Domestic and International Strategic Interactions in Environment Policy Formation*

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Summary

In this paper, we establish the most possible general formulation of the technology governing carbon-gas emission, giving rise to global external diseconomies, and try to explore into the strategic interactions, both domestic and international, when an individual country decides on the environmental policies. Through the comparison among emission taxes, quotas, and standards in the perfectly competitive private economies, we find that the first two policies are equivalent but they are different in effects by virtue of what we may call the tax-exemption effect of emission standards. Such a difference in the policy effect further affects the other country’s welfare through the global externalities, amplified through whether the government can precommit to either the emission tax or the emission standard.

Keywords and Phrases: global warming, emission tax, emission quota, emission standard, strategic interaction, tax exemption

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1 Introduction

The traditional literature on environment regulations as well as the standard policy evaluations assumes that the government can precommit to a certain policy variable before the private sector’s decision. However the recent literature on the political economy effects governing the policy formations emphasizes that there are no policies free from the strategic behavior by the private sector \(^1\). Surprisingly, there has been few literatures in environment economics to capture such theoretical perception.

Furthermore, the analysis in environment economics often employs too specified models concerning the technology conditions concerning substitution between emissions of pollutants and other standards of inputs. The obtained results often hinge on the assumed specifications on abatement of pollutants, and the models employed fail to clarify the essential factors leading to those results.

In this paper, we formalize the economic role of pollutants yielding international external diseconomies, which we call the global warming gas emission \(^2\), as the unpaid factor of production à la Meade [4] in the most possibly general fashion, and elucidate the effects of traditional emission control measures such as emission taxes, standards and quotas. This formulation, as we will see in this paper, enables us to clarify the differences among those three environment regulations in the easiest and clearest way.

The differences in the policy effects do not stem only from the government choice among the three emission control measures but from the sequential-move structure in the government and private decisions. Those differences further yield differences in each country’s policy decision through internationally strategic interdependence through global external diseconomies. In fact, a country’s policy switch from emission taxes to emission standards controls directly affects the other country’s choice of the effective emission tax rate, for such a policy by a country induces its private sector to produce more through the emission tax exemption effect under the emission standard policy and thus increases the marginal environment damage facing the other country.

We formalize the model and clarify the difference among the above emission control mea-

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\(^1\) See Grossman and Helpman [1] for example.

\(^2\) See Barrett [5] for the literature and the issues involved in global warming.
sures in section 2. Comparison of the policy effects is done among them in section 3, elucidating the tax exemption effect inherent to the emission standard policy in section 3. In section 4, we discuss the effect of strategic interactions between the government and the private sector on the formation of the domestic environment regulations. We will find that it critically affects the resulting equilibrium whether the government can precommit to a certain level of the emission control measure, particularly in the case of emission standards. Such differences in policy tools and the sequential-move structure in the domestic policy formation lead to different equilibria in the presence of internationally strategic interactions as we will show in section 5.

2 Basic Model

We first establish a basic model for the discussion throughout the paper. Consider a world consisting of two countries, 1 and 2. Although the two countries are in autarky with regard to trade and investment, they are involved in international interdependence through the globally wide-spread external diseconomies of global warming. Let us first construct each country’s economic structure.

Each country produces and consumes two goods, \(X\) and \(Y\). Sector \(Y\) produces good \(Y\) using the standard inputs, say labor, subject to constant returns to scale. By choosing the units of good \(Y\), we may assume that a unit of good \(Y\) is produced with a unit of labor, so that when we choose good \(Y\) as the numeraire the wage rate is equal to unity, and the earned profit should be equal to zero under perfect competition as we formerly assume later.

Production of good \(X\) requires labor and emits global warming gas. We model this production structure à la Meade [4] so that emission of global warming gas is an unpaid factor of production. Take either of countries 1 and 2 and inquire into its cost structure of sector \(X\). For the time being, we focus our attention to a closed economy until section 5, so that we omit superscripts and subscripts \(i\) representing the name of the country.

2.1 Unpaid Factors and Emission Taxes

As with sector \(X\), let \(\ell\) denote the input of labor, \(z\) the emission of global warming gas, and \(f(\ell, z)\) the production function. We also let \(t\) denote the factor price of global warming

\[3\) Ishikawa and Kiyono [3] discusses the case in the presence of commodity trade.\]
gas emission, and $x$ the output level. Then solution of the standard cost minimization problem yields the following total cost function:

$$C(x, t) = \min_{\ell, z} \{\ell + tz | f(\ell, z) \geq x\}.$$

In the absence of the environmental regulations, the private sector does not have to pay the factor costs on the global warming gas emissions, for they are unpaid factors in the sense of Meade [4]. But once the government imposes the emission taxes, the private sector needs to pay those taxes just as the prices of the standard factors of production. Thus theoretically speaking, the emission tax rate is nothing but the factor price of global warming gas emission.

### 2.2 Properties of Cost Functions

By Shepherd’s lemma, $C_t(x, t)$ (where the subscript $t$ indicates the partial derivative with respect to $t$) represents the emission of global warming gas by sector $X$ when the economy produces $x$ units of good $X$ given the emission factor price $t$, which we often denote by $z(x, t)$. We assume:

**Assumption 1** The total cost function $C(x, t)$ satisfies:

(A 1-1) $C(x, t)$ is strictly increasing and convex in $x$ and strictly increasing and concave in $t$.

In particular, $C_{tt}(x, t) < 0$, i.e., $z_t(x, t) < 0$.

(A 1-2) $C_{tx}(x, t) > 0$, i.e., $z_x(x, t) > 0$.

(A 1-3) $C_{txx}(x, t) < 0$, i.e., $z_{xx}(x, t) < 0$.

(A 1-4) $C_{txx}(x, t) \geq 0$, i.e., $z_{xx}(x, t) \geq 0$.

Assumption 1-1 is all standard. Especially, it says the demand for gas emission is decreasing in its own price given the output level. Assumption 1-2 implies that the global warming gas emission is a normal factor of production. That is, the global warming gas emission increases along with the output. Hereafter we call $C_{tx}(x, t) = z_x(x, t)$ the *marginal emission coefficient*, for it represents the increase in the global warming gas emission caused by a marginal increase in the output.

Assumption 1-3 then implies that the marginal emission coefficient is decreasing in the emission tax rate. This is because such a raise in the emission tax rate induces substitution between global warming gas and labor in production.
Lastly, Assumption 1-4 implies that the marginal emission coefficient is not decreasing in
the output.
For the purpose of describing the production sector, we assume 4): 

**Assumption 2** The markets are all competitive.

Then since sector \( Y \) is perfectly competitive subject to constant returns to scale, it earns
zero profits. To describe sector \( X \), we must specify what policies are employed against its
global warming gas emission.

### 2.3 Emission controls

We are concerned with the following three types of emission controls on good \( X \) sector
throughout this paper.

- Emission taxes
- Emission standards
- Emission quotas

**Emission taxes** The first policy is to impose a certain rate of emission tax, say \( t \), on
sector \( X \). Then the profit earned in sector \( X \) is expressed by:

\[
\tilde{\pi}^T(x, t, p) \overset{\text{def}}{=} px - C(x, t),
\]

where \( p \) represents the market price of good \( X \).

The associated government surplus, denoted by \( G_T \), is given by:

\[
G_T = tC_i(x, t).
\]

Let us call the sum of the private profit (1) and the government surplus (2) the *social profit*
earned in sector \( X \). Then it is given by

\[
\tilde{\pi}^T(x, t, p) + G_T = px - C(x, t) + tC_i(x, t).
\]

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4) See Kiyono [2002] for the discussion on imperfect competition.
The second policy is to regulate the allowable volume of global warming gas emission for each possible output level. That is, it is expressed by a function \( z = \phi(x) \) to assign an allowable volume of global warming gas emission to each output.

One of the extreme types of this policy is a control on the total volume of global warming gas emissions, which we call the \textit{emission quota}. This is expressed by a constant-value function, i.e., \( \phi(x) = \bar{z} \) where \( \bar{z} \) is a positive constant.

In the succeeding discussion, however, our emission standard policies excludes those emission quotas, and focus our attention on the output-emission schedules which realize under emission tax policies. More specifically, we confine our attention to the output-emission schedule \((x, z) = (x, C_t(x, t))\). We call the emission standard expressed by such an output-emission schedule the \textit{tax-equivalent emission standard}. Then the associated emission tax \( t \) represents the effective emission tax rate associated with the emission standard, which we call the \textit{shadow emission tax rate}.

Given the shadow emission tax rate \( t \), the profit earned in sector \( X \) is given by

\[
\bar{\pi}^S (x, t, p) \overset{\text{def}}{=} px - C(x, t) + tC_t(x, t).
\] (4)

The critical difference from the emission tax policy is that the firms are now exempt from the emission tax payment, which is shown by the third refund term.

The associated government surplus, denoted by \( G_S \), is given by:

\[
G_S = 0,
\] (5)

so that the social profit earned in sector \( X \) under the emission standard policy is expressed the same as in the emission tax policy (see (3)).

The last policy is to impose a certain quota on the global warming gas emissions. Given this policy, the firm is constrained to produce the output subject to the emission quota. Using the production function, the profit maximization problem facing the representative firm is expressed as follows:

\[
\max_{[\ell, z, a]} \{ pf(\ell, z) - \ell | z \leq \bar{z} \},
\] (6)

where \( \bar{z} \) denotes the emission quota.

As we have clarified, the firm can choose the combination of the unpaid factor of global warming gas emissions, \( z \), and labor, \( \ell \). The choice depends on the relative factor price given by
When the firm is not taxed on its emissions but it chooses the emission-labor pair different from the one given zero rate of emission tax, it takes into account what we may think as the shadow price of the emissions, the rate of which is equal to the marginal rate of technical substitution between emissions and labor. We express this shadow price with \( t \) as under the emission tax policy, which plays the same role as the shadow emission tax rate under the emission standard.

When the shadow emission tax rate is equal to \( t \), the total production cost, denoted by \( \bar{C}(x, t) \), is given by

\[
\bar{C}(x, t) \equiv C(x, t) - tC_t(x, t).
\] (7)

The first term represents the direct production cost given the emission tax rate \( t \). But since the firm actually does not pay emission taxes, the associated tax payment is exempted as shown by the second term. Using the above cost function, the profit maximization problem under the quota, i.e., (7), is described in the following equivalent fashion.

\[
\max_{\{x, t\}} \left\{ px - \bar{C}(x, t) | C_t(x, t) \leq \bar{z} \right\}.
\] (8)

In view of (4), the above problem can further be rewritten as below:

\[
\max_{\{x, t\}} \left\{ \tilde{\pi}^S(x, t, p) | C_t(x, t) \leq \bar{z} \right\}.
\] (9)

That is, the shadow emission tax rate plays the same role as the effective emission tax rate for the tax-equivalent emission standard. The government surplus under the emission quota policy, denoted by \( G_Q \), is now given by

\[
G_Q = 0,
\] (10)

so that the social profit earned in sector \( X \) is again the same as under the emission tax policy subject to the additional emission quota constraint.

2.4 Consumption and Welfare

We consider the representative consumer, whose utility is assumed to measure the country’s welfare, too. She consumes goods \( X \) and \( Y \), and enjoys utility given by

\[
U(x_c) - px_c + y_c - \theta D(Z),
\] (11)
where $x_c$ (or $y_c$) denotes the consumption of good $X$ (or $Y$), $Z$ the world total emission of global warming gas, $D(Z)$ the world damage from global warming, and $\theta (> 0)$ the rate at which the individual (and thus the country) perceives as the own damage.

The utility function $U(x_c)$ is assumed to satisfy all the standard assumptions:

**Assumption 3** The utility function $U(x_c)$ satisfies:

(A 3-1) $U(x_c)$ is strictly increasing.
(A 3-2) $U(x_c)$ is twice-continuously differentiable.
(A 3-3) $U(x_c)$ is strictly concave.

As with the world environment damage function $D(Z)$, we assume:

**Assumption 4** The world damage from global warming satisfies:

(A 4-1) $D(Z)$ is strictly increasing.
(A 4-2) $D(Z)$ is twice-continuously differentiable.
(A 4-3) $D(Z)$ is strictly convex.

The individual maximizes the own utility (11) subject to

$$px_c + y_c = m,$$

(12)

where $m$ denotes the own income. The first-order condition for utility maximization yields:

$$U'(x_c) = p,$$

(13)

which defines the inverse market demand function, $p = P(x_c)(= U'(x_c))$.

The total income $m$ is the sum of (i) the profits earned in sectors $X$ and $Y$, (ii) the government surplus which is transferred to the individual in a lump-sum fashion, and (iii) the total wage income. Since sector $Y$ earns zero profits and the social profit earned in sector $X$ is given by the right-hand side of (3), the total income is in fact give by

$$m = px - C(x, t) + tC_r(x, t) + \bar{L},$$

(14)

where $L$ represents the constant initial labor endowment.

Let $z^*$ denote the global warming gas emission by the foreign country. Then since $Z = z(x, t) + z^*$ holds, substitution of (12) and (14) into the utility function (11) gives rise to the
following form of the country’s welfare function:

\[ \tilde{V}(x, t, z^*) = U(x) - C(x, t) + tC_t(x, t) - \theta D (C_t(x, t) + z^*) , \]  

(15)

where the wage income is left out from the above equation, for the labor endowment is assumed constant.

3 Comparison of Three Emission Controls

Let us explore into the differences among the three policies

- Emission taxes
- Tax-equivalent emission standards
- Emission quotas

using (1), (4) and (9).

3.1 Emission Taxes

Let us first inquire into the properties of the market equilibrium under the emission tax policy. In view of the profit function (1) and the market demand function (13), the market equilibrium requires:

\[ U'(x) - C_x(x, t) = 0. \]  

(16)

The above condition defines the equilibrium output as a function of the emission tax rate, which we express by \( x_T(t) \). In view of Assumptions 1 and 3, it satisfies:

\[ x'_T(t) = \frac{C_{xt}(x, t)}{U''(x) - C_{xx}(x, t)} < 0, \]  

(17)

where \( x = x_T(t) \) on the RHS. That is, an increase in the emission tax rate decreases the equilibrium output through an increase in the marginal production costs. Such a relation is illustrated by the curve \( x_T(x_0) \) in Figure 1.

3.2 Emission Standards

Second, take the case of the tax-equivalent emission standard with the shadow emission tax rate \( t \). In view of the profit function (4), the equilibrium output should satisfy:

\[ U'(x) - C_x(x, t) + tC_{tx}(x, t) = 0, \]  

(18)
where we assume:

**Assumption 5** The marginal production cost given any non-negative effective emission tax rate is increasing in the output, i.e.,

\[ C_{xx}(x, t) - tC_{xxx}(x, t) > 0. \]

This condition again defines the equilibrium output as a function of the shadow emission tax rate, which we express by \( x_S(t) \). It should satisfy:

\[
x_S'(t) = \frac{-tC_{txx}(x, t)}{U''(x) - C_{xx}(x, t) + tC_{xxx}(x, t)} < 0,
\]

where use was made of Assumption 5.

Since the firms in sector \( X \) produces more than under the emission tax, the volume of global warming gas emission also becomes greater under the emission standard. Thus we
have established 5):

**Proposition 1** Given the same effective emission tax rate, the equilibrium output as well as the emission volume becomes greater under the tax-equivalent emission standard than under the emission tax.

This result has been derived previously, but with restrictive technology conditions concerning emissions and other standard inputs 6).

3.3 Emission Quotas

Lastly consider the effect of imposing an emission quota given by, say $\bar{z}$. Given the market price $p$, the firm is constrained to choose the emission-labor combination subject to the imposed quota constraint. That is, its profit maximization problem is given by

$$\max_{\ell, z} \{ pf(\ell, z) - \ell | z \leq \bar{z}\} \quad (20)$$

One should note that the choice of the emission-labor combination given the output level is equivalent to the choice of the marginal rate of technical substitution between emissions and labor insofar as the output is kept constant. When we express this marginal rate of technical substitution with $t$, the above constrained profit maximization is equivalent to:

$$\max_{x, t} \{ px - C(x, t) + tC_t(x, t)|C_t(x, t) \leq \bar{z}\} \quad (21)$$

Let $L = px - C(x, t) + tC_t(x, t) + \lambda(\bar{z} - C(x, t))$ where $\lambda$ is the Lagrangian multiplier associated with the emission quota constraint. Then the first-order conditions for profit maximization are:

$$0 = p - C_x(x, t) + (t - \lambda)C_{tx}(x, t)$$
$$0 = (t - \lambda)C_t(x, t)$$
$$0 = \bar{z} - C_t(x, t)$$

5) This effect of emission standards are found by some authors, for example [6]. [2] also discusses the effects of pollution standards in various forms, but she does not explore into the differences in their effects on the outputs compared with the emission taxes, because she fixes the total output.

6) See Ulph [6] for example, which clearly points out the tax-exemption effect of emission standards.
These conditions establish:

\[ t = \lambda \]
\[ p = C_s(x, t) \]
\[ \bar{z} = C_t(x, t) \]

Note that the first condition in fact represents that the shadow emission tax rate \( t \) is, in fact, equal to the shadow factor price of the emission. And we find that when the market equilibrium condition is imposed, i.e., \( p = U'(x) \), the second and third conditions above are equivalent to the equilibrium condition under the emission tax policy with the emission tax rate \( t \). Thus we have ascertained in our framework the following tax-quota equivalence.

**Proposition 2** The emission tax and the emission quota policies are equivalent in the sense of achieving the same resource allocation insofar as the market is competitive and the resulting volume of the global warming gas is the same.

Since the emission tax and the emission quota are equivalent, we confine our attention only to possible differences between the emission tax and emission standard policies in the succeeding discussion. We now make a further step in the next section to clarify their difference in the welfare effects by taking an explicit account of the strategic interactions between the government and the private sector in decision making.

### 4 Domestic Strategic Interactions in Environment Regulations

Insofar as we live in a market economy, the government cannot completely control the resource allocation. In the present case of environment regulations, the government can decide on the emission control measures but cannot directly enforce any other decision governing the market. Such an inherently private decision variable is the output in our framework. And the national welfare is affected by both decisions of the government and the private sector. Thus we must resort to the game theory for exploring into how the environment regulations are formed as well as the resulting resource allocation.

But before such an inquiry, it is of a great use to make clear what is the first-best outcome as the reference state of the world.

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7) However this result critically depends on the assumption of perfectly competitive market. See Kiyono [2002].
4.1 First-Best Outcome

Partial differentiation of the national welfare function (15) yields

\[ \tilde{V}_x(x, t, z^*) = U'(x) - C_x(x, t) + (t - \theta D'(\cdot)) C_{ix}(x, t) \]  \hspace{1cm} (22)

\[ \tilde{V}_t(x, t, z^*) = (t - \theta D'(\cdot)) C_{it}(x, t) \]  \hspace{1cm} (23)

\[ \tilde{V}_{z^*}(x, t, z^*) = -\theta D'(\cdot) \]  \hspace{1cm} (24)

The first-best outcome, represented by the output-tax pair \((x_B, t_B)\), should satisfy:

\[ \tilde{V}_x(x_B, t_B, z^*) = 0, \]

\[ \tilde{V}_t(x_B, t_B, z^*) = 0, \]

so that in view of (22) and (23) the following conditions must hold:

\[ U'(x_B) - C_x(x_B, t_B) = 0 \]  \hspace{1cm} (25)

\[ t_B - \theta D'(C_t(x_B, t_B) + z^*) = 0 \]  \hspace{1cm} (26)

The first-best outcome depends on the foreign emission of global warming gas \(z^*\). However in view of (25) and (26), the first-best output depends only on the emission tax rate \(t\). And the relation between the output and the emission tax rate governed by (25) is the same as in the market equilibrium condition under the emission tax policy, (16), i.e, \(x = x_T(t)\). Thus the effect of the change in the foreign emission is confined onto the first-best emission tax rate. We represent such a relation by \(t_B = t_B(z^*)\) and \(x_B = x_T(t_B)\).

The first-best outcome given the foreign emission is illustrated in Figure 2. The curve \(t_B x_B'\) shows the emission tax rate satisfying \(\tilde{V}_t(x, t, z^*) = 0\) for each output \(x\) given \(z^*\). This schedule is upward sloping, for an increase in the output increases the country’s perceived marginal environment damage through an increase in the associated emission. We call this schedule the best emission-tax schedule.

On the other hand, the curve \(x_B x_B'\) shows the output maximizing the welfare given the emission tax rate and the foreign emission, i.e, satisfying \(\tilde{V}_x(x, t, z^*) = 0\) for each emission tax rate given \(z^*\). We call it the best output schedule. This schedule is, at least around its intersection with the best emission-tax schedule, upward-sloping. This is because an increase in the emission tax rate decreases the emission of global warming gas, leading to a decrease in the marginal damage due to the output increase \(^8\)

\(^8\) More rigorously, let \(\hat{x}(t, z^*)\) be the solution to \(\tilde{V}_x(x, t, z^*) = -0\). Then application of the implicit function
The intersection of the two best schedules, point $B$, shows the first-best outcome given the foreign emission $z^*$.

In the following discussion, many of the equilibria are found along the best emission-tax schedule. But along the schedule, the volume of emission becomes greater as the emission tax rate gets higher. This is because the best emission tax rate is always equal to the country’s marginal environment damage $\theta D'(\cdot)$, which is strictly increasing in the output given the foreign emission under Assumption 4, $D''(\cdot) > 0$. We often resort to this result in the succeeding discussion, so that we sum it up in the following lemma.

**Lemma 1** Along the best emission-tax schedule, a rise in the emission tax rate leads to an increase in the global warming gas emission.

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**Figure 2: Emission Controls in a Closed Economy**

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Theorem yields:

$$\hat{x}_f(t,z^*) \propto (1 - \theta D''(\cdot))C_{n}C_{tx} + (t - \theta D')C_{px},$$

where the RHS is positive by virtue of Assumptions 1 and 4.
4.2 Game-Theoretic Formulation

Given this feature of the first-best outcome, let us now inquire into the strategic interaction between the government and the private sector in forming the environment regulations. Its game theoretic exploration requires us to specify

(i) Strategies of the players, the government and the private sector,
(ii) Sequential-move structure specifying who moves first in decision.

Emission Tax and Standard Games Since the private sector is confined to decide on the output, the first issue hinges on which emission control measure the government chooses, either the emission tax or the emission standard. When the government chooses the emission tax rate as its policy variable, the associated game is called the emission tax game. And when the tax-equivalent emission standard is chosen in the form of the shadow emission tax rate, the associated game is called the emission standard game.

Simultaneous-Move and Government-Leader Games As with the second issue, the problem is whether each player can precommit to the own strategic variable in advance. In the standard literature on the policy evaluation, the government is often assumed to move first as the so-called Stackelberg leader against the private sector. We call such a game the government-leader game.

However as has been explored in the recent literature on the political economy of trade and industrial policies, the private sector may act as the leader and strategically distort the succeeding policy decision process. We may call it the private-leader game.

In the present competitive market economy, this private-leader game is difficult to examine theoretically insofar as we keep the commodity market structure perfectly competitive. This is because the private sector’s precommitment to a certain output level requires cartel formation by the firms in sector $X$, which changes the market essentially into a monopoly. For this reason, we do not take up the case of the private-leader game in the present paper.

Thus the last possibility is that the two players move simultaneously, which we call the simultaneous-move game.

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9) See the discussion of the private-leader game in Kiyono [3] for the case of imperfect competition.
4.3 Emission Tax Game

Let us first take up the emission tax game in a simultaneous-move form. To obtain the equilibrium, we must define each player’s reaction function. As with the government, it shows the best emission tax rate given the output. Clearly it is given by the best emission-tax schedule \(t_{B'}\) in Figure 2. As with the private sector, it represents the profit-maximizing output given the emission tax rate, which is given by \(x_T(t)\) derived from the market equilibrium condition given the tax rate, (16). Thus by superimposing the curve \(x_Tx_0\) in Figure 1 on Figure 2, its intersection with the best-emission tax schedule gives the non-cooperative equilibrium for the simultaneous-move emission-tax game.

The equilibrium in fact coincides the first-best outcome \(B\). This is because the market equilibrium condition (16) governing the private sector’s reaction function requires that the tax-inclusive marginal production cost be equal to the market price, as is required for the first-best outcome (25).

As with the government-leader game, the government chooses the output-tax pair along the private sector’s reaction curve so as to maximize the national welfare. Since the private sector’s reaction curve passes through the first-best outcome point \(B\), the associated equilibrium is again the first-best state.

We may summarize the above discussion in the following proposition.

**Proposition 3** Consider the emission-tax game. Then in either the simultaneous-move game or the government-leader one, the first-best outcome realizes as the equilibrium.

Let us consider the effect of an increase in the foreign emission on the equilibrium. Since it has no effect either on the market demand or on the costs, the private sector’s reaction function does not change even with a change in the foreign emission. It affects the government’s reaction function, only. An increase in the foreign emission increases the country’s marginal environment damage, leading to a raise in the best emission tax rate. This implies an outward shift of the government’s reaction curve to, say \(t_{B'}\) in Figure 2. This tax-increasing incentive of the government raises the equilibrium emission tax rate at the new equilibrium \(B^*\), which decreases the output through an increase in the tax-inclusive marginal production costs. The country’s emission of global warming gas emission falls, but the world total emission increases, which is reflected in the tax-rate increase.
The total effect on the welfare is negative. To demonstrate it, define the equilibrium national welfare function in the emission tax game as below:

$$V_T(z^*) \overset{\text{def}}{=} \bar{V}(x_B(t_B(z^*)), t_B(z^*), z^*).$$

Then application of the envelope theorem yields:

$$V'_T(z^*) = \bar{V}_z(\cdot) = -\theta D'(\cdot) < 0.$$

The results are summarized in the following proposition.

**Proposition 4** Consider the emission-tax game either in the simultaneous-move form or in the government-leader one. An increase in the foreign emission leads to (i) an increase in the emission tax rate, (ii) a decrease in the output, (iii) a decrease in the country’s emission, (iv) an increase in the world total emission, and (v) the lower welfare.

### 4.4 Emission Standard Game

Next consider the emission standard game first in the simultaneous-move form and then in the government-leader form.

- **Simultaneous-move game** In the emission standard game, the government chooses the shadow emission tax rate. Since a change in its rate alters the welfare as expressed by (23) and the government maximizes the welfare using only $t$, its reaction function is the same as in the emission tax game. That is, it is given by the best emission-tax schedule in Figure 2.

On the other hand, the private sector is now exempted from emission taxes, so that its output choice is governed by the associated market equilibrium condition (18). That is, its reaction function is given by $x_S(t)$, and is expressed by the curve $x_S x_0$ in Figure 1. Superimpose it over Figure 2. Then its intersection with $t_B t'_B$, denoted by $S$, shows the resulting non-cooperative equilibrium.

Since the private sector has an incentive to produce more under the tax-equivalent emission standard, the resulting equilibrium entails the higher (shadow) emission tax rate and the greater output than under the emission tax policy. Furthermore, the equilibrium $S$ is located along the best emission-tax schedule, so that in view of Lemma 1 the country’s emission also becomes greater. Thus we have established 10) :

10) The third result has been noticed by [6] but only within a too specified technology conditions. In fact, his
**Proposition 5** Consider the simultaneous-move emission standard game. Then compared with the emission tax game, the equilibrium entails (i) the higher (shadow) emission tax rate, (ii) the greater output, (iii) the greater emission, and (iv) the lower welfare.

The effect of an increase in the foreign emission is made clear as in the case of the emission tax policy. Its effects on the resource allocation are qualitatively the same as under the emission tax game, so that we now explore into its welfare effect. Let

\[ V_{S}(z^*) \overset{\text{def}}{=} \tilde{V}(x_{S}(t_{B}(z^*)), t_{B}(z^*), z^*) \]

represent the equilibrium welfare in the present simultaneous-move emission standard game. Then in view of (18), application of the envelope theorem leads to:

\[
V'_{S}(z^*) = -tC_{tx}(x_{S}(t), y)x'_{S}(t)t'_{B}(z^*) - \theta D'(C_{t}(x_{S}(t), t) + z^*)
\]

\[
= t\{1 + C_{tx}(-x'_{S}(t)t'_{B}(z^*))\}
\]

\[
= \frac{t}{1 - \theta D''(\cdot)} \{1 - \theta D''(\cdot)C_{tt}(\cdot)\} < 0,
\]

where \( t = t_{B}(z^*) \) and use was made of \( t_{B} = \theta D'(-) \) from (26), \( x'_{S}(t) < 0 \) from (19), and Assumption 1. Thus, we have established:

**Proposition 6** Consider the simultaneous-move emission standard game. Then an increase in the foreign emission leads to (i) the higher shadow emission tax rate, (ii) the smaller output, (iii) the smaller emission of the country, (iv) the greater world total emission, and (iv) the lower national welfare.

Government-Leader Emission Standard Game Now consider the case in which the government moves first. As we explained in the emission tax game, when the government moves as Stackelberg leader against the private sector, it choose the output-tax pair along the private sector’s reaction curve \( x_{S} s_{0} \) that maximize the national welfare. Such a point is given by point \( G \) where the iso-national welfare curve \( V(G) \) touches the private sector’s reaction curve.

The government understands in advance that the private sector’s best-response output is decreasing in the shadow emission tax rate, so that a raise in the shadow emission tax rate leads to a decrease in the output. Since the output is socially excessive in production, the
government attempts to precommit to the higher shadow emission tax rate than under the simultaneous-move game. This leads to the higher shadow emission tax rate and the smaller output than when it cannot make precommitment. The higher shadow emission tax rate reduces the equilibrium output and emission. But one should note that it is ambiguous in general whether the emission volume is smaller than under the emission tax policy.

The results are summarized in the following proposition.

**Proposition 7** Consider the government-leader emission standard game. Compared with the simultaneous-move game, the equilibrium entails (i) the higher shadow emission tax rate, (ii) the smaller output, and (iii) the smaller emission of global warming gas. But the country’s emission volume may or may not be greater than under the emission tax game.

Lastly consider the effect of an increase in the foreign emission. As under the emission tax game, it shifts the government’s reaction curve outward to \( t^*_G t^*_G' \). The graphical analysis is impotent to clarify the effect, so that we resort to the algebra. Given the private sector’s reaction function \( x^*_S(t) \) the national welfare is expressed in terms of the shadow emission tax rate \( t \) and the foreign emission \( z^* \) as below:

\[
V_G(t, z^*) \overset{\text{def}}{=} \tilde{V}(x^*_S(t), t, z^*).
\] (27)

The first-order condition for welfare maximization with respect to the shadow emission tax rate \( t \) is given by:

\[
0 = \frac{\partial V_G(\cdot)}{\partial t} = \tilde{V}_i(\cdot) + \tilde{V}_t(\cdot) + \tilde{V}_x(\cdot) x^*_S(t) + (t - \theta D(\cdot)) z^*_S(t).
\] (28)

This defines the equilibrium shadow emission tax rate as a function of the foreign emission, which we express by \( t_G(z^*) \). (28) requires that this equilibrium shadow emission tax rate satisfy:

\[
t_G(z^*) = \left\{1 + \frac{C\chi(\cdot)x^*_S(t)}{C^*_n(\cdot)} \right\} \theta D(\cdot).
\] (29)

Application of the implicit function theorem to (28) implies:

\[
t'_G(z^*) \propto -\theta D''(\cdot) z^*_S(t) > 0,
\]
which implies that an increase in the foreign emission leads to an increase in the shadow emission tax rate. Given this effect, the resulting effects on the resource allocation are the same under the emission tax game.

As with the welfare effect, the effect is determinate unlike in the simultaneous-move game. This is because the government decides on the shadow emission tax rate by taking the distortion of socially excessive production into account in advance. More rigorously speaking, application of the envelope theorem in view of (28) yields:

$$\frac{dV_G(t_G(z^*),z^*)}{dz^*} = \tilde{V}_z(z^*) = -\theta D'(\cdot) < 0.$$ 

Thus we have established:

**Proposition 8** Consider the government-leader emission standard game. Then an increase in the foreign emission leads to (i) the higher shadow emission tax rate, (ii) the smaller output, (iii) the smaller emission of the country, and (iii) the lower national welfare.

5 Non-Cooperative Emission Controls

Let us extend the results in the previous closed economy case to an open economy one and explore into the strategic interdependence between two countries, 1 and 2. There are several possible cases for inquiry depending on the emission control measures employed by each country and the sequential-move structure in each country. However the discussion in the preceding sections implies that the following two common properties hold for every possible equilibrium in each country.

(Property i) Given the foreign emission, the country’s emission of global warming gas is decreasing in the emission tax rate as well as the shadow one.

(Property ii) An increase in the foreign emission leads to an increase in the country’s emission tax rate as well as its shadow one.

Thus each country’s best response (shadow) emission tax is decreasing in the other’s. We represent this best response emission tax for country $i$ by $R_i(t_j)$ ($i, j = 1, 2; j \neq i$), and call it country $i$’s reaction function. The associated reaction curve is depicted by the downward-sloping curves $R_i (i = 1, 2)$ in Figure 3.
As we have discussed in the previous sections, the equilibrium (shadow) emission tax rate given the foreign one, or alternatively the shape of the reaction curve depends on (i) the emission control measures employed by the governments and (ii) the sequential-move structure in each country’s policy game. However, for making the discussion in the succeeding section sensible enough, we assume:

**Assumption 6** In each possible case, each country’s reaction curve has a slope greater than \(-1\), so that the resulting equilibrium is stable.

Let us first inquire into the case in which the private sector and the government move simultaneously.
5.1 Simultaneous-Move Games in Each Country

The first issue of interest is how a country’s choice of emission control measures affects the equilibrium. As will be shown later, a country’s policy choice affects the other country’s best response, which has not been noticed in the previous literature.

We begin with the case in which both countries employ emission taxes. Country $i$’s reaction curve for the emission tax is given by $R^{TT}_i$ for $i = 1, 2$ and the associated equilibrium by $E^{TT}$ in Figure 4.

Now what if country 1 switches to emission standards? The discussion in Proposition 5 implies that the (shadow) emission tax rate becomes higher. That is, country 1’s reaction curve shifts outward, from $R^{TT}_1$ to, say $R^{ST}_1$ in the figure. But this is not the end of the
story. For, the same proposition suggests that country 1’s emission increases along with such a policy switch. This result, coupled with Property ii, implies that country 2 also has an incentive to raise the emission tax rate, which leads to the outward shift from $R^{TT}_T$ to, say $R^{ST}_2$ in the figure. The resulting equilibrium is now given by point $E_{ST}$.

When country 2 also switches to emission standards, the reaction curves shift further outward. Country 1’s shifts to, say $R^{TS}_1$, and country 2’s to, say $R^{SS}_2$ with the associated equilibrium $E_{SS}$.

It is of importance to note that each government’s best response tax should be set equal to the own marginal environment damage regardless of its emission control measures given the simultaneous-move structure in each country’s policy game, i.e.,

$$t_i = \theta_i D' (Z) \quad (i = 1, 2),$$  \hspace{1cm} (30)

so that the resulting equilibrium emission taxes should always satisfy:

$$\frac{t_1}{t_2} = \frac{\theta_1}{\theta_2}. \hspace{1cm} (31)$$

Outward shifts of the reaction curves under (31) leads to an increase in the (shadow) emission tax rate by both countries. Furthermore one should note that such an increase in the emission tax rate should be associated with an increase in the total world emission of global warming gas:

**Proposition 9** Suppose that in both countries the government chooses the emission tax rate as its emission control and the private sector decides on the output simultaneously. Then either country’s policy switch from the emission taxes to the emission standards increases the (shadow) emission tax rates of both countries as well as the total world volume of global warming gas.

How does each country’s welfare change when either or both countries switch from emission taxes to emission standards? Let us first consider the change from the initial emission-tax game equilibrium $E_{TT}$ in Figure 4 to $E_{ST}$ where only country 1 switches to the emission standard. By virtue of Proposition 5, such a policy switch increases country 1’s emission, and lowers her own welfare. Proposition 4, then implies that such an increase in country 1’s carbon-gas emission worsens country 2’s welfare, leadint to the latter’s emission-tax rate. Country 2’s raise in the emission-tax rate, decreasing her carbon-gas emission, improves country 1’s welfare as stated in Proposition 6. The total effect is that country 2 should be
worse off at $E_{ST}$ than at $E_{TT}$ but that the change in country 1’s welfare is ambiguous. Similar reasoning applies to the change from $E_{ST}$ to $E_{SS}$. Thus we have established:

**Proposition 10** A country’s switch from the emission tax to the emission standard worsens the other country’s welfare but it is generally ambiguous whether the policy-switching country may be better off.

However one can show that both countries are worse off at $E_{SS}$ than at $E_{TT}$\(^{11}\). That is,

**Proposition 11** Compared with when the two countries choose the emission taxes, they both get worse off when they choose the emission standards.

### 5.2 Government-Leader Games

Similar results hold also for the case in which the governments move before the private sector’s decision. The difference comes from the equilibrium condition governing the emission tax rates for both countries when a government chooses emission standards and moves first.

As in the previous subsection, start with the case in which both government employ emission taxes. Then the reaction curves are the same as in Figure 4, which are reproduced in Figure 5. Suppose then that only the government of country 1 switches to emission standards. Then as stated in Proposition 10, country 1 finds an incentive to raise the shadow emission tax rate, so that its reaction curve shifts outward as under the emission tax policy, say to $R_{1}^{ST}$ in Figure 5. Country 2’s reaction curve is also affected for the same reason in the simultaneous-move game, so that it shifts outward to, say $R_{2}^{ST}$. The resulting equilibrium is shown by point $E_{ST}$. In view of (29) and (30), the resulting equilibrium (shadow) emission tax pair should satisfy:

$$\frac{t_1}{t_2} = \left\{ 1 + \frac{C_{tt}(t)}{C_{tt}(t)} \right\} \frac{\theta_1}{\theta_2},$$

which is greater than $\frac{\theta_1}{\theta_2}$. Thus the policy switch to emission standards by only country 1 raises country 1’s (shadow) emission tax rate relatively higher than under the emission tax policies as shown in Figure 5. This establishes:

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\(^{11}\) The proof is available upon request.
Proposition 12 Consider the government-leader game in each country where each government chooses emission taxes initially. Then either country’s switch to emission standards raises its shadow emission tax rate relatively and absolutely than under the emission tax game.

When both countries switch to emission standards, each country’s reaction curve shifts further outward to, say $R_i^{SS}$ for $i = 1, 2$. Thus there is an increase in the shadow emission tax rate by at least one country. And when the demand and cost conditions are sufficiently similar between the two countries, we find that there should be an increase in the shadow emission tax rate by each country. When it is the case, in view of Proposition 7 it is straightforward to establish that the shadow emission tax rate of each country should be higher than in the simultaneous-move game. Furthermore, Proposition ?? suggests that Pareto-improving international coordination requires the shadow emission tax rates to be raised further in both
Proposition 13 Consider the government-leader game in each country.

1. Compared with the emission tax game, the country switching to emission standards adopts the relatively and absolutely higher shadow emission tax rate.
2. When the demand and cost conditions are sufficiently similar, compared with the emission tax game, the shadow emission tax rates are higher in both countries.
3. In the above situation, Pareto-improving international coordination in environmental regulations requires each country to raise the shadow emission tax rate.

The last remark is concerning the counter-parts to Proposisitions 10 and 11 in the simultaneous-move games. In view of Propositions 7 and 8, it is straightforward to see that the counterpart for Proposition 10 holds. But as with the counterpart to Proposition 11 the result is generally ambiguous because we have to know the sign and value of the higher-order differentials of the final-demand and cost functions.

Proposition 14 When the government commits to the environmental policies before the private sector’s decision and both countries initially choose emission taxes, a country’s switch from the emission tax to the emission standard worsens the other country’s welfare but its effect on the policy-switching country is ambiguous.

6 Concluding Remarks

Let us finally discuss possible possible implications of our analysis. The first is the welfare effect of emission taxes and standards for an individual country. As already discussed, the emission standards has the tax-exemption effect unlike the emission taxes, leading to over-production of the final good and thus over-emission of carbon-gas. Thus even when the private-sector chooses to reduce the carbon-gas emission through any voluntary efforts, unless it bears the marginal environment damages, the country gets worse off because of the allocational inefficiency caused by the tax-exemption effect.

Second, however, from the view-point of international strategic interactions, such a tax-exemption effect of emission standards may play an important role for a country. This is because in its presence there are two types of distortions facing each country, i.e., (i) the domestic distortion caused by environment damages and (ii) the strategic distortion induced
through the global or transboundary external diseconomies. Tinbergen’s theorem of policy assignment tells us that there should be at least two policy variables to remedy those two distortions. A country may choose the emission standard to remedy the domestic distortion and the associated tax-exemption rate to make the best of the strategic position in the international interactions surrounding the environment policy formations.

REFERENCE