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Impure Public Technologies and Environmental Policy

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Summary

Analyses of public goods regularly address the case of pure public goods. However, a large number of (international) public goods exhibit characteristics of different degrees of publicness, i.e. they are impure public goods. In our analysis of transfers helping to overcome the inefficient provision of such goods, we therefore apply the Lancastrian characteristics approach. In contrast to the existing literature, we consider the case of a continuum of impure public goods. We employ the example of international conditional transfers targeting to overcome suboptimal low climate protection efforts by influencing the abatement technology choice of countries.

Keywords: Impure Public Goods, Lancastrian Characteristics Approach, Conditional Transfers, Ancillary Benefits of Climate Policy

JEL Classification: H87, Q54

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1. Introduction

The quality of human life is threatened by various environmental problems ranging from the relatively local (e.g. indoor pollution) up to the universally global (e.g. climate change). There are several different environmental protection options for combating such threats and these options – in turn – involve different kinds of public goods, which yield benefits on different geographical scales.

Individual countries assign divergent relative priorities to the different environmental threats and hence to the benefits of environmental protection options. In this study we represent these divergent priorities in a modelling framework that allows us to understand the potential for international transfers for inducing world-wide optimal provision levels of both locally as well as globally public environmental goods.

There are meanwhile plenty of research contributions addressing issues concerning global public goods and atmospheric externalities (see, e.g., Chakravorty, Roumasset and Tse (1997); Caplan, Cornes and Silva (2003); Sheshinski (2004)). Cornes and Itaya (2004) consider the case where more than one public good can be produced.[1] They assume that the public goods are supplied by 'summation technology'[2] and therefore consider the case of pure public goods. Yet, since most public goods (e.g., climate policy or biodiversity conservation) exhibit impure publicness, we consider them to be impure-public joint-production goods. Therefore, similar to Cornes' and Itaya's idea of the case of more than one pure public good, we develop an approach which allows for the presence of more than one impure public good. Since the pure

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[1] Cornes and Silva (2003) investigate the case of more than one local public good.
[2] Summation technology is used to define the case where the provision of a public good is the sum of the contributions of each of the providers of that good. This essentially defines the 'pure' public good case.

public good case is one specific case in the more general impure public model, we implicitly include the pure public good case as well.

Pioneering work concerning impure public goods has been provided by Cornes and Sandler (1984). They develop an approach to analyze this type of public good where the consumers' utility function is defined over three characteristics. Cornes and Sandler (1994) investigate the comparative static properties of this standard impure public good approach. These deviate significantly from those of the standard pure public good model. Recently, Kotchen (2007) provided an analysis of the impure public good model's equilibrium properties. Cornes and Sandler (1984) suggest applying the impure public good approach to an activity like philanthropy. This idea was elaborated by Andreoni (1986, 1989, 1990) and initiated a new strand of literature that is largely associated with the expression "warm-glow giving". Vicary (1997, 2000) provides an analysis that considers different technologies available for raising the level of the regarded public characteristic. In his model, simple donations only buy the public characteristic while the purchase of an impure public good generates both, private and public characteristics. An example would be a choice between a simple donation to protect a rain forest and the purchase of products from a rainforest, where part of the payment was used to protect the forest. The buyer would then both consume the private good and provide some public good benefit. In contrast, Rübbelke (2003) takes into account alternative technologies to produce the private characteristic associated with the impure public good. An example here would be the choice between buying coffee that is grown in a way that conserves high biodiversity areas and buying coffee that is grown without taking such concerns into account. Finally Kotchen (2005, 2006) allows for both, an independent production of the private characteristic as well as of the public characteristic of the impure public good.

Based on the standard impure public good approach developed by Cornes and Sandler (1984), we will – as a first step – illustrate the case of two impure public goods in a two-country world and we will show that impure public goods are provided in an inefficient way in the absence of coordinated action between countries.

Then – as a second step –, we will generalize the two-impure-public-goods model to the more general case of a continuum of impure public goods and analyze whether transfers may help to overcome inefficiencies in public good provision. Throughout, we employ the example of impure public policies or technologies combating greenhouse gas (GHG) emissions and local/regional air pollution. However, our approach can be applied to all kinds of impure public goods, e.g. refuse collection, green-electricity programs, military defence activity or anti-terrorist activities.[3]

We proceed as follows: We explain the concept of impure public goods in Section 2 and apply it to climate policy. In Section 3, we regard the special case where two alternative impure public technologies, which simultaneously protect the global as well as the local/regional environment, are available. The global effect or characteristic of the regarded environmental policies is climate protection. On the other hand the ancillary local/regional effects of these policies are characterized by the mitigation of local/regional air pollution. We demonstrate that the impure public goods are provided in an inefficient way as long as there is no coordination among countries. In Section 4, we describe and analyze the trade-off between local/regional and global impacts of environmental protection policies in a more general impure public good model which not only considers two different impure public technologies but a

[3] Dubin and Navarro (1988) employ the impure public good approach to analyze refuse collection, Kotchen and Moore (2007) explore green-electricity programs, Sandler and Murdoch (1990) as well as Sandler and Hartley (2001) investigate military alliances and Pittel and Rübbelke (2006) analyze terrorist activities.

continuum of such technologies. We analyze whether international transfers could help to raise the suboptimal (low) provision of global environmental protection, taking account of local/regional co-benefits. In the framework of our model, the transfer-paying industrialized countries induce a technology switch in transfer-receiving developing countries from technologies mainly protecting the local/regional environment (and to a lesser extent the global commons) to technologies mainly combating climate change (and to a lesser extent the local/regional environment). Section 5 concludes.

2. Impure Public Technologies and Climate Protection

In developing countries the main focus of environmental policies is on the combat of local or regional threats. In many cases these local or regional policies also produce global benefits (Eskeland and Xie (1998)). As Gielen and Changhong (2001: 258) stress the order of issues on the political agenda in developing countries like China is: "First the apparent local air pollution problems are tackled; next the more distant GHG problem is considered. Therefore, it is more relevant to study the impact of local air pollution abatement on GHG emission reduction than vice versa." In contrast, policies to protect the global commons are highly ranked in industrialized countries, while local and regional pollution problems are of less interest since the respective pollution levels are already quite low in these countries.[4]

Consequently, there is an asymmetry in the perception of environmental threats and the appreciation of environmental policies in the international arena. Industrialized

[4] Nevertheless there are still significant benefits from local/regional air pollution mitigation in industrialized countries. Burtraw et al. (2003) investigate co-benefits of climate policies in the US and stress that ancillary benefits from reductions in NO_X contribute significantly to justifying the cost of reducing carbon emissions.

countries have mainly an interest in raising the level of environmental policies, which mainly yield the protection of the global commons like the world's climate.[5] In contrast, developing countries prefer policies whose main joint output is the protection of the local/regional environment. Aunan et al. (2003: 289-290) even point out that it is reasonable to believe that geographically limited co-effects of climate policy, like improving air quality in cities and securing energy supply, have had a positive influence on the level of China's climate protection efforts. The benefits derived from such co-effects of climate policy are also called ancillary or secondary benefits. In contrast, the benefits derived from the climate protecting impact of climate policy, which constitutes – of course – the primary aim of such a policy, are called primary benefits (see Markandya and Rübbelke (2004)). Several ancillary benefit assessment studies found out that ancillary benefits even represent a multiple of the benefits derived from climate change mitigation itself (see Pearce (2000)).

Let us illustrate and exemplify the joint-production property of environmental policy by discussing the different effects of climate policy. In doing so we make a distinction between things (commodities or policies) and characteristics (properties or effects), as proposed by Lancaster (1966). Climate policies (*things*) generate different effects (possess different *characteristics*) and the relevant effects/characteristics should all be included in the analysis of these policies. It is these effects/characteristics which agents (*people*) are interested in and not the policies as such. However, not all characteristics are equally relevant for individual agents.

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[5] However, there are joint products of global environmental protection activities that are strongly appreciated by industrialized countries. So climate protection by using renewable energy sources also raises the security of energy supply, which is a topic highly ranked on the political agenda of industrialized as well as developing countries. For a recent analysis of European security of energy supply see Markandya et al. (2007).

Consequently, the relationship between 'things' and people are at least a two-stage affair (see Figure 1). "It is composed of the relationship between things and their characteristics (objective and technical) and the relationship between characteristics and people (personal, involving individual preferences)" (Lancaster (1971: 7)):

CO_2 is the most important gas contributing to the anthropogenic greenhouse effect and therefore climate policies (*things*) may target the reduction of CO_2 emissions in order to protect the climate (*characteristic*). Climate protection, in turn, yields primary benefits for everyone (*people*).

In general such climate policies (*things*) generate the co-effects (*characteristic*) in the shape of local/regional air pollution mitigation, since they regularly also reduce emissions of non-CO_2 pollutants like NO_X, SO_2 and PM.[6] The improved air quality yields ancillary benefits for the climate protecting agents (*people*).

Most of the ancillary benefits are local or regional, i.e. they are enjoyed exclusively by the communities located relatively close to the source of the policy (Pearce (1992: 5); IPCC (1996: 217) and Krupnick, Burtraw and Markandya (2000: 54)).[7] Therefore, we can largely regard ancillary effects to be private to the host country or region where the climate policy is introduced. Consequently, they contrast to the primary effect which exhibits global publicness, i.e. no country can be excluded from enjoying primary benefits generated in any other country and there prevails non-rivalry concerning the consumption of the primary effect (climate stabilization) of climate

[6] Such pollutants are associated with negative health effects, accelerated surface corrosion, weathering of materials and impaired visibility.
[7] However, the abatement of the greenhouse gases CFCs generates an important global ancillary benefit by protecting the ozone layer (Rübbelke (2002: 23)).

policy.[8] Due to the different degrees of publicness of the different characteristics (global climate protection and local/regional air pollution mitigation) of climate policy, it is an impure public good.

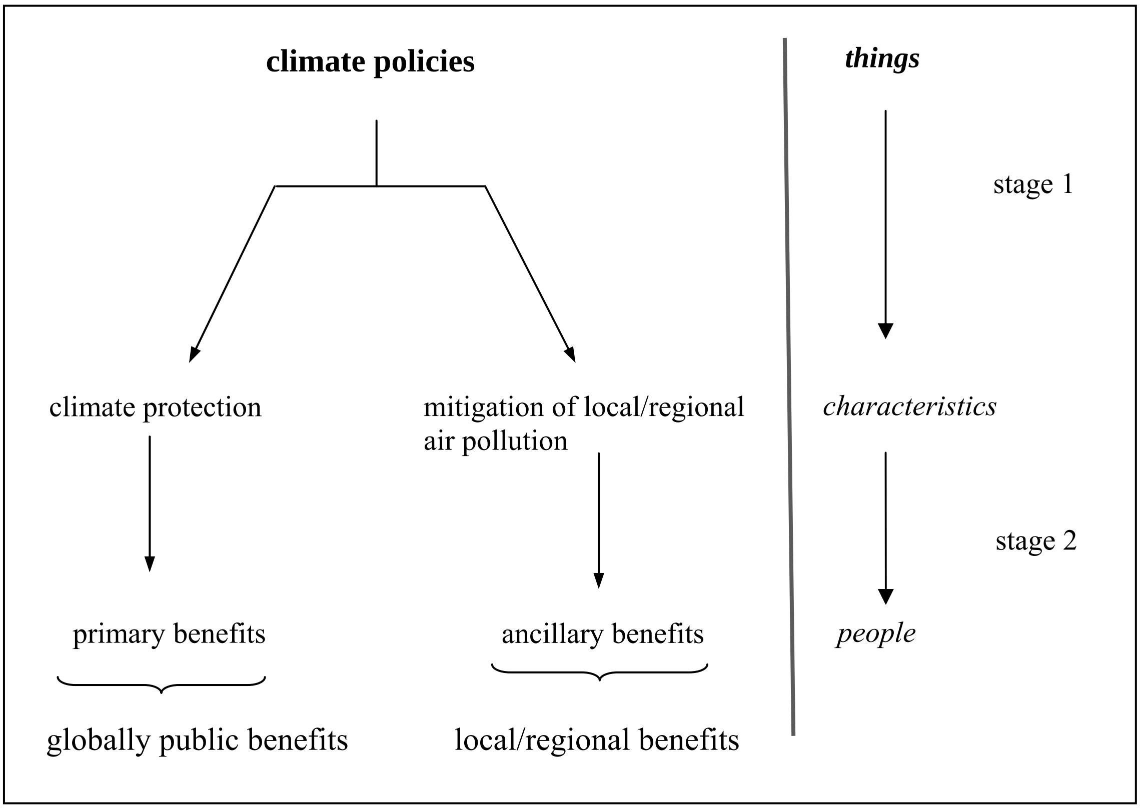


Figure 1: Climate Policies – Impure Public Goods.

3. A Model with Two Impure Public Goods

3.1 Goods and Characteristics

A country can consume a private goods bundle y. Furthermore, we consider two different technologies representing impure public goods. These goods q_1 and q_2 generate the same kinds of characteristics, which are 1) the reduction of global

[8] Yet, as Rypdal et al. (2005) stress, some GHGs not only generate global but also more regionally confined climate effects.

pollutants (GHG emissions) and 2) the mitigation of local/regional pollutants (like NO_X, PM and SO_2 emissions). The reduction of local emissions represents a private characteristic *z* from an individual country's point of view. The mitigation of global pollution is a global public characteristic *x*.

The maximization problem of an individual country *j* that decides on the environmental technology application is:

$$Max \quad U_j(y_j, \sum_j q_{1j}, \sum_j q_{2j}) = U(y_j, z_j, x) \tag{1}$$

s.t.

$$z_j = \alpha_1 q_{1j} + \alpha_2 q_{2j}, \tag{2}$$

$$x = \beta_1 q_{1j} + \beta_2 q_{2j} + \tilde{x}, \tag{3}$$

$$i_j = y_j + q_{1j} + pq_{2j}, \tag{4}$$

where $\frac{\partial U_j}{\partial z_j} = U_z > 0$, $U_{zz} < 0$, $\frac{\partial U_j}{\partial x} = U_x > 0$ and $U_{xx} < 0$. i_j represents the exogenously given income of country *j*. The index of countries (*j*) runs from *1* to *N*. $\tilde{x}$ stands for the amount of the global public good (mitigation of global pollution) produced by the other countries. The price of the first technology is normalized to unity. The price of the second technology is denoted by *p*, with $0 < p$ and the sum of all agents' production of q_1 and q_2 is represented by $\sum q_{1j}$ and $\sum q_{2j}$, respectively. The parameters α and β measure how many units of characteristic *z* and *x*, respectively, are produced by one unit of a technology. Each unit of the private goods bundle, which can be acquired at a price of unity, produces one unit of a private characteristic, so that *y* denotes the amount of the private good as well as the amount of the private characteristic generated by this goods bundle. The characteristic of *y* is different from the private characteristic generated by the environmental technologies. Table 1 summarizes the relations between commodities (y, q_1, q_2) and their characteristics (y, z, x).

Throughout, we will employ the Nash assumption that the utility maximizing agent (country) conjectures that the other agents' provision of the public characteristic does not change in response to modifications in its own public characteristic generation.

	goods	***y***	$\boldsymbol{q_1}$	$\boldsymbol{q_2}$
Characteristics produced by one unit				
y		1	0	0
z		0	α_1	α_2
x		0	β_1	β_2

Table 1: Relations between Goods and Characteristics.

The maximization can be presented in a graphical depiction. Since we face the goods-sphere in the budget constraint while we have the characteristics-sphere in the utility function, we have the options to show the problem in the goods-space (g-space) or in the characteristics-space (c-space). After the graphical depiction in both spaces, we will analyse the maximization problem analytically in characteristics space. In Figure 2, depicting the goods-sphere, the plane *ABC* represents the budget constraint.

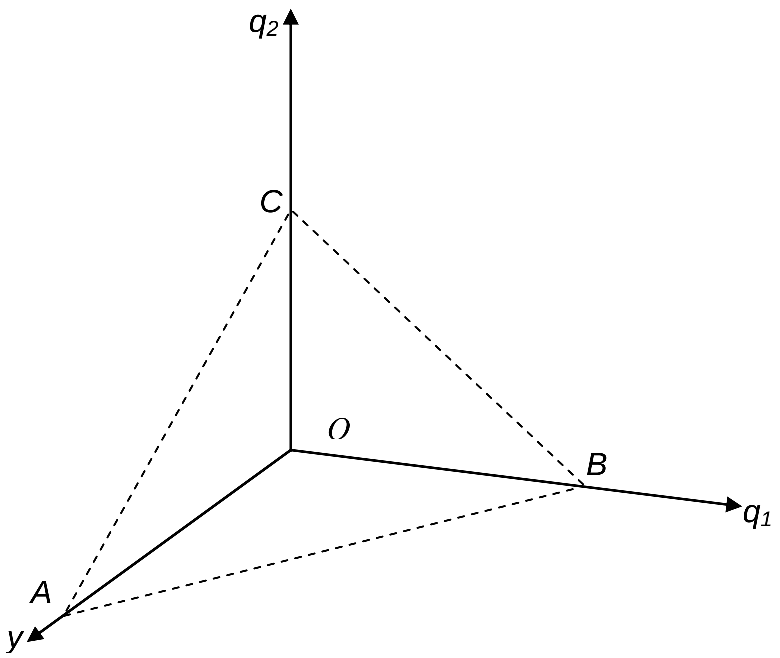


Figure 2: Goods Space.

The budget constraint is associated with the following four extreme points:

$$0 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix},\ A = \begin{bmatrix} i \\ 0 \\ 0 \end{bmatrix},\ B = \begin{bmatrix} 0 \\ i \\ 0 \end{bmatrix},\ C = \begin{bmatrix} 0 \\ 0 \\ \frac{i}{p} \end{bmatrix}.$$

The point where the highest of the set of indifference surfaces - which are not mapped - is tangent to the plane *ABC*, represent the optimal allocation of the three goods.

The transformation between g-space and c-space is determined by the following relationships:

$$y = y, \tag{5}$$

$$z = \alpha_1 q_1 + \alpha_2 q_2, \tag{6}$$

$$x = \beta_1 q_1 + \beta_2 q_2 + \tilde{x}\ . \tag{7}$$

Let us assume that technology 1 has a comparative technological advantage over technology 2 in producing *x* relatively to producing *z*, i.e. we suppose that $\beta_1/\alpha_1 > \beta_2/\alpha_2$.

In Figure 3, we first have a look at the provision of the public characteristic by itself – i.e ignoring the contribution of other countries in producing the public characteristic. This implies that the considered agent is the only provider of impure public goods. Later on, we omit this simplifying assumption.

The vectors $0Q_1$ and $0Q_2$ show the amounts of private (z) and public (x) characteristics that can be produced by different expenditures on technologies 1 and 2, respectively. Another vector coinciding with the axis measuring y shows the amount of the private characteristic (y) which can be acquired by particular expenditures on y.

If the country would pay its total income on technology 1, it would generate $z_1 = \alpha_1 i$ units of the private characteristic and $x_1 = \beta_1 i$ units of the public characteristic. This point is indicated by E in Figure 3. The points x_1 and z_1 are not shown in the figure.

If the country would spend its income i completely on technology 2, it would produce $z_2 = \alpha_2 \frac{i}{p}$ units of the private characteristic and $x_2 = \beta_2 \frac{i}{p}$ units of the public characteristic. This point is indicated by F.

If the country would only consume the private good, it would get $y = i$ units of the private characteristic. This point is indicated by point D.

So, the extreme points that define the hyperplane are:

$$0 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix},\ D = \begin{bmatrix} i \\ 0 \\ 0 \end{bmatrix},\ F = \begin{bmatrix} 0 \\ \alpha_1 i \\ \beta_1 i \end{bmatrix},\ E = \begin{bmatrix} 0 \\ \frac{\alpha_2}{p} i \\ \frac{\beta_2}{p} i \end{bmatrix}.$$

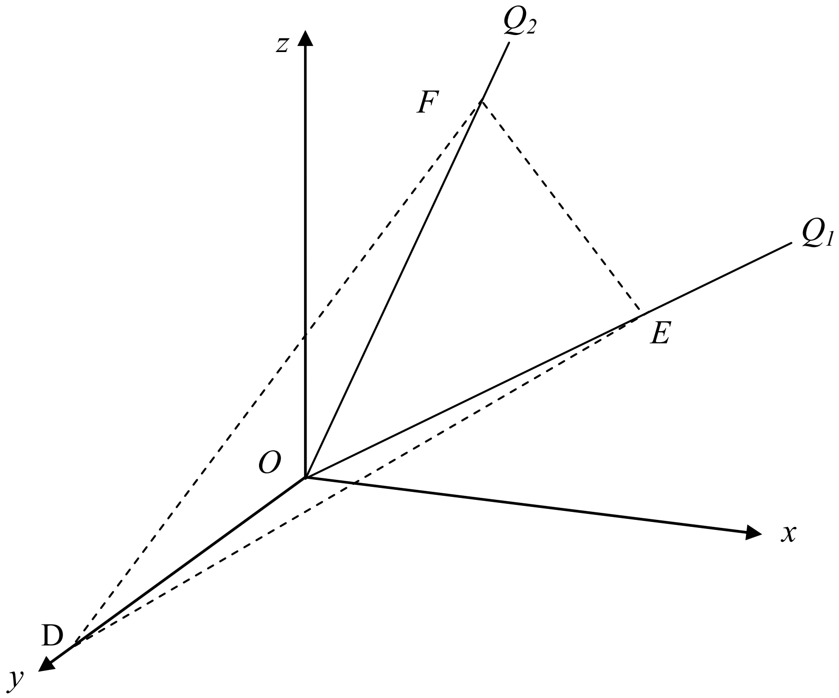


Figure 3: Characteristics Space.

The budget constraint in characteristics space is represented by plane *DEF*. It has a slope that shows the rate at which one characteristic can be transformed into others by varying expenditures on y, q_1 and q_2. Let us assume further that $\frac{\alpha_2}{p} > \alpha_1$ and $\frac{\beta_2}{p} < \beta_1$, i.e. for each monetary unit spent on q_1 the country receives less of the private and more of the public characteristic than it would get for one monetary unit spent on q_2.

If we would, in contrast, consider the case that $\frac{\alpha_2}{p} > \alpha_1$ and $\frac{\beta_2}{p} > \beta_1$, we would be facing a trivial case, where the country exclusively consumes the impure public technology 2 (and no unit of technology 1), since a monetary unit spent on it produces more (than technology 1) of both, the private and the public characteristics.

The case where $\frac{\alpha_2}{p} < \alpha_1$ and $\frac{\beta_2}{p} > \beta_1$ would just be a counterpart of the case we will consider here.

At the efficient point where the highest of the set of indifference curves is tangent to the budget constraint *DEF*, the following efficiency condition holds:

$$\frac{\alpha_1 \frac{\partial U}{\partial z} + \beta_1 \frac{\partial U}{\partial x}}{\alpha_2 \frac{\partial U}{\partial z} + \beta_2 \frac{\partial U}{\partial x}} = \frac{\frac{\partial U}{\partial y}}{\alpha_2 \frac{\partial U}{\partial z} + \beta_2 \frac{\partial U}{\partial x}} = \frac{1}{p}. \tag{8}$$

Therefore, the marginal rate of substitution between both impure public goods MRS_{q_1,q_2} has to be equal to the marginal rate of substitution between private good and the second impure public good MRS_{y,q_2} and this in turn has to be equal to the price ratio $\frac{1}{p}$.

Next, let us consider the more general case where other agents also produce the public good. Then, the graphical depiction has to take account of the fact that there is some exogenously given amount of the public characteristic $\tilde{x}$ provided by the other agents (see Figure 4).

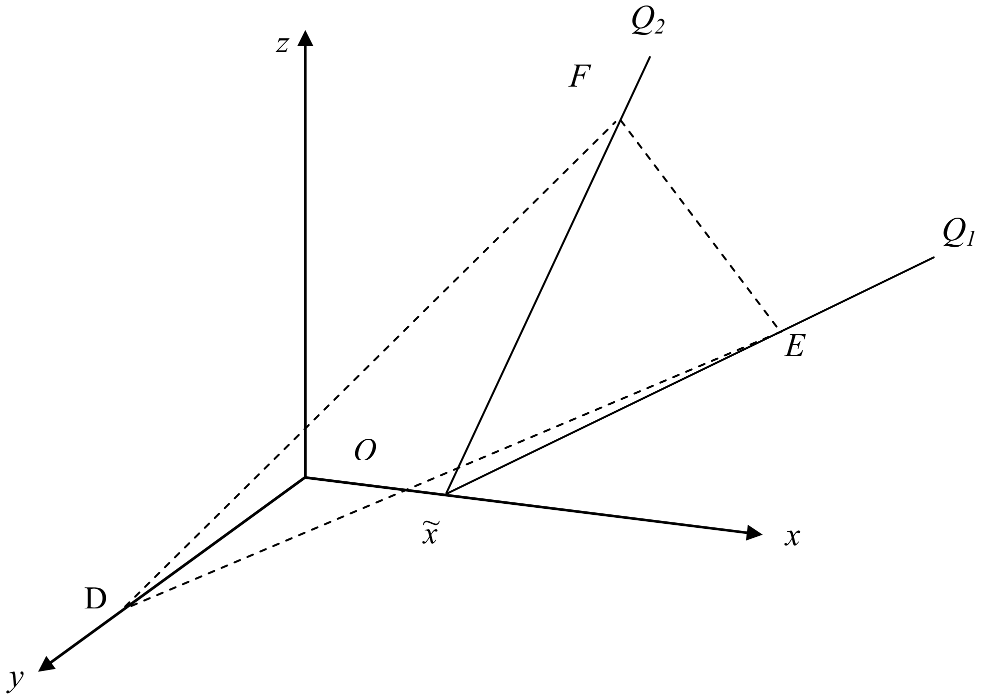


Figure 4: Integration of Other Agents' Provision of the Public Characteristic.

3.2 Impure Public Good Provision in a Two-Country World

Efficiency in a world of more than one country would not be achieved if individual countries would act according to condition (8). In order to illustrate the inefficiency, let us have a look at a world consisting of two regions or countries, which represent the industrialized (indexed by *I*) and developing (indexed by *D*) world, respectively. We omit the private good in the subsequent analysis. Thus we focus on the analysis of the consumption of two impure public goods. This is similar to the approach suggested by Auld and Eden (1990), but they consider three different characteristics. For simplicity we temporarily assume technologies and prices to be equal among regions. Therefore, an individual country *j*'s (with $j = D,I$) maximization problem becomes

$$\underset{q_{1j},q_{2j}}{Max} \quad U_j(\sum_j q_{1j}, \sum_j q_{2j}) = U_j(z_j, x) \tag{9}$$

s.t.

$$z_j = \alpha_1 q_{1j} + \alpha_2 q_{2j}, \tag{10}$$

$$x = \beta_1 q_{1j} + \beta_2 q_{2j} + \tilde{x}, \tag{11}$$

$$i_j = q_{1j} + p q_{2j}. \tag{12}$$

In contrast, Pareto-efficiency would require that global welfare is maximized. In this case we have to maximize the sum $\sum U$ of both countries' utility. Then we obtain

$$Max \quad \sum_j U_j(\sum_j q_{1j}, \sum_j q_{2j}) = \sum_j U_j(z_D, z_I, x) \tag{9'}$$

s.t.

$$z_D = \alpha_1 q_{1D} + \alpha_2 q_{2D}, \tag{10'}$$

$$z_I = \alpha_1 q_{1I} + \alpha_2 q_{2I}, \tag{10''}$$

$$x = \beta_1 \sum_j q_{1j} + \beta_2 \sum_j q_{2j}, \tag{11'}$$

$$i_D + i_I = \sum_j q_{1j} + p \sum_j q_{2j}. \tag{12'}$$

i_D and i_I stand for the developing country's and the industrialized country's monetary income level, respectively. q_{1D} and q_{2D} (q_{1I} and q_{2I}) are the developing (industrialized) country's production of the impure public technology 1 and technology 2, respectively. The respective values for p, α_1, α_2, β_1 and β_2 are assumed to be equal among the individual countries.

Global welfare maximization yields the result that Pareto-efficient public good provision by the developing region requires that

$$\frac{\alpha_1 \frac{\partial U_D}{\partial z_D} + \beta_1 \frac{\partial U_D}{\partial x} + \beta_1 \frac{\partial U_I}{\partial x}}{\alpha_2 \frac{\partial U_D}{\partial z_D} + \beta_2 \frac{\partial U_D}{\partial x} + \beta_2 \frac{\partial U_I}{\partial x}} = \frac{1}{p}. \tag{13}$$

The external effects the considered country exerts on the other country by means of the global public characteristic provision are taken into account in this condition. Comparison of equations (8) and (13) shows that the individual country ignores the externalities it exerts on the other country if it maximizes only its own welfare (see (8)) while global welfare maximization would require that countries take spillovers exerted on others into account.

In the Pareto-efficient outcome it is furthermore required that

$$\frac{1}{p} = \frac{\alpha_1 \frac{\partial U_D}{\partial z_D} + \beta_1 \frac{\partial U_D}{\partial x} + \beta_1 \frac{\partial U_I}{\partial x}}{\alpha_2 \frac{\partial U_D}{\partial z_D} + \beta_2 \frac{\partial U_D}{\partial x} + \beta_2 \frac{\partial U_I}{\partial x}} = \frac{\alpha_1 \frac{\partial U_I}{\partial z_I} + \beta_1 \frac{\partial U_I}{\partial x} + \beta_1 \frac{\partial U_D}{\partial x}}{\alpha_2 \frac{\partial U_I}{\partial z_I} + \beta_2 \frac{\partial U_I}{\partial x} + \beta_2 \frac{\partial U_D}{\partial x}}, \tag{14}$$

i.e., the sum of the individual countries' marginal rates of substitution between the impure public technologies, i.e. $\sum MRS_{q_{1D},q_{2D}}$, in the developing country has not only to be equal to the price ratio but also to be equal to the sum of the marginal rates of substitution between the impure public technologies in the industrialized country, i.e. $\sum MRS_{q_{1I},q_{2I}}$.

In order to correct the resulting inefficiency in public good provision, a transfer or subsidy on behalf of the first technology q_1, which generates a higher amount of global externalities, would be suitable. (Take into account that we assumed: $p\beta_1 > \beta_2$.)

In order to introduce a subsidy, some kind of coordination between both countries must take place. Otherwise, the agents do not change their inefficient behaviour associated with condition (8).

In order to analyse how transfers may improve the outcome, we propose a more general model in the subsequent section by which we can analyze a continuum of impure public goods and not only two alternative technologies.

4. A Generalized Model

In this section we consider a generalized version of the model presented in the previous section, in which the relative prices of the global and local public goods can vary and where there is a continuum of technologies for producing the two types of goods. The model assumes that each country produces a private good (Y), which has as by-products two 'bads' (X and Z). Z is a local public bad, which only affects the country concerned (e.g. air pollution), while X is a global public bad (e.g. GHG emissions).

The country places a penalty on both X and Z, which depend on its level of wealth or potential output (Y_P). We assume this cost or penalty associated with the bad Z is higher than that of X at low levels of wealth but at higher levels of wealth the penalty arising from X becomes higher. Each of the prices of the bads X and Z has an elasticity greater than one with respect to wealth – i.e. a one percent increase in wealth raises the penalty for both by more than one percent. The two functions P_X and P_Z are depicted in Figure 5.

The country has a capacity for Y which is determined by its capital – human, physical and natural, which we refer to as Y_p. The country can sacrifice some of its potential output to have a lower level of X and Z. It decides this based on the objective function V, where:

$$V = Y - P_z Z - P_X X \tag{15}$$

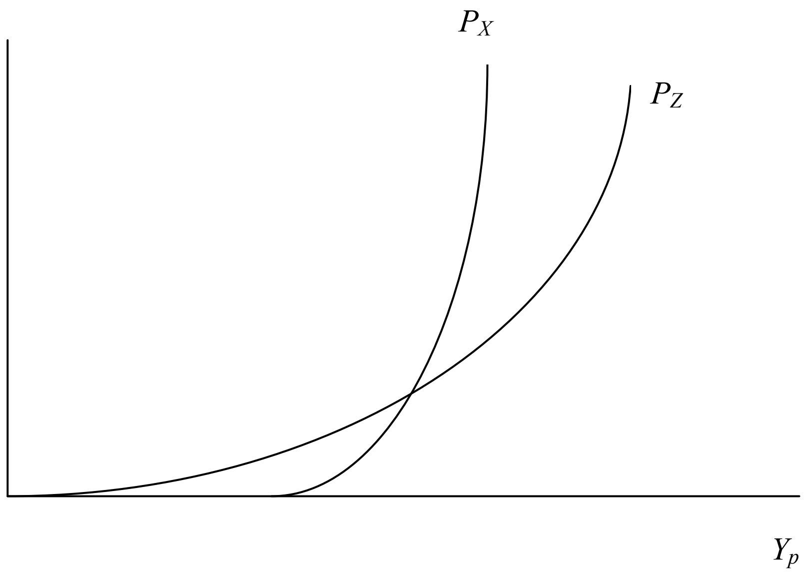


Figure 5: Functional Forms for P_Z and P_X

<u>*Analysis of the case with a unit elasticity of substitution between X and Z*</u>

Initially we consider the case where there is considerable substitutability between X and Z. To fix ideas we take a simple iso-elastic function, which is analytically tractable, and which relates Y to Y_P, X and Z:

$$Y = Y_P \left(\frac{X}{X_P} \right)^{\beta} \left(\frac{Z}{Z_P} \right)^{\alpha} \tag{16}$$
$$1 \geq \alpha \geq 0; 1 \geq \beta \geq 0.$$

X_P and Z_P are the uncontrolled levels of X and Z respectively, which are produced by processes that generate Y. The functions determining P_X and P_Z are given as follows:

$$P_Z = BY_P^{\lambda}$$
$$P_X = A_0 + A_1 Y_P^{\gamma} \qquad (17)$$
$$\gamma \geq \lambda \geq 1$$

Equations (17) reflect the form of the functions as given in Figure 5. The aim is to show a lower penalty associated with Z at low levels of wealth and a higher penalty at higher levels of wealth.

Substituting (16) and (17) into (15) and maximizing with respect to X and Z yields:

$$\frac{\partial V}{\partial X} = \frac{\beta Y}{X} - P_X = 0$$
$$\frac{\partial V}{\partial Z} = \frac{\alpha Y}{Z} - P_Z = 0 \qquad (18)$$

Solving for X and Z in terms of Y, P_X and P_Z and substituting back into (16) we get:

$$Y = \left\{ Y_P (\alpha^{\alpha} \beta^{\beta} X_P^{-\beta} Z_P^{-\alpha})(P_X^{-\beta} P_Z^{-\alpha}) \right\}^{(1/(1-\alpha-\beta))} \qquad (19)$$

From (19) we can see that:

$$\frac{\partial Y}{\partial P_X} \leq 0; \frac{\partial Y}{\partial P_Z} \leq 0$$
$$\frac{\partial X}{\partial P_X} \leq 0; \frac{\partial Z}{\partial P_Z} \leq 0 \qquad (20)$$

As the prices of X and Z increase the country lowers its output relative to its potential output and reduces the corresponding levels of X and Z.

Note that X and Z cannot exceed the values X_P and Z_P respectively. Hence from (18) we have:

$$X = Min\left\{X_P ; (\frac{\beta Y}{P_X})\right\}$$
$$Z = Min\left\{Z_P ; (\frac{\alpha Y}{P_Z})\right\} \quad (21)$$

With the particular forms of the functions (17) we can show that Y as a percentage of Y_P declines with Y_P. Similarly X as a function of X_P and Z as a function of Z_P are non-increasing functions of X_P and Z_P respectively. This implies that as countries get richer they make bigger proportional reductions in the pollutants X and Z (or at least non decreasing proportional reductions in X and Z).

With P_X increasing with Y_P we would expect that richer countries can 'bribe' the poorer countries to reduce emissions of X and still leave themselves better off. We check this below. The extent to which there is potential for such transfers depends on how much price difference there is between the poor country's valuation of X and the rich country's valuation.

If the rich country makes a transfer to a poor country in the form of a payment per unit of X reduced, this is equivalent to an increase in the penalty of X. From (20) we can see that such a price increase will lower Y and X. Furthermore, because it lowers Y it will also lower Z – i.e. the local public bad will decline although not necessarily as a percentage of its maximum value Z_P.[9]

To see how the values of X and Z vary with wealth we have carried out some simulations. In particular we have taken the following parameter values (Table 2).

[9] Note that there is a very important qualification to the above statements. This is to the effect that an increase in P_X may not reduce X but merely leave it unchanged. Corner solutions turn out to be common. So the 'offer' has to be made to a country that is willing to make some reductions in X in the first place. As our example shows, this only happens when per capita income is above a certain threshold.

Table 2: Parameters for Simulation of Results

Parameter	Value	Reason
A_1	0.05	A one percent decline in Z results in a 0.05 percent decline in Y
B	0.05	A one percent decline in Z results in a 0.05 percent decline in X
Y_P	\$300 to \$20000	Normalized to per capita GDP. We ignore the impacts of differences in population.
Z_P	Equal to Y_P	Measured in the same units as Y by normalization
X_P	= 1.8 times Y_P	Assumed measured in kg. per dollar GDP. 1.8 kg carbon is generated per \$ of GDP (WDI) for low income countries. So X is interpreted as a global public bad.
Λ	1.1	Equals elasticity of P_Z with respect to Y_P.
A_0	$-0.5.10^{-4}$	Chosen so that $P_X = 0$ at per capita income of \$300 and increases so that at income of \$20000 it is \$0.05 per kg (i.e. \$50 per ton of carbon). Yields an elasticity w.r.t. Y_P of around 1.2 at low incomes.
A_1	$9.38.10^{-7}$	
Γ	1.1	

Figure 6 shows how the price indices for X and Z move over time, with the price of X overtaking that of Z.

The results for different potential income levels are shown in Table 3. We note the following:

1. Poor countries do not reduce either X or Z at all initially. Gradually, as incomes increase to around \$4,800 they initially desire to reduce Z. Reductions in X follow only after income has reached around \$12,000. Hence any transfers of cash would have to be to countries above this level of income to be effective.

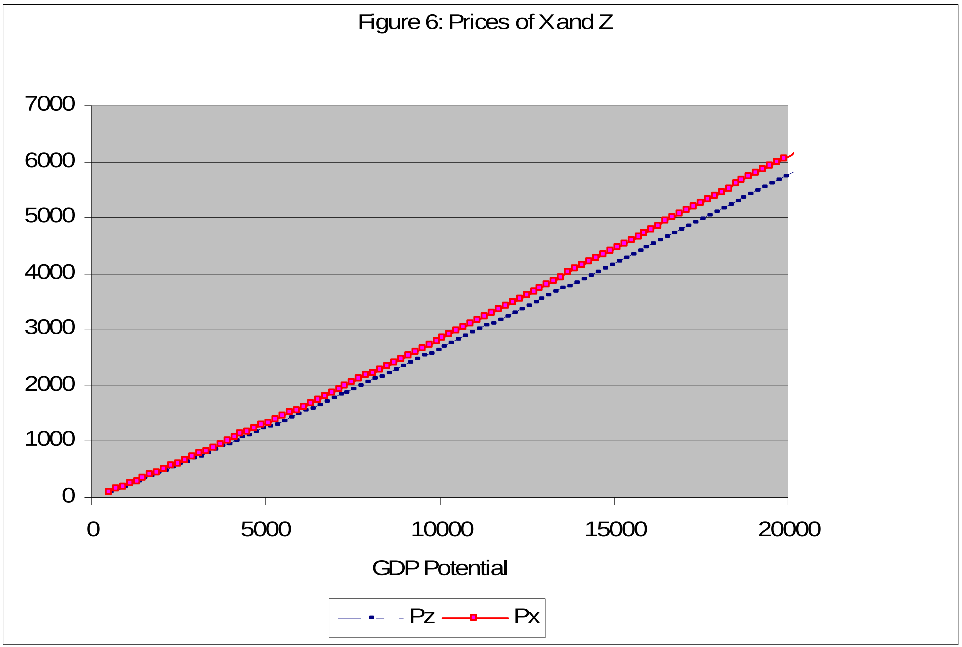


Table 3: Solutions for Different Levels of Wealth: Unit Elasticity

Solutions

Yp ($)	500	4700	5000	10000	15000	20000
Y ($)	500	4683	4944	9084	12966	16691
Z	500	4367	3992	1463	1245	1168
X	900	8460	9000	18000	17641	16542
Z/Zp	100.0%	92.9%	79.8%	14.6%	8.3%	5.8%
X/Xp	100.0%	100.0%	100.0%	100.0%	65.3%	46.0%
PX	0.00082	0.01022	0.01094	0.02351	0.03675	0.05045
PZ	0.01235	0.14524	0.15546	0.33325	0.52055	0.71433

2. The reduction in income relative to potential income is modest. Initially of course it is zero, but at about $5,000 potential income the reduction is about 1.1 percent. At $10,000 income the reduction or sacrifice is about 9 percent and at $20,000 it is about 17 percent. Of course we can calibrate the model so that it reflects the reductions in *Z* more accurately. This would help make the model predictions under varying parameters more credible.

3. The rising price of *X* means that richer countries want to reduce *X* more than poor countries. Poor countries on the other hand have a lower benefit from making reductions and lower costs associated with the reductions. So a transfer from the richer

country to the poor country is possibly to everyone's advantage. For example, suppose a country at $20,000 were to ask a country at $500 to reduce emissions by 10 percent. The cost to the poor country is the loss in *Y* less the value of the reduced emissions, which amount to $2.42 per person. The rich country, however, gains the benefit of the reduction in *X* at the marginal price of *X*, which amounts to $4.54. So there is a gain in making the transfer.

Analysis of the case with no substitutability between X and Z

The above analysis is based on a high degree of substitutability between the goods *X* and *Z*. The form of the 'Cobb Douglas' type utility function implies an elasticity of substitution of one between the two goods. As Cornes and Sandler (1994) noted in a different context this degree of substitutability is important in determining the optimal provision of impure public goods. For this reason we also look at the implied optimal allocations in the case where the two goods X and Z are produced in fixed proportions (i.e. there is no substitutability between them).

The production function can now be represented as

$$Y = Y_P \left(\frac{X}{X_P} \right)^{\beta}$$

$$1 \geq \beta \geq 0.$$

While the level of Z is now a fixed proportion of X. That is:

$$Z = \xi X$$

The maximand is the same as before – i.e. equation (15). The maximization, however now yields the following expression for *Y*:

$$Y = (Y_P \beta^{\beta} X_P{}^{-\beta} \hat{P}_X{}^{-\beta})^{(1/(1-\beta))}$$

where $\hat{P}_X = \xi P_Z + P_X$

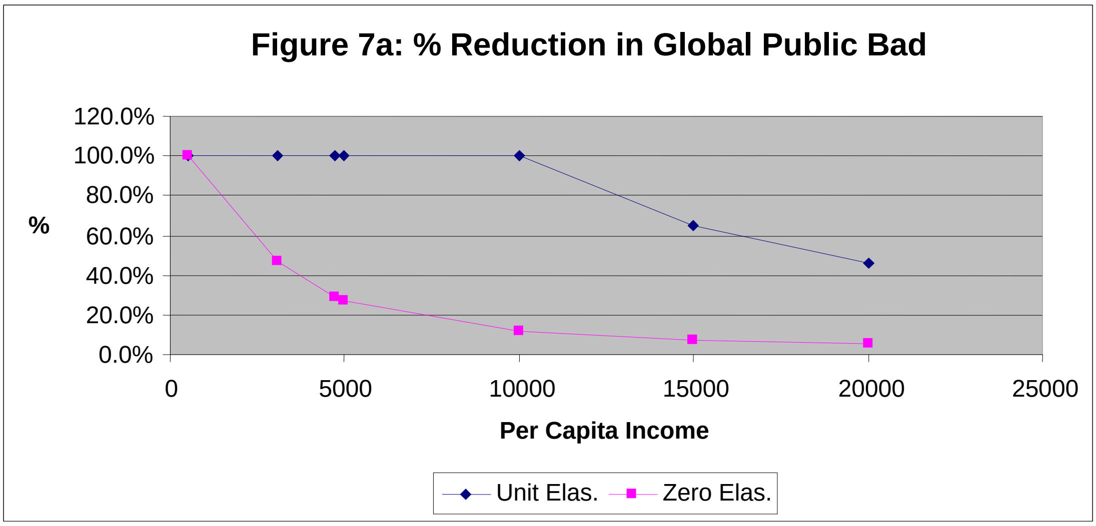
The results of the same analysis as presented for the unit elasticity case are given in Table 4.

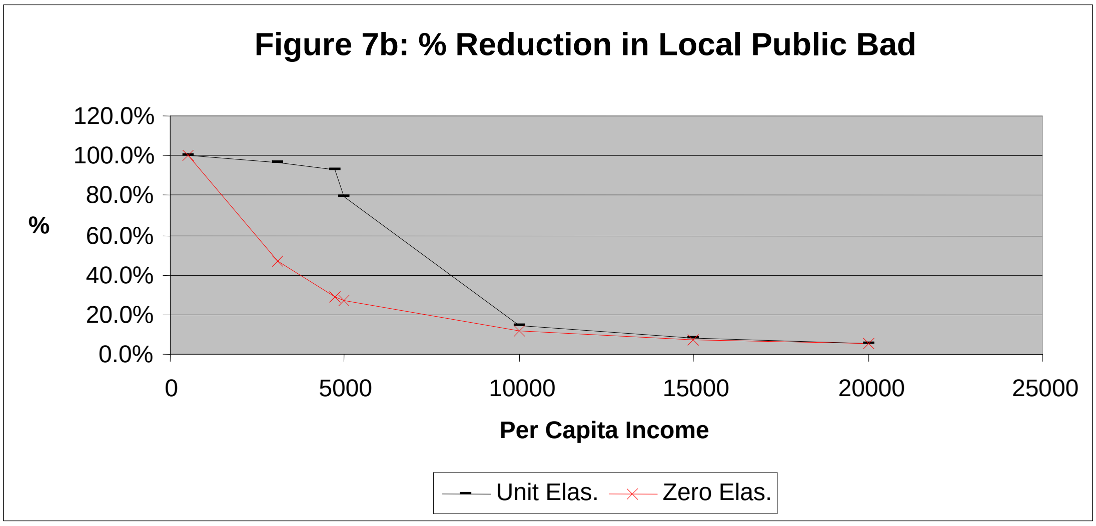
Table 4: Solutions for Different Levels of Wealth: Zero Elasticity Solutions

Yp ($)	500	4700	5000	10000	15000	20000
Y ($)	500	4416	4681	8993	13177	17279
Z	500	1349	1336	1197	1123	1073
X	900	2429	2405	2155	2021	1931
Z/Zp	100.0%	28.7%	26.7%	12.0%	7.5%	5.4%
X/Xp	100.0%	28.7%	26.7%	12.0%	7.5%	5.4%
PX	0.00082	0.01022	0.01094	0.02351	0.03675	0.05045
PZ	0.01235	0.14524	0.15546	0.33325	0.52055	0.71433
Phat	0.00768	0.09090	0.09731	0.20864	0.32595	0.44730

The results compare starkly with the case of unit elasticity of substitution. Now the threshold level of per capita income at which major reductions are made in the local public good decline almost continuously whereas before there was a threshold value at around $6,000 (see Figure 7b). At the same time, the reductions at high income levels remain similar. For example, with unit elasticity the level of the local public bad is reduced to 6% of its maximum value at an income of $20,000, whereas with a zero elasticity it is reduced to 5% of its maximum value.

As far as the global public bad is concerned the difference is even more marked. Whereas with a unit elasticity the income level at which reductions in this bad were sought was around $10,000, with a zero elasticity of substitution a country seeks to make the reductions more of less continuously from a low income. Moreover the final reduction sought at an income of around $20,000 is much higher with a zero elasticity. The scope for conditional transfers from rich to poor countries is now slightly smaller as the reduction in X that the rich country imposes a higher cost in terms of a reduction in Y, as there is no scope for adjusting the amount of Z that it generates. Nevertheless the example considered above for the unit elasticity also generates a net gain through conditional transfers in this case.





5. Conclusions

This paper is a contribution to the literature on impure public goods. In particular we examine the role of international transfers in obtaining an efficient global allocation of resources in the presence of such public goods. To date the analysis of impure public goods has not examined the case of a continuum of technologies where an efficient solution requires conditional transfers – i.e. payments from one country to another to undertake a different supply of global and local public goods than the second country would wish to undertake. Andreoni (1986, 1989, 1990) examined the case of unconditional transfers in the presence of impure public goods. Bergstrom (1989) and Ihori (1996) looked at conditional transfers but only with pure public goods. Posnett and Sandler (1986) investigate impure public goods (charity) and stress the positive effect of fiscal transfers (e.g. tax exemption) on their provision prospects. Finally Auld and Eden (1990) analyzed corrective taxes-cum-subsidies in a two-commodity world, where each of the goods has three characteristics.

Apart from filling this gap in the literature the motivation for our analysis is climate policy in the presence of local air pollution. In this context countries have different preferences for the 'local' (i.e. air pollution) versus the 'global' (i.e. climate change) public goods. Our analysis shows that individual country solution can be improved upon by making transfers from the richer countries to the poorer ones, if the latter have a lower relative preference for the global public goods than the former. The magnitudes of such transfers will depend on the relative benefits of the global and local pollutants in the two countries.

We also need to see how the potential for transfers depends on the degree of complementarity between X and Z. With a 'Cobb Douglas' type of function used here the elasticity of substitution between the two is of course one. With a zero degree of substitutability the adjustment to a lower level of the global public good in fact starts to happen at a lower per capita income level. The scope for conditional transfers is still there, although the gains can be slightly smaller than when adjustment on the 'X-Z' margin is possible.

Further work is needed to examine the potential for conditional transfers more fully and with more realistic characterizations of the relevant functions.

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KTHC	*Knowledge, Technology, Human Capital* (Editor: Gianmarco Ottaviano)
IEM	*International Energy Markets* (Editor: Matteo Manera)
CSRM	*Corporate Social Responsibility and Sustainable Management* (Editor: Giulio Sapelli)
PRCG	*Privatisation Regulation Corporate Governance* (Editor: Bernardo Bortolotti)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)
CTN	*Coalition Theory Network*