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Environmental Funds, Public Abatement and Welfare

Takumi HAIBARA

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Takumi Haibara

Graduate School of International Cooperation Studies, Kobe University, 2-1 Rokkodai-cho, Nada-ku, 657-8501, Kobe, Japan

Abstract

We focus on environmental funds aimed at public abatement financed by tax revenue and obtain the result that governments should finance environmental funds with tariff revenue rather than pollution tax revenue in order to increase the funds and welfare when governments increase a pollution tax or reduce a tariff. These results are relevant for countries where an import competing sector protected by a tariff generates pollution emissions and the government seeks the revenues earmarked for the financing of environmental funds. We also show that the optimal pollution tax rate/tariff rate is higher/lower under tariff revenue-financed public abatement than it is under pollution tax revenue-financed public abatement.

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1. **Introduction**

It is well known that the private sector and/or the public sector undertake environmental protection activities such as pollution abatement. These activities are usually financed by specific funds aimed at environmental protection. This fund is commonly thought of as environmental fund. In particular, comprehensive environmental funds (CEF) established in transition economies in Central and Eastern Europe are the notable example of the above mentioned role of environmental funds. Regarding these countries, governments levy various pollution charges on polluting sectors and the accruing revenues are earmarked for the financing of pollution abatement activities such as waste water treatment plants, municipal waste disposal sites, etc[1] (see OECD 1995). These activities are known as public abatement and it has a significant role in pollution abatement activities. According to a recent survey conducted by Hatzipanayotou et al. (2003), the proportion of public expenditure within total expenditure on the abatement of water pollution in the early 1990s in the USA was 66 percent[2]. As for air pollution abatement, the proportions of public abatement in the Netherlands and the UK are 55 percent and 30 percent, respectively.

In the academic literature, there are many studies concerning public abatement, and most use international trade theory (see, for instance, Bovenberg and Ploeg 1994; Khan, 1995; Chao and Yu 1999; and Hatzipanayotou et al., 2002, 2003, 2005). In particular, Chao and Yu (1999) is a pioneering study in that they introduce tax revenue-financed public abatement in a trade theoretical context. They analyze the welfare consequences of foreign aid when the aid recipient country finances public abatement with pollution taxes and foreign aid. Hatzipanayotou et al. (2002) show the welfare effects of foreign aid in the presence of cross-border pollution when the recipient government adopts public abatement activities financed by foreign aid and pollution taxes. The result indicates that an increase in the perception of cross-border pollution by the donor increases the optimal amount of foreign aid. Hatzipanayotou et al. (2003, 2005) examine comprehensive environmental policy reforms including a change in the pollution tax rate and derive the necessary and sufficient conditions for welfare improvement by the reform in the presence of pollution tax revenue-financed public abatement. Reflecting upon these studies, it is commonly assumed that pollution tax revenue is earmarked for the financing of public abatement. Understandably, this assumption comes from the conventional notion that the purpose of pollution taxes is to ensure environmental protection, and thus pollution tax revenue tends to be used for environmental protection activities. Yet, strong reliance on pollution taxes to finance public abatement activities comes with one important caveat. That is, a reduction in private outputs, and thereby pollution emissions as a result of an increase in pollution taxes (i.e., private abatement) leads to a decrease in pollution tax revenue because the tax base depends primarily on the amount of pollution emissions. Consequently, as the amount of emissions declines, the tax base is eroded, undermining further public abatement activities. This implies that private abatement undertaken by the private sector would be incompatible with public abatement undertaken by the public sector, if the accruing revenues from pollution taxes are earmarked for the financing of public abatement. This is a very serious concern for countries where pollution abatement is undertaken by both the private and public sectors (e.g., Central and Eastern Europe)[3]. In this context, Haibara (2006) examines tariff revenue-financed public abatement and analyzes the welfare consequences of a tariff. Haibara opens up the possibility of considering general tax revenue, including tariff revenue[4], as a possible source of finance for public abatement even when governments reduce a tariff. This finding is a noteworthy for developing countries where the collection of pollution tax revenue is difficult. Based on this finding, however, we can pose the question of which tax revenue—pollution tax revenue or tariff revenue—should be earmarked for the financing of public abatement in order to increase public abatement and welfare when the government alters a pollution tax or a tariff.

The purpose of this paper is to investigate tax revenue-financed public abatement, which is thought of as environmental funds, and obtain a welfare-superior policy between pollution tax revenue-financed public abatement and tariff revenue-financed public abatement for when governments change a pollution tax or a tariff. By doing so, we can obtain an appropriate environmental fund that can sustain public abatement. Also, we derive the optimal tax rate including the optimal tariff rate in order to see whether the harmonization of free trade and environmental protection could be achieved in the presence of tax revenue-financed public abatement. The results obtained in this paper are relevant for countries in which an import competing sector protected by a tariff generates pollution as a by-product[5] and the government seeks the revenues earmarked for the financing of environmental funds (e.g., many economies of Central and Eastern Europe).

This paper proceeds as follows. Section 2 develops the model of tax revenue-financed public abatement. In section 3, we analyze the effects of a pollution tax on welfare under the situations in which either pollution tax revenue or tariff revenue is earmarked for the financing of public abatement. In doing so, we can obtain a welfare-superior policy between pollution tax revenue-financed public abatement and tariff revenue-financed public abatement. Section 4 examines the effects of a tariff on welfare and demonstrates the same analysis of section 3. Section 5 shows the optimal tax rate on the basis of the results shown in sections 3 and 4. Section 6 concludes.

2. The Model

We assume a small open economy producing two private goods, good *x* and good *y*, where good *x* is an importable good protected by a tariff and good *y* is an exportable good. The production of good *x* generates pollution emissions, whereas production of good *y* does not generate any pollution. In this sense, good *x* is a dirty good and good *y* is a clean good. The government imposes a pollution tax on the private producer of good *x* in order to abate pollution through a reduction in production (i.e., private abatement). At the same time, the public sector itself also abates pollution emissions (i.e., public abatement) by importing public abatement from abroad[6]. To describe the production side more formally, we use 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 output levels of good x and good y, respectively, z denotes the amount of pollution emissions generated from the production of good x, t is the pollution tax rate, v denotes the set of private factors used in the production of the private good, and $T(v)$ is the country's technology set. As v does not vary in this paper, we reduce the expression for the revenue function to $R(p,t)$. Also, we assume that the production of good x is protected by a tariff and it thus gives rise to a wedge 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 given international relative price of good x and s denotes the tariff rate. Regarding the revenue function, it is commonly known that $R_p = x, R_{pp} = \partial x / \partial p > 0$. We also have:

$$R(p,t) = -z \tag{1}$$

From equation (1), we make the usual assumption of $R_{tt} = -\partial z / \partial t > 0$, which indicates that an increase in the pollution tax rate reduces pollution emissions. This implies that private abatement is undertaken by the private sector. We also assume that $R_{tp} = -\partial z / \partial p < 0$, which indicates that an increase in the relative price of good x raises the amount of pollution emissions. The opposite case also holds true: that a reduction in the price of good x by reducing the tariff (e.g., trade liberalization) lowers the amount of pollution emissions.

Turning to the demand side of the economy, the following expenditure function characterizes the households' consumption activities:

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

where C_x and C_y denote the compensated demands of good x and good y, respectively, $r = z - g$ [7] denotes the net amount of pollution that households receive, and g denotes the amount of public abatement imported from abroad. Regarding the expenditure function, we know that $E_p = C_x, E_{pp} < 0$ and $E_u > 0$, where E_u is the reciprocal of the marginal utility of income. In this context, we assume that $E_{pu} > 0$ because good x is assumed to be a normal good. Also, we know that $E_z > 0$, which is commonly known as the marginal damage of pollution. Regarding this, pollution harms the utility of households, and thus households should increase their expenditure so as to maintain a constant utility. In this sense, $E_z > 0$ is the marginal willingness to pay for a reduction in pollution (see Copeland 1994).

The economy's budget constraint can be expressed as:

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

The first term of the right-hand side of equation (2) $R(p,t)$ represents factor income from the production of private goods, while the second term, $(1-\alpha)tz$, and the third term, $(1-\beta)sM_p$, indicate pollution tax revenue and tariff revenue redistributed to households, respectively. In this context, one should recall that the government imports public abatement from abroad and the cost incurred is financed by pollution tax revenue and/or tariff revenue. Hence, we assume that a fraction of pollution tax revenue, α, and/or a fraction of tariff revenue, β, is earmarked for the financing of public abatement. With this in mind, the budget constraint for public abatement can be expressed as:

$$P_g g = \alpha tz + \beta sM_p \tag{3}$$

where P_g denotes the exogenously given international price of public abatement, αtz denotes the earmarked pollution tax revenue, and βsM_p denotes the earmarked tariff revenue. In other words, αtz and βsM_p represent environmental funds aimed at public abatement. By using equations (1), (2), and (3), we obtain a change in three endogenous variables, including *z*, *g*, and *u*, by altering two exogenous policy variables, *t* and *s*. As a result, we can obtain a welfare-superior policy between solely pollution tax revenue-financed public abatement (i.e., $\beta = 0$) and solely tariff revenue-financed public abatement (i.e., $\alpha = 0$).

3. The Welfare Consequences of a Pollution Tax

The effects of the pollution tax on the unknown variables *z*, *g*, and *u* are derived with the aid of comparative statics[8]. Firstly, we examine the case in which a fraction of pollution tax revenue is earmarked for the financing of public abatement while tariff revenue is returned to households (i.e., $0 < \alpha < 1, \beta = 0$). We have:

$$dg/dt = (E_u - sE_{pu})\alpha(z - tR_{tt})/\Delta \tag{4}$$

$$du/dt = P_g[(E_r - t - sE_{pr})R_{tt} - sR_{pt}]/\Delta + \alpha(z - tR_{tt})(E_r - P_g - sE_{pr})/\Delta \tag{5}$$

where $\Delta = (E_u - sE_{pu})P_g > 0$ [9] is the determinant of the matrix of the coefficients of the unknown variables. Equation (4), $dg/dt = (E_u - sE_{pu})\alpha(z - tR_{tt})/\Delta = \alpha(z - tR_{tt})P_g^{-1}$, measures the change in public abatement by changing the pollution tax. Regarding the right-hand side of equation (4), the sign is ambiguous when governments increase the pollution tax. The reason for this ambiguity is attributable to the following two opposing effects. Firstly, a reduction in pollution emissions as a result of private abatement reduces the pollution tax revenue earmarked for the financing of public abatement and thereby public abatement, as shown by the second term of the right-hand side of equation (4), $-\alpha t R_{tt} P_g^{-1} < 0$. Secondly, an increase in the pollution tax can increase pollution tax revenue because the tax rate of the pollution tax is higher than before and it raises public abatement, as shown by the first term of the right-hand side of equation (4), $\alpha z P_g^{-1} > 0$. The relative strength of these opposing effects determines the change in public abatement following an increase in the pollution tax. Under these circumstances, let us assume that $z - tR_{tt} > 0$, which is ensured by the elasticity of pollution emissions with respect to the pollution tax rate being smaller than unity $\varepsilon = -tR_{tt} / R_t < 1$! , then an increase in the pollution tax increases public abatement. The reason is that a small elasticity of pollution emissions with respect to the pollution tax rate indicates that a reduction in the amount of pollution emissions would not be so substantial that the government could procure the pollution tax revenue earmarked for the financing of public abatement! , and hence public abatement rises. Conversely, when we assume that $\varepsilon > 1$, an increase in the pollution tax reduces pollution emissions so substantially that it would erode the tax base of public abatement. As a consequence, the government cannot procure the pollution tax revenue earmarked for the financing of public abatement, and public abatement declines. Hence, public abatement would not be compatible with the private abatement undertaken by increasing the pollution tax under $\varepsilon > 1$. Regarding the change in the net amount of pollution following an increase in the pollution tax, we can derive this figure with the aid of equations (1) and (4) such that $dr / dt = -P_g^{-1} [P_g R_{tt} + \alpha(z - tR_{tt})]$. It is straightforward to obtain that an increase in the pollution tax lowers the net amount of pollution if we assume that $z - tR_{tt} \geq 0$, which is ensured by $\varepsilon = -tR_{tt} / R_t \leq 1$.

Equation (5) shows the welfare consequences of the pollution tax when the government finances public abatement with pollution tax revenue. Observing the right-hand side of equation (5), the first bracket of the right-hand side, $P_g [(E_r - t - sE_{pr})R_{tt} - sR_{pt}] / \Delta$, captures the private abatement effect arising from an increase in the pollution tax. Regarding this term, if we assume that the marginal damage of pollution is greater than the pollution tax, $E_r > t$, and the consumption of importable good (i.e., good *x*) is a substitute for pollution, $E_{pr} < 0$, then an increase in the pollution tax has a positive impact on welfare through the pollution abatement undertaken by the private sector (i.e., private abatement). Intuitively, a reduction in pollution emissions by increasing the pollution tax undermines pollution tax revenue returned to households, and, as a result, a welfare loss arises. Nevertheless, under the assumption, which says that the pollution tax is small enough to ensure $E_r > t$, then the tax revenue loss is so negligible that it is dominated by the gains from environmental clean-up undertaken by private abatement. Also, the assumption $E_{pr} < 0$ prevails, that a reduction in pollution emissions by means of private abatement increases the consumption of importable good and thereby imports, which is conducive to an increase in tariff revenue returned to households. Finally, the assumption $R_{pt} = -\partial x / \partial t < 0$ is also conducive to an increase in tariff revenue, because an increase in the pollution tax reduces the production of good *x*, and, as a result, households must rely on imports of good *x*. These private abatement effects, which consist of the gains from an environmental clean-up and an increase in tariff revenue returned to households, increase welfare.

The second bracket in equation (5), $\alpha(z - tR_{tt})(E_r - P_g - sE_{pr}) / \Delta$, measures the public abatement effect. In this context, one should recall that an increase in the pollution tax raises public abatement under the assumption $z - tR_{tt} > 0$, which implies $\varepsilon < 1$. In this case, when public abatement is under-provided, implying $E_r > P_g$, which means that the marginal willingness to pay for pollution abatement is greater than the cost of public abatement, an increase in the pollution tax raises welfare through an increase in public abatement. However, an increase in the pollution tax undermines welfare as a result of a reduction in public abatement if $z - tR_{tt} < 0$, which implies $\varepsilon > 1$.

Next, we analyze the welfare consequences of the pollution tax in the case that all pollution tax revenue is returned to households while a fraction of tariff revenue is earmarked for the financing of public abatement (i.e., $\alpha = 0, 0 < \beta < 1$).The results of comparative statics show:

$$dg / dt = \beta s[E_{pu}(E_z - t)R_{tt} - E_u E_{pr} R_{tt} - E_u R_{pt}] / \Omega \tag{6}$$

$$du / dt = (P_g + \beta sE_{pr})\{[E_r - t - (1 - \beta)sE_{pr}] R_{tt} - (1 - \beta)sR_{pt} \} / \Omega$$

$$- \beta s(E_{pr} R_{tt} + R_{pt})[E_r - (1 - \beta)sE_{pr}] / \Omega \tag{7}$$

Equation (7) can be rewritten as:

$$du / dt = P_g \{[E_r - t - sE_{pr}] R_{tt} - sR_{pt} \} / \Omega$$

$$+ \beta \{ sE_{pr} R_{tt} (P_g - t) + (P_g - E_r)sR_{pt} \} / \Omega \tag{7'}$$

where $\Omega = [E_u - (1 - \beta)sE_{pu}](P_g + \beta sE_{pr}) - \beta sE_{pu} [E_r - (1 - \beta)sE_{pr}]$ is the determinant of the matrix of the coefficients of the unknown variables and its sign is positive by stability[12].

Equation (6) shows the effect of a change in the pollution tax on public abatement when governments finance public abatement using tariff revenue. In this context, under the familiar assumptions that $E_r > t$ and $E_{pr} < 0$ then an increase in the pollution tax increases public abatement. The explanation is straightforward. A reduction in pollution emissions by the pollution tax raises the demand for imports because of the relationship between pollution emissions and the consumption of good *x* (i.e., importable good), $E_{pr} < 0$. The increased imports raise tariff revenue and thereby public abatement because a fraction of tariff revenue is earmarked for the financing of public abatement. Also, as mentioned earlier, an increase in the pollution tax reduces the production of good *x* and raises the imports of good *x*. This is also conducive to an increase in tariff revenue and public abatement, as shown by the final term in the bracket of the right-hand side of equation (6), $-\beta s E_u R_{pt} / \Omega > 0$. Finally, when the gains from an environmental clean-up are greater than the pollution tax revenue loss, an increase in the pollution tax can increase the utility of households and, therefore, the consumption of good *x*, because good *x* is a normal good. This effect also increases tariff revenue and, therefore, public abatement, as captured by the first term in the bracket of the right-hand side of equation (6), $\beta s E_{pu}(E_r - t)R_{tt} / \Omega > 0$. Hence, under the assumptions $E_r > t$ and $E_{pr} < 0$, private abatement undertaken by the private sector is compatible with public abatement undertaken by the public sector when the government increases the pollution tax under tariff revenue-financed public abatement. With this in mind, we can obtain a change in the net amount of pollution with the aid of the equation $dr / dt = dz / dt - dg / dt$. From this equation, we know that $dz / dt = -R_{tt} < 0$, and hence we can obtain $dr / dt < 0$ if $dg / dt > 0$.

Equation (7) shows the welfare consequences of the pollution tax when the government finances public abatement using tariff revenue. The first term of the right-hand side of equation (7)' $P_g \{ [E_r - t - sE_{pr}] R_{tt} - sR_{pt} \} / \Omega$ captures the private abatement effect on welfare. It states that an increase in the pollution tax increases welfare under the familiar assumptions $E_r > t$ and $E_{pr} < 0$. As mentioned earlier, an increase in the pollution tax reduces the amount of pollution emissions and, therefore, raises welfare if we assume that $E_r > t$, which implies that the gains from an environmental clean-up are larger than the pollution tax revenue loss. Also, a reduction in pollution emissions by increasing the pollution tax increases imports and, therefore, tariff revenue returned to households under the assumption $E_{pr} < 0$. Thus, pollution abatement undertaken by the private sector is conducive to welfare improvement when governments increase the pollution tax under tariff revenue-financed public abatement. The second term of the right-hand side of equation (7)' $\beta \{ sE_{pr} R_{tt} (P_g - t) + (P_g - E_r) sR_{pt} \} / \Omega$ captures the public abatement effect, and this has a positive impact on welfare if we assume that $E_{pr} < 0$, $E_r > P_g$, and $t > P_g$. In this context, one should recall equation (6), that an increase in the pollution tax has a positive impact on public abatement under the assumption $E_{pr} < 0$. In these circumstances, if public abatement is under-provided in the economy, $E_r > P_g$, an increase in public abatement by increasing the pollution tax can raise welfare through an increase in public abatement. Also, the assumption, which says that the cost of public abatement is substantially small enough to guarantee $t > P_g$, ensures the welfare improvement by increasing the pollution tax. That is, if the cost of public abatement is substantially high, we should earmark a significant amount of domestic tax revenue for public abatement, which would be otherwise returned to households, thus giving rise to welfare loss. Overall, an increase in the pollution tax leads to a welfare improvement by means of the private and the public abatement effects under the assumptions $E_r > t$, $E_r > P_g$, $t > P_g$ and $E_{pr} < 0$.

With these results in mind, we can obtain a welfare-superior policy between pollution tax revenue-financed public abatement and tariff revenue-financed public abatement. To this end, we compare both the numerators and the denominators of the right-hand side of equations (4) and (7)' such that:

$$A_t = P_g [(E_r - t - sE_{pr})R_{tt} - sR_{pt}] + (\alpha z - \alpha t R_{tt})(E_r - P_g - sE_{pr})$$

$$A_t' = P_g [(E_r - t - sE_{pr})R_{tt} - sR_{pt}] + \beta s[(P_g - E_r)R_{pt} + (P_g - t)E_{pr}R_{tt}]$$

where A_t and A_t' denote the numerators of equation (4) and (7)', respectively. Then we can obtain $A_t' - A_t = \beta s[(P_g - E_r)R_{pt} + (P_g - t)E_{pr}R_{tt}] + \alpha R_t(1-\varepsilon)(E_r - P_g - sE_{pr})$. Regarding this, we have the inequality $A_t' > A_t$ if we assume that $P_g < t, P_g < E_r, E_{pr} < 0$, and $\varepsilon \geq 1$. Turning to the denominators, we know:

$$\Delta = P_g(E_u - sE_{pu})$$

$$\Omega = [E_u - (1-\beta)sE_{pu}](P_g + \beta sE_{pr}) - \beta sE_{pu}[E_r - (1-\beta)sE_{pr}]$$

$$= E_u(P_g + \beta sE_{pr}) - P_g(1-\beta)sE_{pu} - \beta sE_{pu}E_r$$

where Δ and Ω denote the denominators of equations (4) and (7)', respectively and we know $\Delta > 0$ and $\Omega > 0$. Regarding this, we have $\Delta - \Omega = \beta s(E_r E_{pu} - E_u E_{pr}) + P_g(1-\beta)sE_{pu} > 0$ under the assumption $E_{pr} < 0$. Hence, we can conclude that tariff revenue-financed public abatement is a welfare superior policy compared with under pollution tax revenue-financed public abatement when the government increases the pollution tax. We can state the following proposition.

Proposition 1 *Suppose the government increases a pollution tax under pollution tax revenue-financed public abatement or under tariff revenue-financed public abatement. In these circumstances, if the following assumptions are established—(i) the cost of public pollution abatement is so small that $t > P_g$ and public abatement is under-provided $P_g < E_r$; (ii) the marginal willingness to pay for pollution abatement is higher than the pollution tax rate $E_r > t$; (iii) the consumption of the importable good is a substitute for pollution $E_{pr} < 0$; and (iv) the elasticity of pollution emissions with respect to the pollution* *tax rate is substantial enough to guarantee $\varepsilon \geq 1$—then tariff revenue-financed public abatement is a welfare-superior policy.*

As mentioned in the introduction, pollution tax revenue-financed public abatement generates a loss in public abatement because the tax base of public abatement declines as a result of a reduction in the amount of pollution emissions. In particular, when the elasticity of pollution emissions with respect to the pollution tax rate is greater than unity, private abatement undertaken by the private sector cannot increase public abatement under pollution tax revenue-financed public abatement. However, this dilemma may not arise under tariff revenue-financed public abatement. It depends primarily on the assumption that consumption of the importable good is a substitute for pollution. This assumption should be valid in terms of the example provided by Copeland (1994), that when pollution destroys wildness, the demand for hiking boots declines, which implies that the consumption is a substitute for pollution emissions. In these circumstances, we can conclude that tariff revenue is a possible source of environmental funds, as suggested by Haibara (2006), and tariff revenue is a more suitable source of environmental funds than pollution tax revenue in terms of welfare improvement.

4. The Welfare Consequences of a Tariff

We now turn to the welfare consequences of a tariff when either pollution tax revenue or tariff revenue is earmarked for the financing of public abatement. Firstly, we analyze the effects of trade liberalization on unknown variables under pollution tax revenue-financed public abatement. The comparative statics results are:

$$dg / ds = -\alpha t R_{tp} (E_u - sE_{pu}) / \Delta \tag{8}$$

$$du / ds = P_g [(E_r - t - sE_{pr}) R_{tp} + sM_{pp}] / \Delta + \alpha t R_{tp} (P_g - E_r + sE_{pr}) / \Delta \tag{9}$$

Equation (8) measures the effect of the tariff on public abatement under pollution tax revenue-financed public abatement. The right-hand side of equation (8), $-\alpha t R_{tp} (E_u - sE_{pu}) / \Delta = -\alpha t R_{tp} P_g^{-1} > 0$, which implies that an increase in the tariff raises public abatement, suggests that trade liberalization as a result of reducing the tariff decreases public abatement. This can be intuitively explained by the fact that a reduction in the tariff reduces the amount of pollution emissions through a reduction in the output of good *x*, which is pollution generating. The lower pollution emissions reduce pollution tax revenue and, as a result, public abatement declines because pollution tax revenue is earmarked for the financing of it. With respect to a change in pollution by the tariff, we can obtain this figure with the aid of equations (1) and (8) such that

$dr / ds = \alpha t R_{tp} P_g^{-1} - R_{tp}$. In this equation, there are two opposing effects, which consist of the private abatement effect achieved by the tariff, $-R_{tp}$, and the public abatement effect achieved by the earmarking of pollution tax revenue for the financing of public abatement, $\alpha t R_{tp} P_g^{-1}$. In this context, if the private abatement effect dominates the public abatement effect, as ensured by $P_g > \alpha t$, then it follows that $dr / ds > 0$. This implies that trade liberalization undertaken by reducing the tariff lowers the net amount of pollution. Intuitively, when a pollution tax is small, the pollution tax revenue loss would be negligible and, therefore the public abatement effect, which has a negative impact on pollution abatement, would be dominated by the private abatement effect, which has a positive impact on pollution abatement.

Equation (9) shows the welfare consequences of the tariff when governments finance public abatement with pollution tax revenue. Observing the right-hand side of equation (9), the first term, $P_g [(E_r - t - sE_{pr})R_{tp} + sM_{pp}] / \Delta$, captures the private abatement effect arising from reducing the tariff. Regarding this term, the familiar assumptions that , such that $E_r > t$ and $E_{pr} < 0$ ensure that the private abatement effect achieved by trade liberalization has a positive impact on welfare. In particular, the private abatement effect consists of two positive impacts on welfare. They are the gains from environmental clean up and the gains from trade. Namely, the gains from environmental clean-up arise from a reduction in the tariff through a decrease in the production of good *x*, which is pollution generating, and hence the utility of households increases. In contrast, a reduction in pollution emissions reduces the pollution tax revenue returned to households and therefore harms households' utility. However, this negative impact on welfare can be dominated by the gains from environmental clean-up, which has a positive impact on welfare under the assumption $E_r > t$. On the other hand, the gains from trade liberalization can increase the demand for imports, which is achieved by a reduction in the domestic price of good *x*, $M_{pp} < 0$, and by a reduction in pollution (i.e., private abatement), $E_{pr} < 0$. These effects are conducive to welfare improvement achieved by trade liberalization. The second term, $\alpha t R_{tp} (P_g - E_r + sE_{pr}) / \Delta$, captures the public abatement effect. If public abatement is under-provided in the economy and the assumption $E_{pr} < 0$ prevails, then trade liberalization undertaken by reducing the tariff reduces welfare. In this context, one should recall that trade liberalization reduces public abatement under pollution tax revenue-financed public abatement (see equation (8)), and hence it undermines welfare on the ground that the amount of public abatement is under-provided in the economy. Also, a reduction in public abatement may increase the net amount of pollution. As a consequence, the demand for the consumption of good *x*, and thereby tariff revenue, would be undermined because of the assumption that the consumption of good *x* (i.e., importable good) is a substitute for pollution as $E_{pr} < 0$. Hence, the welfare consequences of reducing the tariff under pollution tax revenue-financed public abatement are determined by the relative strengths of the private abatement effect and the public abatement effect.

Next, we analyze the welfare consequences of the tariff under tariff revenue-financed public abatement. The results of comparative statics show:

$$dg/ds = -\beta[E_u - (1-\beta)sE_{pu}](sE_{pr}R_{tp} - M_p - sM_{pp})/\Omega$$

$$+\beta sE_{pu}\{[E_r - (1-\beta)sE_{pr} - t]R_{tp} + sM_{pp}\}/\Omega \quad (10)$$

$$du/ds = \{[E_r - (1-\beta)sE_{pr} - t]R_{tp} + sM_{pp}(1-\beta) - \beta M_p\}(P_g + \beta sE_{pr})/\Omega$$

$$-[E_r - (1-\beta)sE_{pr}](\beta sE_{pr}R_{tp} - \beta M_p - \beta sM_{pp})/\Omega \quad (11)$$

Equation (11) can be rewritten as:

$$du/ds = P_g[(E_r - sE_{pr} - t)R_{tp} + sM_{pp}]/\Omega + \beta E_{pr}[s(P_g - t)R_{tp} + sM_{pp}]/\Omega$$

$$+\beta(E_r - P_g - sE_{pr})(M_p + sM_{pp})/\Omega \quad (11)'$$

Equation (10) shows the effect of a change in public abatement when governments alter the tariff rate. One finds that the sign of the right-hand side of the equation is ambiguous. The reason for this ambiguity is attributed to a change in the tax base of public abatement by the tariff. Whether the amount of the tax base rises or not depends on the elasticity of import demand with respect to the tariff. If we assume that $-M_p - sM_{pp} = -M_p(1-\phi) \geq 0$, which implies that the elasticity of import demand with respect to the tariff rate is greater than or equal to unity, $\phi = -sM_{pp}/M_p \geq 1$, then trade liberalization achieved by reducing the tariff increases public abatement under the assumptions $E_r > t$ and $E_{pr} < 0$. Intuitively, when the elasticity of import demand with respect to a tariff is large, trade liberalization increases the demand for imports so much as a result of a reduction in the domestic price of an importable good that governments can earn substantial tariff revenue, which is earmarked for the financing of public abatement. Hence, public abatement rises by reducing the tariff. Also, a reduction in the tariff raises tariff revenue indirectly through a reduction in the production of the importable good (i.e., good *x*) and by a reduction in the amount of pollution emissions. That is, a reduction in the production of the importable good induces households to increase imports. Furthermore, a reduction in pollution emissions by reducing the tariff increases imports because of the assumption $E_{pr} < 0$. These effects of trade liberalization are conducive to an increase in tariff revenue! , thereby increasing public abatement.

Equation (11) shows the welfare effects of the tariff when tariff revenue is earmarked for the financing of public abatement. Regarding the first term of the right-hand side of equation (11)' $P_g\{[E_r - sE_{pr} - t]R_{tp} + sM_{pp}\}/\Omega$, if we assume that $E_r > t$ and $E_{pr} < 0$, then the sign of these terms are negative. This implies that trade liberalization undertaken by reducing the tariff has a positive impact on welfare. That is, the gains from trade arise $P_g sM_{pp} / \Omega$, such that a reduction in the tariff reduces the consumer price of the importable good and thereby increases imports. Also, the gains from environmental clean-up arise $P_g [E_r - sE_{pr} - t] R_{tp} / \Omega$ because of private abatement, such that a reduction in the tariff reduces pollution and thereby increases welfare under the assumption $E_{pr} < 0$. The second and third terms of the right-hand side of equation (11)' capture the public abatement effect, which has a positive impact on welfare as a result of reducing the tariff under the assumptions, such that $\phi \geq 1$, $E_{pr} < 0$, $P_g - t < -sM_{pp} / R_{tp} < 0$, and $E_r > P_g$. It is straightforward to understand that a reduction in the tariff increases tariff revenue by means of an expansion of imports ensured by the assumption $\phi \geq 1$, and the increased tariff revenue raises public abatement, as shown by equation (10). The increased public abatement increases welfare if public abatement is under-provided, $E_r > P_g$ and the cost of public abatement is small, $P_g < t$.

With these results in mind, we obtain a welfare-superior policy between pollution tax revenue-financed public abatement and tariff revenue-financed public abatement when governments reduce the tariff. In doing so, we define:

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

$$A_s' = P_g \{[E_r - sE_{pr} - t] R_{tp} + sM_{pp}\} + \beta E_{pr}[s(P_g - t)R_{tp} + sM_{pp}]$$
$$+\beta(E_r - P_g - sE_{pr})(M_p + sM_{pp}) / \Omega$$

where A_s and A_s' denote the numerators of equation (9) and (11)', respectively. We have $A_s - A_s' = [\beta M_p(1-\varphi) + \alpha t R_{tp}](P_g - E_r + sE_{pr}) - [(P_g - t)R_{tp} + sM_{pp}]\beta s E_{pr}$. Regarding this equation, if we assume that $P_g - t < -sM_{pp} / R_{tp} < 0$, $E_r > P_g$, $\varphi \geq 1$ and $E_{pr} < 0$, then we have $A_s - A_s' > 0$, which implies $|A_s| < |A_s'|$ if A_s and A_s' are assumed to be nagative. In terms of the denominators of equations (9) and (11), we know $\Delta - \Omega > 0$. Hence, we can conclude that the magnitude of the welfare improvement is higher under tariff revenue-financed public abatement than it is under pollution tax revenue-financed public abatement when governments reduce the tariff. The following proposition summarizes these results.

Proposition 2 *Suppose the government reduces a tariff under pollution tax revenue-financed public abatement or under tariff revenue-financed public abatement. In these circumstances, if the following* *assumptions are established—(i) the cost of public abatement is small enough to ensure $t > P_g$, and public abatement is under-provided $P_g < E_r$; (ii) the marginal willingness to pay for pollution abatement is higher than the pollution tax rate $E_r > t$; (iii) the consumption of the importable good is a substitute for pollution $E_{pr} < 0$; and (iv) the elasticity of import demand with respect to the tariff rate is substantial enough to guarantee $\phi \geq 1$—then tariff revenue-financed public abatement is a welfare-superior policy.*

From propositions 1 and 2, we learn that earmarking pollution tax revenue for the financing of public abatement is not a welfare-superior policy when governments increase the pollution tax or reduce the tariff. The main reason behind this outcome is tax base erosion arising from a reduction in the amount of pollution emissions under pollution tax revenue-financed public abatement. This, however, may call for trade protectionism on the ground that an increase in the tariff or introduction of a tariff can increase the tax base of public abatement as a result of an increase in the amount of pollution emissions. To see this, consider, for instance, the special case in which governments introduce a tariff under pollution tax revenue-financed public abatement. The welfare consequences of the introduction of a tariff can be obtained by setting $s = 0$ in equation (9). We have:

$$du / ds\big|_{s=0} = R_{tp} [P_g (E_r - t) + \alpha t(P_g - E_r)] / \Delta \qquad (9)'$$

Observing the right-hand side of equation (9), the introduction of a tariff increases welfare if the marginal willingness to pay for pollution abatement is equal to the pollution tax rate $E_r = t$, and public abatement is under-provided $E_r > P_g$. Intuitively, if the government imposes a tariff on good x then the amount of pollution emissions rises because good x is a polluting good. In this context, an increase in the amount of pollution emissions does not harm welfare under the assumption $E_r = t$. Because welfare loss arising from an increase in pollution emissions is offset by welfare gain arising from an increase in the pollution tax revenue returned to households.

Furthermore, an increase in pollution emissions undertaken by introducing a tariff increases the tax base of public abatement under pollution tax revenue-financed public abatement, and thus public abatement rises[14]. The increased public abatement raises welfare because public abatement is under-provided $E_r > P_g$. This result may run counter to our intuition in the sense that a tariff is conventionally thought of as an environmentally harmful policy if the tariff protects the dirty sector. However, this negative impact of the tariff on the environment can be outweighed by means of an increase in public abatement as a result of introducing a tariff.

On the other hand, one obtains the welfare consequences of increasing the pollution tax when the tariff is zero and pollution tax revenue is earmarked for the financing of public abatement. By using equation (5), we have:

$$du / dt\big|_{s=0} = P_g (E_r - t)R_{tt} / \Delta + \alpha(z - tR_{tt})(E_r - P_g) / \Delta \quad (5)'$$

Regarding the right-hand side of equation (5)', if we assume $E_r = t$ then the welfare consequences of a pollution tax depend primarily on the elasticity of the pollution emissions with respect to the pollution tax rate $z - tR_{tt} = -R_t(1-\varepsilon)$. It follows that welfare declines by increasing the pollution tax if we assume $\varepsilon > 1$ and $E_r > P_g$. From equations (5)' and (9)', we can state the following proposition.

Proposition 3 *Suppose the government introduces a tariff or increases the pollution tax under pollution tax revenue-financed public abatement. In these circumstances, if the pollution abatement undertaken by the private sector is optimally-provided* $E_r = t$ *while it is by the public sector is under-provided* $E_r > P_g$*, and the elasticity of pollution emissions with respect to the pollution tax rate is greater or equal to unity* $\varepsilon \geq 1$*, then the introduction of a tariff is a welfare-superior policy.*

The result exhibited in proposition 3 calls for trade protectionism because an introduction of a tariff can increase the tax base of public abatement and welfare. However, an introduction of a tariff runs counter to PPP (i.e., polluter pays principle) in the sense that it protects a dirty industry and it thus would not be allowed in reality although it may receive attention in academic literature.

5. Optimal Trade and Environmental Policies

In this section, we derive the optimal tax rate with the aid of the welfare consequences of the tariff and the pollution tax in the situation in which either pollution tax revenue or tariff revenue is earmarked for the financing of public abatement. In the first place, we obtain the optimal pollution tax rate by setting $du / dt = 0$ in equations (5) and (7)'. We have:

$$t_p^o = \{ P_g [(E_r - sE_{pr})R_{tt} - sR_{pt}] + \alpha z(E_r - P_g - sE_{pr})\}/[P_g R_{tt} + \alpha R_{tt} (E_r - P_g - sE_{pr})] \quad (12)$$

$$t_s^o = \{ P_g [(E_r - sE_{pr})R_{tt} - sR_{pt}] + \beta s[R_{pt} (P_g - E_r) + P_g E_{pr} R_{tt}]\}/[(P_g + \beta sE_{pr})R_{tt}] \quad (13)$$

Equation (12) shows the optimal pollution tax rate under pollution tax revenue-financed public abatement, while equation (13) shows it under tariff revenue-financed public abatement. Observing the right-hand side of equations (12) and (13), one should notice that the optimal pollution tax rate is positive regardless of which tax revenue-financed public abatement is used if we assume $E_r > P_g$, $E_{pr} < 0$, and $P_g + \beta sE_{pr} > 0$, as ensured by stability.

Like the optimal pollution tax rate, we can obtain the optimal tariff rate by setting $du/ds = 0$ in equations (9) and (11)'. To make the analysis easier, we assume that pollution does not affect the consumption decision of households (i.e., $E_{pr} = 0$ [15]). We have:

$$s_p^o = R_{tp}[\alpha t(E_r - P_g) - P_g(E_r - t)]/P_g M_{pp} \tag{14}$$

$$s_s^o = [(E_r - t)R_{tp}P_g + (E_r - P_g)\beta M_p]/[(P_g - E_r)\beta M_{pp} - P_g M_{pp}] \tag{15}$$

where s_p^o indicates the optimal tariff rate under pollution tax revenue-financed public abatement and s_s^o indicates the optimal tariff rate under tariff revenue-financed public abatement. If we assume that $E_r = t$ and $E_r > P_g$ then the optimal tariff rate is positive regardless of which tax revenue-financed public abatement, $s_p^o > 0$, $s_s^o > 0$. The reason why the optimal tariff rate is positive is that pollution abatement is undertaken not only by the private sector but also by the public sector. Regarding this, pollution abatement is optimally undertaken by the private sector, such that $E_r = t$, whereas pollution abatement undertaken by the public sector is under-provided, such that $E_r > P_g$. Hence the optimal tariff could be positive to sufficiently provide public abatement regardless of which tax revenue-financed public abatement.

In the final analysis, we show the jointly optimal trade and environmental policies with the aid of equations (12), (13), (14), and (15). In the first place, we derive the optimal environmental policy reflecting the optimal trade policy. In this context we maintain the assumption $E_{pr} = 0$ for the sake of simplicity. Substituting equation (14) into (12) and substituting equation (15) into (13) yield

$$t_p^{oo} = \{P_g E_r[R_{tt}M_{pp} + (R_{pt})^2] + \alpha z(E_r - P_g)M_{pp}\}/\{[R_{tt}M_{pp} + (R_{tp})^2](\alpha E_r - \alpha P_g + P_g)\} \tag{16}$$

$$t_s^{oo} = \{P_g E_r[R_{tt}M_{pp} + (R_{pt})^2] + (E_r - P_g)\beta M_p R_{pt}\}/\{P_g[R_{tt}M_{pp} + (R_{tp})^2]\} \tag{17}$$

Regarding equations (16) and (17), if we assume that $E_r > P_g$, and $R_{tt}M_{pp} + (R_{tp})^2 < 0$, which is ensured by sufficiently large private abatement effect R_{tt}, then the optimal pollution tax rate reflecting the optimal tariff becomes positive regardless of which tax revenue financed public abatement $t_p^{oo} > 0$ and $t_s^{oo} > 0$. By comparing equations (16) and (17), we have

$$t_s^{oo} - t_p^{oo} = (E_r - P_g)\{\beta R_{pt} M_p(\alpha E_r - \alpha P_g + P_g) + \alpha P_g E_r [R_{tt} M_{pp} + (R_{tp})^2] - P_g \alpha z M_{pp}\} / \Pi$$

(18)

Regarding the right-hand side of equation (18), if we suppose that $E_r > P_g$, and the private abatement effect R_{tt} is sufficiently large enough to guarantee

$\Pi = P_g(\alpha E_r - \alpha P_g + P_g)[R_{tt} M_{pp} + (R_{tp})^2] < 0$ and $\alpha P_g E_r [R_{tt} M_{pp} + (R_{tp})^2] - P_g \alpha z M_{pp} < 0$,

then we obtain $t_s^{oo} > t_p^{oo}$. This implies that the optimal pollution tax rate reflecting the optimal tariff rate is higher under tariff revenue-financed public abatement than it is under pollution tax revenue-financed public abatement.

Proposition 4 *Suppose the government maximizes welfare by altering the pollution tax and the tariff. In these circumstances, if the following assumptions are established—(i) public abatement is under-provided* $E_r > P_g$*; (ii) the pollution is independent of the consumption decision of households* $E_{pr} = 0$*; (iii) the effect of private abatement is substantial* R_{tt}*—then the optimal pollution tax rate reflecting the optimal tariff rate is positive regardless of which tax revenue-financed public abatement and higher under tariff revenue-financed public abatement than it is under pollution tax revenue-financed public abatement.*

On the other hand, we also obtain the optimal tariff rate reflecting the optimal pollution tax rate by substituting equation (12) into (14) and substituting equation (13) into (15).

$$s_p^{oo} = R_{tp} \alpha z(E_r - P_g) / \{P_g [R_{tt} M_{pp} + (R_{pt})^2]\} \quad (19)$$

$$s_s^{oo} = -(E_r - P_g)\beta M_p R_{tt} / \{(\beta E_r - \beta P_g + P_g)[R_{tt} M_{pp} + (R_{pt})^2]\} \quad (20)$$

where $s_p^{oo} > 0$ and $s_s^{oo} > 0$ if we assume $E_r > P_g$ and $R_{tt} M_{pp} + (R_{tp})^2 < 0$. By comparing equations (19) and (20), we obtain

$$s_s^{oo} - s_p^{oo} = -(E_r - P_g)\{\alpha z R_{tp}[P_g + (E_r - P_g)\beta] + P_g \beta M_p R_{tt}\} / \Theta \quad (21)$$

where $\Theta = \{ P_g [R_{tt} M_{pp} + (R_{pt})^2] \} \{ (\beta E_r - \beta P_g + P_g) [R_{tt} M_{pp} + (R_{pt})^2] \}$

Observing the right-hand side of equation (21), we obtain $s_s^{oo} < s_p^{oo}$ if we assume $E_r > P_g$, the effect of private abatement is sufficiently large enough to guarantee $R_{tt} M_{pp} + (R_{tp})^2 < 0$, and $\alpha z R_{tp} [P_g + (E_r - P_g) \beta] + P_g \beta M_p R_{tt} > 0$. The following proposition summarizes the result shown in equation (21).

Proposition 5 *Suppose the government maximizes welfare by altering the pollution tax and the tariff. In these circumstances, if the following assumptions are established—(i) public abatement is under-provided $E_r > P_g$; (ii) the pollution emission is independent from the consumption of importable good, $E_{pr} = 0$; and (iii) the effect of private abatement R_{tt} (i.e., private abatement) is substantial —then the optimal tariff rate reflecting the optimal pollution tax rate is positive regardless of which tax revenue-financed public abatement and higher under pollution tax revenue-financed public abatement than it is under tariff revenue-financed public abatement.*

The intuition behind proposition 4 is analogous to proposition 1 except for the assumption $E_{pr} = 0$. Despite this assumption, we can conclude that the magnitude of the welfare improvement is higher under tariff revenue-financed public abatement than it is under pollution tax revenue-financed public abatement when the government increases the pollution tax. That is, an increase in the pollution tax increases tariff revenue by means of a reduction in the output of the importable good. In turn, it increases public abatement and welfare under tariff revenue-financed public abatement as tariff revenue is earmarked for the financing of public abatement and public abatement is under-provided. In contrast, an increase in the pollution tax rate reduces public abatement and welfare under pollution tax revenue-financed public abatement by means of a reduction in the tax base of public abatement under the assumption, which says that the magnitude of private abatement is substantial. This causes a downward pressure to increase the pollution tax. Hence, the optimal pollution tax rate is higher under tariff revenue-financed public abatement than it is under pollution tax revenue-financed public abatement.

In case of the optimal trade policy, it seems interesting that an imposition of a tariff should be justified regardless of which tax revenue-financed public abatement, as suggested by proposition 5.

With regard to pollution tax revenue-financed public abatement, a reduction in the tax base of public abatement would be large under that assumption, which says that private abatement effect is large. As a consequence, welfare declines under pollution tax revenue-financed public abatement because public abatement is assume to be under-provided. In this context, the tariff imposition can be justified in order to increase the tax base of public abatement, thereby welfare, as suggested by proposition 3. With regard to tariff revenue-financed public abatement, the imposition of the tariff can also be justified on the ground that the government budget constraint requires tariff revenue to finance public abatement. Regarding this, the imposition of the tariff raises pollution emissions that harm welfare; however it can be mitigated by increasing the pollution tax. For this reason, the optimal tariff rate reflecting the optimal pollution tax rate is positive even under tariff revenue-financed public abatement. Nevertheless, the optimal tariff rate reflecting the optimal pollution tax rate under tariff revenue-financed public abatement is smaller than it is under pollution tax revenue-financed public abatement. The reason is attributed to the fact that the tax base of public abatement declines under pollution tax revenue-financed public abatement if private abatement effect is large, while the tax base of public abatement may not decline under tariff revenue-financed public abatement. Above all, what we can learn from proposition 5 is that the harmonization of free trade (i.e., zero tariffs) and the environmental protection undertaken by tax revenue-financed public abatement would not be achieved if pollution tax revenue or tariff revenue is earmarked for the financing of public abatement.

6. Concluding remarks

This paper has consistently shown that pollution tax revenue, conventionally known as the source of environmental funds aimed at public abatement, could not be used for that purpose when governments increase a pollution tax or reduce a tariff, whereas tariff revenue, conventionally known as general tax revenue, returned to households could be used for environmental funds aimed at public abatement when governments increase a pollution tax or reduce a tariff. In particular, when governments increase a pollution tax, tariff revenue-financed public abatement is a welfare superior policy compared with pollution tax revenue-financed public abatement if the following assumptions are established: (1) the cost of public abatement is small, and public abatement is under-provided; (2) the marginal willingness to pay for pollution abatement is higher than the pollution tax rate; (3) the consumption of importable goods is a substitute for pollution ; and (4) the elasticity of pollution emissions with respect to the pollution tax rate is greater than unity. The last of these assumptions ensures that a reduction in the amount of pollution emissions undertaken by increasing a pollution tax erodes the tax base of public abatement, and it thus undermines further public abatement activities under pollution tax revenue-financed public abatement. This implies that private abatement undertaken by the private sector would not be compatible with public abatement undertaken by the public sector under pollution tax revenue-financed public abatement. In contrast, the tax base of public abatement may rise under tariff revenue-financed public abatement under the assumption that pollution is a substitute for the demands for importable goods. Relaxing this assumption, however, may not affect the results obtained in this paper. That is, we have another channel to increase tariff revenue such that a reduction in a tariff reduces the production of importable goods and so the demand for import rises. Hence, tariff revenue rises despite the fact that the demands for importable goods are independent from pollution. As a consequence, we can reproduce the same results shown in each proposition.

Another insight obtained in this paper is that trade liberalization, as a result of reducing a tariff, increases welfare when tariff revenue is earmarked for the financing of public abatement, and the magnitude of the welfare improvement is higher under tariff revenue-financed public abatement than it is under pollution tax revenue-financed public abatement. The reason is the same when increasing a pollution tax in the sense that private abatement undertaken by reducing a tariff would not be compatible with public abatement undertaken by the public sector as a result of a reduction in the tax base of public abatement under pollution tax revenue-financed public abatement. These results are relevant for countries where governments seek the fund earmarked for the financing of public abatement and harmonize private abatement with public abatement.

Finally, we should not overlook the case in which the harmonization of free trade and the environmental protection undertaken by public abatement financed by pollution tax revenue or tariff revenue would not be achieved. This may give rise to an unexplored concern regarding free trade and environmental protection to the countries in which an import competing sector protected by a tariff generates pollution emissions and the government seeks the revenues earmarked for the financing of environmental funds.

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Notes

1. The lion’s share of environmental financing in Eastern Europe, Caucasus, and Central Asia (EECCA) goes to water supply and sanitation sector (50-85 % of total expenditure) (see OECD 2006 b p.12).

2. In Georgia, experts from Ministry of the Environment estimated that in 1999 about 1.2% of the government budget was spent on environmental purposes, including water supply. About 80% of the total environmental spending was related to water and waste water infrastructure (see OECD 2006 b, p.45).

3. Brett and Keen (2000) express concern regarding the earmarking of pollution tax revenue for particular spending programs in the presence of political uncertainty.

4. The actual example refers to the Bulgarian environmental fund; in that fully one-third of the environmental fund of Bulgaria in 1993 was generated by a tax on the import of second-hand automobiles (see OECD 1995, p. 45). Another example goes to The State Environment Fund established in Czech republic such that charges on the import substances damaging the Earth’s ozone layer are earmarked for the financing of the fund (see OECD 2006 a, p 41).

5. Many developing countries have historically protected heavy industries from imports, and these industries are relatively pollution-intensive (see Ferrantino 1997).

6. The case of imported public abatement is presented in Hadjiyiannis et al. (2002, 2004) and the case of an imported public good presented in Michael and Hatzipanayotou (2001).

7. In this paper, we assume that $r = z - g > 0$.

8. See Appendix for the derivation of comparative statics.

9. The homogeneity of expenditure function E follows that $E_u = (p^* + s)E_{pu} + E_{1u}$, where 1 denotes the price of good y. Hence one obtains $E_u - sE_{pu} = p^* E_{pu} + E_{1u} > 0$ because good x and good y are assumed to be normal goods.

10. One can obtain $z - tR_{tt} = -R_t(1-\varepsilon) > 0$ when $\varepsilon = -tR_{tt} / R_t < 1$.

11. Totally differentiate the earmarked pollution tax revenue $G = \alpha tz$ with respect to *t*. Then one obtains $dG/dt = \alpha(z - tR_{tt}) = -\alpha R_t(1-\varepsilon)$. Regarding this, one obtains $dG/dt > 0$ if we assume $\varepsilon < 1$.

12. We define the government's budget constraint as $B = \beta s M_p - P_g g$ and assume $d\dot{B}/dg < 0$ if the equilibrium is locally stable. We can obtain $d\dot{B}/dg = -\Omega / [E_u - (1-\beta)sE_{pu}]$ with the aid of equation (2), which implies $\Omega > 0$ and $[E_u - (1-\beta)sE_{pu}] > 0$.

13. Another effect that increases tariff revenue is the income effect such that a reduction in a tariff increases the income level of households (i.e., gains from trade and gains from environmental clean-up), thereby increasing the demand for imports.

14. From equation (8), we can obtain $dg/ds|_{s=0} = -\alpha t R_{tp} / P_g > 0$.

15. The assumption $E_{pr} = 0$, which says that pollution and consumption are separable, does not strain the results shown in proposition 1, 2, and 3. Also the optimal pollution tax rate is positive regardless of which tax revenue-financed public abatement under the assumptions $E_{pr} = 0$ and $E_r > P_g$.

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Appendix

Totally differentiating (1)–(3) yields:

$$[E_u - (1-\beta)sE_{pu}]du + [E_r - (1-\alpha)t - (1-\beta)sE_{pr}]dz - [E_r - (1-\beta)sE_{pr}]dg$$

$$= -[\alpha z + (1-\beta)sR_{pt}]dt + [(1-\beta)sM_{pp} - \beta M_p]ds \qquad \text{(A.1)}$$

$$dz = -R_{tp}ds - R_{tt}dt \qquad \text{(A.2)}$$

$$-\beta sE_{pu} - (\alpha t + \beta sE_{pr})dz + (P_g + \beta sE_{pr})dg = -(\beta sR_{pt} - \alpha z)dt + (\beta M_p + \beta sM_{pp})ds \tag{A.3}$$

Substituting equation (A.2) into (A.1) and (A.3) yields:

$$\begin{bmatrix} [E_u - (1-\beta)sE_{pu}] & -[E_r - (1-\beta)sE_{pr}] \\ -\beta sE_{pu} & (P_g + \beta sE_{pr}) \end{bmatrix} \begin{bmatrix} du \\ dg \end{bmatrix}$$

$$= \begin{bmatrix} \{[E_r - t - (1-\beta)sE_{pr}]R_{tt} + \alpha(tR_{tt} - z) - (1-\beta)sR_{pt}\} \\ -[\alpha(tR_{tt} - z) + \beta s(E_{pr}R_{tt} + R_{pt})] \end{bmatrix} dt$$

$$+ \begin{bmatrix} \{[E_r - (1-\alpha)t - (1-\beta)sE_{pr}]R_{tp} + (1-\beta)sM_{pp} - \beta M_p\} \\ -[\alpha tR_{tp} + \beta(sE_{pr}R_{tp} - M_p - sM_{pp})] \end{bmatrix} ds \tag{A.4}$$

The determinant of the coefficient matrix of the unknown variables is Ω, which is:

$$\Omega = [E_u - (1-\beta)sE_{pu}](P_g + \beta sE_{pr}) - \beta sE_{pu}[E_r - (1-\beta)sE_{pr}]$$

which can be rewritten as:

$$\Omega = E_u(P_g + \beta sE_{pr}) - P_g(1-\beta)sE_{pu} - \beta sE_{pu}E_r$$

The sign of Ω is positive by the stability shown in footnote 8.
One also obtains equations (4) and (5) by setting $0 < \alpha < 0, \beta = 0$ and obtains equations (6) and (7) by setting $\alpha = 0, 0 < \beta < 1$ in equation (A.4).