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# Optimal Policies for International Recycling Between Developed and Developing Countries

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**Abstract**

This paper presents a model of waste product trade between a developed and a developing country. North firms produce products that are consumed exclusively in North. After consumption, parts of them are exported from North to South. This export may be illegal. The remaining portion of the waste products are collected and recycled by firms in North. Firms in South engage exclusively only in recycling. The South government is unable to find illegal dumping of recycled waste products because of an inadequate governance capacity. Therefore, we assume that the South government subsidizes recycled material.

The model addresses five scenarios: closed economy, the first best, strategic government, selfish North government and inactive South government, and benevolent North government and inactive South government.

Among these scenarios, only the first best outcome needs a negative tariff for waste-product import to South. A limitation of the strategic government case is that the South government must finance the subsidy. In the selfish North government case, North benefits by avoiding collection and recycling costs by outflow of waste into South. The South environment, however, would enormously deteriorate due to the absence of a policy. If the North government is benevolent, it imposes an export tax on waste products to South to curb it.

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## Introduction

The waste electrical and electronic equipment (WEEE) directed by the European Union (EU) requires that a producer recycles its own products in EU regions. Japan's WEEE recycling system also requires products to be recycled within the country. However, recycling is incomplete within the consuming country. Post-consumer products are legally or illegally exported from developed to developing countries. For example, Fuse et al. (2011) estimate that more than 50% of indium and 20–30% of barium, lead, antimony, strontium, zirconium, silver, gold, and tin in domestically discarded products are not recycled in Japan, but instead are exported to other Asian countries. Kellenberg (2012) empirically shows the international *waste haven effects* that include the export of physical waste by-products, rather than goods production, to low environmental regulation countries.

There have been many studies on recycling within a country. Fullerton and Kinnaman (1995) propose a deposit-refund system with a tax on output and with a rebate on proper disposal. Palmer and Walls (1997) present a formal theoretical model on production-recycling. It is a pioneering study on waste and recycling, but is limited to domestic recycling. Walls and Palmer (2001) extend the previous model in order to formulate the so-called integrated product policy by treating three externalities: waste by-product, emission, and waste. The central issue in waste research is that the first best policy is prevented by illegal disposal and dumping. Therefore, waste-recycling policies to achieve the second best have been explored by many authors. Shinkuma (2003) shows that the second best policy among the three policies (unit pricing with an advance disposal fee, a deposit-refund system, and a producer take-back requirement system) depends on the price of the recycled good and the marginal transaction cost. Koide (2008) investigates optimal sets of take-back fees for collecting and recycling, and fines for illegal dumping in order to analyze the situation under Japan's Home Appliance Recycling Law. Honma and Chang (2010) examine recycling with and without cooperation of oligopoly firms. They show that virgin material taxes or final disposal taxes discourage firms from engaging in recycling R&D efforts in normal situations,

regardless of R&D cooperation. Ino (2011) allows for the possibility of firms' illegal disposal and advocates a second-best deposit-refund system.

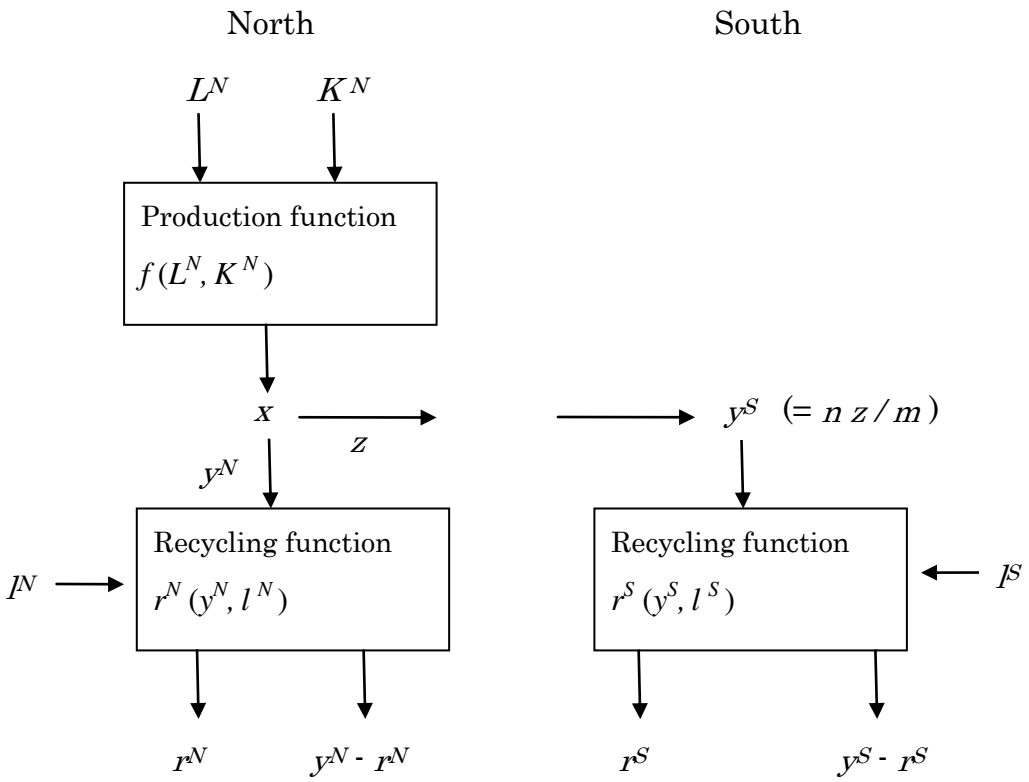
Although recycling activities reach beyond national borders, there are fewer studies on international recycling than on the domestic recycling referenced above. Copeland (1991) shows that trade restrictions on waste disposal enhance welfare when firms illegally dispose waste. Cassing and Kuhn (2003) formulate a model for international trade in hazardous waste where waste-importing and waste-exporting countries cooperate strategically. Higashida and Jinji (2006) study the strategic use of recycled content standard in an international duopoly. Kinnaman and Yokoo (2011) investigate a tax-subsidy system on durable goods, which are consumed as new goods in a developed country and as second-hand goods in a developing country. Shinkuma and Managi (2011, Chapter 8) analyze international trade in second-hand goods and scraps between developed and developing countries. They state that an extended product responsibility (EPR) policy in a developed country is nationally but not globally optimal.

Despite several papers' analyses of international-reuse trade, international recycling that has been actually performed has not been analyzed theoretically. This paper presents a North–South recycling trade model. In this model, there are two countries—developed North and developing South. North firms produce products exclusively for North consumption. After consumption, parts of them are exported from North to South. This export may be done illegally. The remaining portion of the waste products are collected and recycled by firms in North. South firms engage exclusively in recycling. However, the South government cannot find illegal dumping of residuals after recycling because of an inadequate governance capacity. Therefore, we assume that South subsidizes recycled material.

The model addresses five scenarios: closed economy, the first best, strategic government, selfish North government and inactive South government, and benevolent North government and inactive South government.

The rest of the paper is organized as follows. Section 2 presents our model. Section 3 presents optimal policies under five different scenarios. Section 4 compares tax-subsidy rates among the five outcomes. Section 5 concludes.

Figure 1 Production and recycling process in North and South




1. Model

There are two countries, North and South. Due to differences in technology, the end product is produced exclusively in North using two production factors (labor and capital); however, waste product is recycled in both countries. An outline of our model is shown in Figure 1.

1.1 Production and recycling in North

In North, there are $n$ identical perfectly-competitive firms. A representative firm in North produces units of a final consumer good, $x$, by using labor, $L^N$, and capital, $K^N$. Let $f(L^N, K^N)$ be the production function. We assume that the production function is strictly concave, that is, $f_L > 0, f_K > 0, f_{LL} < 0, f_{KK} < 0, f_{LL} f_{KK} - (f_{LK})^2 > 0$, and that the cross derivatives are

positive, $f_{LK} = f_{KL} > 0$[1]. We assume that each firm in North has to collect and recycle its own waste products in compliance with the EPR policy of the North government.

Some randomly chosen North consumers sell used products to waste-product exporters. This amount is given by $z$. The per unit export cost is given as $p^y$. For simplicity, the exporters are located in North and face perfect competition[2]. To concentrate on the environmental damage caused by final disposal waste in both countries, we do not treat second-hand demand in South[3]. Therefore, North firms recycle parts of the products, that is, $y^N = x - z$. Without loss of generality, we assume that the number of units equal its volume for $x$, $y^N$, and $z$, respectively. We do not consider illegal disposal by North consumers. We assume that North firms collect waste products except those exported to South, and that North consumers do not illegally dispose used products. Note that North firms cannot directly control $y^N$, which depends on recycling demand in South. North firms' recycling function is given by, $r^N(l^N, y^N)$, where $l^N$ is labor for the recycling process. We assume that the recycling function is strictly concave, that is, $r_l^N > 0, r_y^N > 0, r_{ll}^N < 0, r_{yy}^N < 0, r_{ll}^N r_{yy}^N - (r_{ly}^N)^2 > 0$, and that the cross derivatives are positive, $r_{ly}^N = r_{yl}^N > 0$. Note that $r_y^N$ is always less than unity, because a firm cannot extract any additional weight of recycled material beyond one unit of the waste product. The recycled material is sold at a constant price, $q$, in the market. The final disposal waste, $x - z - r^N(y^N, l^N)$, is taxed at the waste tax rate, $t^N$. Firms take the price of output, *P*, the price of labor, $w_N$, and the price of capital, $p^K$ as given. Let $c$ be the collection cost per unit. A representative firm's profit in North is written as follows:

$$\pi^N = Pf(L^N, K^N) - w_N(L^N + l^N) - p^K K^N + qr^{N,i}(l^N, f(L^N, K^N) - z)$$
$$- c(f(L^N, K^N) - z) - t^N(f(L^N, K^N) - z - r^N(l^N, f(L^N, K^N) - z)). \qquad (1)$$

The first-order conditions of the profit maximization are as follows[4]:

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[1] Subscripts denote partial derivatives.

[2] Assuming the constant marginal cost and perfect competition on discarded products, which country the exporting firms belong to does not affect our results.

[3] The second-hand good consumed in country South will be finally recycled and landfilled. To avoid complexity by introducing consumer surplus from the second-hand goods, we exclusively deal with used products.

[4] We assume that second-order conditions hold throughout the paper.

$$Pf_L = w_N - qr_y^N f_L + cf_L + t^N f_L (1 - r_y^N), \quad (2)$$

$$Pf_K = p^K - qr_y^N f_K + cf_K + t^N f_K (1 - r_y^N), \quad (3)$$

$$qr_l^N = w_N - t^N r_l^N. \quad (4)$$

1.2 Recycling in South

In South, *m* identical firms engage exclusively in recycling because we assume that production technology in unavailable in South and because recycling is labor intensive. A representative South firm purchases a waste product, $y^S$, from North exporters for a constant price $p^y$. Then, $y^S = (n/m)z$ holds. South recycling activity is described by a recycling function, $r^S(l^S, y^S)$. South firms extract recycled material, $r^S(l^S, y^S)$, from $y^S$, using labor $l^S$. The recycling function of South firms is strictly concave, that is, $r_l^S > 0, r_y^S > 0, r_{ll}^S < 0, r_{yy}^S < 0, r_{ll}^S r_{yy}^S - (r_{ly}^S)^2 > 0$ and $r_{ly}^S = r_{yl}^S > 0$.

Because of inadequate administrative capacities of the South government, it cannot impose a fine for illegal dumping of the residuals or a tax on final disposal of waste. South firms can dispose the residual without a cost or fine. We assume that the South government can introduce only two policy instruments in order to alleviate environmental damage by final disposal of waste and illegal dumping after recycling.

First, the South government subsidizes the residual, $y^S - r^S(l^S, y^S)$, after recycling it at the subsidized rate, $\tau^S$. Because there is no fine for illegal dumping in South, when $\tau^S = 0$, South firms freely dispose the residuals. Let $\bar{l}_S$ and $\bar{y}_S$ be the business as usual, with labor input and waste product purchased by the representative South firm

when $\tau^S = 0$, respectively. If $\tau^S = 0$, the firm recycles $\bar{r}^S = r^S(\bar{l}^S, \bar{y}^S)$ to extract recycling resources but disposes the rest, $\bar{y}^S - \bar{r}^S$, which is the amount of the residuals without a policy. When $\tau^S > 0$, the South firm receives the subsidy, $\tau^S((\bar{y}^S - \bar{r}^S) - (y^S - r^S(l^S, y^S)))$. For simplicity, the South government properly disposes $y^S - r^S(l^S, y^S)$.

Second, the South government introduces a tariff on a waste product imported from North with the tariff rate, $\sigma^y$. An South firm's profit is written as follows:

$$\pi^S = qr^S(l^S, y^S) - w_S l^S - (p^y + \sigma^y) y^S + \tau^S((\bar{y}^S - \bar{r}^S) - (y^S - r^S(l^S, y^S))). \quad (5)$$

The first-order conditions are

$$qr_l^S = w_S - \tau^S r_l^S, \quad (6)$$

$$qr_y^S = p^y + \sigma^y + \tau^S(1 - r_y^S). \quad (7)$$

In (6) and (7), the marginal revenue of each input equals the marginal cost including the tariff and subsidy.

1.3 Welfare

Let $P(Q)$ be the demand function of the product in North, where $Q = nf(L^N, K^N)$. We assume that $P'(Q) < 0$. North welfare is defined as

$$W^N = \int_0^{nf(L,K)} P(Q)dQ - nw_N(L^N + l^N) - np^k K^N + nqr^N(l^N, f(L^N, K^N) - \frac{m}{n} y^S)$$

$$- nc(f^{N,i}(L^N, K^N) - \frac{m}{n} y^S) - D_N(nf(L^N, K^N) - nr^N(l^N, f(L^N, K^N) - \frac{m}{n} y^S) - my^S), \quad (8)$$

where $D_N(\cdot)$ is the environmental cost associated with residuals in North . South welfare is defined as

$$W^S = m(qr^S(l^S, y^S) - p^y y^S - w_S l^S)$$
$$- \rho D_{S,ILL}(my^S - mr^S(l^S, y^S)) - (1-\rho) D_S(my^S - mr^S(l^S, y^S)), \quad (9)$$

where $D_{S,ILL}(\cdot)$ is environmental cost when the residuals are illegally disposed and $D_S(\cdot)$ is environmental cost when the residuals are properly disposed by the South

government. The later includes the government's disposal cost. The parameter $\rho$ denotes whether illegal dumping has taken place. If the South firm engages in illegal dumping, then $\rho = 1$. Otherwise, $\rho = 0$. To account for the difference of pollution abatement technology between North and South, and the difference of pollution between legal and illegal disposal in South, we presume that $D_N(u) < D_S(u) < D_{S,ILL}(u)$ and $D'_N(u) < D'_S(u) < D'_{S,ILL}(u)$ for all $u$.

## 2. Results

### 2.1 Closed North economy case: Trade liberalization of waste products

As a benchmark, we consider the case where production as well as recycling is carried out in North and no waste-product trade takes place between the two countries. A simple calculation yields a standard Pigovian tax,

$$t^{NC} = D'_N(ny^{NC} - nr^{NC}),$$

where $y^{NC}$ and $r^{NC}$ are the corresponding production and recycled material in North.

What happens when waste product is traded? An increase in $y^S$ must raise the North firm's profit due to a drop in collection and recycling cost, which in turn, may result in an increase in output. Therefore, waste product leakage into South causes the *output enhancing effect*, $dx/dy^S > 0$, and the *recycling damping effect*, $dy^N/dy^S < 0$. One or both effects may occur. This depends on the curvatures of production and recycling functions.

Needless to say, if $D'_S(0)$ is extraordinary large, the closed North economy is the first best. If so, the first best policy set includes a Pigovian tax in North and a ban of the waste-product trade. This is an uninteresting case because the international waste-trade problem has vanished. Therefore, we presume that the closed North economy cannot be the first best.

### 2.2 The first best case

In the first best case, we consider a policy that maximizes the joint welfare, $W = W^N + W^S$. To avoid illegal dumping in South, we assume a positive value of $\tau^S$. Therefore, the joint welfare to be maximized is

$$W = \int_0^{nf(L,K)} P(Q)dQ - nw_N(L^N + l^N) - np^k K^N + nqr^N(l^N, f(L^N, K^N) - \frac{m}{n} y^S)$$

$$- nc(f^{N,i}(L^N, K^N) - \frac{m}{n} y^S) - D_N(nf(L^N, K^N) - nr^N(l^N, f(L^N, K^N) - \frac{m}{n} y^S) - my^S)$$

$$+ m(qr^S(l^S, y^S) - p^y y^S - w_S l^S) - D_S(my^S - mr^S(l^S, y^S)). \quad (10)$$

Maximizing with respect to $L^N, l^N, K^N, l^S, y^S$ yields the following first-order conditions:

$$P^E f_L^N = w_N - qr_z^N f_L^N + cf_L^N + D'_N(f_L^N(1 - r_z^N)), \quad (11)$$

$$P^E f_K^N = p^K - qr_z^N f_K^N + cf_K^N + D'_N(f_K^N(1 - r_z^N)), \quad (12)$$

$$qr_l^N = w_N - D'_N r_l^N, \quad (13)$$

$$qr_y^S = p^y + qr_y^N - c - D'_N(1 - r_y^N) + D'_S(1 - r_y^S), \quad (14)$$

$$qr_l^S = w_S - D'_S r_l^S, \quad (15)$$

where $P^E$ satisfies the market-clearing price for the product market in North. Equations (11) to (15) state that the marginal social benefit should equal the marginal social cost. For example, the value of marginal product of labor equals the sum of wages, marginal collecting cost, and marginal environmental damage, minus the value of marginal recycled material. Combining the above welfare maximization with the profit-maximizing first-order conditions, we obtain the following tax-subsidy rates:

$$t^{N**} = D'_N(y^{N**} - r^{N**}), \quad (16)$$

$$\tau_S^{**} = D'_S(y^{S**} - r^{S**}), \quad (17)$$

$$\sigma^{**} = qr_y^{N**} - c - (1 - r_y^{N**})D'_N(y^{N**} - r^{N**}), \quad (18)$$

where "**" denotes tax and subsidy rates on the first best case, and $r_y^{N**} = r_y^N(l^{N**}, y^{N**})$. Obviously, $t^{N**}$ and $\tau_S^{**}$ are the Pigovian tax and subsidy in North and South, respectively. The absolute value of $\sigma^{**}$ is the marginal social cost of one unit of waste product, which equals the sum of the marginal environmental damage and the collection cost, minus the revenue from the recycled material sold. If the sign of $\sigma^{**}$ is positive, an additional one unit of waste product generates positive social benefit. This cannot occur at the optimum level. The sign of $\sigma^{**}$ should be negative. The negative import tariff seems to be irregular; however, it is required to adjust the difference of marginal social costs between the two countries. Furthermore, if this

negative import tariff is absent, North firms produce less than the optimum because of burden of waste tax. A part of the subsidy in South, $m\tau_S^{**}(y^{S**}-r^{S**})$ may be financed by the tax revenue, $nt^{N**}(z^{N**}-r^{N**})$, in North.

2.3 Strategic case

In a strategic case, each country's government maximizes its own welfare and does not take into account a spillover effect to the foreign country. The first-order conditions of welfare maximization in North are

$$Pf_L = w_N - qr_z^N f_L + cf_L + D'_N(f_L(1-r_y^N)), \tag{19}$$

$$Pf_K = p^K - qr_y^N f_K + cf_K + D'_N(f_K(1-r_y^N)), \tag{20}$$

$$qr_l^N = w_N - c - D'_N r_l^N, \tag{21}$$

Combining the above welfare maximization with the profit-maximizing first-order conditions for North, we obtain the following strategic tax rate.

$$t^{N*} = D'_N(ny^{N*} - nr^{N*}) \tag{22}$$

"*" denotes tax and subsidy rates in the strategic case. The first-order conditions of welfare maximization in South are

$$qr_l^S = w_S - D'_S r_l^S, \tag{23}$$

$$qr_z^S = p^y + D'_S(1-r_y^S). \tag{24}$$

Combining the above welfare maximization with the profit-maximizing first-order conditions for South, we obtain the following strategic subsidy and tariff rates:

$$\tau_S^* = D'_S(my^{S*} - mr^{S*}), \tag{25}$$

$$\sigma^* = 0. \tag{26}$$

Note that South must finance $m\tau^S((\bar{y}^S - \bar{r}^S) - (y^S - r^S))$ to subsidize firms.

Proposition 1 The amount of waste product imported by South in the first best case is greater than that in the strategic case.

Proof

Applying Cramer's rule to (6) and (7), we obtain

$$\frac{dy^S}{d\sigma^y} = \frac{\begin{vmatrix} \pi^S_{ll} & 0 \\ \pi^S_{ly} & 1 \end{vmatrix}}{\begin{vmatrix} \pi^S_{ll} & \pi^S_{ly} \\ \pi^S_{yl} & \pi^S_{yy} \end{vmatrix}} < 0. \tag{27}$$

The sign of the numerator is negative while that of the denominator is positive because it is the Hessian of the South profit function. Because $\sigma^* = 0 > \sigma^{**}$, we conclude that $y^*_S < y^{**}_S$. QED

Note that the results of the strategic case are identical to the Stackelberg case in which North is the leader and South is the follower because the demand of South for the waste product is not affected by North actions. This is determined by the marginal recycling values of waste and labor in South.

Again applying Cramer's rule to (6) and (7), we obtain

$$\frac{dl^S}{dw_S} = \frac{\begin{vmatrix} 1 & \pi^S_{ly} \\ 0 & \pi^S_{yy} \end{vmatrix}}{\begin{vmatrix} \pi^S_{ll} & \pi^S_{ly} \\ \pi^S_{yl} & \pi^S_{yy} \end{vmatrix}} < 0, \tag{28}$$

$$\frac{dy^S}{dw_S} = \frac{\begin{vmatrix} \pi^S_{ll} & 1 \\ \pi^S_{ly} & 0 \end{vmatrix}}{\begin{vmatrix} \pi^S_{ll} & \pi^S_{ly} \\ \pi^S_{yl} & \pi^S_{yy} \end{vmatrix}} < 0, \tag{29}$$

We state the following proposition.

Proposition 2 An increase in the wage rate of South decreases labor and waste product demand, and then improves South environment in both strategic and first best cases.

2.4 Selfish policy in North and no policy in South

We assume that the South government does not implement an environmental or trade policy due to its administrative limitations—a valid assumption for least developing countries. Therefore, only the North government implements policies. In this and the

next subsection, the residuals after recycling in South are exclusively disposed by illegal dumping. Hence, environmental damage in South is given by $D_{S,ILL}(\cdot)$ and the parameter is set by $\rho = 1$. In this subsection, we consider that the North government is selfish and maximizes its own welfare. This case is the same as the closed economy case except that the waste product is exported to South. The North government implements the Pigovian tax, $t^{NSelf} = D'_N(ny^{NSelf} - nr^{NSelf})$. "NSelf" denotes the selfish North government. In this case, the first-order conditions of the South firm are rewritten as

$$qr_l^S = w_S, \tag{30}$$

$$qr_y^S = p^y. \tag{31}$$

Due to the lack of subsidy, the South environment deteriorates due to the illegal dumping of residuals.

2.5 Benevolent policy in North and no policy in South

This subsection considers the North government as benevolent and the South government remains with no policy. Due to the absence of a policy in South, the value of marginal recycling of labor should equal the South wage rate. Then the North government should solve the following constrained maximization problem,

$$\text{Max} \quad W + \lambda(w_S - qr_l^S), \tag{32}$$

where $\lambda$ is a Lagrange multiplier. The first-order conditions on $L^N, K^N, l^N$ are the same as the non-constrained case. The rest of the first-order conditions on South follows:

$$qr_l^S - \frac{\lambda}{m} qr_{ll}^S = w_S - r_l^S D'_{S,ILL}(my^{S,NBenev} - mr^{S,NBenev}), \tag{33}$$

$$qr_y^S - \frac{\lambda}{m} qr_{ly}^S = p^y - [c + (1 - r_y^N) D'_N(ny^{NBenev} - nr^{NBenev}) - qr_y^N]. \\ + (1 - r_y^S) D'_{S,ILL}(my^{S,NBenev} - mr^{S,NBenev}) \tag{34}$$

"NBenev" denotes the benevolent North government case. $\lambda$ is marginal welfare by an additional increase in South wage rate. Equations (33) and (34) indicate that the marginal social benefit equals the marginal social cost. In (33), the left-hand side

represents the marginal social benefit of the labor of South, which comprises the marginal recycling value of labor and its marginal increase of labor in the optimum. The right-hand side represents the marginal social cost, which is South wage rate minus the marginal environmental damage caused by the additional recycling labor. In (34), the left-hand side represents the marginal social benefit of the waste product in South, which comprises the marginal recycling value of waste product and its marginal increase of recycling labor productivity caused by the additional waste product in the optimum. The right-hand side represents export cost, alleviated marginal social cost in North[5], and marginal environmental damage caused by the additional waste product. Because of the constraint, $w_S = qr_l^S$, (33) is reduced to $(\lambda / m)qr_{ll}^S = r_l^S D'_{S,ILL}$. Then,

$$\lambda = \frac{mD'_{S,ILL} r_l^S}{qr_{ll}^S}. \tag{35}$$

The sign of $\lambda$ is negative. We state the following proposition.

Proposition 3 If the North government is benevolent, an increase in the wage rate of South reduces the sum of the welfares of North and South on account of added recycling in South.

The reason behind Proposition 3 is that the benevolent North government chooses its policy based on the amount of recycling labor available in South dependent on South wage rate. A rising South wage rate provokes additional labor in recycling activity in South and, in turn, causes more extensive illegal dumping.

We assume that $D'_{S,ILL}(\cdot)$ is sufficiently large in the range considered; therefore, the sign of $-[c+(1-r_y^N)D'_N - qr_y^N]+(1-r_y^S)D'_{S,ILL}+(\lambda/m)qr_{ly}^S$ which is obtained after some manipulation of (34) is positive. Consider that the benevolent North government introduces an export tax on waste products[6]. Let $T^{NBenev}$ be the export tax rate on waste

[5] The square bracket in the right-hand side in (34) represents the marginal social cost of waste product in North. It is alleviated through an additional waste product from North to South. It is reasonable to presume that the sign of the square bracket is positive.

[6] We allow the possibility that trade on waste product is illegal, and in violation of the

products to South. By (34), the optimal $T^{NBenev}$ is given by

$$T^{NBenev} = -[c + (1 - r_y^{NBenev})D'_N - qr_y^{NBenev}] + (1 - r_y^{S,NBenev})D'_{S,ILL} + \frac{\lambda}{m} qr_{ly}^{S,NBenev} \tag{36}$$

where $r_y^{NBenev} = r_y^N(l^{NBenev}, y^{NBenev})$, $r_y^{S,NBenev} = r_y^S(l^{S,NBenev}, y^{S,NBenev})$, and $r_{ly}^{S,NBenev}(l^{S,NBenev}, y^{S,NBenev})$. The benevolent North government controls waste products by its export tax together with the usual Pigovian tax within the country.

$$t^{NBenev} = D'_N(y^{NBenev} - r^{NBenev}). \tag{37}$$

3. Discussion

Table 1 summarizes the tax-subsidy system for the five scenarios. Only the first best outcome needs a negative tariff for the import of waste products to South. In the strategic government case, one problem is that the South government must finance the subsidy. In the selfish North government case, North benefits by avoiding collection and recycling costs by outflow of waste into South. The South environment, however, would enormously deteriorate due to the absence of a policy. Considering the responsibility of developed countries, when South implements no policy, the North government should adopt the benevolent policy that contains the export tax to curb the inflow of waste products to South.

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Basel Convention up to here. However, when the export tax on waste product is considered, we assume that trade on waste product is legal.

Table 1 Tax-subsidy systems for five scenarios

| Scenario | Government | Optimal policy |
|---|---|---|
| Closed economy | North is a closed economy. South is no activity. | $t^{NC} = D'_N(ny^{NC} - nr^{NC}) > 0$<br>$\tau_S^{NC} = \sigma^{NC} = 0$ |
| First best | Social planner maximizes the sum of North and South welfares. | $t^{N**} = D'_N(ny^{N**} - nr^{N**}) > 0$<br>$\tau_S^{**} = D'_S(my^{S**} - mr^{S**}) > 0$<br>$\sigma^{**} = qr_y^{N**} - (1 - r_y^{N**})D'_N(ny^{N**} - nr^{N**})$<br>$-c < 0$ |
| Strategic governments | Each government maximizes their own welfare. | $t^{N*} = D'_N(ny^{N*} - nr^{N*}) > 0$<br>$\tau_S^{*} = D'_S(my^{S*} - mr^{S*}) > 0$<br>$\sigma^{*} = 0$ |
| Selfish North government | North government maximizes own welfare. South has no policy. | $t^{NSelf} = D'_N(ny^{NSelf} - nr^{NSelf}) > 0$<br>$\tau_S^{NSelf} = \sigma^{NSelf} = 0$ |
| Benevolent North government | North government maximizes the joint welfare. South has no policy. | $t^{NBenev} = D'_N(ny^{NBenev} - nr^{NBenev}) > 0$<br>$T^{NBenev} = -(c + (1 - r_y^{NBenev})D'_N(ny^{NBenev} - nr^{NBenev}) - qr_y^{NBene})$<br>$+ (1 - r_y^{S,NBenev})D'_{S,ILL}(my^{S,NBenev} - mr^{S,NBenev}) + \frac{\lambda}{m} qr_{ly}^{S,NBenev} < 0$<br>$\tau_S^{NBenev} = \sigma^{NBenev} = 0$ |

4. Conclusions

This paper presents a model of waste product trade between a developed and a developing country. We find that the negative import tariff is required to adjust the difference of marginal social costs between the two countries in the first best case. If the North government is selfish, North benefits by avoiding collection and recycling costs by outflow of waste into South. In this case, if possible, the South government should subsidize the residual after recycling to prevent the illegal dumping. If the North government is benevolent and the South has no policy, the North government should impose an export tax on waste products to South to curb environmental damage resulting from the illegal dumping in South together with the domestic Pigovian tax.

In our model, the North government and firms cannot observe whether the waste products exported are properly disposed of in South. If a traceability system of waste flow is available in both countries, improper recycling in South can be controlled with more effective policy instruments.

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