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A Note on Trade Liberalization, Public Abatement and Welfare

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Abstract: This paper extends Haibara (2006) in order to focus on the welfare consequences of foreign aid and pollution taxes in the context of trade liberalization and public abatement. The main finding is that trade liberalization achieved by a tariff reduction increases, under certain conditions, the optimal value of foreign aid and pollution taxes. This implies that trade liberalization is compatible with environmental protection achieved through pollution taxes and foreign aid, given the existence of public abatement.

1. Introduction

In the case of environmental protection, it is widely known that both the private and public sectors undertake pollution abatement activities. In this context, pollution abatement undertaken by the private sector is called as private abatement, while that undertaken by the public sector is known as public abatement[1]. Notable examples of these activities are the environmental funds established by some transition economies in Central and Eastern Europe. Accordingly, the OECD (1995) shows that the governments in these countries impose various environmental charges on the private sector in order to reduce pollution emissions generated by that sector (i.e., private abatement), and the revenues accrued are used for environmental protection activities, including pollution abatement undertaken by the public sector (i.e., public abatement).

In terms of public abatement, the share of public abatement compared with private abatement varies by country depending on the type of pollution emission. However, in some cases public abatement plays a dominant role in pollution abatement activities. For example, a recent survey conducted by the OECD (1996) and Hatzipanayotou *et al.* (2003) both found that the share of public expenditure in water pollution abatement expenditure is 66% in the USA in the early 1990s, while the share of public expenditure in air pollution abatement expenditure is 55% in the Netherlands. This implies that the role of public abatement cannot be ignored in terms of overall pollution abatement activities.

Turning to the literature concerned with public abatement, some researchers have focused on public abatement in an international trade context. In particular, Khan (1995) introduces public abatement and analyzes the welfare consequences of trade liberalization. Chao and Yu (1999) introduce public abatement within a foreign aid framework and derive the conditions for welfare enhancement of both the donor and the recipient when foreign aid is tied to public abatement activities in the recipient. Hatzipanayotou *et al.* (2002) assume that pollution emissions affect both the donor and the recipient (i.e., cross-border pollution), and analyze the welfare consequences of foreign aid tied to public abatement in the recipient. They also derive the conditions where an increase in the perception of cross-border pollution by the donor increases the optimal amount of foreign aid. Hatzipanayotou *et al.* (2003, 2005) address a number of comprehensive environmental policy reforms, including a change in pollution taxes, and obtain the welfare enhancement conditions with the existence of public abatement and cross-border pollution.

Reflecting upon these past studies, one may observe that very few have focused on trade policies in the context of public abatement, although there is an abundance of literature concerned with trade policies and the environment (see, for example, Markusen 1975, Merrifield 1988, Copeland 1994, 1996, Antweiler *et al.* 2001, Copeland and Taylor 2003). In particular, Khan (1995) analyzes the effects of trade liberalization on welfare under the existence of public abatement. However, his analysis lies in a somewhat extreme setting such that pollution abatement is undertaken only by the public sector. As discussed, both

[1] See Hatzipanayotou *et al.* (2003).

the private and public sectors abate pollution and therefore focusing on only private abatement is rather unrealistic. Haibara (2006) remedies this deficiency and deals with both private and public abatements in the context of trade liberalization. He shows the effects of trade liberalization on public abatement and welfare when governments undertake public abatement using pollution taxes and/or tariff revenues. In this analysis, he provides an important caveat concerning the harmonization of trade liberalization and environmental protection such that trade liberalization may actually increase pollution emissions when governments undertake public abatement.

Nevertheless, a number of tasks remain regarding the analysis first demonstrated by Haibara (2006). To start with, Haibara (2006) does not analyze the welfare consequences of pollution taxes and foreign aid given the existence of cross-border pollution as in Hatzipanayotou *et al.* (2002). In particular, a pollution tax is the first-best environmental policy and its revenue is earmarked for the financing of public abatement. Hence, ignoring a change in the tax is not satisfactory in terms of environmental protection. Also, foreign aid is worth analyzing for environmental protection in a global context because foreign aid tied to public abatement is conducive to reducing the spread of global pollution.

With these remarks in mind, this paper extends the analysis provided by Haibara (2006) so that we can examine the welfare consequences of pollution taxes and foreign aid in the context of trade liberalization. This analysis is meaningful from the societal point of view. That is, the harmonization of trade liberalization and environmental protection is one of the central themes in globalization. Therefore, addressing it in terms of foreign aid can yield useful insights regarding international cooperation to enhance free trade and environmental protection. Also, the results obtained in this paper can provide various policy implications for countries where governments intend to implement trade liberalization and where environmental protection is undertaken through both private and public abatements.

The remainder of this paper is structured as follows. Section 2 presents the model. Section 3 analyzes the welfare consequences of tariffs, foreign aid and pollution taxes. Section 4 shows the effects of a tariff on the optimal value of foreign aid and pollution taxes. Section 5 concludes the paper.

2. The model

We assume two small open economies exist in the world: a developed donor and a developing recipient[2], each of which produces two internationally tradable goods, Good x and Good y. Good x is an importable good, while Good y is an exportable good in both countries[3]. In the recipient country we assume that the production of Good x is protected by a tariff, and the production of that good generates pollution emissions. However, in the donor country, the production of Good x is not protected and it does not generate pollution emissions. Those assumptions appear to be plausible where developing countries tend to protect an

[2] The model is similar to Hatzipanayotou *et al.* (2002).

[3] Both countries do not necessarily trade with each other. Each of them trades their goods with the rest of the world by exogenously determined international commodity prices.

importable good that sometimes generates pollution emissions. The pollution harms household utility in both countries (i.e., cross-border pollution). To abate pollution, the government in the recipient country increases pollution taxes or reduces tariffs on the private sector so that the private sector reduces output (i.e., private abatement). Another way of abating pollution is where the government in the recipient country provides pollution abatement (i.e., public abatement) imported from abroad[4]. In this context, the cost of public abatement is financed by revenue from pollution taxes, and foreign aid provided by the developed donor. The production side of the recipient can be characterized by the following revenue function.

$$R(p,t,v) = \max_{x,y,z}\{px + y - tz : (x,y,z) \in T(v)\}$$

where p denotes the domestic relative price of Good x in terms of Good y, x and y are the respective outputs of Good x and Good y, z is the amount of pollution emissions generated from the production of Good x, t denotes the pollution tax rate, v denotes private factors used for the production of the private goods, and $T(v)$ is the country's technology set. Since we assume that the production of Good x is protected by a tariff in the recipient country, a wedge arises between the international relative price of Good x and the domestic relative price of Good x such that $p = p^* + s$, where p^* denotes the exogenously determined international relative price of Good x and s denotes the tariff rate. Regarding the expression of the revenue function, v does not vary in this paper and hereafter we reduce the expression of the revenue function to $R(p,t)$ for the sake of notational simplicity. The usual properties of a revenue function prevails such that $R_p = x, R_{pp} = \partial x / \partial p > 0$. Also, we have

$$R_t(p,t) = -z. \qquad (1)$$

Equation (1) indicates the pollution equation. From the equation, one observes the usual assumption $R_{tt} = -\partial z / \partial t > 0$, which implies that an increase in the pollution tax rate can reduce pollution emissions. This can be thought of as private abatement undertaken by the private sector. We also assume that $R_{tp} = -\partial z / \partial p < 0$, which implies that an increase in the relative price of Good x raises pollution emissions generated from the production of Good x. That is, an increase in the domestic relative price of Good x can increase the production of Good x, thereby increasing the amount of pollution emissions. Hence, an increase in the domestic relative price of Good x obtained by raising tariffs increases pollution. The opposite case also holds true where a reduction in the price of Good x by reducing a tariff (i.e., trade liberalization) leads to lower pollution emissions.

Turning to the demand side, the following expenditure function shows the consumption activities of recipient households.

[4] The government in the recipient country does not import public abatement from the developed donor, rather from the rest of the world. This assumption is shown in Hadjiyiannis *et al.* (2002), and Hadjiyiannis *et al.* (2004).

$$E(p, r, u) = \min_{C_x, C_y} \{pC_x + C_y : u(C_x, C_y, r) \le \bar{u}\}$$

where C_x and C_y denote the compensated demands of Good x and Good y, respectively, and $r = z - g$ denotes the net amount of pollution emissions that the households of the recipient receive. Note that g denotes the amount of public abatement imported from abroad. Regarding the expenditure function, it is commonly known that $E_p = C_x, E_{pp} < 0$, and $E_u > 0$, where E_u is the reciprocal of the marginal utility of income. Also, it is usual to assume $E_z > 0$, which is commonly thought of as the marginal damage of pollution. In this regard, pollution emissions harm the utility of households, and thus households should increase their expenditure so as to maintain constant utility. In this sense, $E_z > 0$ is thought of as the marginal willingness to pay for a reduction in pollution (see Copeland 1994).

The recipient's budget constraint can be expressed as follows.

$$E(p, r, u) = R(p, t) + (1 - \alpha)tz + (1 - \beta)T + sM_p(p, r, t, u) \qquad (2)$$

where $M_p = E_p - R_p > 0$ denotes the amount of imports of Good x into the recipient. Hence sM_p represents tariff revenue returned to households of the recipient. Regarding the right-hand side of equation (2), the first term $R(p, t)$ indicates factor income from private production of Good x and Good y, the second term $(1 - \alpha)tz$ indicates the pollution tax revenue returned to households, and the third term $(1 - \beta)T$ indicates foreign aid provided to the households of the recipient from the donor. In this context, one should recall the assumption that the recipient imports public abatement from abroad and its cost is financed by revenue form pollution taxes and foreign aid. Hence, α fraction of pollution tax revenue and β fraction of foreign aid is earmarked for the financing of public abatement. With this in mind, the budget constraint of public abatement in the recipient can be written as

$$P_g g = \alpha tz + \beta T \qquad (3)$$

where P_g represents the exogenously determined international price of public abatement.

Turning to the developed donor, the economy's budget constraint can be expressed as

$$E^*(\theta r, u^*) = R^* - T \qquad (4)$$

where θ stands for the perceived degree of cross-border pollution by the developed donor (see Hatzipanayotou *et al.* 2002) and T denotes the amount of foreign aid transferring to the recipient.

From equations (1)–(4), one can examine the change in four endogenous variables, z, g, u, and u^*, by altering exogenous policy variables T, t, and s. The next section exhibits the results obtained by comparative statics.

3. Welfare analysis

In this section, we analyze the welfare consequences of a tariff, pollution taxes, and foreign aid. The results obtained by comparative statics show (see appendix A)

$$\Delta du = E_u^*[A_s ds + A_T dT + A_t dt]$$
$$\rightarrow P_g(E_u - sE_{pu})du = A_s ds + A_T dT + A_t dt \quad (5)$$

$$\Delta du^* = (E_u - sE_{pu})[B_s ds + B_T dT + B_t dt]$$

$$\rightarrow P_g E^*_u du^* = B_s ds + B_T dT + B_t dt \quad (6)$$

where $E_u - sE_{pu} > 0, \Delta = P_g E_u^*(E_u - sE_{pu}) > 0$

$A_s = [P_g(E_r - t)R_{tp} + \alpha t R_{tp}(P_g - E_r) + sE_{pr}R_{tp}(\alpha t - P_g) + P_g sM_{pp}]$ $A_T = [P_g(1-\beta) + \beta(E_r - sE_{pr})]$

$A_t = P_g[(\alpha t R_{tt} - \alpha z) - sR_{pt} + (E_r - t - sE_{pr})R_{tt}] + (\alpha z - \alpha t R_{tt})(E_r - sE_{pr})$, $B_s = \theta E_r^* R_{tp}(P_g - \alpha t)$

$B_T = (\theta E_r^* \beta - P_g)$, $B_t = \theta E_r^*(R_{tt}P_g + \alpha z - \alpha t R_{tt})$.

To facilitate the welfare analysis, we examine the net amount of pollution change as

$$P_g dr = R_{tp}(\alpha t - P_g)ds - \beta dT + (\alpha t R_{tt} - \alpha z - P_g R_{tt})dt. \quad (7)$$

Regarding equation (7), the change in the net amount of pollution by a tariff $P_g dr = R_{tp}(\alpha t - P_g)ds$ is, in general, ambiguous. Consider, for example, if the government reduces the tariff rate (i.e., $ds < 0$) for the purposes of trade liberalization and environmental protection, the amount of pollution generated from the production of Good x declines because of a reduction in the output of Good x. This effect is the private abatement effect (see Haibara 2006). By contrast, the public abatement effect arises through an increase in the tariff rate. That is, a reduction in pollution reduces the pollution tax revenue earmarked for the financing of public abatement, and therefore lowers public abatement. The relative strength of these opposing effects can determine the change in the net amount of pollution emissions. In this regard, when the pollution tax rate t is substantially small such that $P_g > \alpha t$, the net amount of pollution emissions decline as a result of reducing a tariff . The reason behind this is that when the pollution tax rate is small, a reduction in the tax base of public abatement is so negligible that the public abatement effect, which causes a negative impact on pollution abatement, can be dominated by the private abatement, which causes a positive impact on pollution abatement. Turning to the effects of foreign aid on the net amount of pollution emissions $P_g dr = -\beta dT$, it is obvious that an increase in foreign aid provided by the developed donor can lower the net amount of pollution. It is straightforward enough to understand that foreign aid is provided for the financing of public abatement and that an increase in foreign aid can thus raise public abatement, thereby reducing the net amount of pollution emissions.

The effects of an increase in pollution taxes by the recipient government on the net amount of pollution emissions $P_g dr = (\alpha z - \alpha t R_{tt} - P_g R_{tt})dt$ are also, in general, ambiguous. As with tariffs, two opposing effects arise. These are a private abatement effect and a public abatement effect. First, the private abatement effect prevails such that an increase in the pollution tax rate reduces pollution emissions generated from the production of Good x, $R_{tt} = -\partial z / \partial t > 0$. Second, the public abatement effect prevails such that a reduction in pollution emissions obtained by increasing pollution taxes reduces the pollution tax revenue earmarked for the financing of public abatement, and as a result, public abatement declines. Hence, the change in the net amount of pollution by pollution taxes is ambiguous. One way to reconcile this ambiguity is to suppose that the elasticity of pollution with respect to the pollution tax rate is equal to unity $\varphi = -tR_{tt} / R_t = 1$[5]. We can then simplify the net pollution change as $P_g dr = -R_{tt} dt$. In these circumstances, the public abatement effect vanishes by increasing pollution taxes. The reason behind this is that when the elasticity of pollution with respect to the pollution tax rate is unity, the tax base of public abatement (i.e., earmarked pollution tax revenue) vanishes. Namely, an increase in pollution taxes can increase pollution tax revenue because the tax rate is higher than before, whereas an increase in pollution taxes lowers pollution tax revenue because the amount of pollution declines. In this context, when the elasticity is equal to unity, these opposing effects offset each other as $z - tR_{tt} = 0$. Hence, the tax base of public abatement vanishes and the change in pollution taxes cannot affect public abatement such that $\Delta^{-1} dg / dt = \alpha(z - tR_{tt}) = 0$. This implies that private abatement is the only form of abatement when we increase pollution taxes under the assumption $\varphi = -tR_{tt} / R_t = 1$.

Turning to the recipient country's welfare, the expression A_s indicates the welfare effects of a tariff. To determine the sign of A_s, we establish the following assumptions such that $E_r > t, P_g > E_r$[6], and $E_{pr} < 0$. Under these assumptions, a reduction in a tariff leads to a welfare improvement in the recipient. As discussed earlier, a reduction in a tariff leads to a decrease in the tax base of public abatement as a result of a reduction in pollution emissions: there is a decline in public abatement. Nevertheless, a reduction in public abatement is not welfare decreasing when public abatement is over-provided in the developing recipient such that $P_g > E_r$, which states the marginal cost of public abatement is higher than the marginal willingness to pay for that good. In addition, the assumptions $E_r > t$ and $P_g > \alpha t$, which can be ensured with small pollution taxes, means that pollution tax revenue loss as a result of a reduction in pollution is dominated by the gains from a reduction in pollution as a result of lowering a tariff (i.e., the private

[5] In this case, we rewrite $z - tR_{tt} = -R_t(1-\varphi)$ and obtain $z - tR_{tt} = 0$ when $\varphi = 1$. Hence, the net amount of pollution emissions can be simplified as $P_g dr = -R_{tt} dt$.

[6] The assumption $P_g > \alpha t$ can be automatically obtained by assuming $P_g > E_r$ and $E_r > t$.

abatement effect). Also the assumption $E_{pr} < 0$, which states that the consumption of Good x is a substitute for pollution, is conducive to a welfare improvement in the recipient by reducing a tariff. In this regard, a reduction in pollution as a result of reducing a tariff increases the consumption of Good x and therefore tariff revenue, thereby increasing the welfare of the recipient. The expression of A_T indicates the effects of foreign aid on the recipient's welfare. It states that an increase in foreign aid from the developed donor can enhance the welfare of the recipient when we assume $E_{pr} < 0$. It seems obvious that an increase in foreign aid can reduce pollution emissions in the recipient because it earmarks foreign aid for the financing of public abatement. In addition, an increase in foreign aid can increase tariff revenue through an expansion of the imports of Good x in the recipient under the assumption $E_{pr} < 0$. Those effects are conducive to the welfare improvement of the recipient as a result of an increase in foreign aid. The expression A_t indicates the effects of pollution taxes on the recipient's welfare. When we assume that the elasticity of pollution with respect to the pollution tax rate is unity, the expression A_t can be simplified as $A_t = P_g[(E_r - t - sE_{pr}) - sR_{pt}]$. From the simplified expression, we can state that an increase in pollution taxes can increase the recipient country's welfare under the assumptions $E_r > t$, $E_{pr} < 0$, and $R_{pt} = \partial x / \partial t < 0$. In this context, we recall equation (7) such that when the elasticity of pollution with respect to the pollution tax rate is equal to unity, the public abatement effect that causes a negative effect on pollution abatement vanishes. Hence, only the private abatement effect arises and this has a positive impact on the recipient's welfare under the familiar assumptions $E_r > t$, $E_{pr} < 0$. Also, a reduction in the output of Good x from raising the pollution tax rate $R_{pt} = \partial x / \partial t < 0$ increases the imports of Good x and therefore tariff revenue, both of which can magnify welfare improvement in the recipient gained by raising pollution taxes.

Turning to the developed donor's welfare, the expression B_s indicates the welfare effects of a tariff on the donor country's welfare. As in the recipient's welfare, when the pollution tax rate t is sufficiently small, $P_g > \alpha t$, then a reduction in a tariff raises the donor country's welfare through a reduction in pollution emissions $P_g dr / ds = (\alpha t - P_g) R_{tp} > 0$. The reason behind this is that when a pollution tax is small, the public abatement effect, which has a negative impact on welfare as a result of a reduction in pollution tax revenue by lowering a tariff, is dominated by the private abatement effect, which has a positive impact on welfare as a result of a reduction in pollution by lowering a tariff.

The expression $B_T = (\theta E_r^* - P_g)/\Delta = \theta E_r^* / \Delta - 1$ represents the welfare effects of foreign aid on the donor country's welfare. Although foreign aid generates an income loss for the donor country, the welfare of the donor country rises because foreign aid can reduce pollution emissions that households in the donor country may otherwise suffer. Hence, when the marginal willingness to pay for a reduction in pollution by the households of the donor country E_r^* is sufficiently high, $\theta E_r^* / \Delta > 1$, an increase in foreign aid can increase the donor country's welfare. The expression B_t represents the effects of pollution taxes on the donor country's welfare. When we invoke the familiar assumption that the elasticity of pollution with respect to the pollution tax rate is equal to unity $\varphi = 1$, the expression of B_t can be simplified as $B_t = \theta E_r^* P_g R_{tt} > 0$, which indicates that the donor country's welfare improves as a result of an increase in pollution taxes achieved by the recipient's government.

4. The effects of a tariff on other policy variables

With these results in mind, we proceed to the next step. That is, as in Hatzipanayotou *et al.* (2002), we attempt to analyze the optimal choice of instruments by the two countries. In doing so, we consider noncooperative strategic behavior in both countries (i.e., Nash equilibrium) such that the donor country optimally chooses the amount of foreign aid (T), while the recipient country chooses the pollution tax rate (t). To this end, from equations (5) and (6), one obtains[7]

$$(E_u - sE_{pu})(du/dt) = A'_t = 0 \qquad (8)$$

$$P_g E_u^* (du^*/dT) = B_T = 0 \qquad (9)$$

where $A'_t = [(E_r - t - sE_{pr}) - sR_{pt}]$, $B_T = \theta E_r^* \beta - P_g$.

Equations (8) and (9) simultaneously determine the optimal values of t and T. In doing so, we totally differentiate as follows.

$$A'_{tt}\, dt + A'_{tT}\, dT = -A'_{ts}\, ds \qquad (10)$$

$$B_{Tt} dt + B_{TT} dT = -B_{Ts} ds \qquad (11)$$

where

$$A'_{tT} = P_g^{-1}\Theta^{-1}R_{tt}[\beta s(E_{rr}E_{pu} - E_{pr}E_{ru}) + \beta E_u E_r r^{-1}(\varepsilon_{ru} - \varepsilon_{rr}) + E_{ru}P_g(1-\beta)]$$

$$A'_{ts} = \Theta^{-1}P_g^{-1}[\alpha t E_{rr}R_{tp}R_{tt}\Theta + P_g R_{tp}(sE_{pu} - r^{-1}R_{tt}E_r\varepsilon_{rr}\Theta)]$$

$$+ \Theta^{-1}P_g^{-1}E_{ru}R_{tt}[P_g(E_r - t)R_{tp} + \alpha t R_{tp}(P_g - E_r) + P_g sM_{pp}]$$

$$+ \Theta^{-1}P_g^{-1}E_u R_{tp}r^{-1}[sE_{pr}\varepsilon_{ru}R_{tt}(\alpha t - P_g) - rP_g],\ A'_{tt} = -R_{tt}(E_{rr}R_{tt} + 1) < 0$$

[7] We assume that $\varphi = 1$ in the derivation of each equation for the sake of simplicity (see appendix B). Also we assume that the third derivatives are zero.

$B_{TT} = -\theta E^*_{rr}\beta^2 P_g^{-1} < 0$, $B_{Ts} = R_{tp}\beta P_g^{-1}\theta E^*_r r^{-1}(P_g - \alpha t)(\theta\varepsilon^*_{ru} - \varepsilon^*_{rr})$, $B_{Tt} = \theta R_{tt}\beta E^*_r r^{-1}(\theta\varepsilon^*_{ru} - \varepsilon^*_{rr})$

where $\Theta = E_u - sE_{pu} > 0$. And let us define $\varepsilon_{ru} = rE_{ru} / E_u > 0$ and $\varepsilon_{rr} = rE_{rr} / E_r > 0$[8] as the recipient's elasticity of the marginal willingness to pay for a reduction in pollution with respect to income and the elasticity of the marginal willingness to pay for reduction in pollution with respect to pollution, respectively. Those of the donor country are $\varepsilon^*_{ru} = rE^*_{ru} / E^*_u > 0$ and $\varepsilon^*_{rr} = rE^*_{rr} / E^*_r > 0$. From equations (10) and (11), one obtains

$$\Phi(dt / ds) = (A'_{ts} B_{Tt} - A'_{tt} B_{Ts}) \tag{12}$$

$$\Phi(dT / ds) = (A'_{tT} B_{Ts} - A'_{ts} B_{TT}) \tag{13}$$

where $\Phi = A'_{TT} B_{tt} - A'_{Ts} B_{ts}$ is the determinant of the matrix of coefficients of dt, dT. The sign of Φ is assumed to be positive. Regarding equation (12), we require the following assumptions in order to determine the sign of the right-hand sides of equations (12) and (13). These are a) $P_g > E_r, E_r > t$, and $E_{pr} < 0$ b) zero or small $\varepsilon_{rr}, \varepsilon^*_{rr}$ c) substantially high $\varepsilon_{ru}, \varepsilon^*_{ru}$, which imply $\varepsilon_{ru} > \varepsilon_{rr}$, $\varepsilon^*_{ru} > \varepsilon^*_{rr}$. Under these assumptions, it is possible to obtain the following inequalities $A'_{tT} > 0$, $A'_{ts} < 0$, $B_{Ts} < 0$, and $B_{Tt} > 0$. Hence, we can derive $dt / ds < 0$ and $dT / ds < 0$. This implies that a reduction in a tariff increases the optimal value of the pollution tax rate (t) and foreign aid (T).

Turning to the change in the net amount of pollution, one obtains

$$dr / ds = \partial r / \partial s + (\partial r / \partial t)(dt / ds) + (\partial r / \partial T)(dT / ds) = -R_{tp} - P_g R_{tt}\Delta^{-1}(dt / ds) - \beta\Delta^{-1}(dT / ds) \tag{14}$$

Regarding equation (14), one has $dr / ds > 0$ when $dt / ds < 0$ and $dT / ds < 0$.
The following proposition summarizes these results.

Proposition. *Suppose that the donor country optimally chooses foreign aid while the recipient country optimally chooses the pollution tax rate*[9]*. In these circumstances, if the following assumptions are established; a)* $P_g > E_r, E_r > t, P_g > \alpha t$ *and* $E_{pr} < 0$; *b)the elasticity of the marginal willingness to pay for a reduction in pollution with respect to utility* $\varepsilon_{ru}, \varepsilon^*_{ru}$ *is large, while that with respect to pollution* $\varepsilon_{rr}, \varepsilon^*_{rr}$ *is zero or small; and c) the elasticity of the pollution tax rate with respect to pollution is unity* $\varphi = 1$, *then a reduction in a tariff reduces the net amount of cross-border pollution through an increase in the amount of foreign aid and the pollution tax rate.*

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[8] We assume that $E_{ru} > 0, E_{rr} > 0$.

[9] Although we assume that the recipient country optimally chooses the tariff rate while the donor country optimally chooses foreign aid, the result is essentially the same as that expressed in the proposition: an increase in the pollution tax rate reduces the optimal value of tariffs and increases foreign aid.

An explanation of the proposition is that a reduction in a tariff in the recipient leads to an increase in the welfare of the recipient when public abatement of the recipient is over-provided $P_g > E_r$, the pollution tax rate is substantially small $E_r > t, P_g > \alpha t$, and the consumption of Good x is a substitute for pollution $E_{pr} < 0$. In these circumstances, the assumption $E_{ru} > 0$ prevails such that the recipient increases the pollution tax rate because an increase in welfare in the recipient raises the recipient's marginal willingness to pay for a reduction in pollution. By contrast, the assumption $E_{rr} > 0$, holds such that the recipient reduces the pollution tax rate by reducing the tariff when the marginal willingness to pay falls as a result of a decrease in pollution emissions. However, when the elasticity of the marginal willingness to pay for a reduction in pollution with respect to pollution ε_{rr} is substantially small, while that with respect to utility ε_{ru} is large, the recipient tends to increase rather than decrease pollution taxes. Analogously, a reduction in a tariff raises the optimal amount of foreign aid if we suppose that $P_g > \alpha t$, and the donor's elasticity of the marginal willingness to pay for a reduction in pollution with respect to utility ε^*_{ru} is large, whereas that with respect to pollution ε^*_{rr} is small. In these circumstances, the welfare of the donor country rises and therefore the donor country tends to increase the amount of foreign aid earmarked for the financing of public abatement in the recipient. With regard to the net amount of pollution emissions, they are reduced by a reduction in a tariff through an increase in foreign aid and the pollution tax rate. These results reveal that the recipient country can harmonize trade liberalization with environmental protection undertaken by both the private and public sectors. Also, the results show that trade liberalization undertaken by the recipient for the purpose of environmental protection can increase foreign aid whose purpose is to protect the environment. In this sense, the international cooperation of environmental protection can be achieved through trade liberalization and foreign aid. These outcomes are not explored in Haibara (2006) in the sense that we show the harmonization of free trade, environmental protection, and foreign aid in the context of two small open economies. Hence, the results described by the proposition extend the analysis demonstrated by Haibara (2006) and show unexplored insights regarding trade liberalization, foreign aid, and environmental protection undertaken by both private and public abatements.

5. Concluding remarks

In this paper, we have addressed environmental protection undertaken by both the private and public sectors and analyzed the welfare consequences of tariffs, pollution taxes, and foreign aid when pollution tax revenue and foreign aid are earmarked for the financing of public abatement. In particular, we show that when the government in the aid recipient earmarks foreign aid and pollution taxes for public abatement, trade liberalization as a result of reducing a tariff increases pollution taxes and foreign aid. This outcome depends on the following assumptions: a) the pollution tax rate is small, public abatement is over- provided, and the consumption of an importable good is a substitute for pollution emissions; b) the elasticity of the marginal willingness to pay for a reduction in pollution with respect to utility is large, while that with respect to pollution is zero or substantially small; and c) the elasticity of pollution with respect to pollution is unity.

The result, which trade liberalization achieved by reducing a tariff increases environmental protection undertaken by both private and public abatements, is applicable to many economies in Central and Eastern Europe, where governments in these countries implement environmental protection undertaken by both private and public abatements, and trade liberalization. In this sense, we can provide useful insights for these countries in order to harmonize trade liberalization with environmental protection undertaken by both private and public abatements. With regard to the developed donor, although an increase in foreign aid generates an income loss, it is beneficial for the donor country to increase the amount of foreign aid as a result of trade liberalization by the recipient. That is, an increase in foreign aid can increase the donor country's welfare as a result of a decrease in pollution emissions that the donor country suffers. In this context, when the donor country's elasticity of the marginal willingness to pay for a reduction in pollution with respect to utility is large, while that with respect to pollution is substantially small, the donor country increases the amount of foreign aid. This result is meaningful from the point of view of international cooperation in the sense that we can harmonize environmental protection achieved through trade liberalization in the recipient with through foreign aid provided by the donor.

Finally, this paper has addressed an interaction between each policy variable by extending the model of Haibara (2006). Nevertheless, we have not examined the effects of the perception of cross-border pollution on foreign aid as addressed by Hatzipanayotou *et al.* (2002). However, we can obtain this by examining the effects of an increase in the perception of cross-border pollution on the optimal value of foreign aid (T), and reproduce the same results obtained by Hatzipanayotou *et al.* (2002). That is, an increase in the perception of cross-border pollution reduces the developed donor country's welfare. To redress its welfare loss, the government of the donor increases the amount of foreign aid earmarked for financing public abatement in the recipient.

Appendix A

Totally differentiate equations (1) and (4) yields,

$$dz = -R_{tp}ds - R_{tt}dt \qquad (A.1)$$

$$[E_u - sE_{pu}]du + [E_r - (1-\alpha)t - sE_{pr}]dz - (E_r - sE_{pr})dg = (1-\beta)dT - (\alpha z + sR_{pt})dt + sM_{pp}ds \qquad (A.2)$$

$$\theta E_r^* dz - \theta E_r^* dg + E_u^* du = -dT - rE_r d\theta \qquad (A.3)$$

$$P_g dg = \alpha t dz + \alpha z dt + \beta dT \qquad (A.4)$$

By substituting equation (A.1) into equations (A.2), (A.3), and (A.4), one has the following matrix.

$$\begin{bmatrix} (E_u - sE_{pu}) & 0 & -(E_r - sE_{pr}) \\ 0 & E_u^* & -\theta E_r^* \\ 0 & 0 & P_g \end{bmatrix} \begin{bmatrix} du \\ du^* \\ dg \end{bmatrix} = \begin{bmatrix} \{[E_r - (1-\alpha)t - sE_{pr}]R_{tp} + sM_{pp}\} \\ \theta E_r^* R_{tp} \\ -\alpha t R_{tp} \end{bmatrix} ds + \begin{bmatrix} (1-\beta) \\ -1 \\ \beta \end{bmatrix} dT$$

$$\begin{bmatrix} \{(\alpha t R_{tt} - \alpha z) - sR_{pt} + (E_r - t - sE_{pr})\} \\ \theta E_r R_{tt} \\ (\alpha z - \alpha t R_{tt}) \end{bmatrix} dt + \begin{bmatrix} 0 \\ -E_r \\ o \end{bmatrix} d\theta \qquad \text{(A.5)}$$

where $\Delta = E_u^*(E_u - sE_{pu})P_g > 0$ is the determinant of coefficient matrix of (A.5). By solving (A.5), one obtains equations (5) ,(6), and (7). In particular, the change in the net amount of pollution emissions can be derived as

$$dr = dz - dg$$

$$dr/ds = dz/ds - dg/ds, \; dr/dt = dz/dt - dg/dt, \; dr/dT = -dg/dT$$

Appendix B

We suppose that $\varphi = 1$ and derive A'_{tT}, A'_{tt}, A'_{ts}, B_{Ts}, and B_{Tt}.

$$A'_{tT} = R_{tt}E_{rr}(dr/dT) + R_{tt}E_{ru}(du/dT)$$

$$= -P_g^{-1}E_{rr}R_{tt}\beta + P_g^{-1}\Theta^{-1}R_{tt}E_{ru}[P_g(1-\beta) + \beta(E_r - sE_{pr})]$$

$$= P_g^{-1}\Theta^{-1}R_{tt}\{E_{ru}[P_g(1-\beta) + \beta(E_r - sE_{pr})] - E_{rr}(E_u - sE_{pu})\beta\}$$

$$= P_g^{-1}\Theta^{-1}R_{tt}[\beta s(E_{rr}E_{pu} - E_{pr}E_{ru}) + \beta E_u E_r r^{-1}(\varepsilon_{ru} - \varepsilon_{rr}) + E_{ru}P_g(1-\beta)] \qquad \text{(B.1)}$$

where $\Theta = (E_u - sE_{pu}) > 0, \varepsilon_{ru} = rE_{ru}/E_u > 0$, and $\varepsilon_{rr} = rE_{rr}/E_r > 0$.

$$A'_{tt} = E_{rr}(dr/dt) - R_{tt} = -R_{tt}(E_{rr}R_{tt} + 1) < 0 \qquad \text{(B.2)}$$

$$A'_{ts} = -R_{pt} + E_{rr}R_{tt}(dr/ds) + E_{ru}R_{tt}(du/ds)$$

$$= -R_{pt} + R_{tt}E_{rr}R_{tp}P_g^{-1}(\alpha t - P_g) + E_{ru}\Theta^{-1}P_g^{-1}R_{tt}[P_g(E_r - t - sE_{pr})R_{tp} + \alpha t R_{tp}(P_g - E_r + sE_{pr}) + P_g sM_{pp}]$$

$$= \Theta^{-1}P_g^{-1}[-R_{pt}(E_u - sE_{pu})P_g + E_{rr}R_{tp}R_{tt}(\alpha t - P_g)\Theta]$$

$$+ \Theta^{-1}P_g^{-1}E_{ru}R_{tt}[P_g(E_r - t)R_{tp} + \alpha t R_{tp}(P_g - E_r) + sE_{pr}R_{tp}(\alpha t - P_g) + P_g sM_{pp}]$$

$$= \Theta^{-1}P_g^{-1}[\alpha t E_{rr}R_{tp}R_{tt}\Theta + P_g R_{tp}(sE_{pu} - r^{-1}R_{tt}E_r\varepsilon_{rr}\Theta)]$$

$$+ \Theta^{-1}P_g^{-1}E_{ru}R_{tt}[P_g(E_r - t)R_{tp} + \alpha t R_{tp}(P_g - E_r) + P_g sM_{pp}]$$

$$+\Theta^{-1}P_g^{-1}E_u R_{tp} r^{-1}[sE_{pr}\varepsilon_{ru}R_{tt}(\alpha t - P_g) - rP_g] \quad \text{(B.3)}$$

$$B_{TT} = \theta E^*_{rr}(dr/dT)\beta = -\theta E^*_{rr}\beta^2 P_g^{-1} < 0 \quad \text{(B.4)}$$

$$B_{Tt} = \beta\theta E^*_{rr}(dr/dt)\beta + \beta\theta E^*_{ru}(du/dt) = -\beta\theta E^*_{rr}R_{tt}\beta + \theta^2 E^*_r E^*_{ru}E_u^{*-1}\beta = \theta R_{tt}\beta E^*_r r^{-1}(\theta\varepsilon^*_{ru} - \varepsilon^*_{rr}) \quad \text{(B.5)}$$

$$B_{Ts} = \beta\theta E^*_{rr}(dr/ds) + \beta\theta E^*_{ru}(du/ds)$$

$$= \theta E^*_{rr}P_g^{-1}R_{tp}(\alpha t - P_g)\beta + \theta E^*_{ru}\theta E^*_r R_{tp}P_g^{-1}(P_g - \alpha t)$$

$$= R_{tp}\beta P_g^{-1}\theta E^*_r r^{-1}(P_g - \alpha t)(\theta\varepsilon^*_{ru} - \varepsilon^*{}_{rr}) \quad \text{(B.6)}$$

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