CESifo *Working Paper Series*

CAN CROSS-BORDER POLLUTION REDUCE POLLUTION?

Panos Hatzipanayotou
Sajal Lahiri
Michael S. Michael*

Working Paper No. 360

November 2000

CESifo
Poschingerstr. 5
81679 Munich
Germany
Phone: +49 (89) 9224-1410/1425
Fax: +49 (89) 9224-1409
http://www.CESifo.de

* The authors are grateful to Saqib Jafarey for helpful comments on an earlier draft of the paper.

CESifo *Working Paper No. 360*
November 2000

CAN CROSS-BORDER POLLUTION REDUCE POLLUTION?

Abstract

We develop a North-South model of foreign aid and cross-border pollution resulting from production activities in the recipient country. There is both private and public abatement of pollution, the latter being financed through emissions tax revenue and foreign aid. We characterise a Nash equilibrium where the donor country chooses the amount of aid, and the recipient chooses the fraction of aid allocated to pollution abatement and/or the emission tax rate. At this equilibrium, an increase in the donor's perceived rate of cross-border pollution reduces net emission levels.

Keywords: Cross-border pollution, pollution abatement, foreign aid

JEL Classification: Q28, F35, H41

Panos Hatzipanayotou
Athens University of Economics and Business
Department of International and
European Economic Studies
76 Patission str.
Athens 104 34
Greece

Sajal Lahiri
University of Essex
Department of Economics
Colchester C04 3SQ
UK
email: lahiri@essex.ac.uk

Michael S. Michael
University of Cyprus
Department of Economics
P.O. Box 20537
CY 1678, Nicosia
Cyprus

1. Introduction

In recent years, policy makers and environmental activists have been voicing strong concerns against the widespread environmental degradation due to the intensification of economic activity. More often than not, the externalities associated with pollution are not confined to a particular country or region. For this reason, the issue of cross-border (or, transboundary) pollution has been the subject of discussion in many international fora, and it is widely acknowledged that concerted international actions are necessary to deal with the problem. It is also accepted that the developing countries need help from the developed ones in order for the former to pursue environmental-friendly policies.

The purpose of this paper is to demonstrate a positive aspect of the international dimension of pollution. In particular, we consider a scenario in which pollution knows no international boundary and the developed countries provide aid to the developing countries to help the latter with pollution abatement. In this scenario, we show that an increase in the developed world's perception of the effect of cross-border pollution will in fact reduce the total amount of pollution emission in the developing world.

In the literature on environment and the international economy, international trade and trade policies play key roles (see, for example, Copeland (1994) and Beghin *et al* (1997)).[1] In our analysis, international linkages come via cross-border pollution and transfers. We assume both countries to be small open economies so that the commodity prices are exogenous and we do not consider trade polices. Instead, we allow the donor country to determine endogenously the amount of aid, and the recipient country is free to choose the emission tax rate and how much of the aid it wants to allocate for public abatement of pollution.[2] In other words, we assume that the developed country applies "carrots" in the form of foreign aid rather than "sticks" such as trade sanctions, in order to persuade the developing countries to follow sensible environmental polices.

[1] For an extensive survey of the earlier literature on environmental policies, see Cropper and Oats (1992).
[2] Implicitly, we assume that the donor cannot tie aid to pollution abatement, i.e. aid is perfectly fungible. This assumption is consistent with the findings of many empirical studies that aid is, for all intents and purposes, highly fungible (see, for example, Pack and Pack (1993) **and** Khilji and Zampelli (1994)).

There is a substantial literature on the economics of cross-border pollution. For example, Merrifield (1988) in a two-country general equilibrium model with internationally mobile goods, capital and pollution flows, examines the welfare effects of selected abatement strategies (*e.g.,* production taxes, abatement equipment standards). Ludema and Wooton (1994) develop a two-country model with production generated pollution in the exporting country and cross-border pollution externalities. Within this framework, they examine the welfare effects of environmental policies (*e.g.,* adoption of pollution abating technology) *vis-a-vis* trade policies (*e.g.,* reduction of import tariffs) when the two countries either can non-cooperatively restrict trade, or when they are bound by a free trade agreement. Ludema and Wooton (1997) extend their previous theoretical framework by incorporating administrative costs and asymmetric information in pollution abatement (known only to the exporting country), in order to examine the welfare implications of cooperative and non-cooperative trade and environmental policies. Copeland and Taylor (1995) consider a model of a world economy consisting of two regions --North and South-- each composed of many countries. Governments set national pollution quotas treating the rest of the world's pollution as given. They demonstrate, *inter alia*, that reduction in pollution by a coalition of countries may be Pareto improving and that income transfers tied to pollution reduction can be welfare enhancing. On the other hand, untied income transfers may not have an impact on global pollution, terms of trade and levels of national welfare. Copeland (1996), in a two country model of cross-border pollution, examines the effectiveness of a "pollution content tariff", *i.e.* an import tariff whose magnitude varies with the amount of pollution generated by the production of the imported good.

In the bulk of the relevant literature, it is assumed that all abatement activities are carried out by private agencies. Khan (1995) considers the other extreme where pollution abatement is entirely provided by a central agency (*e.g.,* government). Chao and Yu (1999) examine the welfare implications of foreign aid tied to pollution abatement, in the context of a two-country general equilibrium trade model where pollution is generated in and inflicted upon the aid-receiving country only. In their model, private sectors undertake abatement in response to emission taxes, and, on the top of it, the public sector carries out further abatement with the help of foreign aid. They examine the welfare effects of an exogenous increase in foreign aid. We follow Chao and Yu (1999) in considering the co-existence of private and public abatement of pollution. However, the relationship between the two papers ends with that, both in terms of the model formulation and the analysis.

The model is spelt out in the following section. Section 3 carries out the welfare analysis. The Nash equilibrium is characterised in section 4, which also carries out the main exercise of the paper, i.e. the effect of a change in the donor's perceived rate of cross-border pollution on net emission of pollution. Finally, some concluding remarks are made in section 5.

2. The Model

In our model there are two small open economies --a developed donor and a developing recipient country. Pollution takes place in the recipient country, as a by-product of production. For simplicity, we assume that no pollution is generated in the donor country. However, pollution created in the recipient country finds its way to the developed country, and the latter suffers disutility from this cross-border pollution.

In both countries, a number of goods, which are freely traded in the international market, are produced. The endowments of the internationally immobile factors of production are inelastically supplied and the factor markets are perfectly competitive. In the recipient country, both the private producers and the public sector take part in pollution abatement. The private producers do so in response to an emission tax, t, and the public sector abates some of the remaining pollution with the help of emission tax revenue and foreign aid. The private and the public sectors compete in the factor market on equal terms. The total factor endowment vector, V, in the recipient country can be decomposed into the part that is used in the private sector, V^p, and the part that used in the public abatement activities, V^g, i.e. $V=V^p+V^g$. The gross domestic product, or the restricted revenue function, $R(P, t, V^p)$, which is the country's maximum value of domestic production of private goods, is defined as

$$R(P,t,V^p) = \max_{x,z}\{P'x - tz : (x,z) \in T(V^p)\},$$

where P is the vector of world commodity prices, $T(V^p)$ is the country's aggregate technology set and x and z are respectively the vector of net outputs and the amount of pollution emission. The technology set includes pollution abatement technologies in the various sectors. For a given level of abatement carried out by the public sector g, the vector of factor uses in the public sector V^g and therefore V^p are uniquely determined. Moreover, since P does not vary in our analysis, the revenue function can be written as $R(t,g)$.

The $R(t,g)$ function is strictly convex in the effluent tax rate (*i.e.,* $R_{tt} > 0$), implying that an increase in the emissions tax rate lowers the amount of pollution emissions by the private sector, and for the rest of the analysis we assume that $R_{gg} = 0$.[3] It is well known (see, for example, Abe (1992)) that $-R_g [= -(\partial R/\partial g) = C^g(w)]$ is the unit cost of public pollution abatement, where (w) is the vector of factor returns. It is also well known (see, for example, Copeland (1994)) that

$$z = -R_t(g,t) \tag{1}$$

is the amount of pollution emissions by the private sectors. Therefore, taking both public and private abatement of pollution, the net emission of pollution, r, is defined as

$$r = z - g = -R_t(g,t) - g\,. \tag{2}$$

We also assume that $R_{tg}(= -\partial z/\partial g) > 0$. That is, an increase in the government provided pollution abatement reduces emission by the private sector. The justification for this assumption is as follows. Heuristically speaking, if g increases, the supply of factor endowments available for the production of the private goods becomes lower. This means

---

[3] This assumption implies that changes in (g), which change factor supplies available to produce private goods, do not affect its unit cost of production. For example, in a conventional H-O model, factor prices are determined by commodity prices and are independent of changes in factor endowments. Thus, when (g) changes then $C^g_g(w) = -R_{gg} = 0$. Abe (1992), Hatzipanayotou and Michael (1995) use this assumption in an alternative framework. Chao and Yu (1999) use the same assumption in a context similar to the one presented here.

that, on the whole, private production is reduced, which in turn implies that total pollution (*i.e.,* $-R_t$) falls, *i.e.,* $\partial(-R_t)/\partial g = -R_{tg} < 0$ or $R_{tg} > 0$.

Turning to the demand side in the recipient economy, the expenditure function $E(r,u)$ denotes the minimum expenditure required to achieve a level of utility u at the prevailing commodity prices,[4] when the level of net pollution is r. The partial derivative of the expenditure function with respect to u (E_u) denotes the reciprocal of marginal utility of income. Since pollution adversely affects household utility, the partial derivative of the expenditure function with respect to r (E_r) is positive and denotes the households' *marginal willingness to pay for the reduction in pollution* (*e.g.,* see Chao and Yu (1999)). That is, a higher level of pollution requires a higher level of spending on private goods to mitigate its detrimental effects in order to maintain a constant level of utility. The expenditure function is assumed to be strictly convex in r, $E_{rr} > 0$. That is, a higher level of net pollution raises the households' marginal willingness to pay for its reduction.

As for the recipient country government's budget constraint, we assume that the government finances the cost of publicly provided abatement (*i.e.,* $gC^g = -gR_g(g,t)$) by using a fraction $0 < b < 1$ of foreign aid provided by the donor country, [5] and the entire revenue raised from emission tax revenue (*i.e.,* $tz = -tR_t(g,t)$. Thus, the government's budget constraint can be written as:

$$bT + tz + gR_g(g,t) = bT - tR_t(g,t) + gR_g(g,t) = 0. \qquad (3)$$

The description of the aid-receiving pollution-emitting country is completed by writing its income-expenditure identity. The country's budget constraint requires that private spending ($E(r,u)$) must equal income from the production of private goods ($R(g,t)$) and from publicly provided pollution abatement ($-gR_g(g,t)$) plus the fraction

---

[4] For reasons mentioned before, prices are omitted from the arguments of the expenditure function.

[5] Our assumption that $b < 1$ implies that the recipient government is not required to provide matching funds for pollution abatement.

of aid distributed to domestic households in a lump-sum manner ($(1-b)T$). Using equation (2), the recipient country's budget constraint can be written as:

$$E(r,u) = R(g,t) - tR_t(g,t) + T\,. \tag{4}$$

Turning to the donor country, as noted before we assume that it does not generate any pollution. The utility of this country, however, is affected adversely by cross-border pollution originated in the recipient country (*i.e.* r). Denoting by q the perceived degree of cross-border pollution, the welfare of the donor country is affected adversely by the perceived amount of cross-border pollution qr.[6] Therefore**,** the country's income-expenditure identity requires that private spending, denoted by the expenditure function $E^*(qr,u^*)$, must equal revenue from production of the private goods, R^*, minus the amount of foreign aid transferred to the recipient country. That is,

$$E^*(qr,u^*) = R^* - T\,. \tag{5}$$

As before E_u^* denotes the reciprocal of the marginal utility of income in the donor country, and we assume that $E_{rr}^* > 0$. Since the commodity prices are exogenous, the factors of production are inelstically supplied, and there is no pollution or pollution abatement --- private or public --- in the donor country, R^* is exogenous to our analysis.

Equations (1)-(4) constitute a system of four equations in terms of the four primary unknowns, namely u, u^*, g and z. The model contains one policy parameter for the donor country, namely the amount of foreign aid (T), and two for the recipient country: the fraction of foreign aid allocated to pollution abatement (b) and the emissions tax rate (t).

[6] See Ishikawa and Kiyono (2000) for the concept of perceived degree of cross-border pollution.

3. Welfare Effects in the Recipient and Donor Countries

In this section we characterize the Nash optimal levels of the policy parameters under a number of scenarios, depending on the scope of the instruments. First of all differentiating equations (1)-(4), we obtain changes in the level of welfare in the donor and the recipient countries as follows:[7]

$$E_u \Delta du = A_T dT + A_b d\boldsymbol{b} + A_t dt \,, \tag{6}$$

$$E_u^* \Delta du^* = C_T dT + C_b d\boldsymbol{b} + C_t dt + C_q d\boldsymbol{q} \,, \tag{7}$$

where $A_T = \boldsymbol{b}(1 + R_{tg})E_r + (1 - \boldsymbol{b})(tR_{tg} - R_g) > 0$, $A_b = T[(1 + R_{tg})E_r + R_g - tR_{tg}]$,

$A_t = (z + gR_{gt})[(1 + R_{tg})E_r + R_g - tR_{tg}] - E_r R_{tt}(R_g + t)$, $\Delta = tR_{tg} - R_g > 0$,

$C_T = \boldsymbol{bq}(1 + R_{tg})E_r^* - (tR_{tg} - R_g)$, $C_b = T\boldsymbol{q}E_r^*(1 + R_{tg}) > 0$,

$C_t = \boldsymbol{q}E_r^*[(1 + R_{tg})(z + gR_{gt}) - R_{tt}(R_g + t)]$, and $C_q = -rE_r^*(tR_{tg} - R_g) < 0$.[8]

Before explaining the above equations, it may be helpful to explain how the policy parameters affect the level of net emission. These are found to be:

$$\Delta dr = -\boldsymbol{b}(1 + R_{tg})dT - T(1 + R_{tg})d\boldsymbol{b} + [R_{tt}(R_g + t) - (1 + R_{tg})(z + gR_{gt})]\,dt \,. \tag{8}$$

It is clear from equation (8) that an increase in T or $\boldsymbol{b}$, as one would expect, unambiguously reduces net pollution. However, an increase in t has an ambiguous effect on net emission. An increase in t reduces pollution emission by the private sector. However, a reduction in pollution emission by the private sector reduces the tax base for public sector abatement. The net effect of an increase in t on net emission is therefore ambiguous.

Turning to the effects on welfare levels, since $R_{tg}>0$ and $R_g<0$, the term A_T is positive and therefore aid unambiguously improves welfare in the recipient country.

[7] The system of basic equations for deriving these is stated in the matrix form in the Appendix.
[8] Note that a change in $\boldsymbol{q}$ has no direct effect on u.

There is a direct positive effect due to the transfer *per se*, and an indirect positive effect ($\beta(1+R_{tg})E_r$). The expression C_T in equation (7) indicates that for the donor country, foreign aid has an ambiguous effect. That is, aid induces the direct negative effect due to the income transfer, but so long as a fraction is spent on pollution abatement (*i.e.* $\beta > 0$), there is a positive indirect impact ($\beta(1+R_{tg})E_r$) on the donor's welfare. The expression A_b and A_t are ambiguous in sign. An increase in either t or β on one hand reduces pollution, but on the other hand takes resources away from the private sector to the public sector, reducing private income. An increase in β reduces net pollution and thus, as indicated by the term C_b, unambiguously improves welfare of the donor country. The term C_t indicates that an increase in t has an ambiguous effect on the welfare of the donor country. This is because, as noted before, an increase in t has an ambiguous effect on the level of net emission.

Finally, as shown by the term C_q, an increase in the perceived rate of cross-border pollution (θ) in the donor country exerts a detrimental effect on the donor country's welfare level, while it has no direct effect on the welfare level in the recipient country.

Turning now to the equilibrium choice of the instruments, we assume that the donor decides on the amount of aid (T), while the recipient selects the proportion (β) of aid allocated to pollution abatement and the rate of emission tax (t). We assume that the two countries behave non-cooperatively (Nash), so that the first order conditions are given by:

$$E_u^* \Delta(du^* / dT) = C_T = 0, \tag{9}$$

$$E_u \Delta(du / d\beta) = A_b = 0, \tag{10}$$

$$E_u \Delta(du / dt) = A_t = 0. \tag{11}$$

Equations (9), (10) and (11) simultaneously determine the optimal values of T, β and t. Having obtained the optimality conditions, we examine the effect of an increase in the perception parameter q on the level of net emission r. To this end we differentiate (9)-(11) and using (6)-(8), we obtain

$$C_{TT}dT + C_{Tb}db + C_{Tt}dt = -C_{Tq}dq \qquad (12)$$

$$A_{bT}dT + A_{bb}db + A_{bt}dt = 0, \qquad (13)$$

$$A_{tT}dT + A_{tb}db + A_{tt}dt = 0. \qquad (14)$$

where[9]

$$C_{TT} = -\Delta^{-1}b^{2}q(1+R_{tg})^{2}E^{*}_{rr},\ C_{Tb} = q(1+R_{tg})E^{*}_{r}[1+bT(\Delta r)^{-1}(1+R_{tg})(qh^{*}_{ru} - h^{*}_{rr})],$$

$$C_{Tt} = (\Delta r)^{-1}b(1+R_{tg})C_{t}(qh^{*}_{ru} - h^{*}_{rr}), \quad C_{Tq} = b(1+R_{tg})E^{*}_{r}(1-qh^{*}_{ru}),$$

$$A_{bT} = A_{b} + T\Delta^{-1}(1+R_{tg})[A_{T}E_{ru}E^{-1}_{u} - b(1+R_{tg})E_{rr}], \quad A_{bb} = -\Delta^{-1}T^{2}(1+R_{tg})^{2}E_{rr},$$

$$A_{bt} = -\Delta^{-1}T(1+R_{tg})[(1+R_{tg})(z+gR_{gt}) - R_{tt}(R_{g}+t)]E_{rr},$$

$$A_{tT} = [(1+R_{tg})(z+gR_{gt}) - R_{tt}(R_{g}+t)][(1-b)E_{ru} + (\Delta r)^{-1}b(1+R_{tg})E_{r}(h_{ru} - h_{rr})],$$

$$A_{tt} = -T^{-1}R_{tt}A_{b} - \Delta^{-1}[(1+R_{tg})(z+gR_{gt}) - R_{tt}(R_{g}+t)]^{2}E_{rr} - (1+R_{tg})E_{r}R_{tt},$$

$$h_{ru} = r(E_{ru}/E_{u}),\ h_{rr} = r(E_{rr}/E_{r}),\ h^{*}_{ru} = r(E^{*}_{ru}/E^{*}_{u}),\ h^{*}_{rr} = r(E^{*}_{rr}/E^{*}_{r}).$$

Having obtained the general expression for changes in the policy variables, we shall now examine the effect of a change in q on the level of net emission r, under a number of special cases.

3.1 A Benchmark Case: Passive Recipient

First, we consider a case where the donor government optimally chooses the amount of foreign aid (T), but the recipient government treats (b, t) as exogenous. In this case, the effect of a change in the perceived rate (q) of cross-border pollution on net pollution is given by:

$$(dr\ /d\boldsymbol{q}) = [(\partial r\ /\partial \boldsymbol{q}) + (\partial r\ /\partial T)(dT\ \ /d\boldsymbol{q})] = -\Delta^{-1}\boldsymbol{b}(1 + \mathrm{R}_{tg})(dT\ \ /d\boldsymbol{q})\ , \qquad (15)$$

where $(\partial r / \partial \boldsymbol{q}) = 0$ and $(\partial r\ /\partial T)$ is given by equations (8). Equation (15) indicates that a higher value of $\boldsymbol{q}$ reduces net emission if and only if it increases the amount of the transfer. In order to find the effect on transfer, letting $d\boldsymbol{b} = dt = 0$ in equation (12), we get:

$$(dT\ \ /d\boldsymbol{q}) = \Delta^{-1}(1 - \boldsymbol{h}^{*}_{ru})E^{*}_{r}[\boldsymbol{q}(1 + \mathrm{R}_{tg})E^{*}_{rr}]^{-1}\ , \qquad (16)$$

where $\boldsymbol{h}^{*}_{ru} (= rE^{*}_{ru} / E^{*}_{u})$ is the donor country's marginal propensity to pay for pollution abatement. Since it is natural to assume that the consumers will not be willing, at the margin, to pay more than their additional income for pollution abatement, we assume that $\boldsymbol{h}^{*}_{ru} < 1$. It then immediately follows from (15) and (16) that an increase in $\boldsymbol{q}$ unambiguously reduces net emission.

Proposition 1: *Consider two countries, a donor that optimally chooses the amount of aid, and a recipient pollution-emitting that uses a fixed fraction of aid and pollution tax revenue, at a constant tax rate, to finance pollution abatement. Then, an increase in the donor's perceived rate of cross-border pollution, unambiguously raises the amount of foreign aid, and reduces the level of net emission.*

The intuition of this result can be as follows. An increase in $\boldsymbol{q}$ increases the marginal benefit of aid as the recipient country spends a positive fraction of it on pollution abatement. This induces the donor to increase the amount of aid, and thus reducing net emission level.

---

[9] Note that $C_{TT}<0$ and $A_{bb} <0$, and therefore the respective welfare functions are concave in T and $\boldsymbol{b}$. A sufficient condition for A_{tt} to be negative is that $A_{b} \geq 0$. Note also that third derivatives are assumed zero.

3.2 The Case of Nash Equilibrium

Next we consider the case in which the donor, as before, decides on the level of aid, and the recipient chooses the instruments at its disposal. We consider three sub-cases depending on the instruments the recipient decides to use.

Case 1: *The donor country optimally chooses the amount of foreign aid (T), and the recipient sets optimally the fraction* (b) *of foreign aid allocated to pollution abatement. The emission tax rate (t) is assumed to be exogenous.*

In this case, the effect of a change in q on net emission is given as:

$$(dr/dq) = (\partial r/\partial T)(dT/dq) + (\partial r/\partial b)(db/dq) =$$

$$-(1+R_{tg})\Delta^{-1}[b(dT/dq) + T(db/dq)]\,, \qquad (17)$$

where the expressions for $(\partial r/\partial T)$ and $(\partial r/\partial b)$ are given in (8). Equation (17) indicates that if q raises foreign aid and its fraction allocated to pollution abatement in the recipient country (*i.e.* if $(dT/dq) > 0$ and $(db/dq) > 0$), then it will reduce emission, *i.e.* $(dr/dq) < 0$.

The Nash equilibrium in this case is derived by setting $C_T = 0$ and $A_b = 0$. Totally differentiating these two equations, we can solve for the effects on T and b as:

$$\Omega(dT/dq) = -C_{Tq}A_{bb}\text{, and} \qquad (18)$$

$$\Omega(db/dq) = A_{bT}C_{Tq}\,, \qquad (19)$$

where $\Omega(= A_{bb}C_{TT} - A_{bT}C_{Tb}) > 0$ for stability of the system.[10]

From (18) it is clear that an increase in the perception parameter q unambiguously increases aid, as in the previous case. But, the effect on b is ambiguous. In particular, if the marginal propensity to pay for the pollution abatement is very small in

[10] See, for example, Takayama (1985), pp. 313-319.

the recipient country, we have $A_{bT} < 0$, and therefore an increase in $\mathbf{q}$ will reduce $\mathbf{b}$. The intuition is simple. If the marginal propensity to pay for pollution abatement is small, the recipient government would allocate a smaller proportion of aid to public abatement and thus increasing the activities of the private sector.

Next, substituting equation (18) and (19) into (17), and after some manipulations, we get

$$(dr / d\mathbf{q}) = -T^{2} (1 + R_{tg})^{3} (\Delta\Omega)^{-1} C_{T\mathbf{q}} E_{ru} , \qquad (20)$$

Equation (20) shows that an increase in $\mathbf{q}$ unambiguously reduces net emission, regardless of its ambiguous effect on $\mathbf{b}$.

<u>Case 2:</u> *The donor country optimally chooses the amount of foreign aid (T), and the recipient sets optimally the emission tax rate (t). The fraction of foreign aid allocated to pollution abatement $(\mathbf{b})$ is set exogenously.*

The Nash equilibrium in this case is derived by setting $C_T = 0$ and $A_t = 0$. Differentiating these equilibrium conditions, we obtain:

$$\Omega_1 (dT / d\mathbf{q}) = -C_{T\mathbf{q}} A_{tt} \text{, and} \qquad (21)$$

$$\Omega_1 (dt / d\mathbf{q}) = A_{tT} C_{T\mathbf{q}} , \qquad (22)$$

where $\Omega_1 (= A_{tt} C_{TT} - A_{tT} C_{Tt})$ >0 for the stability of the system.

Since A_{tt} <*0* and $C_{Tq} > 0$, it follows from (21) that an increase in $\mathbf{q}$ increases the optimal level of aid. However, A_{tT}, and therefore $dt / d\mathbf{q}$, cannot be signed unambiguously. Using the Nash equilibrium conditions, the expression for A_{tT} can be simplified as:

$$A_{tT} = (z + gR_{gt}) E_r^{-1} [-\mathbf{b}(1 + R_{tg}) E_{rr} + (\mathbf{b}T^{-1} A_{\mathbf{b}} + \Delta) E_{ru} E_u^{-1}] .$$

From the above expression it is clear that A_{tT}, and therefore $dt/d\theta$, are negative if the marginal propensity to pay for pollution abatement in the recipient country is very small. The intuition is similar to that given for $d\beta/d\theta$ in the previous case. The effect on net emission in this case is given by:

$$(dr/d\theta) = (\partial r/\partial T)(dT/d\theta) + (\partial r/\partial t)(dt/d\theta) =$$

$$-(1+R_{tg})\Delta^{-1}\beta(dT/d\theta) - (z+gR_{gt})E_r^{-1}(dt/d\theta)\ , \qquad (23)$$

where the expressions for $(\partial r/\partial T)$ and $(\partial r/\partial t)$ are given in equation (8).[11] Substituting (21) and (22) into (23), we get:

$$(dr/d\theta) = \Omega_1 C_{T\theta}[\Delta^{-1}\beta(1+R_{tg})A_{tt} - (z+gR_{gt})E_r^{-1}A_{tT}] =$$

$$\Omega_1 C_{T\theta}\{-T^{-1}\beta A_b[\Delta^{-1}(1+R_{tg})R_{tt} + (z+gR_{gt})^2(E_r^{-1})^2 E_{ru}E_u^{-1}] - \Delta(z+gR_{gt})^2(E_r^{-1})^2 E_{ru}$$

$$-\Delta^{-1}\beta(1+R_{tg})^2 E_r R_{tt}\}\ . \qquad (24)$$

Unlike in the previous two cases, the effect on net emission is no longer unambiguous. However, a sufficient condition for the effect to be negative is that A_b is non-negative. However, if the marginal propensity to pay for pollution abatement is small and A_b is negative, an increase in θ may increase net emission. Note that A_b is negative, when the exogenously given value of β is higher than the optimal one. It is also to be noted that a higher β means more resources are spent in the public sector at the expense of the private one. In this case, therefore, the recipient government redresses this imbalance by reducing emission tax rate and thus increasing net emission.

[11] Using $A_t = 0$, it can be shown that $[(1+R_{tg})(z+gR_{gt}) - R_{tt}(R_g+t)] = (z+gR_{gt})\Delta E_r^{-1} > 0.$

<u>Case 3:</u> The donor country optimally chooses the amount of (T), *and the recipient country optimally sets both the fraction of aid allocated to pollution abatement* $(\boldsymbol{b})$, *and the emission tax rate* (t).

In this case, the Nash equilibrium is obtained by setting $A_b = A_t = C_T = 0$. Differentiating these equations, we get:

$$D(dT/d\boldsymbol{q}) = -C_{Tq}\,(A_{bb}\,A_{tt} - A_{tb}\,A_{bt})\,, \tag{25}$$

$$D(dt/d\boldsymbol{q}) = -C_{Tq}\,(A_{bT}\,A_{tb} - A_{bb}\,A_{tT})\,, \tag{26}$$

$$D(d\boldsymbol{b}/d\boldsymbol{q}) = C_{Tq}\,(A_{tt}A_{bT} - A_{bt}\,A_{tT})\,, \tag{27}$$

where D is the determinant of the matrix of coefficients for dT, $d\boldsymbol{b}$ and dt in equations (12)-(14). Stability requires that D is negative. Note that the equilibrium conditions in this case, *i.e.* $A_b = A_t = C_T = 0$, imply that $E_r = -\mathrm{R}_g = t$, and thus the expressions of the individual coefficients on the right hand sides are simplified as:

$$A_{bT} = T(1+\mathrm{R}_{tg})[E_{ru}\,E_u^{-1} - \boldsymbol{b}\Delta^{-1}(1+\mathrm{R}_{tg})E_{rr}]\,,$$

$$A_{bt} = A_{tb} = \Delta^{-1}T(1+\mathrm{R}_{tg})^2(z + g\mathrm{R}_{tg})E_{rr}\,,$$

$$A_{tT} = (1+\mathrm{R}_{tg})(z + g\mathrm{R}_{tg})[E_{ru}\,E_u^{-1} - \Delta^{-1}\boldsymbol{b}(1+\mathrm{R}_{tg})E_{rr}]\,,$$

$$A_{tt} = -\Delta^{-1}(1+\mathrm{R}_{tg})^2(z + g\mathrm{R}_{tg})^2 E_{rr} - E_r\,\mathrm{R}_{tt}(1+\mathrm{R}_{tg})\,.$$

Substituting the above expressions in (25)-(27), we get:

$$D(dT/d\boldsymbol{q}) = -C_{Tq}\,T^2\Delta^{-1}(1+R_{tg})^3 E_{rr}E_r R_{tt}\,, \tag{28}$$

$$D(dt/d\boldsymbol{q}) = 0\,, \tag{29}$$

$$D(d\boldsymbol{b}/d\boldsymbol{q}) = C_{Tq}\,[\Delta^{-1}\boldsymbol{b}T^2(1+\mathrm{R}_{tg})^3 E_{rr}\,E_r\,\mathrm{R}_{tt} - T^2(1+\mathrm{R}_{tg})^2 E_r\,E_{ru}\,E_u^{-1}\,\mathrm{R}_{tt}]\,. \tag{30}$$

From (28) and (29) it is clear that an increase in the perception parameter q unambiguously raises the amount of aid ($dT/dq > 0$), and has no effect on the emission tax rate ($dt/dq = 0$). Finally, the impact on the fraction of aid allocated to pollution, b, abatement is ambiguous. The reason for this ambiguity in the effect on b is the same as before. Our assumption that a change in g does not affect R_g *(R_{gg}=0)* and the fact the optimality requires t=-R_g together means that a change in q has no effect on the optimal level of t.

The effect on net emission in this case is:

$$
\begin{aligned}
(dr/dq) &= -\Delta^{-1}(1+R_{tg})[b(dT/dq)+T(db/dq)] \\
&= (\Delta D)^{-1} T^2 C_{Tq}(1+R_{tg})^3 E_r E_{ru} E_u^{-1} R_{tt}. \qquad (31)
\end{aligned}
$$

Since $D < 0$, it is evident from the above equation that an increase in q unambiguously reduces net emission. Summarizing our results for the two Nash equilibrium regimes, we state:

Proposition 2: *Consider a Nash equilibrium where a donor country optimally chooses the amount of transfer to a pollution emitting country, which sets optimally either the fraction of aid allocated to pollution abatement and/or the emission tax rate. In all cases an increase in the perceived rate of cross-border pollution in the donor country unambiguously raises the amount of foreign aid. In all the cases, except when the recipient chooses only the emission tax rate, it also reduces net pollution, regardless of its effect on either the fraction of aid allocated to pollution abatement or the effluent tax rate. When the recipient country chooses only the emission tax rate, an increase in the perception factor reduces net emission if the exogenous level of the fraction of aid allocated to pollution abatement is lower than or equal to the equilibrium level.*

4. Concluding Remarks

A dominant issue in current economic policy debates is the interaction between international trade and negative cross-border environmental externalities due to increased production of pollution-intensive goods, and due to the use of environmentally unfriendly production technologies. This negative link allegedly has been exacerbated because of the recent surge in the volume of international trade and because of the conscious and systematic efforts by international institution, organizations, and many countries to liberalize the international mobility of commodities and factors of production. To limit the damaging impact of cross-border pollution, the affected countries often use threat of trade sanction to persuade the pollution-generating countries to get their acts together. However, following a number of very high profile international summits --- the latest one being the 1997 summit in Kyoto --- the developed countries have been advised to take a less combative approach and follow a "carrots" rather than "sticks" approach to cross-border pollution.

Motivated by such aspects of the recent environmental agreements, we develop a two-country model with income transfers, transboundary pollution, and co-existence of private and public abatement. We find that, even in the absence of international cooperation, cross-border pollution can reduce the total amount of net pollution emission by inducing more international transfer, which in turn brings about more sensible pollution policies in the polluting country. In this respect the fact that the externalities associated with pollution often knows no international border, is a blessing in disguise.

Appendix A: The Matrix System of Changes in the Variable

Total differentiation of equations (1)-(4) yields:

$$\begin{bmatrix} E_u & 0 & (E_r - t) & -(E_r + R_g) \\ 0 & E_u^* & \boldsymbol{q}E_r^* & -\boldsymbol{q}E_r^* \\ 0 & 0 & t & R_g \\ 0 & 0 & 1 & R_{tg} \end{bmatrix} \begin{bmatrix} du \\ du^* \\ dz \\ dg \end{bmatrix} = \begin{bmatrix} 1 \\ -1 \\ -\boldsymbol{b} \\ 0 \end{bmatrix} dT + \begin{bmatrix} 0 \\ -rE_r^* \\ 0 \\ 0 \end{bmatrix} d\boldsymbol{q}$$

$$+ \begin{bmatrix} 0 \\ 0 \\ -T \\ 0 \end{bmatrix} d\boldsymbol{b} + \begin{bmatrix} 0 \\ 0 \\ -(z + gR_{gt}) \\ -R_{tt} \end{bmatrix} dt \ .$$

References

Abe, K., 1992, Tariff reform in a small open economy with public production, International Economic Review 33, 209-222.

Baumol, W. and W. Oates, 1988, The theory of environmental policy, Cambridge: Cambridge University Press.

Beghin, J., D. Roland-Holst and D. van der Mensbrugghe, 1997, Trade and pollution linkages: piecemeal policy reform and optimal intervention, Canadian Journal of Economics 30, 442-455.

Chao, C.C. and E. Yu, 1999, Foreign aid, the environment, and welfare, Journal of Development Economics 59, 553-564.

Copeland, B., 1994, International trade and the environment: policy reform in a polluted small open economy, Journal of Environmental Economics and Management, 26, 44-65.

Copeland, B.R., 1996, Pollution content tariffs, environmental rent shifting, and the control of cross-border pollution, Journal of International Economics, 40, 459-476.

Copeland, B.R., and M.S. Taylor, 1995, Trade and transboundary pollution, American Economic Review, 85, 716-737.

Cropper, M.L. and W.E. Oates, 1992, Environmental economics: a survey, Journal of Economic Literature 30, 675-740.

Hatzipanayotou, P. and M.S. Michael, 1995, Foreign aid and public goods, Journal of Development Economics 47, 455-467.

Ishikawa, J. and K. Kiyono, 2000, International trade and global warming, mimeo, Hitotsubashi University, Japan.

Khan, A., 1995, Free trade and the environment, Journal of International Trade and Economic Development 5, 113-136.

Khilji, N.M. and E.M.Zampelli, 1994, The fungibility of U.S. military and non-military assistance and the impacts on major aid recipients, Journal of Development Economics, 43, 345-362.

Ludema, R. and I. Wooton, 1994, Cross-border externalities and trade liberalization: the strategic control of pollution, Canadian Journal of Economics 27, 950-966.

Ludema, R. and I. Wooton, 1997, International trade rules and environmental cooperation under asymmetric information, International Economic Review 38, 605-625.

Merrifield, J., 1988, The impact of selected abatement strategies on transnational pollution, the terms of trade, and factor rewards: A general equilibrium approach, Journal of Environmental Economics and Management 15, 259-284.

Pack, H. and J. R. Pack, 1994, Foreign aid the question of fungibility, Review of Economic and Statistics, 75, 258-265.

Takayama, A., 1986, Mathematical economics 2nd edition, Cambridge: Cambridge University Press.