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Waste Management Technology Transfer and an Incentive to Free-Ride[*]

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Abstract

Waste emission is becoming a serious problem around the world, especially in developing countries. Although it is pointed out that part of the problem facing developing countries arises from the lack of a waste disposal technology: technology transfer from a country possessing advanced technology is rarely undertaken. We investigate this problem by focusing upon the role of international technology transfer motivated by trade liberalization. We show that in expecting tariff reductions, the exporting country has an incentive to transfer technology for waste disposal but this is below socially optimum level since the tariff has a property of public bads for the exporting countries. In addition, we consider the effects of an increase in market competitiveness on national welfare.

Key words: waste management, technology transfer, tariff, free rider.

JEL code: F18, H87, Q58

1 Introduction

Interdependence between trade policy and environmental quality is a major topic in both the fields of international and environmental economics. In many developing countries, a trade policy such as tariff imposition is frequently used to protect domestic environment as well as domestic industry. One of the central issues is whether trade liberalization, for instance tariff reduction, can be compatible with maintaining or improving environmental quality. We address this issue by using the analytical framework of an international oligopolistic market.

In general, an importing country imposes a tariff at a higher rate or restricts the importing of goods when this would harm the environmental quality and human health in the process of its consumption and waste management. For example, in 2009 the government of Thailand reduced the tariff rate for materials and parts to equip a the clean car by 90 percent[1]. The Chinese government also imposed a tariff at a relatively low rate for some parts of wind power generation[2].

Among the wide range of environmental problems facing developing countries today, it is feared that electronic waste (e-waste) such as mobile phones and PCs will damage the environment and human health since it contains harmful metals. Widmer et al. (2005) pointed out that a substantial increase in e-waste induces serious environmental and health damage in countries with rapid economic growth, such as China and India. Although effective countermeasures for e-waste management have introduced the principle of product liability, its enforcement may be difficult for many developing countries due to administrative reasons.

One difficulty with waste management arises from the lack of relevant management technology. In many developing countries, low-skilled waste management technology harms both the health and environmental quality. However, introducing advanced technology may be difficult for developing countries, since many of them face other serious problems apart from waste management. Thus, their governments may not be able to devote resources necessary to mitigate the damage arising from waste emission due to budget constraint. In such a situation, tariff imposition is preferred over introducing highly skilled technology in order to mitigate the damage from waste emission since the government can obtain revenue from the tariff.

This paper considers the effects of technology transfer for waste management on welfare of the countries engaged in trade. By using the framework of a familiar strategic trade model with imperfect competition, such as that propounded by Brander and Spencer (1985), we consider the relationship between an incentive behind technology transfer and tariff reduction. If advanced technology for waste management owned by developed countries is transferred to a developing country, a latter may reduce the tariff and as a result, welfare of relating countries can be improved. Furthermore, if the exporting countries

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[1] http://business.nikkeibp.co.jp.
[2] http://www.peoplechina.com.cn.

expect that technology transfer will induce a tariff reduction, then such transfer may be undertaken voluntarily by the exporting countries.

In a later section, it will be shown that technology transfer from the exporting countries to an importing country induces tariff reduction. In addition, we will show that the exporting country has an incentive to transfer technology voluntarily. In this sense, the solution to environmental problems promotes trade liberalization. Of course, much literature has focused on the effects of trade policy on environmental quality, which is assumed to have transboundary properties (e.g. Kennedy, 1993; Barrett, 1994 and 1997). An interesting result of this study is that the exporting countries have an incentive to transfer technology even though the damage arising from waste management in the importing country does not spill over onto the exporting countries[3].

In the real world, however, technology transfer or financial aid seem not to be active in the field of waste management. We will show that the level of voluntary technology transfer is inefficiently low. The reason for this is that the tariff imposed by the importing country has a property of the public bads for the exporting countries. This means, a tariff reduction resulting from technology transfer by one exporting country benefits the other exporting countries. Thus, all exporting countries have an incentive to free-ride. As a result, only the country having the largest market share within the group of the exporting countries provides technology transfer. Therefore, a non-cooperative solution has certain limitations.

We also consider the effects of a change in market competitiveness on the level of technology transfer and national welfare. In the standard model of strategic trade policy, such as Brander and Spencer (1985), an increase in the number of the firms in an oligopolistic market benefits the importing country by reducing the distortion caused by imperfect competition. Therefore, an increase in the number of firms provides an incentive for the importing country to reduce the tariff. However, if the level of technology transfer is reduced by an increase in the number of the firms, the importing country may have an incentive to increase the tariff. In the standard model of strategic trade policy, an increase in the number of firms in one exporting country will harm another exporting country through a reduction in the profit of the existing firms[4]. In this paper, we can find a situation in which all countries benefit from the increase in the level of technology transfer induced by an increase in the number of firms of a specific country when the number of the firms is relatively small.

Our analysis is closely related to the studies in the literature concerning technology transfer, strategic trade policy and voluntary provision of public goods. Kabiraj and Marjit (2003) argued that the protection of domestic industry via the tariffs attracts

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[3]In the literature, Kox and Van der Tak (1996) argued that an international cooperation will be useful in some situations whereby governments use environmental policy as a strategic trade instrument even if there are no transboundary environmental externalities. The present study can be regarded as a typical case of this aspect.

[4]Schoonbeek and de Vries (2009) focused on the relationship between an environmental policy and market structure. They argued that the government might induce profitable monopolization by using a emission tax.

technology transfer from efficient countries. Hence, committed tariff imposition improves national welfare. In contrast to their analysis, our results imply that a tariff intended for the protection of the domestic environment should be altered according to the level of technology transfer. Stranlund (1996) analyzed the effect of technological aid on welfare under a situation where two countries non-cooperatively adopt environmental policies; it was argued that the transfer of a superior control technology will induce Pareto-superior abatement.

In the literature concerning strategic trade policy, Lahiri et al. (2002), using a framework of perfect competition, considered the relationship between an optimal tariff and foreign aid. They argued that a Pareto-efficient outcome is achieved if the foreign aid takes place in exchange for tariff reduction in the recipient country. Their analysis is similar to our results such that foreign aid (transfer) should be implemented before choosing a tariff to improve welfare. However, the driving force behind voluntary transfer in our framework is pure profit for the firm that exports the goods to the importing country[5]. Thus, as the number of firms increases, the incentive for transferring the technology is lost. In the context of imperfect competition, Kennedy (1994) and Burguet and Sempere (2003) investigate how trade liberalization affects environmental policies using an intra-industry trade model[6].

When we focus on the free riding behavior of the exporting country, our results can be related to the literature concerning voluntary provision of public goods, such as Boadway and Hayashi (1999). That is, the result that only the country having the largest market share contributes the technology transfer can be interpreted as an application of the Olson and Zeckhauser(1966) theorem. This paper reveals that an import tariff has a property of the international public bads under certain conditions. Thus our analysis is also closely related to the literature concerning strategic transfers in the presence of privately provided public goods (e.g. Buchholz and Konrad, 1995; Buchholz et al. 1997).

The remainder of this paper is organized as follows. In Section 2, we present a model. In Section 3, we present a non-cooperative equilibrium and investigate its properties. In Section 4, we consider the effect of a change in the number of firms on trade liberalization and on welfare. In Section 5, we extend the basic model and derive some results. Section 6 is the final section presenting the conclusions.

2 The Model

Consider an economy consisting of m exporting countries and one importing country. The index set of the exporting country is denoted by $M = \{1, ..., m\}$, where $1 \leq m < \infty$.

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[5] In a framework of oligopoly, Puller (2006) argued that the interdependence among oligopolistic firms can mitigate the welfare loss arising from having no regulatory commitment. In the present analysis, if the importing country commits to an environmental policy taking the form of a tariff, then the welfare is Pareto-inferior.

[6] In a model of international oligopoly for waste, Cassing and Kuhn (2003) considered strategic environmental policy under various situations and characterized a globally optimal environmental policy.

The importing country is indexed by 0. In country $j \in M$ there are n_j firms producing homogenous consumer goods. The total number of firms is $n = \sum_{j \in M} n_j$. The index set of the firms is denoted by $N = \{1, ..., n\}$, where $m \leq n < \infty$. For $j \in M$, N_j is the index set of the firms located in country j: $N = \cup_{j \in M} N_j$. For analytical purposes, the index $j \in M$ is arranged in decreasing order of the number of the firms operating in each country: $n_1 \geq, ..., \geq n_m$. Let x_i, for $i \in N$, denote the quantity of goods produced by firm i. Thus, the total supply the goods is $X = \sum_{i \in N} x_i$.

We assume that one unit of consumption good generates one unit of waste. However, consumers in the importing country do not take account of the environmental damage arising from their consumption. For analytical simplicity, consumer demand in the importing country, which is a function of the market price, is assumed to be linear. The inverse demand function can be written as follows:

$$P = a - bX, \tag{1}$$

where P denotes the consumer price.

In the importing country, the public sector implements waste management. Let g denote the quantity of waste treated by the government. The cost function of waste management is represented by $C(g, S)$, where S denotes the level of waste management technology. It is assumed that $C(g, S)$ is non-decreasing and convex in g and that the marginal cost of disposal is reduced by an increase of S: $\partial^2 C / \partial g \partial S < 0$. The waste that is not treated, $X - g$, causes environmental or health damage to consumers living in the importing country by $H(X - g)$. The damage function H is assumed to increase in a strictly convex manner in non-treated waste: H' and $H'' > 0$. The public sector minimizes the social cost of the waste, defined as $C(g, S) + H(X - g)$, for a given level of waste and treatment technology. Thus, we can define the minimum cost function as

$$D(X, S) = \min \{C(g, S) + H(X - g) | \ X \text{ and } S \text{ are given}\}.$$

It can easily be verified that $\partial D / \partial X = H' > 0$, $\partial^2 D / (\partial X)^2 = H'' > 0$, $\partial D / \partial S = \partial C / \partial S < 0$ and $\partial^2 D / \partial S \partial g = (\partial^2 C / \partial S \partial g)(\partial g / \partial X) < 0$. In addition, we assume that the minimum cost function is convex in S: $\partial^2 D / (\partial S)^2 > 0$. For analytical simplicity, we consider a specific form of minimum social cost as

$$D(X, S) = \frac{\phi(S)}{2} X^2, \tag{2}$$

where $\phi(S)$ is assumed to be a decreasing convex function: $\phi' < 0$ and $\phi'' > 0$ hold.

At the initial situation, waste management technology is assumed to be $S = s_0$. As described in the Introduction, we consider a situation in which the importing country cannot introduce any advanced technology for waste management by itself due to financial or technical reasons. Thus, S cannot be altered without technology transfer being undertaken by other countries. The governments of the exporting countries can transfer

advanced technology for waste management if they intend to do so. Let us denote the technology transferred to the importing country from the exporting country j as s_j. We assume that the level of technology is determined by the sum of contributions improving the waste management technology by the exporting countries. Thus, the level of technology after technology transfer is as follows[7]:

$$S = s_0 + \sum_{j=1}^{m} s_j. \tag{3}$$

In the exporting countries, each firm produces x_i with identical constant marginal cost c. The profit of the firm is denoted as follows:

$$\pi_i = (P - c - t) x_i, \quad i \in N, \tag{4}$$

where t is a specific form of the tariff imposed by the importing country. For a given the level of import tariff, each firm maximizes its profit under the Cournout conjecture. From the profit maximization behavior of firms, quantity of products can be written as a function of the tariff and the number of firms such that $x_i = x(t, n)$[8]. Hereafter, we omit the subscripts distinguishing the firm in cases where no confusion arises. The total output of the firms is $X = X(t, n)$. It is clear that $\partial X(t, n) / \partial t = n (\partial x(t, n) / \partial t) < 0$[9]. Since $\pi = bx^2$, we can write $\pi = \pi(t, n)$ and $\partial \pi(t, n) / \partial t = 2bx (\partial x / \partial t) < 0$.

The welfare of the importing country is defined as the sum of consumer surplus and the tariff revenue minus the social cost of waste management. From (1) and (2), the welfare of the importing country W_0 can be written as follows:

$$W_0(t, S, n) = \frac{b - \phi}{2} X^2 + tX. \tag{5}$$

The welfare of the exporting countries is defined as the sum of profits of the firms minus the cost of technology transfer:

$$W_j(t, S, n_j, n) = n_j \pi - q s_j, \tag{6}$$

where q denotes the unit cost of technology transfer, which is assumed to be proportional to the level of the technology to be transferred. The world welfare, SW, can be written as $SW = W_0 + \sum_{j=1}^{m} W_j$. From (3), (5), and (6), we obtain

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[7]For example, advanced technology may be embedded in equipment and utilities. In this case, total amounts of such equipment or of utilities transferred to the importing country represent the level of technology. In another example, developed countries impart advanced technology or knowledge to workers employed in the waste management sector. In such a situation, the number of workers and managers receiving training represent the level of technology. In both these examples, additive form of technology can be appropriate. Of course, in order to capture the characteristics of certain kinds of technology, we should consider other specifications. We will discuss this issue in the later section.

[8]In detail, $x_i = (a - c - t) / [(n + 1) b]$.

[9]In detail, $\partial X / \partial t = -n / [(n + 1) b]$.

$$SW(t, S, n) = kX - \frac{b + \phi}{2}X^2 - q(S - s_0), \tag{7}$$

where $k \equiv a - c$ is assumed to be positive.

Prior to an investigation of the strategic behavior of the governments, we confirm the first best outcome. Differentiating (7) in t and S, we have the first best level of tariff t_{OP} and of technology S_{OP} as follows[10]:

$$t_{OP} = k\frac{n\phi - b}{n(b + \phi(S_{OP}))}, \tag{8}$$

$$q = -\frac{1}{2}\phi'(S_{OP})\left(\frac{k}{b + \phi(S_{OP})}\right)^2. \tag{9}$$

Eq.(8) implies that the socially optimal tax can be decomposed into two parts. One is the Pigouvian tax corresponding to $k\phi/(b + \phi)$. The other that corresponds to $-bk/[n(b + \phi)]$ is the corrective device of the imperfect competition.

3   Non-Cooperative Policy Game

In what follows, we consider a policy game consisting of three stages[11]. At the first stage of the game, the exporting countries independently and simultaneously choose the level of technology transfer such as to improve the cost efficiency of waste management in order to maximize each country's welfare. At the second stage, the importing country sets the tariff rate to maximize the domestic welfare. At the third stage, the firms independently and simultaneously choose their outputs to maximize their profit.

3.1   Non-Cooperative Tariff by the Importing Country

The third stage of the game has already been mentioned in the previous subsection. We begin with the second stage of the game in which the importing country decides the tariff under the firms' reactions. The government of the importing country sets the tariff rate to maximize its welfare under the given waste management technology. Thus, solving the

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[10]The second-order condition is that the Hessian matrix,

$$H_{OP} = \left(\frac{n}{(n + 1)b}\right)^2 \begin{bmatrix} -(b + \phi) & \phi'(k - t) \\ \phi'(k - t) & -\phi''\frac{(k - t)^2}{2} \end{bmatrix},$$

is negative definite, which is satisfied if and only if

$$\frac{b}{\phi} > 2\frac{\varepsilon_\phi}{\varepsilon_{\phi'}} - 1$$

where $\varepsilon_\phi \equiv (\phi'/\phi)S$ and $\varepsilon_\phi \equiv (\phi''/\phi')S$ under the assumption of $\phi'' \geq 0$.

[11]It should be noted that technology transfer is not implemented if the importing country commits to the tariff. Under the committed tariff T, since the welfare of the exporting countries can be written as $W_j = n_j\pi(T, n) - qs_j$, the exporting countries never transfer the waste management technology. As a result, the tariff with no commitment improves welfare compared with the situation of commitment.

first-order condition of welfare maximization represented by $\partial W_0/\partial t = 0$, we obtain the optimal tariff as follows:

$$t^* (S, n) = \frac{b + n\phi}{2b + nb + n\phi} k. \tag{10}$$

The second-order condition, $\partial^2 W_0/\partial t^2 < 0$, is always satisfied for $\forall n$[12].

In (10), $bk/[(n+2)b + n\phi]$ corresponds to a part of the rent-shifting effect. That is, if the consumption goods do not bring any negative externality in their use, which means $\phi = 0$, (10) can be reduced as $t_R^* = k/(n+2)$, which is familiar in the literature concerning strategic trade policy. On the other hand, $n\phi k/[(n+2)b + n\phi]$ can be interpreted as the Pigouvian tax. If the number of firms approaches to infinity, the optimal tariff imposed by the importing country will become $t_P^* = \phi k/(b + \phi)$ which equals the social marginal cost of waste management under perfect competition: $t_P^* = \phi X$. From (10), it can easily be verified that an increase in the level of the waste management technology reduces the tariff.

$$\frac{\partial t^*}{\partial S} = \frac{(n+1)bnk}{(2b + nb + n\phi)^2} \phi' < 0.$$

From (10), we obtain the quantity of products at the second stage of the game:

$$X^* (S, n) = \frac{nk}{2b + nb + n\phi}. \tag{11}$$

Differentiating (11) with respect to S, we obtain

$$\frac{\partial X^*}{\partial S} = -\frac{n^2 k\phi'}{(2b + nb + n\phi)^2} > 0. \tag{12}$$

Inserting (10) and (11) into (5), for a given S and n the maximum welfare of the importing country can be defined as

$$
\begin{aligned}
W_0^* (S, n) &= \max_t \{W_0 : S \text{ and } n \text{ are given}\} \\
&= \frac{1}{2} \frac{nk^2}{2b + nb + n\phi}.
\end{aligned}
$$

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[12] Differentiating (10) with respect to t, we obtain the first order condition as follows:

$$\frac{\partial W_0}{\partial t} = ((b - \phi) X + t) \frac{\partial X}{\partial t} + X = 0$$

The second-order condition can be represented by

$$
\begin{aligned}
\frac{\partial^2 W_0}{\partial t^2} &= -\left(\frac{2b + n(\phi + b)}{n}\right) \left(\frac{\partial X}{\partial t}\right)^2 \\
&= -\left(\frac{2b + n(\phi + b)}{n}\right) \left(\frac{n}{(n+1)b}\right)^2 < 0
\end{aligned}
$$

From the envelope property, we obtain $W_0^*/\partial S = -\frac{1}{2}\phi'(X^*)^2 > 0$.

Using (11), we have the profit of the firm at the second stage of the game as follows:

$$\pi^*(S,n) = b\left(\frac{k}{2b + nb + n\phi}\right)^2. \tag{13}$$

From (13), we can verify that $\pi^*(S,n)$ is a strictly increasing function in S:

$$\frac{\partial \pi^*(S,n)}{\partial S} = -\frac{2bnk^2}{(2b + nb + n\phi)^3}\phi' > 0. \tag{14}$$

It should be noted that a technological improvement in waste management increases the profit of the firm through a reduction of the import tariff corresponding to the reduction of the social marginal cost.

In order to further the investigation, we assume that marginal increase in the profit for an increase in the technology of waste management is a decreasing function of S. That is,

$$\frac{\partial^2 \pi^*(S,n)}{\partial S^2} = -\frac{2bk^2n^2\phi\phi''}{(2b + nb + n\phi)^4}\left(1 + \frac{n+2}{n}\frac{b}{\phi} - 3E\right) < 0, \tag{15}$$

where $E(S) = (\phi')^2/(\phi\phi'') > 0$. In (15), $E(S)$ can be interpreted as the ratio of two elasticities. That is, one is $\phi'/\phi = (\partial D/\partial S)(S/D)$, which represents the elasticity of social cost with respect to the waste management technology, and the other is $\phi''/\phi' = (\partial^2 D/\partial S^2)(S/(\partial D/\partial S))$, which is the elasticity of marginal effect of technological improvement on the social cost with respect to the waste management technology.

The following lemma describes a sufficient condition for concavity of the profit function.

Lemma 1. For $n \in [m, \infty)$, $\pi^*(S,n)$ is strictly increasing and concave in S if the following conditions are satisfied:

$$\frac{b}{\phi(s_0)} > 3E(s_0) - 1, \tag{C1}$$

$$E(S) \text{ is a non-increasing function in } S. \tag{C2}$$

Proof. See Appendix. ∎

Conditions (C1) and (C2) imply that the absolute value of ϕ' is sufficiently small relative to ϕ''. For example, if we specify $\phi(S)$ as $\phi(S) = S^{-\gamma}$, then $E = \gamma/(1+\gamma)$. In this case, $b \geq \phi(s_0)$ is a sufficient for (C1) under the condition of $\gamma < 1/2$. Alternatively, if $\phi(S)$ takes the form of $\phi(S) = e^{-\gamma S}$ then $E = 1$. In this case, Condition (C1) is satisfied if and only if $b > 2\phi(s_0)$.

3.2 Technology Transfer by the Exporting Country

We now turn to the first stage of the game. At this stage, the exporting countries simultaneously decide the level of technology transfer. The welfare of the exporting country is represented by (6).

The maximization problem of the country $j \in M$ can be written as follows:

$$\max_{s_j} n_j \pi^* (S, n) - q s_j, \tag{P1}$$

subject to (3) and

$$s_j \geq 0.$$

The first-order condition can be summarized as

$$n_j \frac{\partial \pi^*}{\partial S} - q \leq 0, \tag{16}$$

$$\left(n_j \frac{\partial \pi^*}{\partial S} - q \right) s_j = 0. \tag{17}$$

The second-order condition is satisfied if $\partial \pi^* / \partial S$ is decreasing in S.

Since we assume that the firms are identical in case of their technology, for a sufficiently small q, we obtain

$$n_1 \frac{\partial \pi^*}{\partial S} - q = 0, \tag{18}$$

and

$$n_j \frac{\partial \pi^*}{\partial S} - q > 0, \quad j \neq 1. \tag{19}$$

Thus, we can write the level of technology transfer as a function of the distribution of the firms among the exporting countries.

$$S = S(\mathbf{n}, q), \tag{20}$$

where $\mathbf{n} = (n_1, ..., n_m)$ denotes a vector consisting of the number of firms in each country. From (18) and (19), the following result can be easily verified:

Proposition 1. *At the equilibrium, (i) only the countries having the largest share of goods in the importing country contribute to technology transfer, and (ii) for a given number of the firms, the level of technology transfer is increased by an increase in the number of n_1.*

Proof. Part (i) is obvious from (18) and (19). Part (ii) follows from the concavity of the profit function $\pi^* (S, n)$ in S and (18). ∎

Proposition 1 states that if the number of firms differs across the countries, there exist

free-riders who enjoy the benefit of tariff reduction without any technology transfer. The reason why the free-rider emerges at the equilibrium is quite simple. The tariff is imposed on all the exporting countries at a uniform rate. Thus, a tariff reduction resulting from technology transfer by one country can benefit all exporting countries. In this sense, the tariff has a property of a kind of public goods (bads). Hence all exporting countries have an incentive to free-ride on the technological assistance provided by the other country. If the exporting countries are perfectly symmetric with respect to the number of firms, every country may become a contributor of technology transfer[13]. However, the situation in which all the exporting countries implement technology transfer is never desirable from the viewpoint of world welfare. The following is a straightforward application of well-known results in the literature concerning voluntary provision of public goods[14].

Corollary 1. *Suppose that all the exporting countries equally share the market of the importing country: $n_j = n/m$ for $\forall j \in M$ holds. Then all exporting countries may become the contributors of the technology transfer at which the level of the technology transfer is the lowest level among any possible distribution of firms.*

Proof. For a fixed number of firms and exporting countries,

$$\frac{n}{m} = \min\max\left\{ n_j : j \in M, \sum_{j \in M} n_j = n \right\}.$$

The claim directly follows from the above expression. ∎

As a result of free-rider problems, it is not always the case that the contributing country that has the maximum market share obtains the highest level of welfare among the exporting countries. Welfare of the contributing country can be written as $W_1 = n_1 \pi^* (S_1^*, n) - q s_1^*$, while welfare of the noncontributing country j can be written as $W_j = n_j \pi^* (S_1^*, n)$, where $S_1^* = s_0 + s_1^*$. Therefore, if the difference in the number of firms between the contributing country and the noncontributing country j is relatively small such that $(n_1 - n_j)/n_1 < -2\phi' s_1^* n/(2b + n(b + \phi))$, then the welfare of the contributing country is lower than that of the non-contributing country j[15].

Example 1. Consider a numerical example such that $m = 3$, $n_1 = 6$, $n_2 = 5$, $n_3 = 4$, $b = 3/2$, $k = 10$, $\phi(S) = e^{-S}$, $s_0 = 0$ and $q = 1/4$. At equilibrium, the level of technology transfer $S^* = s_1^* = 1.506$ and profit of the firm is $\pi^* = 0.181$. Thus, welfare of the exporting countries are $W_1 = 0.707$, $W_2 = 0.903$ and $W_3 = 0.722$, respectively. □

This result is well-known in the literature concerning voluntary provision of public goods by governments having different sizes of populations (e.g., Olson and Zeckhauser,

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[13]In the case of $n_1 = n_2 =, ..., = n_k$, each country's contribution is indefinite, but the total contribution $\sum_{j=1}^{k} s_j$ is determined according to the first-order conditions represented by $n_j (\partial\pi/\partial S) = q$ for $j = 1, ..., k$.

[14]For example, see Andreoni (1988).

[15]To derive the inequality, we use the first-order condition $n_1 (\partial\pi/\partial S) - q = 0$ and $\partial\pi^*/\partial S = -[2n\phi'/(2b + n(b + \phi))]\pi^*$ obtained from (13) and (14).

1966; Boadway and Hayashi, 1999).

3.3   Coordination of Tariff and Technology Transfer Policies

The result obtained in the previous subsection indicates that the equilibrium level of technology transfer is inefficiently low. This inefficiency can be divided into two parts. One arises from the non-cooperative behavior among the exporting countries. The other is due to lack of coordination between the exporting countries and the importing country.

Starting from the initial equilibrium characterized by (18) and (19), we consider the cooperative behavior among the exporting countries. The importing country still sets the tariff strategically according to (10). Cooperative change in technology transfer of country j is represented by $ds_j = \delta_i dS$ where $\sum_{j=1}^{m} \delta_j = 1$. Noting that the initial situation is characterized by (18) and (19), we can write the change in welfare as follows:

$$dW_j = \left(\frac{n_j}{n_1} - \delta_i \right) q dS.$$

Thus, we can consider the cooperative increase in technology transfer to be Pareto-improving. That is, $\delta_i = n_j/n_1 - \varepsilon_j$, $\varepsilon_j > 0$, and $\sum_{j=1}^{m} \varepsilon_j = (n - n_1)/n_1 \geq 0$. As long as $m > 1$, this coordinated increase in S is feasible and achieves Pareto-improving such that $dW_j = \varepsilon_j dS$, for $j \in M$ and $dW_0 = -\left(\phi'/2 \right) X^2 dS$. Sequential coordination is also possible to the extent that $n\left(\partial \pi/\partial S \right) > q$ holds. Once $n\left(\partial \pi/\partial S \right) = q$ is achieved, Pareto improving is impossible as a result of coordination only among the exporting countries.

Now we consider the coordination between the exporting countries and the importing country. Let us suppose that the initial situation is characterized by

$$n\frac{\partial \pi^*}{\partial S} - q = 0. \tag{21}$$

That is, we assume that the coordination between the exporting countries and the importing country begins after the coordination among the exporting countries. Welfare effects of the infinitesimal changes in the tariff and technology transfer can be written as

$$dW_0 = -\frac{\phi'}{2} X^2 dS,$$

$$\begin{aligned} dW_j &= n_j \frac{\partial \pi}{\partial t} dt - q ds_j \\ &= \frac{q}{\partial t^*/\partial S} \left(\frac{n_j}{n} dt - \frac{\partial t^*}{\partial S} ds_j \right), \quad j \in M. \end{aligned}$$

Thus, changes in the tariff and the level of technology transfer that satisfy $(n_j/n)\, dt - (\partial t^*/\partial S)\, ds_j \leq 0$ and $\sum_{j \in M} ds_j \geq 0$ improve the welfare in the sense of Pareto.

4 Market Competitiveness and Welfare

Trade liberalization can be achieved not only by a reduction of the tariff but also by an enhancement of market openness. In this section, we consider the effect of a change in the number of firms on the tariff and on national welfare. For analytical simplicity, we assume that $n_1 > n_2 \geq, ..., n_m$ holds at the initial situation. That is, only one country contributes to technology transfer initially. In addition, we consider a small change in the number of firms such that the contributing country is not altered by this change.

4.1 The Number of Firms and Trade Liberalization

In the previous section, it is revealed that technology transfer by the exporting countries reduces the import tariff. However, the incentive for the exporting country to transfer technology lies in the pure profit of firms. An increase in the number of firms has two opposing effects on welfare of the importing country. One is a beneficial effect arising from an increase in the competitiveness of the market. The other is a harmful effect arising from a decline in the level of technology transfer since a reduction of the firms' profits may lower the incentive behind technology transfer.

First, we consider the effect of the number of firms on the level of technology transfer. Under a fixed level of the technology transfer, an increase in the number of the firms changes the output of the firms as follows[16]:

$$\frac{\partial X^* (S, n)}{\partial n} = \frac{2bk}{(2b + nb + n\phi)^2} > 0. \tag{22}$$

As in the standard literature concerning imperfect competition, total output of the firms increases with increase in the number of firms. On the other hand, under a fixed level of technology transfer, the effect of the number of the firms on the tariff can be represented as follows:

$$\frac{\partial t^* (S, n)}{\partial n} = \frac{(\phi - b)\, bk}{(2b + nb + n\phi)^2}. \tag{23}$$

The above equation implies that the tariff is reduced by an increase in the number of firms if the marginal benefit of consumption of goods exceeds the marginal damage arising from waste management at a fixed level of management technology. However, we should take into account the change in the technology since the level of technology transfer may change depending on the number of firms.

From (20), change in the level of technology transfer can be written as $dS = \sum_{j=1}^{m} (\partial S / \partial n_j)\, dn_j$, where

$$\frac{\partial S}{\partial n_1} = -\frac{\partial \pi^* / \partial S + n_1 \left(\partial^2 \pi^* / \partial S \partial n \right)}{n_1 \left(\partial^2 \pi^* / \partial S^2 \right)}, \tag{24}$$

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[16] Throughout this section, for analytical simplicity we treat the number of firms as a continuous variable.

and

$$\frac{\partial S}{\partial n_j} = -\frac{\partial^2 \pi^*/\partial S \partial n}{\partial^2 \pi^*/\partial S^2}, \quad j \neq 1. \tag{25}$$

Thus, we obtain

$$dS = -\frac{\partial \pi^*/\partial S}{n_1 \left(\partial^2 \pi^*/\partial S^2\right)} dn_1 - \frac{\partial^2 \pi^*/\partial S \partial n}{\partial^2 \pi^*/\partial S^2} dn, \tag{26}$$

where $dn = \sum_{j=1}^m dn_j$. In (26), the first term of the right-hand side is positive from (14) and the second-order condition for welfare maximization. As shown in Corollary 1, if the total number of firms does not change, concentration of firms to the contributing country increases the level of technology transfer. In the second term on the right-hand side in (26), marginal effect of technology transfer on profit is a decreasing function of the total number of the firms, since an increase in market competitiveness reduces profit. Differentiating (14) with respect to n, we obtain

$$\frac{\partial^2 \pi^*}{\partial S \partial n} = 4bk^2 \phi' \frac{n\phi + b\left(n-1\right)}{\left(2b + bn + n\phi\right)^4} < 0. \tag{27}$$

Substituting $dn_1 = 0$ into (26), we can verify that an increase in the number of firms in the non-contributing country reduces the level of technology transfer.

Substituting (14), (15) and (27) into (26), we obtain

$$dS = \phi' \frac{\left(2b + nb + n\phi\right)\hat{n}_1 - 2\left(n\left(\phi + b\right) - b\right)\hat{n}}{\Delta}, \tag{28}$$

where $\hat{n}_1 \equiv dn_1/n_1$ and $\hat{n} \equiv dn/n$ denote the rate of change in the number of firms in the contributing country and in the total number of firms, respectively, and

$$\Delta \equiv n\phi'' \left(3E - \frac{n+2}{n}\frac{b}{\phi} - 1\right) < 0.$$

The last inequality of the above expression follows from the second-order condition for optimization of the exporting country.

The effect of change in the number of firms on the level of the technology transfer depends on the country whose number of firms has increased. From (28), we obtain the following result.

Lemma 2. *If and only if the number of firms changes according to satisfying the following inequality, then the level of the technology transfer is increased.*

$$\hat{n}_1 > 2\frac{n\left(\phi + b\right) - b}{n\left(\phi + b\right) + 2b}\hat{n}. \tag{29}$$

Proof. This is obvious from (28). ∎

Intuitively saying, Lemma 2 states that the level of technology transfer will be increased if the initial number of firms is small and if an increase in the number of firms occurs

mainly in the country having the largest share in the importing country. It is clear that a small increase in the number of firms in the non-contributing country decreases the level of technology transfer. Since $\sup\{(n(b+\phi)-b)/(n(b+\phi)+2b)\}$ for $n \in [1,\infty)$ is "1", a sufficient condition for Proposition 3 to hold is $\hat{n}_1 > 2\hat{n}$. If the market share of country 1 is less than 50%, then a small increase in the number of firms in the country 1 increases the level of technology transfer[17]. It is notable that a proportional expansion of competitiveness such that $\hat{n}_j = \hat{n}$ for $\forall j \in M$ does not always lead to an increase the technological assistance. From (29), if the initial number of firms is greater than four, such expansion reduces the level of technology transfer.

Now we consider the effect of change in the number of firms on the import tariff. The change in the tariff can be represented by the following expression.

$$dt^*\left(S\left(\mathbf{n}\right),n\right) = \frac{\partial t^*}{\partial n}dn + \frac{\partial t^*}{\partial S}dS. \tag{30}$$

The first term on the left-hand side in (30) is negative if and only if $b > \phi$ holds. The sign of the second term depends on the change in the level of technology transfer. In the standard model of strategic trade policy, which does not take account of waste management, any increase in the number of firms reduces the tariff, since the rent-shifting effect is decreased by an increase in competitiveness. In the present model, from (28) and (30), the tariff is reduced as a result of increase in the number of firms if $b > \phi$ and $\hat{n}_1 > 2\hat{n}$ hold. However, this is not always the case. Substituting (23) and (28) into (30), we obtain

$$dt^* = \frac{bk\phi\phi''}{(2b+nb+n\phi)\Delta}\left\{\left(\frac{b}{\phi}-1-(2n-1)E\right)\hat{n}+(n+1)E\hat{n}_1\right\}. \tag{31}$$

Thus, we obtain the following proposition.

Proposition 2. *Starting from the initial equilibrium, a small increase in the number of firms reduces the tariff if and only if the following inequality is satisfied.*

$$\hat{n}_1 > \frac{1}{(n+1)E}\left(1-\frac{b}{\phi}+(2n-1)E\right)\hat{n}.$$

Proof. This is obvious from (31). ∎

Proposition 2 implies that an increase in competitiveness may increase the tariff when the number of firms increases in the non-contributing countries. As an extreme situation, suppose that only the number of the firms in the non-contributing country is increased. That is, $\hat{n}_1 = 0$ holds. From Lemma 2, we can see that the level of technology transfer is decreased by such a change in the number of firms. Therefore, if

$$1+(2n-1)E > \frac{b}{\phi},$$

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[17]Because of $\hat{n} = (n_1/n)\hat{n}_1$ under $dn_1 = dn$, $\hat{n}_1 > 2\hat{n}$ implies $n_1/n < 1/2$. Since production technology of the firms is symmetric, market share of the country 1, $\sum_{i\in n_1} x_1/X$, is equal to n_1/n.

holds, then the tariff is increased.

An increase in competitiveness represented by an increase in the number of firms has two effects on the importing country. One is a beneficial effect brought about by increased consumption of the goods, which is represented by b. The other, which is represented by ϕ, is a harmful effect resulting from an increase in waste. An increase in the number of firms in the contributing country partly mitigates the harmful effect through an increase in technology transfer when the initial number of firms in the contributing country is sufficiently small. In contrast, if the beneficial effect is sufficiently small such that $b/\phi \approx 1$, then the importing country intends to prevent the trade by increasing the tariff.

4.2 Welfare Effects of Market Competition

We now turn to the effects on welfare. First, we consider welfare of the importing country. At the non-cooperative policy equilibrium, welfare of the importing country can be written as $W_0(n, S(\mathbf{n})) = (k/2) X(S(\mathbf{n}), n)$. Change in the number of firms affects welfare as follows:

$$dW_0 = \frac{k}{2} \left(\frac{\partial X}{\partial n} dn + \frac{\partial X}{\partial S} dS \right). \tag{32}$$

From (32), it is obvious that welfare is increased by an increase in the number of firms if the level of technology transfer is increased. More generally, welfare of the importing country can be increased if and only if the following inequality is satisfied[18].

$$\left(2\frac{b}{\phi} - nE \right) \hat{n} + (\hat{n}_1 - \hat{n}) nE > 0. \tag{33}$$

Eq. (33) implies that if the initial market share of country 1 is sufficiently small, then welfare of the importing country is improved. In contrast, if the number of exporting countries is 1, which means $\hat{n}_1 = \hat{n}$, welfare may be improved under a small number of n.

Next, we consider the change in the welfare of the contributing country indexed by 1. Since we assume that the contributing country does not change before or after the change in the number of firms $ds_1 = dS$ holds. Using the envelope property, we can write the change in welfare as follows:

$$dW_1 = n_1 \left(\pi^* \hat{n}_1 + n\frac{\partial \pi^*}{\partial n} \hat{n} \right). \tag{34}$$

Obviously, an increase in the number of firms in the own country is a necessary condition for improving welfare[19]. After some manipulation, we can verify that if the following inequality is satisfied, then welfare of the contributing country is improved.

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[18]See Appendix for the derivation of (33).

[19]In (34),

$$\frac{\partial \pi^*}{\partial n} = -\frac{2(b+\phi) bk^2}{(2b + n\phi + bn)^3} < 0$$

$$\hat{n}_1 > \frac{2n(b+\phi)}{2b+n(b+\phi)}\hat{n}. \tag{35}$$

A necessary condition for improving welfare of the contributing country is that the level of technology transfer due to change in the number of the firms is increased. Therefore, if the welfare of the contributing country is improved, then the welfare of the importing country is also improved.

Next, the change in the welfare of the non-contributing country indexed by i can be written as follows:

$$dW_j = n_j \frac{\partial \pi^*}{\partial n}dn + \pi^* dn_j + n_j \frac{\partial \pi^*}{\partial S}dS. \tag{36}$$

Inserting (36) into (36), we obtain

$$dW_j = n_j bk^2 \frac{2\left(E - \dfrac{b}{\phi} - 1\right)\hat{n} + \left(\dfrac{n+2}{n}\dfrac{b}{\phi} - 3E + 1\right)\hat{n}_j + 2E\hat{n}_1}{(2b+nb+n\phi)^2 \left(\dfrac{(n+2)}{n}\dfrac{b}{\phi} - 3E + 1\right)}, \tag{37}$$

where $\hat{n}_j \equiv dn_j/n_j$. Although (37) seems to be complicated, we can consider some special situations. First, if both the number of firms in both the contributing country and country j does not change, the change in welfare of country j can be written as

$$dW_j|_{dn_1=dn_j=0} < 0. \tag{38}$$

On the other hand, if only the number of the firms in the contributing country is increased the change in welfare can be written as follows:

$$dW_j|_{dn_1=dn} > 0 \Leftrightarrow \frac{n_1}{n} < \frac{E}{1 - E + (b/\phi)}. \tag{39}$$

In (39), (C1) implies $1 - E + (b/\phi) > 2E$. Thus, welfare of the noncontributing country is reduced if n_1/n is greater than $1/2$. In contrast, if the number of firms in the contributing country at the initial equilibrium is sufficiently small, then an increase in the number of firms in the contributing country can improve the welfare of the contributing country.

From (32), (34) and (39), we have the following result.

Proposition 3. *At the initial equilibrium, if the number of the firms in the contributing country is sufficiently small such that*

$$\frac{n_1}{n} < \frac{E}{1 - E + (b/\phi)}, \tag{40}$$

then a small increase in the number of firms in the contributing country achieves Pareto-improvement.

Proof. A sufficient condition for satisfying (35) is $n_1/n < 1/2$. From (29), if $n_1/n < 1/2$

holds, then $dW_0 > 0$ and $dW_1 > 0$ also hold. In addition, $n_1/n < 1/2$ is a necessary condition for $dW_j > 0$ for $j \neq 1$. Therefore, if (40) is satisfied, then $dW_0 > 0$, $dW_1 > 0$, and $dW_j > 0$ hold. ∎

The condition stated in Proposition 3 tends to be satisfied if the initial distribution of firms is spread across the countries. For example, suppose that the damage function that takes a form of $\phi(S) = e^{-rS}$, $r > 0$, which means $E = 1$. In this situation (40) implies $1/2 > \phi/b > n_1/n$.

5 Extensions

5.1 Endogenous Timing of the Policy Instruments

Thus far, we assume that the timing of the game is determined exogenously. The results obtained in the previous section crucially depend on the timing of the game. In this subsection we consider a game where the timing of the moves is determined endogenously. We consider the observable delay game of Hamilton and Slutsky (1990)[20]. At the beginning of the extended game, stage zero, the exporting countries and the importing country choose independently and simultaneously whether to set a tariff, and the level of technology transfer at stage one or at stage two. Then, each country sets the policy variable at the chosen stage. At the third stage, each firm decides its output to maximize the profit.

It is notable that the exporting country has an incentive to transfer technology in exchange for a tariff reduction. If the importing country chooses the tariff at the first stage of the game, the exporting country does not transfer the technology. Therefore, the importing country will decide to choose the tariff rate at stage two. When the importing country is a second-mover, the exporting country choosing the first move decides the level of technology transfer according to (P1). Thus, among the exporting countries that choose the first move, only the country having the largest share contributes to technology transfer. The exporting countries that have small shares in the market do not transfer technology even if they decide to become the first-mover.

In order to investigate the behavior of the exporting country, let us denote s_j^* as the level of technology transfer chosen by the exporting country j that becomes the only contributor.

$$s_j^* = \arg \max_{s_j} W_j(S, n_j, q). \tag{41}$$

From (P1), it can be easily verified that $s_1^* \geq, ..., \geq s_m^*$ holds.

Consider a situation in which country j chooses the first move, while the countries indexed by $r(< j)$ are the second-movers. In this situation country $h(> j)$ is indifferent

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[20] In the literature concerning strategic trade policy, Collie (1994) and Supasri and Tawada (2007) deal with the endogenous timing model.

between the first and the second moves. On the other hand, country r has an incentive to become a first-mover if the following inequality is satisfied.

$$W_r^*(s_r^*) - W_r^*(s_j^*) \geq 0.$$

In contrast, if $W_r^*(s_r^*) - W_r^*(s_j^*) < 0$ holds, country r remains the second-mover. In general, the level of technology transfer possible at equilibrium depends on the distribution of firms among the exporting countries.

Proposition 4. *Let us denote Ω as a set of possible levels of technology transfer. If the following inequalities are satisfied for $j \in M$ then $\Omega = \{s_1^*, ..., s_j^*\}$.*

$$n_1 \frac{\pi\left(s_0 + s_1^*, n\right) - \pi\left(s_0 + s_j^*, n\right)}{s_1^*} \leq q, \tag{42}$$

and

$$n_1 \frac{\pi\left(s_0 + s_1^*, n\right) - \pi\left(s_0 + s_{j+1}^*, n\right)}{s_1^*} > q. \tag{43}$$

Proof. See Appendix. ∎

Since s_j^* is an increasing function in n_j, Proposition 3 states that if the market share of country 1 is sufficiently large such that (43) holds for $j = 2$, then the result obtained in the previous section does not change. On the other hand, if (42) holds for $j = m$ then every country could be a contributor. That is, there exists an equilibrium in which the country having the largest share in the market is a free-rider.

5.2   Technology of Waste Management

To derive the results, we assume that the level of technology is additive. In some situations this setting may not be realistic. For example, the technology to be transferred sometimes takes the form of intangibles such as knowledge or know-how. Once knowledge is transferred to the importing country, it flows throughout the country without any learning cost. Furthermore, even if inferior knowledge is transferred to a country that has already received an advanced technology, this is not effective in improving the waste management system.

In this subsection, taking into account the characteristics of such technology, let us consider a situation in which technology takes the form of best-shot, as propounded by Hirshleifer (1983)[21]. That is, (3) is replaced by the following equation.

$$S = \max\{s_0, s_1, ..., s_m\}. \tag{44}$$

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[21]See also Sandler (1998).

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As in the previous subsection, from (16) and (17), we can define the level of technology transfer which maximizes the welfare of the contributing country in the absence of other countries' transfer.

$$\tilde{s}_j^* = \arg\max_{\tilde{s}_j \geq 0, \tilde{s}_{-j}=0} \left(n_j \pi \left(\tilde{s}_j^* \right) - q\tilde{s}_j^* \right).$$

Similar to the literature concerning voluntary provision of best-shot public goods, the equilibrium may not be unique. The following proposition, similar to Proposition 3, implies that we can not exclude multiple equilibria.

Proposition 5. *Suppose that the technology takes the form of best-shot. If the following inequalities are satisfied for $j \in M$, then the number of the equilibria at the first stage of the game is j.*

$$n_1 \frac{\pi \left(\tilde{s}_1^* \right) - \pi(\tilde{s}_j^*)}{s_1^*} \leq q,$$

$$n_1 \frac{\pi \left(\tilde{s}_1^* \right) - \pi(\tilde{s}_{j+1}^*)}{s_1^*} > q.$$

Proof. A procedure similar to that in Proposition 3 can be applied. ∎

Proposition 5 states that the number of equilibria depends on the distribution of firms among the exporting countries. As with Proposition 4, if there are sufficiently large number of firms, the number of the possible equilibria will increase as the distribution of firms approaches to uniformity.

We can also consider technology taking the form of

$$S = f \left(s_0, s_1, ..., s_m \right), \tag{45}$$

and $\partial f / \partial s_i \geq 0$, $i \in \{0\} \cup M$. If the technology is specified by (45), two or more countries might contribute to the technology transfer. However, at the equilibrium the country having the largest share in the market contributes more transfer of technology as long as the marginal effects of transfer on the waste management technology do not differ among countries[22].

5.3 Heterogeneity of the Firms

The basic results presented above are still valid if we take account of non-identical production cost. Suppose that the profit of the firm i can be written as

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[22]For example, suppose that $S = s_0 \Pi_{j \in M} s_j^a$ for $a \in (0, 1)$ and that $\phi(S) = S$. Thus, the first order condition for welfare maximization of the exporting country can be written by

$$n_j \frac{\partial \pi^*}{\partial S} = q \frac{a s_j}{S}$$

For a sufficiently low value of q, at the equilibrium, $s_j > s_i > 0$ holds if and only if $n_j > n_i$ for $i, j \in M$.

$$\pi_i = (P - c_i - t) x_i. \tag{46}$$

From the first-order condition for profit maximization, we obtain the output of firm i as $x_i(t,n) = (\hat{k}_i - t)/[(n+1)b]$, where $k_i = a - c_i$ and $\hat{k}_i \equiv (n+1)k_i - \sum k_j$. Total output can be written as $X(t) = n(\bar{k} - t)/[(n+1)b]$, where $\bar{k} \equiv (1/n)\sum k_j$. Thus, the optimal tariff to maximize the welfare of the importing country can be written as $t^*(S) = (b + n\phi)\bar{k}/[(n+2)b + n\phi]$. Together with the expressions noted above, the output of firm i can be written as follows:

$$x_i^*(S, n) = \frac{\bar{k}}{2b + nb + n\phi} + \frac{k_i - \bar{k}}{b}. \tag{47}$$

Therefore, total output can be written as $X(S, n) = \bar{k}/[(n+2)b + n\phi]$. Each exporting country decides the level of technology transfer s_j to maximize the welfare.

$$\max_{s_j} W_j = \sum_{i \in N_j} \pi_i^*(S) - qs_j, \tag{48}$$

subject to $S = \sum_{j=0}^{m} s_j$ and $s_j \geq 0$. The first-order condition can be summarized as follows:

$$\sum_{i \in N_j} \frac{\partial \pi_i}{\partial S} - q \leq 0,$$

$$\left(\sum_{i \in N_j} \frac{\partial \pi_i}{\partial S} - q \right) s_j = 0.$$

After some manipulation the marginal benefit of technology transfer can be written as follows:

$$\sum_{i \in N_j} \frac{\partial \pi_i}{\partial S} = -\frac{2b\phi'}{2b + nb + n\phi} X^2 \theta_j - q, \tag{49}$$

where $\theta_j \equiv \sum_{i \in N_j} x_i/X$ denotes the market share of country j. Therefore, at the equilibrium, the exporting country having largest share in the importing country becomes a contributor. Unlike the results in Section 2, market share depends not only on the number of firms but also on the marginal costs of firms. By using (47), the market share of country j can be written as follows:

$$\theta_j = \frac{2b + nb + n\phi}{b\bar{k}n} \sum_{i \in N_j} k_i - \frac{n_j}{bn}(b + n\phi + bn).$$

Therefore, the difference between the market share of country j and r is

$$\theta_j - \theta_r = \frac{2b + nb + n\phi}{b\bar{k}n} \left(\sum_{i \in nN_j} k_i - \sum_{i \in N_r} k_i \right) - \frac{b + n\phi + bn}{bn} \left(n_j - n_r \right). \qquad (50)$$

If marginal costs of the firms are identical, (50) can be reduced as

$$\theta_j - \theta_r = \frac{1}{n} \left(n_j - n_r \right).$$

If two countries have the same number of firms, difference in the market share is

$$\theta_j - \theta_r = \frac{2b + nb + n\phi}{b\bar{k}n} \left(\sum_{i \in N_j} k_i - \sum_{i \in N_r} k_i \right).$$

Basic results obtained in the previous section will not change even if we allow the difference in marginal costs. In Section 4 we argued that an increase in the number of firms in the non-contributing country does not lead to Pareto-improving. In line with this argument, reduction in the marginal cost of less-efficient firms in the non-contributing country may have a negative impact on the other countries.

6 Conclusions

This paper considers the effectiveness of international aid for technological improvement that reduces the damage arising from waste management. We revealed that the exporting country has an incentive to transfer the waste management technology even if the damage arising from the waste does not spill over onto the exporting country. Technology transfer is voluntarily motivated by tariff reduction implemented by the importing country. However, a non-cooperative solution leads to an inefficiently low level of technology transfer. Since the benefit of tariff reduction implemented in exchange for technology transfer by one country spreads among all the exporting countries, every exporting country has an incentive to free-ride. In this sense, the tariff can be regarded as public bads for the exporting countries.

Our results also show that the level of technology transfer at the equilibrium depends on the distribution of firms among the exporting countries. For a fixed total number of the firms, the level of transfer is increased by concentrating the firms within the contributing country. In practice, the government of the importing country could restrict the entry of the foreign firms by using non tariff barriers such as quality standards and other administrative measures. The present analysis suggests that the government may use discriminative entry regulation as a policy device to improve the welfare. However, such an entry regulation does not seem to be a desirable policy: the government should first construct a scheme to mitigate the free-rider problem. We do not address this issue in the present paper. It shall be pursued in the future.

7 Appendices

7.1 Proof of Lemma 1

Differentiating (14) with respect to S, we obtain

$$\frac{\partial^2 \pi^* (S, n)}{\partial S^2} = -\frac{2bk^2 n \left(-3n(\phi')^2 + \phi'' (2b + n\phi + bn)\right)}{(2b + nb + n\phi)^4}. \tag{A1}$$

Noting that $\phi' < 0$ and $\phi'' > 0$, we have

$$\frac{\partial^2 \pi^* (S, n)}{\partial S^2} < 0 \Leftrightarrow \frac{\phi''}{\phi'} \left((n + 2) \frac{b}{\phi} + n\right) - 3n \frac{\phi'}{\phi} < 0.$$

Thus, we obtain

$$\frac{\partial^2 \pi^* (S, n)}{\partial S^2} < 0 \Leftrightarrow \frac{b}{\phi} > \frac{n}{n + 2} (3E - 1).$$

Since $\phi(S)$ is a decreasing function we have

$$\min_S \frac{b}{\phi} = \frac{b}{\phi(s_0)}.$$

If (C1) is satisfied, we obtain

$$\max_{n,S} \left\{ \frac{n}{n + 2} (3E - 1) \right\} = 3E - 1.$$

Hence, (C2) implies that

$$\frac{b}{\phi} \geq \frac{b}{\phi(s_0)} > 3E - 1 \geq \frac{n}{n + 2} (3E - 1).$$

Thus, the claim of Lemma 1 is proved.

7.2 Derivation of (33)

Substituting (12) (22) and (28) into (32), we have

$$
\begin{aligned}
dW_0 &= \frac{nk^2}{2 (2b + n (b + \phi))^2} \left(2b\hat{n} - n (\phi')^2 \frac{(2b + nb + n\phi) \hat{n}_1 - 2 (n (\phi + b) - b) \hat{n}}{3n (\phi')^2 - \phi'' (2b + nb + n\phi)}\right) \\
&= -\frac{k^2 \left(\left(2\frac{b}{\phi} - nE\right) \hat{n} + (\hat{n}_1 - \hat{n}) nE\right)}{2 (2b + nb + n\phi) \left(3E - \frac{n+2}{n} \frac{b}{\phi} - 1\right)}. \tag{A2}
\end{aligned}
$$

Since $3E - \frac{n+2}{n} \frac{b}{\phi} - 1 < 0$ from (C1), we obtain (33).

7.3 Proof of Proposition 4

First, we define a critical value of technology transfer that distinguishes the contributor from the noncontributor. For $j \in M$, $\hat{s}_j$ is defined as a value satisfying the following equation.

$$n_j \pi_j [s_j^*(n_j), n] - q s_j^*(n_j) = n_j \pi_j (\hat{s}_j, n). \tag{A3}$$

If a country other than j contributes s_r^* to the technological assistance, country j decides whether to become a contributor according to $s_r^* > \hat{s}_j$. Since $\partial \pi_j (\hat{s}_j, n) / \partial \hat{s}_j > 0$, we can write $\hat{s}_j$ as a function of n_j such that $\hat{s}_j = \hat{s}_j (n_j)$. For a fixed n, differentiating $\hat{s}_j$, we obtain

$$\frac{d\hat{s}_j}{dn_j} = -\frac{\pi_j [s_j^*(n_j), n] - n_j \pi_j (\hat{s}_j, n)}{-n_j \partial \pi_j / \partial \hat{s}_j}. \tag{A4}$$

In (A3), we use the envelope property of $\left(\partial \pi_j / \partial s_j^* \right) \left(ds_j^* / dn_j^* \right) - q \left(ds_j^* / dn_j^* \right) = 0$. Since π_j is an increasing function in s, (A3) and (A4) imply that $d\hat{s}_j / dn_j > 0$. That is, the country's critical value is an increasing function of the number of firms which means that if country j chooses noncontributor for a given level of s_r^*, country $j+1$ also chooses the noncontributor because of $s_r^* > \hat{s}_j > \hat{s}_{j+1}$. Next, suppose a situation in which country r chooses the first move and that countries 1 and $j \in (2, r-1)$ choose the second move. If (42), which means $W_1^*(s_1^*) - W_1^*(s_r^*) \leq 0$, holds then country 1 does not have an incentive to change its timing. This means that country $j \in (2, r-1)$ also does not change the timing. Furthermore, country $h(> r)$ does not contribute regardless of its decision concerning timing. Thus, if (42) holds for $j = r$ then $s_r^* \in \Omega$. Next, suppose that country $r+1$ chooses the first move and that country $j < r+1$ chooses the second move. In this situation if (43) holds country 1 has an incentive to change its timing since (43) means $W_1^*(s_r^*) - W_1^*(s_{r+1}^*) > 0$. In this case, country $r+1$ can not be a contributor. Therefore if (43) holds for $j = r$ then $s_{r+1}^* \notin \Omega$. ∎

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