined by $\pi^{EC}(q;\bar{E}) := P(q)q - C(q) - K(g(q) - \bar{E})$. The equilibrium output, $q^{EC}(\bar{E})$, is characterized by the following first-order condition:

$$\frac{\partial \pi^{EC}}{\partial q} = P'q + P - C' - K'g' = 0. \tag{5}$$

The second-order condition is satisfied. We obtain $x^{EC}(\bar{E}) = g(q^{EC}(\bar{E})) - \bar{E}$. Differentiating (5) leads to

$$\frac{dq^{EC}}{d\bar{E}} = -\frac{\partial^2\pi/\partial q\partial\bar{E}}{\partial^2\pi/\partial q^2} > 0, \tag{6}$$

where we use $\partial^2\pi/\partial q\partial \quad = K''g' > 0$ and $\partial^2\pi/\partial q^2 = 2P' + P''q - C'' - g''K' - g'^2K'' < 0$. Similar to the emission intensity case, an increase in $\bar{E}$ increases q.

3.3 Comparison

In this subsection, we compare the two instruments. First, we consider the equilibrium output. Comparing emission intensity commitment with emission cap commitment, we present the following result.

Lemma 1 *The equilibrium output is larger under emission intensity commitment than under emission cap commitment, that is,* $q^{EI}(\bar{E}) > q^{EC}(\bar{E})$.

Proof.

By using (3), (5), and the emission equivalence, we obtain

$$\begin{aligned} \left.\frac{\partial \pi^{EC}}{\partial q}\right|_{q=q^{EI}} &= K'(g(q^{EI}) - \bar{\alpha}q^{EI})\left[(g'(q^{EI}) - \bar{\alpha}\right] - K'(g(q^{EI}) - \bar{E})g'(q^{EI}) \\ &= -K'(g(q^{EI}) - \bar{\alpha}q^{EI})\bar{\alpha} < 0. \end{aligned}$$

This implies that the output level of q^{EI} exceeds the profit-maximizing level under emission cap commitment, because the second-order condition is satisfied. ■

Lemma 1 states that the firm produces more outputs under emission intensity commitment than under emission cap commitment even though the resulting emissions from the pollutant are the same in both regimes. We explain the intuition behind Lemma 1 after presenting Proposition 1.

From Lemma 1 and the emission equivalence, we obtain the following lemma.

Lemma 2 *Emission intensity commitment yields greater net consumer surplus than emission cap commitment, that is,* $CS(q^{EI}(\bar{E}) - \eta(\bar{E}) > CS(q^{EC}(\bar{E})) - \eta(\bar{E})$.

Proof.

It is straightforward from the emission equivalence and Lemma 1. ■

We now present our result on the firm's profit.

Proposition 1 *Emission cap commitment yields higher profit than does emission intensity commitment (i.e.,* $\pi^{EC}(q^{EC}(\bar{E}), \bar{E}) > \pi^{EI}(q^{EI}(\bar{E}), \bar{\alpha})$*).*

Proof.

Using the resulting profit and the emission equivalence, we obtain

$$\begin{aligned} \pi^{EC}(q^{EC}, \bar{E}) &= P(q^{EC})q^{EC} - C(q^{EC}) - K(g(q^{EC}) - \bar{E}) \\ &> P(q^{EI})q^{EI} - C(q^{EI}) - K(g(q^{EI}) - \bar{E}) \\ &= P(q^{EI})q^{EI} - C(q^{EI}) - K(g(q^{EI}) - \bar{\alpha} q^{EI}) = \pi^{EI}(q^{EI}, \bar{\alpha}), \end{aligned}$$

where the inequality follows from the fact that $\arg\max_{\{q\}} P(q)q - C(q) - K(g(q) - \bar{E}) = q^{EC}$ and $q^{EI} \neq q^{EC}$. ■

We explain the intuition behind Lemma 1 and Proposition 1. Under emission intensity, the firm faces a time-inconsistency problem. In the second stage, given α, an increase in q increases the upper limit of emissions. Therefore, the firm has a stronger incentive to increase its output than under emission cap commitment (Lemma 1). However, this makes it stricter for the required α in the first stage to meet the emission target $\bar{E}$. This reduces the firm's profit. Therefore, the firm's profit is larger under emission cap commitment, which does not yield such a time-inconsistency problem, than under emission intensity commitment.

We now discuss social welfare. Emission intensity commitment is superior for consumer welfare than is emission cap commitment (Lemma 2), but is less profitable for the firm (Proposition 1). Thus, it is generally ambiguous which is socially preferable. Let $W^{EI}(\bar{E})$ and $W^{EC}(\bar{E})$ be the equilibrium welfare under emission intensity commitment and emission cap commitment, respectively. We present two cases in which emission intensity commitment yields greater welfare than emission cap commitment (i.e., $W^{EI}(\bar{E}) > W^{EC}(\bar{E})$). First, we consider the case with the most stringent target case ($\bar{E}$ is close to zero). When the firm is not allowed to pollute in the process of producing output (i.e., $\bar{E} = \bar{\alpha} = 0$), all emissions are reduced by the abatement activities and there are no emissions in the industry. Regardless of the output level, the total emissions are zero if and only if emissions per unit of output are zero. Therefore, when $\bar{E} = 0$, emission cap commitment and emission intensity commitment yield the same outcome. Let q^Z and x^Z be common q and x under the zero-emission constraint (i.e., when $\bar{E} = 0$).

We now present a result when $\bar{E}$ is close to zero.

Proposition 2 *If $\bar{E}$ is sufficiently close to zero, emission intensity commitment yields greater welfare than does emission cap commitment.*

Proof.

For $i = EC, EI$, we obtain

$$\begin{aligned}
\frac{\partial W^i}{\partial \bar{E}}\Big|_{\bar{E}=0} &= \frac{\partial W}{\partial q}\frac{dq^i}{d\bar{E}} + \frac{\partial W^i}{\partial x}\frac{dx^i}{d\bar{E}} + \frac{\partial W^i}{\partial E} \\
&= (P(q^Z) - C'(q^Z))\frac{dq^i}{d\bar{E}} - K'(x^Z)\frac{dx^i}{d\bar{E}} - \eta'(0) \\
&= (P(q^Z) - C'(q^Z))\frac{dq^i}{d\bar{E}} - K'(x^Z)\left(g'(q^Z)\frac{dq^i}{d\bar{E}} - 1\right) - \eta'(0) \\
&= (P(q^Z) - C'(q^Z) - K'(x^Z)g'(q^Z))\frac{dq^i}{d\bar{E}} + K'(x^Z) - \eta'(0),
\end{aligned}$$

where we use $g - x = \bar{E}$ (and thus, $dx^i/d\bar{E} = g'(dq^i/d\bar{E}) - 1$), and $(q^{EC}, x^{EC}) = (q^{EI}, x^{EI}) = (q^Z, x^Z)$ when $\bar{E} = 0$. Because $q^Z < q^{EC} < q^{EI}$ for all $\bar{E} > 0$, we obtain

$$\frac{dq^{EI}}{d\bar{E}}\bigg|_{\bar{E}=0} > \frac{dq^{EC}}{d\bar{E}}\bigg|_{\bar{E}=0}.$$

From (5), we obtain $P - C' - K'g' > P + P'q - C' - K'g' = 0$. Under these conditions, we obtain

$$\frac{\partial W^{EI}}{\partial \bar{E}}\bigg|_{\bar{E}=0} > \frac{\partial W^{EC}}{\partial \bar{E}}\bigg|_{\bar{E}=0}.$$

Because $W^{EI} = W^{EC}$ when $\bar{E} = 0$, we obtain Proposition 2. ■

The intuition behind the result is as follows. As we explained after Proposition 1, given $\bar{\alpha} > 0$, the firm has a stronger incentive to expand its output under emission intensity commitment than under emission cap commitment, because under emission intensity, the firm can increase the upper limit of emissions in the second stage (time-inconsistency problem). However, this problem does not exist when $\bar{E} = \bar{\alpha} = 0$. Therefore, $q^{EC} = q^{EI}$ and $x^{EC} = x^{EI}$ when $\bar{E} = \bar{\alpha} = 0$.

An increase in $\bar{\alpha}$ relaxes the restriction on emissions. This leads to an increase in emissions, resulting in larger disutility from the emissions (emission effect). However, by the assumption of emission equivalence between two regimes, the emission effect is the same for two regimes. An increase in $\bar{E}$ and $\bar{\alpha}$ affects q and x (allocation effect). As stated above, emission intensity commitment yields larger q and x than emission cap commitment does.

Given the emission level, under emission cap commitment, the marginal social cost of the reduction of emissions by reduction of q is P/g' and that by the increase of x is K'. The marginal private cost for meeting the constraint by the reduction of q for the firm is $(P + P'q)/g'$ and that by the increase of x is K'. Thus, both x and q chosen by the firm are too small for social welfare. Given the emission level, under emission intensity, the marginal private cost for meeting the constraint by the reduction of q for the firm is $(P + P'q)/(g' - \alpha)$ and that by the increase of x is K'. When α is small, both x and q chosen by the firm are still too small for social welfare, but both are larger than under emission cap commitment. Therefore, emission intensity commitment is better for social welfare than is emission cap commitment.

We believe that the most stringent case discussed in Proposition 2 is important. Under the Paris Climate Agreement, many countries, such as the UK, France, Germany, and Japan, plan to reduce CO2 emissions drastically by 2050 (about 80% reduction at least against a business-as-usual scenario). To achieve this goal, several industries, such as electric power and transport, an emission constraint that is close to zero emissions might be imposed. Thus, the most stringent case discussed in Proposition 2 might be realistic.

Next, we examine the opposite case, the loosest constraint case in which $\bar{E}$ is close to E^B.

Proposition 3 *Suppose that $\bar{E}$ is sufficiently close to E^B. Emission intensity commitment yields greater welfare than does emission cap commitment.*

Proof.

For $i = EC, EI$, we obtain

$$\begin{aligned}\frac{\partial W^i}{\partial \bar{E}}\Big|_{\bar{E}=E^B} &= \frac{\partial W}{\partial q}\frac{dq^i}{d\bar{E}} + \frac{\partial W^i}{\partial x}\frac{dx^i}{d\bar{E}} + \frac{\partial W^i}{\partial E} \\ &= (P(q^B) - C'(q^B))\frac{dq^i}{d\bar{E}} - K'(x^B)\frac{dx^i}{d\bar{E}} - \eta'(\bar{E}) \\ &= (P(q^B) - C'(q^B))\frac{dq^i}{d\bar{E}} - \eta',\end{aligned}$$

where we use $q^{EC} = q^{EI} = q^B$ and $x^{EC} = x^{EI} = 0$ when $\bar{E} = E^B$ and $K'(0) = 0$. Because $q^{EC} < q^{EI} < q^B$ for all $\bar{E} < E^B$, we obtain

$$\frac{dq^{EI}}{d\bar{E}}\Big|_{\bar{E}=E^B} > \frac{dq^{EC}}{d\bar{E}}\Big|_{\bar{E}=E^B}.$$

From (5), we obtain $P - C' > 0$. Under these conditions,

$$\frac{\partial W^{EI}}{\partial \bar{E}}\Big|_{\bar{E}=E^B} > \frac{\partial W^{EC}}{\partial \bar{E}}\Big|_{\bar{E}=E^B}.$$

Because $W^{EI} = W^{EC}$ when $\bar{E} = E^B$, we obtain Proposition 3. ■

We explain the intuition behind Proposition 3. Because of emission equivalence, the emission effect is the same between two regimes. When $\bar{E} = E^B$, $q^{EC} = q^{EI} = q^B$ and $x^{EC} = x^{EI} = 0$. Because $K'(0) = 0$, this abatement level is too low for social welfare, and a marginal reduction of emissions by an increase in x is much more efficient than that by a reduction in q for social welfare. In other words, given the emission, q is too large and x is too small for social welfare. A marginal decrease in $\bar{\alpha}$ increases x and reduces q under both emission cap commitment and emission intensity commitment, which improves welfare. The magnitude of this effect is stronger under emission intensity commitment. Note that $q^{EI} > q^{EC}$ and thus, $x^{EI} > x^{EC}$ for $\bar{E} \in (0, E^B)$.

In Propositions 2 and 3, we show that when the target level is close to the strictest and loosest cases, emission intensity commitment is better for social welfare than emission cap commitment. Emission intensity commitment stimulates production and mitigates the problem of suboptimal production and abatement investment, which improves welfare under emission equivalence. Because emission intensity commitment is better for social welfare in the two polar cases, it might be natural to guess that emission intensity commitment is better for any $\bar{E} \in (0, E^B)$. However, this is not true.

Let $\big(x^*(\bar{E}), q^*(\bar{E})\big)$ be the pair of the second–best abatement and output level (social optimum x and q given $E = \bar{E}$). The derivation is as follows. Given $\bar{E}$, the social planner's problem is

$$\begin{aligned} \max_{q,x} \quad & W = \int_0^q P(z)dz - C(q) - K(x) - \eta(\bar{E}) \\ s.t. \quad & \bar{E} = g(q) - x. \end{aligned}$$

The second-best output level, $q^*(\bar{E})$, is characterized by the following first-order condition:

$$\frac{\partial W}{\partial q} = P - C' - K'g' = 0. \tag{7}$$

$x^*(\bar{E})$ is derived from $\bar{E} = g(q^*) - x^*$.

As discussed above, $q^{EC}(\bar{E}) < q^*(\bar{E})$ and thus, $x^{EC}(\bar{E}) < x^*(\bar{E})$. Note that $q^{EC}(\bar{E})$ is derived $P + P'q - C' - K'g' = 0$. In the two polar cases (the strictest and loosest cases), $\big(x^{EC}(\bar{E}), q^{EC}(\bar{E})\big) = \big(x^{EI}(\bar{E}), q^{EI}(\bar{E})\big)$. Except for the two polar cases, $\big(x^{EC}(\bar{E}), q^{EC}(\bar{E})\big) < \big(x^{EI}(\bar{E}), q^{EI}(\bar{E})\big)$ holds. As long as $\big(x^{EC}(\bar{E}), q^{EC}(\bar{E})\big) < \big(x^{EI}(\bar{E}), q^{EI}(\bar{E})\big) < \big(x^*(\bar{E}), q^*(\bar{E})\big)$, the outcome under emission intensity commitment is closer to the second-best outcome than that under emission cap commitment, and thus, emission intensity commitment naturally yields greater welfare than emission intensity commitment. However, it is possible that $\big(x^{EI}(\bar{E}), q^{EI}(\bar{E})\big) > \big(x^*(\bar{E}), q^*(\bar{E})\big)$. Because emission intensity can yield excessive production and excessive abatement investment, emission cap commitment might be better than emission intensity commitment for social welfare.

We present an example showing that emission cap commitment could be better than emission intensity commitment for welfare. Suppose that the inverse demand is linear ($P = a - bq$), the marginal production cost is constant (normalized to zero), emissions are proportional to output ($g = eq$), and the abatement cost is quadratic ($K = kx^2/2$). In this example, $E^B = ae/2b$ and $\bar{\alpha} = e$ when $\bar{E} = E^B$.

Straightforward calculation yields the resulting welfare for each regime. Comparing W^{EI} with W^{EC}, we obtain the following result.

Proposition 4 *Suppose that* $P = a - bq$, $C = 0$, $g = eq$, *and* $K = kx^2/2$. *Then,*

$$W^{EI} > (<) W^{EC} \quad \text{if} \;\; k < (>) \tilde{k},$$

where

$$\tilde{k} := \frac{b(2e^2 - 3e\bar{\alpha} + 3\bar{\alpha}^2 + \sqrt{4e^4 + 4e^3\bar{\alpha} + 5e^2\bar{\alpha}^2 - 18e\bar{\alpha}^3 + 9\bar{\alpha}^4})}{2e^2\bar{\alpha}(e - \bar{\alpha})},$$

$\lim_{\bar{E}\to 0} \tilde{k} = \lim_{\bar{E}\to E^B} \tilde{k} = \infty$, *$\tilde{k}$ is U-shaped with respect to $\bar{E}$, and* $\tilde{k} \geq \underline{k} := (5b + b\sqrt{89})/2e^2$ *for any* $\bar{E} \in (0, E^B)$.

Proof See the Appendix.

Figure 1 shows this result graphically (the case in which $a = 5$, $b = 1$, and $e = 2$).

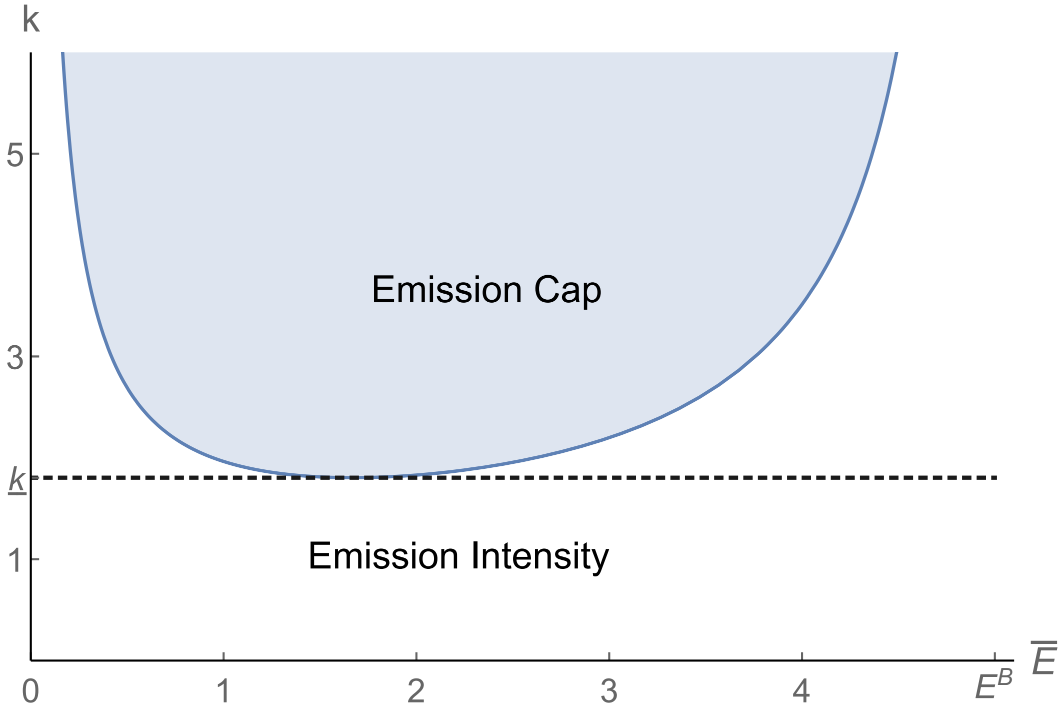

Figure 1: Welfare Comparison:

If k is not large, emission intensity commitment yields greater welfare regardless of $\bar{E}$. However, if k is large, emission cap commitment yields greater welfare, because x can be excessive under emission intensity commitment.

As discussed above, production and abatement can be excessive under emission intensity commitment, leading to Proposition 4. Figure 2 shows that x^* can be smaller than x^{EI}, although x^* is larger than x^{EI} regardless of $\bar{E}$ (the case in which $a = 5$, $b = 1$, $k = 3$, and $e = 2$). In other words, the abatement level under emission intensity commitment is too large (and the output level is also too large) to achieve the target level of emissions.

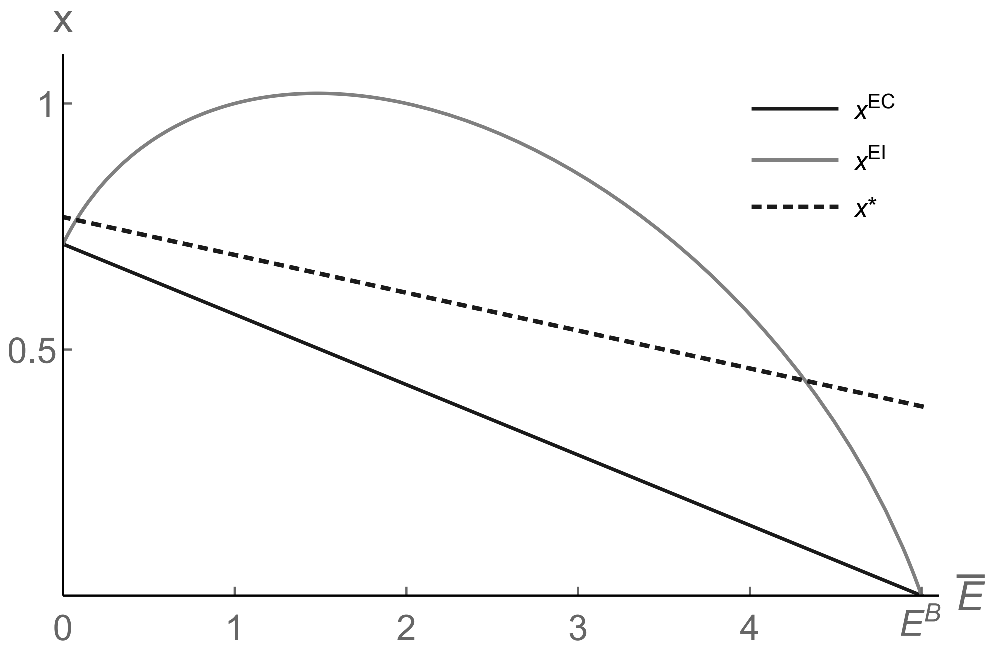

Figure 2: Abatement Level Comparison

4 Concluding Remarks

In this study, we compare two self-regulation tools, emission cap commitment and emission intensity commitment. We find that profit-maximizing firms always choose emission cap commitment. However, emission intensity commitment always yields greater consumer welfare and can yield greater welfare. Moreover, we present two cases in which emission intensity commitment yields greater welfare than emission cap commitment does: the case of the strictest target, which is close to a zero-emission target, and the case of the loosest target, which is close to business as usual. Our result suggests that the government should encourage the adoption of emission intensity commitment, especially to achieve a zero-emission society efficiently, because firms prefer emission cap commitment to emission intensity commitment, even when it is not desirable for welfare.

Our study neglects any uncertainty of demand or cost. If the firms commit to self-regulation before knowing the demand parameter, an increase of the degree of demand uncertainty increases the advantage of emission intensity commitment over emission cap commitment for both the welfare and profits of the firms. This is because the firms can expand (shrink) their output more flexibly under emission intensity commitment than under emission cap commitment when demand is high (low). We consider this is the reason that some companies, such as Japanese electric power companies, choose emission intensity commitments as their favored form of self-regulation. Comparing the two tools after introducing demand uncertainty is left to future research.

A Proof of Proposition 4

First, we consider the equilibrium outputs for each regime. From (3) and (5), we obtain

$$q^{EI} = \frac{a}{2b + k(e - \alpha)}, \quad q^{EC} = \frac{a + ke\bar{E}}{2b + e^2 k}.$$

Substituting the equilibrium outputs into total surplus, we obtain

$$\begin{aligned} W^{EI}(\bar{\alpha}) &= \frac{a(a(3b + k(e - \bar{\alpha})^2) - 2\bar{\alpha}\eta(2b + k(e - \bar{\alpha})^2))}{2(2b + k(e - \bar{\alpha})^2)^2}, \\ W^{EC}(\bar{E}) &= \frac{(a^2 + 2ake\bar{E})(3b + ke^2) - \bar{E}(bk\bar{E}(4b + ke^2) + 2\eta(2b + ke^2)^2)}{2(2b + ke^2)^2}. \end{aligned}$$

Using $E^{EI}(\bar{\alpha}) = \bar{\alpha} q^{EI} = \bar{E}$, $W^{EC}(\bar{E})$ can be rewritten as a function of $\bar{\alpha}$. Thus, we obtain

$$W^{EI}(\bar{\alpha}) - W^{EC}(\bar{E}) = \frac{a^2 k\bar{\alpha}(e - \bar{\alpha})H}{2(2b + k(e - \bar{\alpha})^2)^2(2b + ke^2)^2}$$

where $H := 4b^2 - k^2 e^2 \bar{\alpha}(e - \bar{\alpha}) + bk(2e^2 - 3e\bar{\alpha} + 3\bar{\alpha}^2)$. $W^{EI}(\bar{\alpha}) - W^{EC}(\bar{E})$ is positive if and only if $H > 0$ and

$$H > (<) 0 \ \text{ if } k < (>) \tilde{k} = \frac{b(2e^2 - 3e\bar{\alpha} + 3\bar{\alpha}^2 + \sqrt{4e^4 + 4e^3\bar{\alpha} + 5e^2\bar{\alpha}^2 - 18e\bar{\alpha}^3 + 9\bar{\alpha}^4})}{2e^2\bar{\alpha}(e - \bar{\alpha})}.$$

Remember that $\bar{\alpha}$ is determined by $E^{EI}(\bar{\alpha}) = \bar{E}$, thus, $\tilde{k}$ also depends on the emission target via $\bar{\alpha}$. It implies that $W^{EI}(\bar{\alpha}) > (<) W^{EC}(\bar{E})$ if $k < (>) \tilde{k}$. Because $\lim_{\bar{\alpha} \to 0} \tilde{k} = \lim_{\bar{\alpha} \to e} \tilde{k} = \infty$, we obtain $\lim_{\bar{E} \to 0} \tilde{k} = \lim_{\bar{E} \to E^B} \tilde{k} = \infty$.

Differentiating $\tilde{k}$ with $\bar{\alpha}$, we obtain

$$\frac{\partial \tilde{k}}{\partial \bar{\alpha}} = \frac{b(e - 2\bar{\alpha})(2e^2 + e\bar{\alpha} - \bar{\alpha}^2 + \sqrt{4e^4 + 4e^3\bar{\alpha} + 5e^2\bar{\alpha}^2 - 18e\bar{\alpha}^3 + 9\bar{\alpha}^4})}{\bar{\alpha}^2(e - \bar{\alpha})^2\sqrt{4e^4 + 4e^3\bar{\alpha} + 5e^2\bar{\alpha}^2 - 18e\bar{\alpha}^3 + 9\bar{\alpha}^4}}.$$

Because $\partial \tilde{k}/\partial \bar{\alpha}$ is negative (positive) when $\bar{\alpha} < (>) \ e/2$, $\tilde{k}(\bar{E})$ is U-shaped and is minimized at $\bar{\alpha} = e/2$. Because $\tilde{k}$ is minimized when $\bar{\alpha} = e/2$, we obtain $\underline{k} = (5b + b\sqrt{89})/2e^2$. Note that $\bar{\alpha}(\bar{E})$ is increasing, $\bar{\alpha}(0) = 0$, and $\bar{\alpha}(E^B) = e$. ■

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