Oligopolistic eco-industries with free entry and trade liberalization of environmental goods[1]

Yasuyuki Sugiyama[†]

Yungho Weng

Kenzo Abe

Fukui Prefectural University

National Chengchi University

Osaka University

Abstract

In this paper, we assume two countries with trade of environmental goods (EGs), and then investigate the impacts of the emission tax, the tariff on imported EGs, and the subsidy for purchasing EGs. In our model, EGs are produced only in the exporting country, and the firms in the eco-industry which produces EGs engage in Cournot competition with free entry, while a polluting final goods sector in EGs' importing country is perfectly competitive. Then, assuming the end of pipe pollution abatement in the polluting sector, we can obtain the following results: (I) Trade liberalization of EGs, that is, a decrease in the tariff on EGs and the subsidy for purchasing EGs increase the total output of EGs, and thus decrease the amount of emissions. (II) The impact of the subsidy on the price of EGs depends on the shape of the demand curve for EGs, while trade liberalization decreases the price. (III) The optimal emission tax level will be lower than the Pigouvian one if the level of the subsidy is higher than that of the tariff. (IV) The optimal tariff evaluating at the optimal emission tax level is negative, that is, the import subsidy can be optimal when the demand curve for EGs is linear or weak convex. (V) Under the same demand condition, the optimal purchasing subsidy is positive even when EGs' importing country implements the optimal emission tax.

JEL Classification: F12, F18, Q58

Key words: environmental goods, eco-industry, emission tax, trade liberalization, abatement subsidy, free entry oligopoly

1.　Introduction

　　The industries which supply environmental goods and services such as pollution

Oligopolistic eco-industries with free entry and trade liberalization of environmental goods

Table 1: Classification of articles for imperfectly competitive eco-industries

(ii) / (i)	Closed economy (without trade of EGs)	Open economy (with trade of EGs)
Short run	David and Sinclair-Desgagné (2005) Canton, et al. (2008) David and Sinclair-Desgagné (2010) Schwartz and Stahn (2014) Nimubona and Benchekroun (2015) *There are many papers.	Canton (2007) Greaker and Rosendahl (2008) Nimubona (2012) Dijkstra and Mathew (2015)
Long run	David, et al. (2011) Lee and Park (2011)	None

management, resource management, and cleaner technology and products are called environmental industries or eco-industries. Assignment of environmental goods (hereafter, EGs) to be liberalized has become one of the important subjects in WTO and other negotiations regarding trade and the environment because the expansion of domestic eco-industries and the dissemination of EGs through international trade can simultaneously achieve economic development and environmental protection. For example, APEC member countries agreed to reduce the applied tariff rate on EGs to 5% or less by the end of 2015, and then determined 54 items as EGs to be covered in 2012. Given this actual situation, it is very important for us to investigate the economic and environmental impact of trade liberalization of EGs, and to clarify the relation between the liberalization and domestic environmental policies.[2]

David and Sinclair-Desgagné (2005) noted that "significant segments of the eco-industry, such as waste management, are dominated by a small number of large suppliers. These environment firms certainly enjoy some market power and matter to each other." Since their literature, the research for imperfectly competitive eco-industries has been actively conducted. Then, sorting these papers from the perspective of (i) with or without international trade of EGs, (ii) with or without free entry and exit, that is, long run or short run; we obtain the following Table 1.[3]

As denoted in David, et al. (2011) and Lee and Park (2011), an emission tax imposed on polluting downstream producers can increase the number of firms in the upstream eco-industry, while it reduces the output of each incumbent firm which produces EGs. Due to this effect, they show that, unlike the case of the short run, the level of optimal emission tax can be not only higher but also lower than that of the Pigouvian tax. Therefore, in addition to (i), we need to consider the difference between the short-run and long-run effect when we investigate the impacts of trade and environmental policies on the upstream and downstream markets and

---

2) Sinclair-Desgagné (2008) is a comprehensive survey in this filed.

3) In a small open economy, Abe and Koonsed (2016) examined the impacts of the tariffs and the emission tax on the imports of polluting final goods and EGs. They then considered the optimal combination of these policies. As different types of EGs, e.g., Wan, et al. (2018) supposed final goods whose consumption improves the environment, and then analyzed the impact of trade liberalization in such EGs.

pollution emissions.[4]

On the other hand, Canton (2007), Greaker and Rosendahl (2008), Nimubona (2012), and Dijkstra and Mathew (2015) have analyzed international trade of EGs in the short run. Canton (2007) supposed two countries whose abatement technologies are different, then examined the role of cooperative and non-cooperative environmental taxation. Greaker and Rosendahl (2008) investigated the impact of environmental standards on the output of EGs, the level of cost reducing R&D in upstream firms which produce EGs, and welfare under reciprocal market model. Nimubona (2012) examined the relation between optimal emission tax and the tariff on an imported EG in the case where the developing country cannot domestically produce the EG. Dijkstra and Mathew (2015) analyzed R&D incentive for introducing cleaner technology in the upstream firms under autarky and free trade.

Despite the significant contribution of previous studies so far, there is still room for an anatomy in this field with respect to the following two points. First, as shown in Table 1, the effect of trade liberalization of EGs has not yet been analyzed in the model of oligopolistic eco-industry with free entry and exit. Second, the role of a subsidy for purchasing EGs in their importing country has not been investigated, too.[5]

Under Ricardian two countries' model, Abe and Sugiyama (2010) analyzed the role of the purchasing subsidy, and then revealed that the subsidy can be substitute for the emission tax. However, as far as we know, there are no papers which treat the subsidy in the model of oligopolistic eco-industry with trade of EGs. Hence, in this paper, we aim for elucidating the impacts of trade liberalization in EGs and the subsidy for purchasing EGs in addition to the emission tax on markets of polluting final goods (hereafter, FGs) and EGs, the amount of emissions, and welfare of EGs' importing country. We then reveal the relation between these policies from the viewpoint of welfare maximization of the country.

As shown in Fig. 1, we combine the model of David, et al. (2011) with that of Nimubona (2012) in order to implement our analysis. In detail, our model consists of the exporting and importing countries of EGs. The importing country does not domestically produce EGs, and free entry and exit prevails in the eco-industry of EGs' exporting country. Then, assuming the end of pipe type's emissions abatement activity, we can obtain the following results: (I) Trade liberalization, that is, a decrease in the tariff of EGs and the subsidy for purchasing them increase the total output of EGs, and thus decrease the amount of emissions. (II) The impact of the subsidy on the price of EGs depends on the shape of the demand curve for EGs, while trade liberalization definitely decreases the price. (III) The optimal emission tax level will be lower than the Pigouvian one if the level of the subsidy is higher than that of the tariff. (IV) The optimal tariff evaluating at the optimal emission tax level seems to be negative, that is, the import subsidy for EGs can be optimal when the demand curve for EGs is linear or weak convex. (V) Under the same demand condition, the optimal purchasing subsidy seems to be positive even when EGs' importing country implements the optimal emission tax.

The remainder of the paper is organized as follows. Section 2 presents our model. Sec-

---

4) For example, see Katsoulacos and Xepapadeas (1995) for the impact of environmental policy on oligopolistic final goods market with free entry.

5) In the case of a closed economy, David and Sinclair-Desgagné (2010) show that to achieve the first best outcome, instead of the purchasing subsidy to downstream firms, it is necessary to combine the production subsidy to upstream firms with the emission tax on the polluting downstream sector.

Oligopolistic eco-industries with free entry and trade liberalization of environmental goods

Fig. 1: The model structure
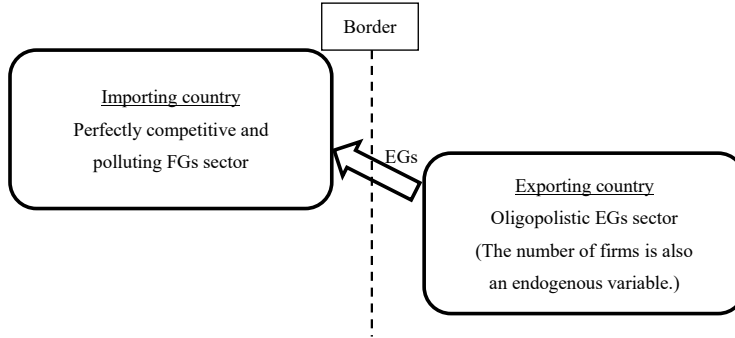
tion 3 discusses the impacts of the emission tax, the tariff on imported EGs, and the subsidy for purchasing EGs on the supply side of the economy. Section 4 derives the optimal level of each policy. Section 5 provides some concluding remarks.

2. Model

There are two countries in our model. One is the importing country of EGs and the other is their exporting country. The importing country has a polluting and perfectly competitive FGs sector. The firms in this sector abate their emissions by purchasing the imported EGs. We assume that all FGs are consumed within the importing country.

On the other hand, the eco-industry which produces EGs is assumed as an oligopolistic market with free entry and exit, and is located in the exporting country. There are no domestic production and consumption of FGs in this country.

Emissions from FGs sector are expressed by the following emission function:

$$E(X, A) = \alpha(X) - \beta(A), \tag{1}$$

where E, X, and A represent the amount of emissions, the output of FGs, and the input of EGs, respectively. Moreover, we assume $\alpha'(X) > 0$, $\alpha''(X) \geq 0$, $\beta'(A) > 0$, $\beta''(A) < 0$, and $\beta'''(A) \lesseqgtr 0$ like David, et al. (2011).[6]

As shown in Fig. 2, an increase in the output of FGs increases pollution emissions at an increasing $(\alpha''(X) > 0)$, or constant rate $(\alpha''(X) = 0)$. Along with above mentioned papers starting with David and Sinclair-Desgagné (2005), we also assume that although an increase in the input of EGs decreases the emissions, the abatement effect of EGs is gradually decreased, that is, $\beta''(A) < 0$. As a result, the remainder after deducting the abated emissions causes the external diseconomy.

In the following analysis, we examine a two-stage game. In the first stage, the government of EGs' importing country sets the emission tax, the tariff on imported EGs, and the sub-

---

6) Hereafter, the symbols " $'$ ", " $''$ ", and " $'''$ " attached to a function represent the first, second, and third-order derivatives of the function, respectively.

Y. Sugiyama, Y. Weng and K. Abe

Fig. 2: The emission function under the case of $\alpha''(X)=0$
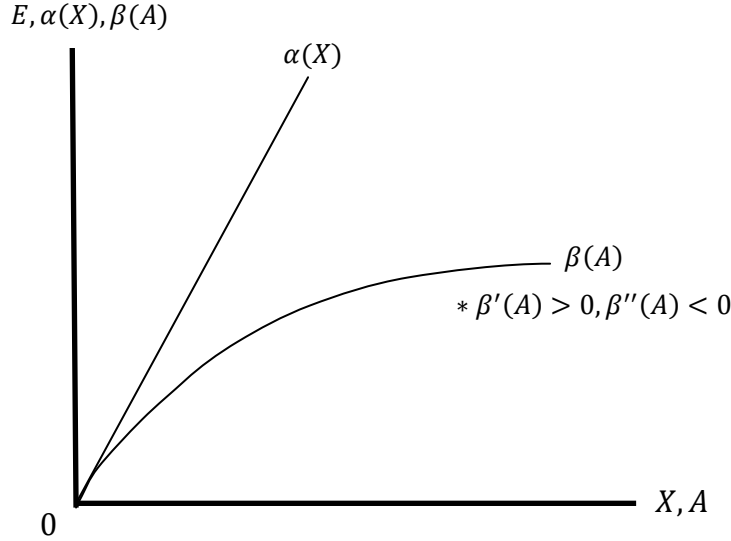
sidy to polluting downstream firms for purchasing the EGs to maximize welfare of the country. In the second stage, firms in the upstream eco-industry choose each output level of EGs. Note that there are many potential entry firms in this sector. These firms will enter as long as incumbent firms earn excess profits. In addition, polluting downstream sector determines both the output level of FGs and the input demand for EGs. The subgame-perfect Nash equilibrium is deduced by using backward induction.

2.1 The profit maximization of FGs sector

Here, we consider the profit maximization in FGs sector. Note that the price of FGs (P) is given for each firm because of perfect competition. Let the price of EGs, the emission tax, and the subsidy to purchase EGs be p, t, and s respectively. The profit (Π) of the FGs producers is written as follows:[7]

$$\Pi(X,A)=PX-C(X)-(p-s)A-t\{\alpha(X)-\beta(A)\}, \tag{2}$$

where $C(X)$ is cost function for producing FGs, and we suppose $C'(X)>0$, $C''(X)>0$. From (2), the first order conditions are represented as follows:

$$\partial\Pi/\partial X=P-C'(X)-t\alpha'(X)=0, \tag{3}$$

$$\partial\Pi/\partial A=-(p-s)+t\beta'(A)=0. \tag{4}$$

In (3), P intends to the supply price of FGs. Here, let us denote the demand price for FGs as the inverse demand function ($P(X)$). Since the market clearing condition of FGs means that

---

7) Our model is closely related to the vertical oligopoly model involving trade of intermediate goods. For example, see Ishikawa and Lee (1997) and Ishikawa and Spencer (1999) for this subject.

the supply price of FGs is equal to the demand price, the condition from (3) can be expressed as follows:

$$P(X) = C'(X) + t\alpha'(X). \tag{5}$$

From (5), we obtain $X = X(t)$. Note that this output does not depend on the tariff and the purchasing subsidy because of the dichotomy between (3) and (4) stemming from the end of pipe type's emission function.

On the other hand, from (4), we obtain the inverse demand function for EGs as follows:

$$p(A,t,s) = t\beta'(A) + s. \tag{6}$$

Hence we have,[8]

$$
\begin{aligned}
&p_A(A,t,s) = t\beta''(A) < 0,\ p_{AA}(A,t,s) = t\beta'''(A) \gtreqless 0, \\
&p_t(A,t,s) = \beta'(A) > 0,\ p_{tt}(A,t,s) = 0,\ p_s(A,t,s) = 1, \\
&p_{At}(A,t,s) = p_{tA}(A,t,s) = \beta''(A) < 0.
\end{aligned}
\tag{7}
$$

From (6) and (7), we find that the signs of first-, second-, and third-order derivatives of $\beta(A)$ are closely related to the demand curve for EGs. Fig. 3 summarizes the properties of the curve. At first, since we assume $\beta''(A) < 0$, the demand curve becomes downward sloping. It also means that the abatement function increases with the input of EGs at a decreasing rate. Next, the third-order derivative of $\beta(A)$ expresses the shape of this demand curve. As shown in Fig. 3, $\beta'''(A) < 0$, $\beta'''(A) = 0$, and $\beta'''(A) > 0$ correspond that the

Fig. 3: The properties of the inverse demand function for EGs

$P(A, t, s) = t\,\beta'(A) + s$

$t\beta'''(A) < 0$

$t\beta'''(A) = 0$

$t\beta'''(A) > 0$

A

0

---
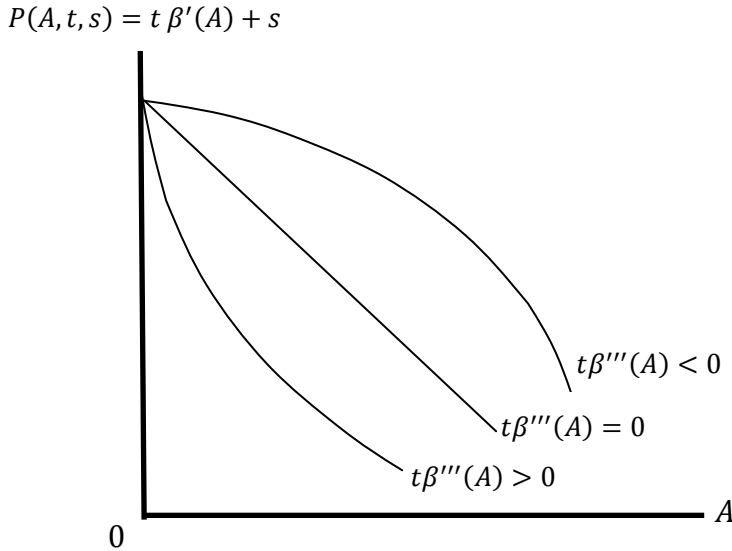
8) Hereafter, subscripts on $p(A,t,s)$ represent the first- or second-order partial derivative of $p(A,t,s)$ with respect to the corresponding variables.

demand curve is concave, linear, and convex, respectively. As shown in David, et al. (2011), and then in our analysis, this sign plays an important role as the determinant factor when we examine the impacts of the emission tax, the tariff on imported EGs, and the subsidy for purchasing EGs.

2.2　The profit maximization of EGs firms

Next, we consider the profit maximization of an upstream oligopolistic firm which produces an EG. Let firm i's output and the tariff on EGs be a^i and τ, respectively, the profit function (π) is written as follows:

$$\pi^i\left(a^i, A^{-i}, t, \tau, s\right) = p\left(A, t, s\right)a^i - g\left(a^i\right) - \tau a^i - F, \tag{8}$$

where $A = \sum_{j=1}^{n} a^j$ and $A^{-i} \equiv A - a^i$. In addition, $g\left(a^i\right)$ and F denote firm i's variable cost function and fixed cost, respectively. We suppose $g'\left(a^i\right) > 0$ and $g''\left(a^i\right) > 0$.

From (8), the first order condition is represented as follows:

$$\partial \pi^i / \partial a^i = p_A\left(A, t, s\right)a^i + p\left(A, t, s\right) - g'\left(a^i\right) - \tau = 0. \tag{9}$$

Considering symmetric "n" firms, the first order and free entry conditions in the eco-industry are written as follows, respectively:

$$p_A\left(na, t, s\right)a + p\left(na, t, s\right) - g'\left(a\right) - \tau = 0, \tag{10}$$

$$p\left(na, t, s\right)a - g\left(a\right) - \tau a - F = 0, \tag{11}$$

where a is the output of a representative firm in eco-industry. From (10) and (11), each firm's output of EGs (a) and the number of firms (n) are determined as the function of the emission tax (t), the tariff on imported EGs (τ), and the subsidy for purchasing EGs (s). Namely, they are expressed as $a = a(t, \tau, s)$ and $n = n(t, \tau, s)$.

3.　Preliminaries

Total differentiation of (10) and (11) is represented as follows:

$$\begin{bmatrix} p_{AA}A + (n+1)p_A - g'' & p_{AA}a^2 + p_A a \\ (n-1)p_A a & p_A a^2 \end{bmatrix} \begin{bmatrix} da \\ dn \end{bmatrix} = \begin{bmatrix} -(p_{At}a + p_t) \\ -p_t a \end{bmatrix} dt + \begin{bmatrix} 1 \\ a \end{bmatrix} d\tau - \begin{bmatrix} 1 \\ a \end{bmatrix} ds, \tag{12}$$

where the determinant of matrix of the left-hand side is $|J| = p_A a^2 \left(p_{AA}a + 2p_A - g''\right)$. Moreover, in the following analysis, we define $|\tilde{J}| \equiv p_{AA}a + 2p_A - g'' = t\left(\beta'''a + 2\beta''\right) - g''$, where $|\tilde{J}| < 0$ if the second-order condition for the profit maximization of upstream oligopolistic firms is satisfied, and the demand for EGs is downward sloping with respect to the corresponding price (i.e., $p_A = t\beta'' < 0$). Therefore, we obtain $|J| = p_A a^2 |\tilde{J}| > 0$. [9]

---

9) In our model, $p_{AA} = \beta''' > 0$ corresponds to convexity of the demand for EGs. We assume that the sec-

40

Oligopolistic eco-industries with free entry and trade liberalization of environmental goods

3.1 The effect of the emission tax

At the beginning, we show the effect of the emission tax on the output of each upstream firm and the number of firms in the eco-industry. From (12), we obtain

$$\partial a / \partial t = a\left(p_t p_{AA} - p_A p_{At} \right) / p_A \left| \tilde{J} \right|, \tag{13}$$

$$\partial n / \partial t = \left\{ (A-a) p_A p_{At} - p_t \left(p_{AA} A + 2 p_A - g'' \right) \right\} / p_A a \left| \tilde{J} \right|. \tag{14}$$

Hence, if the demand curve for EGs is linear $\left(p_{AA} = 0 \right)$ or concave $\left(p_{AA} < 0 \right)$, or if $p_t p_{AA} < p_A p_{At}$ is satisfied even in the case of convex $\left(p_{AA} > 0 \right)$; we obtain $\partial a / \partial t < 0$. That is, the output of each upstream firm is decreased with an increase in the emission tax as long as the demand curve for EGs is not very convex. Similarly, the sign of $\partial n / \partial t$ also hinges on that of p_{AA}. If $p_{AA} \leq 0$ or $p_{AA} A + 2 p_A - g'' \leq 0$ even in $p_{AA} > 0$, $\partial n / \partial t > 0$ is obtained. However, we cannot exclude $p_{AA} A + 2 p_A - g'' > 0$ because of $A > a$.[10]

Moreover, noting $dA = n da + a dn$, we get as follows:

$$\partial A / \partial t = \left\{ p_t g'' - p_A \left(p_{At} a + 2 p_t \right) \right\} / p_A \left| \tilde{J} \right| = \left\{ p_t g'' - p_A \beta'(2 - \varepsilon / n) \right\} / p_A \left| \tilde{J} \right|, \tag{15}$$

where $\varepsilon \equiv -A\beta'' / \beta' > 0$ denotes the relative curvature degree of the abatement function β regarding A. The larger the degree is, the less efficient the input of EGs becomes. Considering an increase in the number of firms leads to an increase in the total output of EGs, we can confirm that the emission tax increases the total output of EGs if $2n \geq \varepsilon$.[11]

On the other hand, from (5), the impact of the emission tax on the output of FGs is as follows:

$$dX / dt = \alpha' / \left(P' - C'' - t\alpha'' \right) < 0. \tag{16}$$

That is, the emission tax definitely reduces the output of FGs because of $P' < 0$, $C'' > 0$, $\alpha' > 0$, and $\alpha'' \geq 0$.

In addition, considering (1), the impact on the amount of emissions is written as follows:

$$\partial E / \partial t = \alpha' \partial X / \partial t - \beta' \partial A / \partial t. \tag{17}$$

Hence, considering (15) and (16), we can find the emission tax decreases pollution emissions when $2n \geq \varepsilon$ and thus $\partial A / \partial t > 0$.

Lastly, we confirm that the impact of the emission tax on the price of EGs. In the equilibrium, (6) is expressed as $p\left(A, t, \tau, s \right) = t\beta'\left[A(t, \tau, s) \right] + s$. In such a case, the influence

---

ond-order condition for the profit maximization of upstream firms is satisfied even in this case. It means that the demand curve for EGs is not very convex.

10) As shown in David, et al. (2011), the expected higher profits attract entry of new firms, and then the output of each incumbent firm decreases with new entry. This effect is called as a "business-stealing effect". In this case, the phenomenon where the number of firms under free entry is larger than the socially optimal number is well known as "the excess entry theorem". See Mankiw and Whinston (1986) and Suzumura and Kiyono (1987) for the theorem.

11) If the purchasing subsidy is zero ($s = 0$), $\partial A / \partial t > 0$ is definitely realized as long as $g'' \geq 0$. See David, et al. (2011) regarding this point.

on the price is written as follows:

$$dp / dt = p_A \partial A / \partial t + p_t = a\left(p_t p_{AA} - p_A p_{At} \right) / \left| \tilde{J} \right|. \tag{18}$$

The determinant factor of the sign of dp / dt is $p_t p_{AA} - p_A p_{At}$. If the demand curve for EGs is linear or concave $\left(p_{AA} \leq 0 \right)$, or if $p_t p_{AA} < p_A p_{At}$ is satisfied even in the case of convex $\left(p_{AA} > 0 \right)$, we obtain $dp / dt > 0$. This condition is similar to (13). That is, although the emission tax has a negative influence on the price via the increase in the total output of EGs, this impact is relatively small because the tax decreases each firm's output of EGs. It means that the indirect effect $\left(p_A \partial A / \partial t < 0 \right)$ is smaller than the direct effect of the emission tax $\left(p_t > 0 \right)$ as long as the demand curve for EGs is not very convex.

3.2 The effects of trade liberalization and purchase subsidy

Next, we examine the impacts of trade liberalization of EGs and the subsidy to purchase the EGs. However, from (12), we can confirm that both a decrease in the import tariff on EGs and an increase in the subsidy for purchasing them have same impacts on the supply side of the economy except for the influence on the price of EGs.

$$\partial a / \partial \tau \left(= -\partial a / \partial s \right) = -p_{AA} a / p_A \left| \tilde{J} \right|, \tag{19}$$

$$\partial n / \partial \tau \left(= -\partial n / \partial s \right) = \left(p_{AA} A + 2 p_A - g'' \right) / p_A a \left| \tilde{J} \right|. \tag{20}$$

From (19), we find that the sign of $\partial a / \partial \tau$ depends on that of p_{AA}, in other words, β'''. Noting that $\left| \tilde{J} \right| < 0$ and our model includes the case where the demand curve for EGs is weakly convex, we have $\partial a / \partial \tau \gtreqless 0$ if and only if $p_{AA} \lesseqgtr 0$. On the other hand, in (20), the sign of $\partial n / \partial \tau$ depends on that of $p_{AA} A + 2 p_A - g''$ such as (14).

Moreover, noting $dA = nda + adn$, we obtain as following equation:

$$\partial A / \partial \tau \left(= -\partial A / \partial s \right) = \left(2 p_A - g'' \right) / p_A \left| \tilde{J} \right| < 0. \tag{21}$$

That is, both trade liberalization of EGs and the subsidy to purchase them definitely increase the total output of EGs.

Referring to (5), the effect on the output of FGs becomes $dX / d\tau = dX / ds = 0$. Hence, from (21), we find that trade liberalization of EGs decreases pollution emissions because the liberalization increases entry firms, and then the amount of imported EGs, although it may decrease the each firm's output in the eco-industry. That is,

$$\partial E / \partial \tau \left(= -\partial E / \partial s \right) = -\beta' \partial A / \partial \tau \left(= \beta' \partial A / \partial s \right) > 0. \tag{22}$$

Finally, we verify that the impacts of the liberalization and the subsidy on the price of EGs. As denoted above, we obtain $p\left(A, t, \tau, s \right) = t\beta'\left[A\left(t, \tau, s \right) \right] + s$ in the equilibrium. Therefore, the impacts are expressed as follows:

$$dp / d\tau = p_A \partial A / \partial \tau = \left(2 p_A - g'' \right) / \left| \tilde{J} \right| > 0, \tag{23}$$

Oligopolistic eco-industries with free entry and trade liberalization of environmental goods

$$dp/ds = p_A \partial A/\partial s + 1 = p_{AA} a/|\tilde{J}|, \tag{24}$$

where $p_s = 1$ from (7).

From (23), trade liberalization of EGs clearly decreases the price of the goods because the liberalization does not influence on the output of FGs. On the other hand, the sign of dp/ds depends on that of p_{AA}, in other words, β'''. This condition is similar to (19). Hence, noting that $|\tilde{J}| < 0$, we find that $\partial p/\partial s \gtreqless 0$ if and only if $p_{AA} \lesseqgtr 0$. That is, if the demand curve is weak convex, the subsidy can swell not only each firm's output of EGs but also the number of firms in the eco-industry. In such a case, the indirect effect of the subsidy $(p_A \partial A/\partial s < 0)$ is larger than the direct effect $(p_s = 1 > 0)$.

We summarize above results as Proposition 1.

Proposition 1: *Suppose that $|\tilde{J}| \equiv p_{AA} a + 2 p_A - g'' < 0$. In this case, we obtain the following results:*

(I) Trade liberalization of EGs, that is, a decrease in the import tariff on the goods decreases (increases) the each firm's output of EGs if $p_{AA} < (>) 0$, while the tariff does not affect the output if $p_{AA} = 0$. The liberalization increases the number of firms in the eco-industry as long as the demand curve for EGs is not very convex. Then, the liberalization definitely increases the total output of EGs while it does not change the output of FGs. Hence, pollution emissions also decreases with trade liberalization. Moreover, the liberalization definitely drops the price of EGs.

(II) In the case where there are no domestic producers for EGs, the impact of the subsidy for purchasing EGs on the supply side of the economy is equivalent to that of trade liberalization except for the influence on the price of EGs. The price increases (decreases) with the subsidy if $p_{AA} < (>) 0$, while it does not affect the price if $p_{AA} = 0$.

4. The importing country's welfare

In the following analysis, we express welfare of the importing country as W. Tax revenue from the emission tax and the tariff on imported EGs is distributed to domestic consumers in a lump-sum fashion. The subsidy for purchasing EGs is also collected from the consumers in the same method.

Considering this point, welfare of the country is written as follows:

$$
\begin{aligned}
W(t,\tau,s) &= \left[\int_0^X P(z)dz - PX \right] + \left[PX - C(X) - (p-s)A - t\{\alpha(X) - \beta(A)\} \right] \\
&\quad + t\{\alpha(X) - \beta(A)\} + \tau A - sA - v\{\alpha(X) - \beta(A)\} \\
&= \int_0^X P(z)dz - C(X) - (p-\tau)A - v\{\alpha(X) - \beta(A)\},
\end{aligned} \tag{25}
$$

where $\int_0^X P(z)dz - PX$ denotes consumer's surplus, and v is the marginal environmental damage from pollution emissions.

Y. Sugiyama, Y. Weng and K. Abe

4.1   The optimal emission tax

Considering (3) and (4), and noting $A = na$, we can derive the following welfare effect with respect to the emission tax:

$$\partial W / \partial t = (t - v)\{\alpha'\partial X / \partial t - \beta'(n\partial a / \partial t + a\partial n / \partial t)\}$$
$$+ (\tau - s)(n\partial a / \partial t + a\partial n / \partial t) - A\partial p / \partial t, \tag{26}$$

where $\partial A / \partial t = n\partial a / \partial t + a\partial n / \partial t$, denoting that the impact on the total output of EGs is constructed from the changes of the each firm's output and the number of firms.

As shown in the right-hand side of (26), there are three terms regarding the impact on the welfare. The first term represents the negative externality caused by pollution emissions. This term exists even when we suppose that both downstream and upstream markets are perfectly competitive, in other words, we suppose a small open economy. The first term consists of two components. The first component $(t - v)$ is the difference between the emission tax and the marginal environmental damage or the Pigouvian tax. The second component is the influence of the emission tax on the amount of emissions. Note that from (15) and (16), $\partial A / \partial t > 0$ if $2n \geq \varepsilon$ and $\partial X / \partial t < 0$. In this case, we can obtain $\partial E / \partial t < 0$ from (17). Hence, the second component in the first term becomes negative.

The second term of the right-hand side in (26) denotes the (net) tariff revenue effect. This effect also exists whether the firms in the eco-industry engage in perfect competition or imperfect one, as long as either τ or s is not zero. Considering the government provides the subsidy to purchase EGs, this effect becomes positive when $\tau > s$ because $\partial A / \partial t > 0$ if $2n \geq \varepsilon$.

Finally, the third-term of the right hand side in (26) corresponds to the terms of trade effect. This effect does not occur in the case of a small open economy (see Abe and Koonsed, 2016). We find that this term gives a negative impact to the importing country's welfare because $\partial p / \partial t > 0$ as long as the demand curve for EGs is not very convex.[12]

Hence, setting $\partial W / \partial t = 0$ in (26), the optimal emission tax rate ($\hat{t}$) is represented as follows:

$$\hat{t} = v + \{A\partial p / \partial t - (\tau - s)\partial A / \partial t\} / (\alpha'\partial X / \partial t - \beta'\partial A / \partial t), \tag{27}$$

where, noting $\partial A / \partial t > 0$ if $2n \geq \epsilon$, the denominator in the second term of the right-hand side is negative. As denoted in Nimubona (2012), the level of optimal emission tax hinges on the terms of trade effect $(A\partial p / \partial t)$ and the net tariff revenue effect $(-(\tau - s)\partial A / \partial t)$ by raising the tax, although in our model, the latter effect includes the influence on the subsidy expenditure.

Considering that $\partial p / \partial t > 0$, namely, the tax worsens the terms of trade as long as the demand curve for EGs is not very convex, the former becomes a determinant factor for cutting the emission tax. Moreover, considering $\partial A / \partial t > 0$, the net tariff revenue effect also becomes

---

12) Bayindir-Upmann (2003) supposed the asymmetric two countries with Cournot competition where the number of firms in the polluting FGs sector endogenously determined in one country but is exogenously given in the other country. Bayindir-Upmann (2003) showed that the optimal environmental tax in the former country is constructed from (i) the negative externality from emissions, (ii) the terms of trade effect, and (iii) the rent sifting effect, in other words, imperfect competition effect. Note that there is not the imperfect-competition effect in our model because the firms which produce EGs are located only the exporting country, and then we consider welfare of the importing country.

44

Oligopolistic eco-industries with free entry and trade liberalization of environmental goods

a determinant factor for reducing the tax if $s > \tau$ because the government has an incentive for reducing the tax in order to cut the subsidy expenditure. In such a case, the numerator in the second term of the right-hand side becomes positive. However, the net tariff revenue effect can become a determinant factor for raising the tax if $s < \tau$.

We summarize above discussion as the following proposition:

Proposition 2: *Suppose* $|\tilde{J}| \equiv p_{AA}a + 2p_A - g'' < 0$ *and* $2n \geq \epsilon$. *In this case, the level of optimal emission tax is clearly lower than that of Pigouvian tax, that is,* $\hat{t} < v$ *if* $s > \tau$, *and thus the net tariff revenue effect is positive* ($-(\tau - s)\partial A / \partial t > 0$). *On the other hand, if this term is negative* ($-(\tau - s)\partial A / \partial t < 0$), *the level of optimal emission tax is determined by the terms of trade effect of EGs' import and the net tariff revenue effect, namely, the sign of* $A\partial p / \partial t - (\tau - s)\partial A / \partial t$.

4.2 The optimal tariff on imported EGs

Considering (4) and (6) in addition to $dX / d\tau = 0$, and noting $A = na$, we can derive the following welfare effect with respect to a decrease in the import tariff on EGs.

$$\partial W / \partial \tau = -\{(t - v)\beta' - (\tau - s)\}(n\partial a / \partial \tau + a\partial n / \partial \tau) - A(\partial p / \partial \tau - 1). \tag{28}$$

From (28), we can confirm that the welfare effect of trade liberalization of EGs consists of the negative externality from emissions, the net tariff revenue effect, and the terms of trade effect. For the last term of the right hand side in (28), we can derive $\partial p / \partial \tau - 1 = p_A \partial A / \partial \tau$

$-1 = -p_{AA}a / |\tilde{J}| \gtrless 0$ if $p_{AA} \gtrless 0$. Then, the terms of trade effect becomes $\partial p / \partial \tau - 1 \leq 0$ as long as the demand curve for EGs is linear or concave. Adversely, $\partial p / \partial \tau - 1 > 0$ if the curve is convex, whereas $|\tilde{J}| \equiv p_{AA}a + 2p_A - g'' < 0$.

Hence, setting $\partial W / \partial \tau = 0$ in (28), we obtain the optimal tariff on imported EGs $(\hat{\tau})$.

$$\hat{\tau} = (t - v)\beta' + s + A(\partial p / \partial \tau - 1) / (\partial A / \partial \tau). \tag{29}$$

From (29), the tariff is complementary with the purchasing subsidy. Moreover, since $\partial A / \partial \tau < 0$ and $\partial E / \partial \tau > 0$ from (21) and (22), respectively, a decrease in the tariff reduces the amount of emissions. Therefore, we find that in the case of $s = 0$, the optimal tariff on EGs is definitely positive (negative) if $t > (<)v$ and the terms of trade effect gives the negative (positive) impact on the welfare, that is, $p_{AA} \leq (\geq)0$, and thus $\partial p / \partial \tau - 1 \leq (\geq)0$.

Moreover, as a benchmark, we evaluate the optimal tariff at the level of the optimal emission tax. In this case, by substituting $\hat{t}$ in (27) into t in (29) and assuming $s = 0$, $\hat{\tau}$ is rearranged as follows:

$$\begin{aligned}\hat{\tau}|_{t=\hat{t}} &= (\hat{t} - v)\beta' + A(\partial p / \partial \tau - 1) / (\partial A / \partial \tau) \\ &= A\{\beta'(\partial p / \partial t) / (\alpha'\partial X / \partial t - \beta'\partial A / \partial t) + (\partial p / \partial \tau - 1) / (\partial A / \partial \tau)\} / H.\end{aligned} \tag{30}$$

As mentioned in footnote 11, we can derive $\partial A / \partial t > 0$ without the condition $2n \geq \varepsilon$ if $s = 0$. Therefore, $\alpha'\partial X / \partial t - \beta'\partial A / \partial t < 0$ and then $H \equiv \alpha'\partial X / \partial t / (\alpha'\partial X / \partial t - \beta'\partial A / \partial t) > 0$.

In this case, noting that $\partial A / \partial \tau < 0$ in (30), we obtain $p_{AA} \geq 0$, and thus $\partial p / \partial \tau - 1 \geq 0$ as the sufficient condition for $\hat{\tau}|_{t=\hat{t}} < 0$. That is, if the government implements the optimal emission tax, and the demand curve for EGs is linear or weak convex, the level of optimal tariff seems to be negative.

We summarize above discussion as the following proposition:

Proposition 3: *Suppose $|\tilde{J}| \equiv p_{AA}a + 2p_A - g'' < 0$ and $s = 0$. In this case, the level of optimal tariff on imported EGs is positive (negative) if $t > (<)v$ and $p_{AA} \leq (\geq)0$, and thus $\partial p / \partial \tau - 1 \leq (\geq)0$. Moreover, the optimal tariff evaluating at the level of optimal emission tax is negative if $p_{AA} \geq 0$, and thus $\partial p / \partial \tau - 1 \geq 0$.*

4.3 The optimal subsidy to purchase EGs

Considering (4) and (6) in addition to $dX / ds = 0$, and noting $A = na$, we can derive the following welfare effect with respect to the subsidy for purchasing EGs.

$$\partial W / \partial s = -\{(t-v)\beta' - (\tau-s)\}(n\partial a / \partial s + a\partial n / \partial s) - A\partial p / \partial s. \tag{31}$$

Again, we can confirm that the welfare effect of the subsidy consists of the negative externality from emissions, the net tariff revenue effect, and the terms of trade effect. For the second term of the right hand side in (31), $\partial p / \partial s = p_{AA}a / |\tilde{J}| \gtreqless 0$ if $p_{AA} \lesseqgtr 0$. That is, the price of EGs is increased or unchanged with the subsidy as long as the demand curve is concave or linear. Adversely, it decreases with the subsidy if the curve is convex, while $|\tilde{J}| \equiv p_{AA}a + 2p_A - g'' < 0$.

Setting $\partial W / \partial s = 0$ in (31), the optimal subsidy for purchasing EGs $(\hat{s})$ is

$$\hat{s} = -(t-v)\beta' + \tau - A(\partial p / \partial s) / (\partial A / \partial s). \tag{32}$$

From (32), the purchasing subsidy is complementary with the tariff on imported EGs. Moreover, since $\partial A / \partial s > 0$ and $\partial E / \partial s < 0$ from (21) and (22), respectively, the subsidy decreases pollution emissions. Therefore, we find that in the case of $\tau = 0$, the optimal purchasing subsidy is definitely positive (negative) if $t < (>)v$ and the terms of trade effect gives the positive (negative) impact on the welfare, that is, $p_{AA} \geq (\leq)0$, then $\partial p / \partial s \leq (\geq)0$.

Moreover, as a benchmark, we evaluate the optimal subsidy at the level of the optimal emission tax. In this case, by substituting $\hat{t}$ in (27) into t in (32) and assuming $\tau = 0$, $\hat{s}$ is rearranged as follows:

$$\begin{aligned}
\hat{s}|_{t=\hat{t}} &= -(\hat{t}-v)\beta' - A(\partial p / \partial s) / (\partial A / \partial s) \\
&= -A\{\beta'(\partial p / \partial t) / (\alpha'\partial X / \partial t - \beta'\partial A / \partial t) + (\partial p / \partial s) / (\partial A / \partial s)\} / H,
\end{aligned} \tag{33}$$

where $H \equiv \alpha'\partial X / \partial t / (\alpha'\partial X / \partial t - \beta'\partial A / \partial t) > 0$ if $2n \geq \varepsilon$, and thus $\partial A / \partial t > 0$.

Note that $\partial A / \partial s > 0$ in (33). In this case, we can show that $p_{AA} \geq 0$ and thus $\partial p / \partial s \leq 0$ is the sufficient condition for $\hat{s}|_{t=\hat{t}} > 0$. That is, if the government implements the optimal emission tax, and the demand curve for EGs is linear or weak convex, the level of optimal subsidy seems to be positive.

46

Oligopolistic eco-industries with free entry and trade liberalization of environmental goods

We summarize above discussion as the following proposition:

Proposition 4: *Suppose* $\left|\tilde{J}\right| \equiv p_{AA}a + 2p_A - g'' < 0$ *and* $\tau = 0$. *In this case, the level of optimal subsidy to purchase EGs is positive (negative) if* $t < (>)v$ *and* $p_{AA} \geq (\leq)0$, *and thus* $\partial p / \partial s \leq (\geq)0$. *Moreover, the optimal subsidy evaluating at the level of optimal emission tax is positive if* $2n \geq \epsilon$, *and* $p_{AA} \geq 0$ *thus* $\partial p / \partial s \leq 0$.

5. Concluding Remarks

In this paper, we investigate the impacts of the emission tax, trade liberalization of EGs, and the subsidy to purchase EGs in a model of oligopolistic eco-industry with free entry. We then evaluate the relation between these policies from the perspective of the importing country's welfare. As our main results, we then show that both trade liberalization of EGs and the subsidy for purchasing EGs increase the total output of EGs, and hence, decrease pollution emissions. The optimal emission tax level will be lower than the Pigouvian one if the level of the subsidy is higher than that of the tariff. Moreover, if the government sets the emission tax at the optimal level, the subsidy to import EGs or to purchase them seems to be optimal.

As a further research in this subject, we need to introduce the domestic production of EGs, and then consider asymmetric entry policies between developed and developing countries (e.g., a fixed number of firms in a developing country and free entry in a developed country). In this setting, we will examine the economic and environmental impacts of easing entry regulations in a developing country and the subsidy to domestic eco-industries in addition to the emission tax.

References

Abe, K. and P. Koonsed (2016) "Trade liberalization of environmental and final goods," *Ritsumeikan Economic Review*, vol. 64, no. 5, pp. 19-30.

Abe, K. and Y. Sugiyama (2010) "The environmental industry, environmental policies, and international trade," *The International Economy*, vol. 14, pp. 77-94.

Bayindir-Upmann, T. (2003) "Strategic environmental policy under free entry of firms," *Review of International Economics*, vol. 11, no. 2, pp. 379-396.

Canton, J. (2007) "Environmental taxation and international eco-industries," *FEEM Working Paper No. 26-2007.*

Canton, J., Soubeyran, A. and H. Stahn (2008) "Environmental taxation and vertical Cournot oligopolies: How eco-industries matter," *Environmental and Resource Economics*, vol. 40, no. 3, pp. 369-382.

David, M., Nimubona, A.D. and B. Sinclair-Desgagné (2011) "Emission taxes and the market for abatement goods and services," *Resource and Energy Economics*, vol. 33, no. 1, pp. 179-191.

David, M. and B. Sinclair-Desgagné (2005) "Environmental regulation and the eco-industry," *Journal of Regulatory Economics*, vol. 28, no. 2, pp. 141-155.

David, M. and B. Sinclair-Desgagné (2010) "Pollution abatement subsidies and the eco-industry," *Environmental and Resource of Economics*, vol. 45, no. 2, pp. 271-282.

Dijkstra, B.R. and A.J. Mathew (2015) "Liberalizing trade in environmental goods and services," *Environmental Economics and Policy Studies*, vol. 18, no. 4, pp. 499-526.

Greaker, M. and K.E. Rosendahl (2008) "Environmental policy with upstream pollution abatement technology firms," *Journal of Environmental Economics and Management*, vol. 56, no. 3, pp. 246-259.

Ishikawa, J. and K.D. Lee (1997) "Backfiring tariff in vertically related markets," *Journal of International Economics*, vol. 42, no. 3-4, pp. 395-423.

Ishikawa, J. and B.J. Spencer (1999) "Rent-shifting export subsidies with an imported intermediate product," *Journal of International Economics*, vol. 48, no. 2, pp. 199-232.

Katsoulacos, Y. and A. Xepapadeas (1995) "Environmental policy under oligopoly with endogenous market structure," *Scandinavian Journal of Economics*, vol. 97, no. 3, pp. 411-420.

Lee, S.H. and C.H. Park (2011) "Environmental regulations on vertical oligopolies with eco-industry," *Korean Economics Review*, vol. 27, no. 2, pp. 311-327.

Mankiw, N.G. and M.D. Whinston (1986) "Free entry and social inefficiency," *RAND Journal of Economics*, vol. 17, no. 1, pp. 48-58.

Nimubona, A.D. (2012) "Pollution policy and trade liberalization of environmental goods," *Environmental and Resource Economics*, vol. 53, no. 3, pp. 323-346.

Nimubona, A.D. and H. Benchekroun (2015) "Environmental R&D in the presence of an eco-industry," *Environmental Modeling and Assessment*, vol. 20, no. 5, pp. 491-507.

Schwartz, S. and H. Stahn (2014) "Competitive permit markets and vertical structures: The relevance of imperfectly competitive eco-industries," *Journal of Public Economic Theory*, vol. 16, no. 1, pp. 69-95.

Sinclair-Desgagné, B. (2008) "The environmental goods and services industry," *International Review of Environmental and Resource Economics*, vol. 2, no. 1, pp. 69-99.

Suzumura, K. and K. Kiyono (1987) "Entry barriers and economic welfare," *Review of Economic Studies*, vol. 54, no. 1, pp. 157-167.

Wan, R., Nakada, M. and Y. Takarada (2018) "Trade liberalization in environmental goods," *Resource and Energy Economics*, vol. 51, no.1, pp. 44-66.