Aid, economic growth and environmental sustainability: rich-poor interactions and environmental choices in developing countries

Alexander Pfaff*

SIPA, Economics, CERC/EEEB & IRI,
Room 1306 IAB, 420 West 118th Street,
Columbia Unniversity, New York, NY 10027, USA
Fax: (212) 854-5765 E-mail: ap196@columbia.edu
*Corresponding author

Paulo Barelli

University of Rochester, 236 Harkness Hall,
Rochester, NY 14627, USA

Shubham Chaudhuri

Department of International and Public Affairs,
Department of Economics, Columbia University,
MC-3323, New York, NY 10027, USA
Fax: (212) 854-5765 E-mail: sc301@columbia.edu

Abstract: Rich-poor interactions complicate the search for a stable Environmental Kuznets Curve (an 'inverted U' relationship between income per-capita and environmental degradation). We show that aid from richer to poorer countries to support investments in environment, in either of two forms, alters the income-environment relationships that otherwise exist, lowering levels of degradation in the poorer countries conditional upon their incomes. Yet even with environmental aid, in our model environmental quality eventually falls as economic growth continues, although ongoing innovation could change that conclusion. In light of this result, we show that subsidies to clean goods, one form of technological-transfer aid programme, dominate income transfers as environmental aid policy by the rich. Given that aid matters, we then show that when rich countries degrade the environment, a perverse effect exists: when an aid-giving country becomes richer, it gives less aid to the poor country. This is stronger when that degradation is durable, that is, when consumption and degradation by the rich country in the past has durable effects upon the environment.

Keywords: aid; development; environment; growth; technology; transfer.

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Biographical notes: Alexander Pfaff received his BA Summa cum Laude from Yale in 1988, and his PhD in Economics from MIT in 1995. His research focus is the interaction between the environment and economic development. He has studied land use and its implications for carbon sequestration and species habitat, with empirical analysis of deforestation in the Brazilian Amazon and Costa Rica. He is also researching, theoretically and empirically, the relationship between economic development and environment, incentives for firms to do environmental self-audits and to disclose the quality of water within multidisciplinary projects in Bangladesh and Brazil.

Paulo Barelli is finishing his thesis in the Department of Economics at Columbia University in New York, USA, in the field of economic theory. His bachelor's degree is in Economics from the University of Sao Paulo, Brazil, from which he has also received a Masters degree in Economics. As of July 1, 2004, he will be an Assistant Professor at the University of Rochester.

Shubham Chaudhuri is Assistant Professor of economics at Columbia University in New York, USA. He obtained his bachelor's degree from Harvard University and his PhD from Princeton University, both in economics. Professor Chaudhuri is an applied microeconomist and microeconometrician. He is also currently a consultant to the World Bank on empirical methods for assessing the vulnerability of households to poverty.

1 Introduction

Many researchers have studied, empirically and theoretically, the possible existence of inverted-U relationships between per-capita income and various indicators of environmental (for example, air or water) degradation at the aggregate level.[1] Theoretical analyses have suggested that there could be, and empirical analyses have suggested that there may be non-monotonic, income-environment relationships.

This paper considers environmental aid and how it might affect such relationships. Environmental aid is assumed to flow from richer to poorer countries. While all people are assumed to value the environment in principle, those better able to satisfy other needs and desires given higher incomes or wealth may express greater value on the margin for an improved environment. Here, we permit richer actors the option of spending on aid to express that value and thereby influencing the choices of poorer actors. Thus environmental aid occurs endogenously, driven by income levels.

Analogous endogeneity of environmental regulation as incomes rise within a country is a common interpretation of Environmental Kuznets Curves (EKCs). Note then that a political economic model formalising such an interpretation, one starting with household preferences and adding interactions between many households, is lacking. Representative agent models that have dominated theoretical work in this area, for instance, growth models, often lack an explicit mechanism (political economic or other) through which initial effects of economic growth might in reality be reversed.[2]

For our purposes, such growth models make it more complex to study aid interactions between even single representative agents used to model whole countries. Yet many types of environmental degradation involve externalities, including across borders. To focus on these interactions, and specifically on interactions between rich and poor countries, this paper applies the simple, static, single-actor model in (Pfaff, Chaudhuri and Nye, 2004) that quite naturally yields the *possibility* of non-monotonic environmental paths ('U' or other) as development proceeds. We explore how environmental quality responds to growth when richer countries optimally use aid to influence environmentally relevant choices by the poorer countries. We consider income transfers and subsidies to clean goods as forms of environmental aid.

We analyse first the case in which only the poor country degrades a global public good that is valued in principle (even if in practice only trivially at times) by both rich and poor. The existence of globally valued species in poor countries is one class of relevant examples. We show that aid alters the environment-income relationships that would otherwise have existed, lowering levels of degradation in poorer countries conditional on their incomes. While the optimally chosen level of aid can be zero, we know that aid is a realistic feature of the environmental landscape, so this result complicates the search for a *stable* EKC. Otherwise identical developing countries that start identical economic growth paths at different points in time will enjoy different paths of environmental quality if the conditions that affect environmental aid (including income) have changed in the aid-giving countries.

Even when optimal environmental aid is positive and at high levels in our model eventually the quality of the environment will fall as economic growth occurs unless environmental innovation is ongoing. This raises the issue of technological transfer.

We consider the case of a subsidy to existing clean goods, a form of technological transfer programme (as effective access to an existing technology is affected by its price). Such a policy dominates income transfers (the optimal income transfer is relatively often zero). An implication of this is that a positive level of aid is more likely in this form. Thus, offering aid may well be attractive to rich countries, such that the presence of rich countries and their optimal offers of aid may in fact influence observed relationships between per capita income and quality of the environment.

Finally, we consider the case in which richer countries also degrade the environmental amenity level enjoyed by both the poor and the rich countries. An example of this case is greenhouse gas emissions, which mix globally. A Clean Development Mechanism, for instance, could include subsidies such as those we analyse. We find that although the rich country is now responsible for some of the degradation, it will *reduce* environmental aid. Underlying this perhaps perverse result is the fact that degradation of the global public good is one way to push the poor country to spend money on being clean. It substitutes for the transfer within inducement by rich countries of the use of clean goods in poor countries. This result is stronger if degradation is durable, that is, if historical consumption and degradation by the richer countries yields lasting degradation of the environment.

Below, Section 2 briefly summarises the single-actor framework we will apply. Then for the case in which the rich country does not degrade the environment, Section 3 explores and compares the cases of different levels of alternative forms of environmental aid, income transfers and subsidies to clean goods. Section 4 then presents the case in which rich countries do degrade the quality of the environment, finding that this degradation can lower the level of environmental aid. Section 5 briefly summarises and suggests an area for further research.

2 Choice of technology by a single country

The single-actor model in (Pfaff, Chaudhuri and Nye, 2004) is our starting point. The valued environmental services are not directly purchased. Instead, a country starts with an environmental endowment that is degraded through the production and consumption of marketed commodities that provide valued services. Non-monotonic paths of environmental quality quite easily may arise as economic growth proceeds.

Let s denote consumption of a non-environmental service and a the level of the environmental amenity. Neither is directly purchased. They are jointly produced using marketed goods. Consider the case of two such goods, a 'dirty' good d and a 'clean' good c. Assuming linearity, define units so the total volume of services s is:

$$s(\vec{q}) = q_d + q_c \tag{2.1}$$

where $\vec{q} = (q_d, q_c)$ are quantities of dirty and clean goods. Total emissions e are:

$$e(\vec{q}) = \alpha q_d + \beta q_c \tag{2.2}$$

where $\alpha > \beta > 0$. Finally, assuming that the environmental amenity is linear in total emissions, where A is the initial environmental endowment and $A > 0$:

$$a(e) = A - e \tag{2.3}$$

A country chooses the marketed $\vec{q}$ to maximise (2.4) subject to (2.5):

$$U(s,a) \tag{2.4}$$

$$p_d q_d + p_c q_c = y \tag{2.5}$$

where y is household income and p_d and p_c are, respectively, the per-unit (of services) prices of the dirty and clean goods. We assume $p_d < p_c$, that is, the dirty good is cheaper.

Ignoring for the moment the fact that the demand functions may not be differentiable at all incomes because of binding non-negativity constraints on the use of goods, we can represent the slope of the Engel curve linking a to y as:

$$\frac{da(\vec{q}(y))}{dy} = \sum_j \left(\frac{\partial a(\vec{q})}{\partial q_j}\right)\frac{\partial q_j}{\partial y}(y) \tag{2.6}$$

The key intuition for non-monotonicity relies on the point that the demand for the marketed goods $\vec{q}$ is *derived* from preferences for s and a, and should not be presumed to be normal (that is, the $\frac{\partial q_j}{\partial y}$ may not be positive). In a characteristics framework, inferior marketed goods can be quite common (Deaton and Muellbauer, 1980; Lipsey and Rosenbluth, 1971). If dirty marketed commodities are inferior after a certain income while clean goods are normal, for instance, it is possible the Engel curve for the environmental amenity will be U-shaped.

Put another way, the intuition for non-monotonic paths of a as y rises is that the ability to substitute between marketed goods, in the production of s, allows a separation of two decisions: how much service to consume, and how to produce that service. The fact that these two decisions may move independently with respect to income allows for their combined effect to be non-monotonic.

Figure 1 Potential for non-monotonic income-environment paths

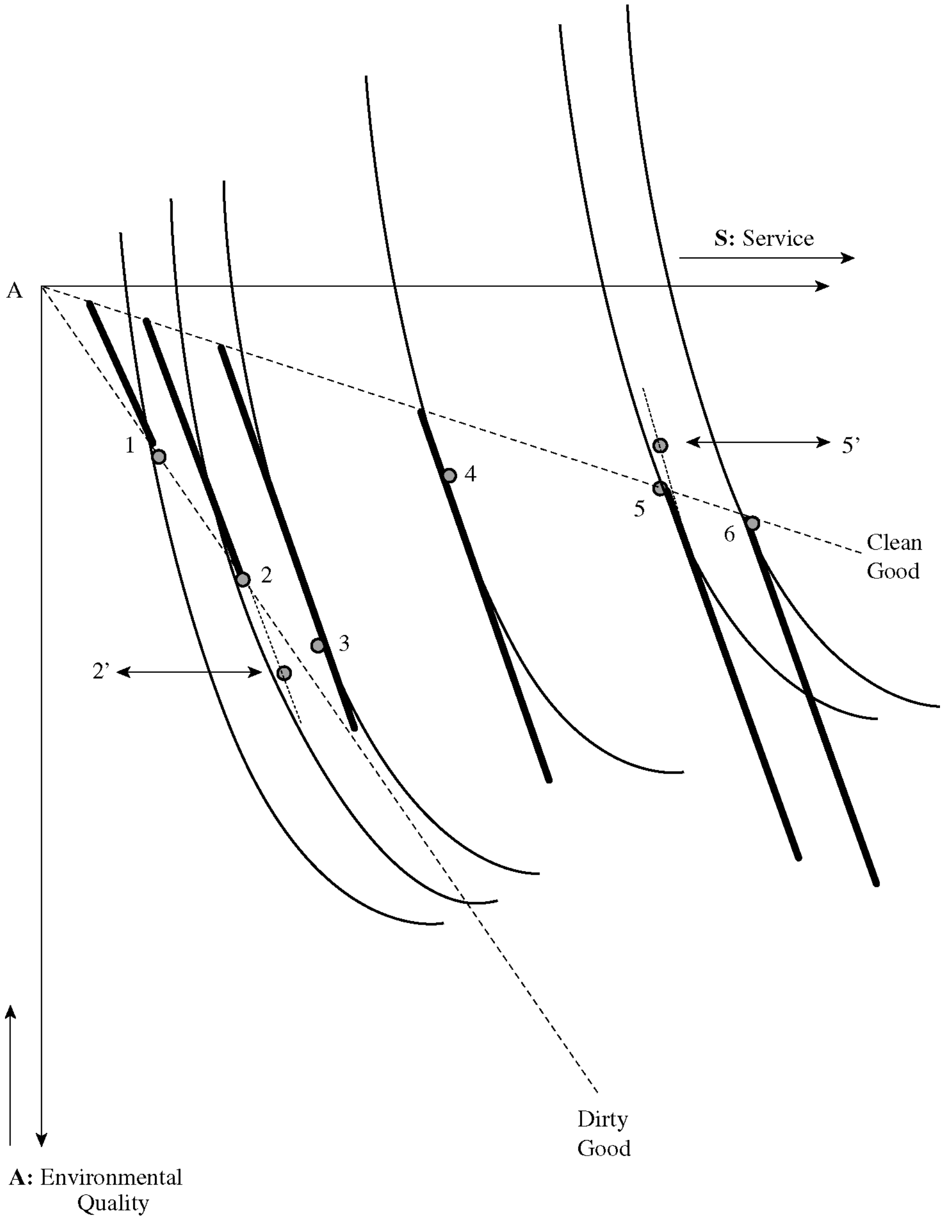


Figure 1 (from (Pfaff, Chaudhuri and Nye, 2004), which has more detail and analytical results) graphically summarises this intuition. The endowment *A* is at the upper left ($s = 0$, $a > 0$). The dashed rays are the combinations of a and s attainable through exclusive use of one good. The solid lines connecting the rays are budget constraints for different levels of income; larger budgets are farther from the endowment. The budget slopes indicate the relative shadow price of environment and services – that is, the rate at which one can trade off environment and services given the underlying technologies and the prices of the marketed goods being consumed. The negative slope reflects our assumption that dirtier goods are cheaper than cleaner goods per unit of service produced. The shape of the indifference curves comes from the concavity of the utility function, into which both a and s enter positively.

In the lowest-income transition, from 1 to 2, while a country could substitute from dirtier to cleaner goods, it does not. Because of the endowment, moving as rapidly as possible to greater balance of s and a is preferable. This dictates using only the dirty good. No substitution to less degrading goods occurs. In the transition from 2 to 3, rising income can lower environmental quality since over much of this income range, again no substitution is preferred. In sum, at low incomes the asymmetric endowment discourages substitution to cleaner goods, and rising income degrades the environment.

In the transition from 3 to 4, environmental quality improves. Substitution is both desirable and feasible, so a country's choices can raise both s and a. Thus, the transitions from 1 to 4 trace out a U-shaped relationship between y and a. However, environmental improvement is unfeasible once the household is at point 5, using only the clean good. Then further substitution is impossible, such that further abatement cannot occur. Thus, the full set of transitions traces out an 'inverted-N' relationship of quality to income. This could be the expected path of environmental quality with economic growth if a country made its choices without relevant interactions with other countries (such as those explored below).

3 Two countries, degradation by the poor

3.1 Income transfers as environmental aid

Now we allow for two countries, one rich and one poor. Throughout the paper, these countries have the same preferences over a common environmental amenity (a global public good), though their marginal valuations of environmental improvements will differ. In our first model, production and consumption of marketed commodities by the poor degrades this amenity but that by the rich does not (the source of the amenity may be in the poor country, for instance in species-rich tropical forests). The rich country does affect the environmental outcome through aid to the poor country. In this sub-section, aid takes the form of income transfers, while in the next sub-section it will take the form of a subsidy to clean goods.

If the consumption and production of the rich does not degrade, the environmental amenity could not be the atmospheric services due to emissions of greenhouse gases that mix globally (see Section 4 for the case of production and consumption in both countries affecting global public goods). It could be the existence of globally valued species located in poor countries whose habitat is threatened by local production and consumption but not by production and consumption located in the richer countries. Globally valued species surely exist in richer countries as well, in which case only the production and consumption of the rich may degrade the amenity. However, those cases are not relevant for the discussion of aid between rich and poor countries, since we do not expect poor countries to send environmental aid to rich countries (nor would this find support within our modelling below).

Further, we would expect to see the rich sending environmental aid to the poor because, as noted just above and in Section 2, even with the same preference functions their marginal valuations for environmental improvement will differ. Thus, after the poor have done all that they will choose to do to protect the quality of the environment within their own countries, rich countries may desire more protection in poor countries due to the public good nature of the amenity.

We assume two countries with utilities:

$$u_i(s_i, a) = s_i^m a^{1-m} \text{ for } i = 1,2 \tag{3.1}$$

where $i = 1$ indicates the rich country, $s_i = q_{id} + q_{ic}$ and $a = A - e_2$, for $e_2 = \alpha q_{2d} + \beta q_{2c}$. The budget constraints are $p_d q_{id} + p_c q_{ic} = y_i$. Assume $y_1 > y_2$ such that $q_{1d} = 0$ and $q_{2c} = 0$. The rich country is rich enough to consume only clean goods and the poor country is poor enough that it consumes only dirty goods. A rich country may want to induce a poor country to switch to clean goods by transferring income τ. Then the budget constraints become:

$$p_d q_{1d} + p_c q_{1c} = y_1 - \tau$$

$$p_d q_{2d} + p_c q_{2c} = y_2 + \tau. \tag{3.2}$$

3.1.1 Large transfer

First, we consider a 'large' transfer, defined as one sufficient to induce the poor country to use only the clean good. A transfer τ such that:

$$\frac{1-m}{m}\mu\frac{y_2+\tau}{p_c} \geq A - \frac{\beta}{p_c}(y_2+\tau), \tag{3.3}$$

where $\mu = \frac{\alpha p_c - \beta p_d}{p_c - p_d}$ (the slope of the budget in Figure 1), induces the poor country to do so. Note that the rich country will always act to maintain an equality in this expression. It will vary the transfer so that the poor country is just barely willing to use only the clean good, such as at point 5 in Figure 1. A larger transfer would only cause a deterioration of the environmental amenity, as in a shift from point 5 to point 6 in Figure 1, and that would be worse for the rich country. Rearranging terms given an equality yields:

$$\tau_L^* = \frac{mp_c A}{(1-m)\mu + m\beta} - y_2. \tag{3.4}$$

Consistent with this logic, the transfer in (3.4) decreases one for one as y_2 increases.

The level of utility for the rich country from this optimal large transfer is:

$$u_1(\tau_L^*) = \frac{1}{p_c}\left(y_1 - \tau_L^*\right)^m \left(p_c A - \beta(y_2 + \tau_L^*)\right)^{1-m} \tag{3.5}$$

or

$$u_1(\tau_L^*) = \frac{1}{p_c}\left(y_1 + y_2 - \frac{mp_c A}{(1-m)\mu + m\beta}\right)^m \left(\frac{A(1-m)\mu}{(1-m)\mu + m\beta}\right)^{1-m}. \tag{3.6}$$

Notice that:

$$a_{\tau_L^*}(y_1, y_2) = A - \frac{1}{p_c}\beta(y_2 + \tau_L^*) = \frac{A(1-m)\mu}{(1-m)\mu + m\beta} \tag{3.7}$$

such that

$$\frac{\partial a_{\tau_L^*}(y_1, y_2)}{\partial y_1} = \frac{\partial a_{\tau_L^*}(y_1, y_2)}{\partial y_2} = 0. \tag{3.8}$$

The intuition for constant $a_{\tau_L^*}$ [as in (3.8)] as income rises in either country is that the optimal large transfer from the perspective of the richer country always moves the poor country to the same level of income at which it is just willing to use only clean goods, for example, to point 5 in Figure 1. As seen in (3.4), the rich country simply raises and lowers the transfer to keep the $(y_2 + \tau_L^*)$ term constant, that is, to keep the poor country at the same effective income and thus same level of degradation. Clearly this aid policy alters the income-environment path.

3.1.2 Intermediate transfer

Now we consider the possibility that the transfer is not large enough to induce the poor country to use only the clean good, but still induces the poor country to consume positive amounts of it. Such a transfer would satisfy:

$$\tau < \frac{mp_c A - [(1-m)\mu + m\beta]y_2}{(1-m)\mu + m\beta} \tag{3.9}$$

and

$$\frac{1-m}{m}\mu\frac{y_2 + \tau}{p_d} > A - \frac{\alpha}{p_d}(y_2 + \tau), \tag{3.10}$$

which can be rearranged to:

$$\tau > \frac{mp_c p_d A - [(1-m)\mu + m\alpha]p_c y_2}{(1-m)p_c\mu + m\alpha p_c} \tag{3.11}$$

For such values of τ, the interior solution for the poor country generates:

$$a = \frac{1-m}{p_c}\left(p_c A + (\mu-\beta)y_2 + (\mu-\beta)\tau\right) \tag{3.12}$$

and the utility level achieved by the rich country is then:

$$\frac{1}{p_c}(y_1-\tau)^m\left((1-m)\left(p_c A + (\mu-\beta)y_2 + (\mu-\beta)\tau\right)\right)^{1-m}. \tag{3.13}$$

This case differs from that above. Now the optimal point for the poor country in the view of the rich country will change with the income level of the rich. This is because leading the poor country to use more of the clean good will improve the environment (as in the shifts from point 3 to point 5 in Figure 1). Thus the rich country will choose its optimal transfer as a function of its own income as well. Maximizing the utility of the rich with respect to τ leads to:

$$\tau_I^* = \frac{(1-m)\mu y_1 - mp_c A - m(\mu-\beta)y_2}{\mu - m\beta} \tag{3.14}$$

The τ must also satisfy the inequalities above that define the interval in which an intermediate transfer would be optimal. Within that range, τ_I^* is decreasing in y_2 and increasing in y_1, per (3.14). These results imply that above a given gap in income levels the optimal transfer per (3.14) will no longer satisfy the inequalities above but instead will be too high and the large transfer will be preferred.

When it applies, this τ_I^* implies:

$$a_{\tau_I^*}(y_1, y_2) = \frac{1-m}{p_c}\left(p_c A + (\mu-\beta)(y_2 + \tau_I^*)\right), \tag{3.15}$$

$$\frac{\partial a_{\tau_I^*}(y_1, y_2)}{\partial y_1} = \frac{(1-m)^2\mu(\mu-\beta)}{p_c(\mu-m\beta)} > 0 \tag{3.16}$$

$$\frac{\partial a_{\tau_I^*}(y_1, y_2)}{\partial y_2} = \frac{1-m}{p_c}[(\mu-\beta)(1-k)] > 0, \tag{3.17}$$

where $k = \frac{m(\mu-\beta)}{\mu-m\beta}$, $0 < k < 1$. Now a increases in y_1 and in y_2, and specifically:

$$a_{\tau_I^*} = \frac{(1-m)^2\mu}{p_c(\mu-m\beta)}[p_c A + (\mu-\beta)(y_1+y_2)]. \tag{3.18}$$

where $\mu-\beta = \frac{(\alpha-\beta)p_c}{p_c-p_d} > 0$ and $\mu - m\beta > 0$. From the income expansion path:

$$s_{\tau_I^*} = \frac{m}{1-m}\frac{a_{\tau_I^*}}{\mu} = \frac{m(1-m)}{p_c(\mu-m\beta)}[p_c A + (\mu-\beta)(y_1+y_2)], \tag{3.19}$$

and substituting both $a_{\tau_I^*}$ and $s_{\tau_I^*}$ in the utility function yields:

$$u_1(\tau_I^*) = \frac{p_c A + (\mu - \beta)(y_1 + y_2)}{p_c(\mu - m\beta)} (m(1-m))^m (\mu(1-m)^2)^{1-m}. \quad 3.20)$$

The intuition differs from the large transfer case. Here, increased income of the rich raises a trade off between consumption of services by the rich (a lowering of which will not help the environment since the rich do not degrade a) and improving the environment by increasing the transfer to the poor country [as in (3.14)], to shift it further along in the abatement process. The rich country divides income between these goals, and thus increasing its income will improve the environment.

Increased poor-country income has essentially the same effect, with one additional step to start. It functions like increased rich-country income because if the poor country is richer then the rich country can lower its transfer while achieving the same outcome in the poor country [as suggested by (3.14)]. Then, just as for an increase in the income of the rich, the rich country will divide this gain in effective income from the lowered transfer between consumption and inducing more abatement through transfers to the poor country. Thus more y_2 will lead to higher a. Again, this type of environmental aid policy clearly alters the income-environment path relative to what would have occurred without any aid.

3.1.3 Comparing transfer options

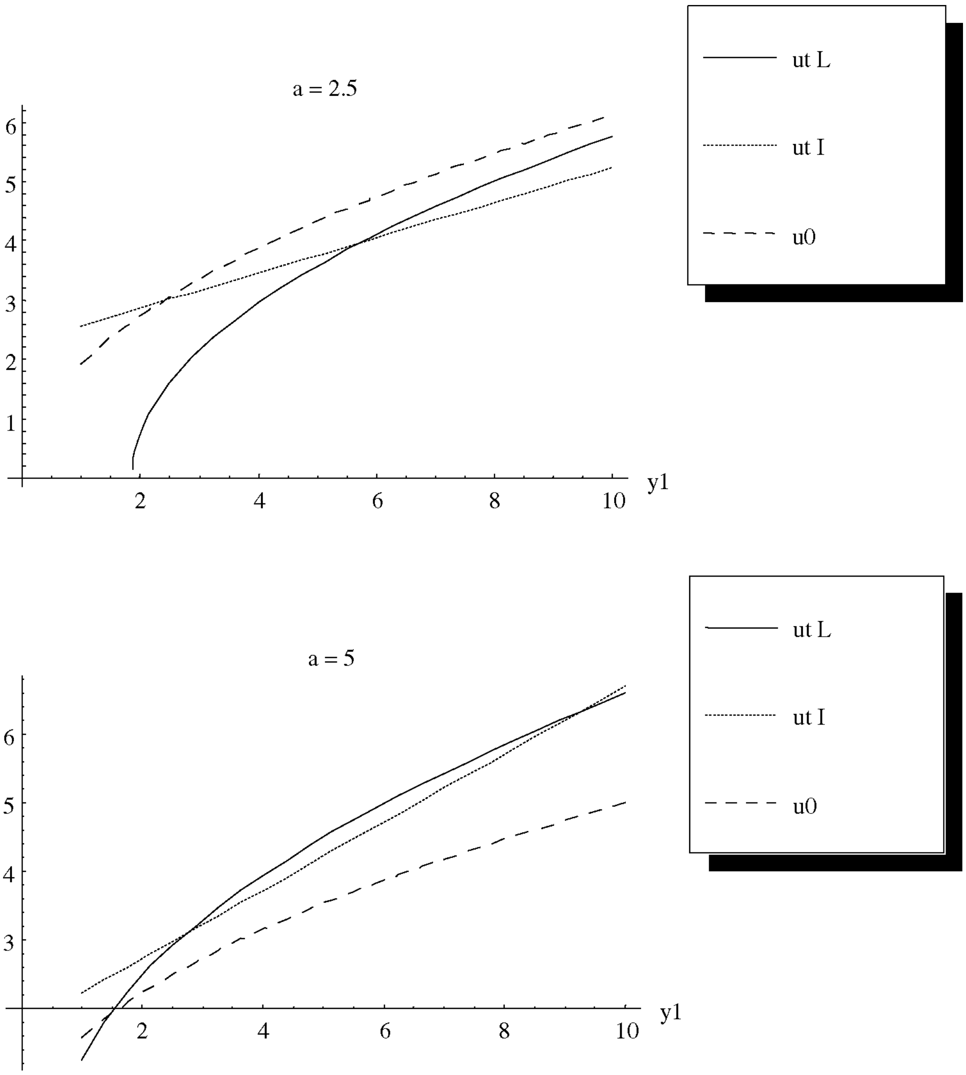
Finally, the rich country might find it better not to induce the poor country to be cleaner, that is, not to give aid at all. In such a case, the utility attained is:

$$u_1(0) = \left(\frac{y_1}{p_c}\right)^m \left(A - \frac{\alpha y_2}{p_d}\right)^{1-m}. \quad (3.21)$$

Comparing the utilities obtained by the rich country in each of these cases, we see in Figure 2 that $u_1(\tau_L^*)$ may be higher or lower than $u_1(\tau_I^*)$. Recall, however, that the range of relative incomes for which the τ_I^* computations apply is limited, such that if the rich country is much richer than the poor country, it will use large transfers.

Interestingly, $u_1(0)$ dominates $u_1(\tau_L^*)$ and $u_1(\tau_I^*)$ in the upper figure, though not in the lower one in which the poor country degrades the environment quite a bit when using dirty goods. That is, the rich country is likely to be better off not making an income transfer unless α is high (with the other parameters set at A =10, y_2 =1, p_c =2, p_d =1 and m =.5). Analytically, this result is suggested by the fact that $u_1(0) \to 0$ as $\alpha \to \frac{p_d A}{y_2}$ whereas $u_1(\tau_L^*)$ and $u_1(\tau_I^*)$ do not depend on α. Thus, it is clear that environmental outcomes change (conditional on poor-country income) when the optimal level of aid in the form of income transfers is positive. Yet income transfers may not be a great option for environmental aid.

Figure 2 Comparing transfer options



3.1.4 Environmental sustainability and innovation

Our focus above is the effect of aid upon income-environment paths. Given that aid has an effect, note that even with the large transfer policy, environmental quality stays constant for a while but when the poor country is rich enough (that is, on its own would use only the clean good) the transfer becomes zero and the environment is degraded by further growth. For intermediate transfers, environmental quality rises for a while with growth but eventually both countries use only the clean good, yielding degradation of the environment from any further economic growth.

What would be required for ongoing economic growth not to degrade the environment in the long run is the ongoing innovation of cleaner goods. These new cleaner goods might well originate in the richer countries, where environmental R&D may be ongoing in response to the market or to environmental regulation endogenously worth adopting at higher incomes. The new goods could then be made available to poorer countries by direct technological transfer that would enable the poorer countries to produce these goods. Richer countries could also induce the poorer countries to switch to these cleaner and possibly more expensive new goods by subsidising their production and/or consumption.

Yet, for the moment, let us remain with the static approach chosen in this paper. The development of new products is outside of its scope. Instead we consider a 'technological transfer' programme that subsidises the use within the poorer countries of existing clean goods. This increases effective access to those goods. It is a conditional transfer, based on 'cleaner behaviour', and thus might be expected to be a more efficient form of aid (this is confirmed below). It functions as a technological transfer policy that is, 'access' to a technology is a function of price. Even if a cleaner good or technology already exists, and thus in some sense can be said to be available to all, many people in the world will effectively not have access to it as they can not afford to pay.

In the environmental area, there are multiple examples of changing prices to affect outcomes. Japan has supported the dissemination of cleaner energy technologies in China. The Montreal Protocol agreement included a Multilateral Fund to lower costs for developing nations. Thus, we believe that effective transfer of technologies can be increased by subsidy policies. The following subsection will consider this type of subsidy to existing clean goods as an alternative to income transfers.

3.2 *Subsidy to clean goods: an environmental aid alternative*

Again a rich and a poor country value a global public good that is degraded only by the poor country. Everything is as above except that now the rich country may induce the poor country to switch to clean goods by lowering the relative price through a subsidy. Let σ be the subsidy. The price of the clean good in the poor country becomes $p_c(1-\sigma)$ and the budget constraints become:

$$p_d q_{1d} + p_c q_{1c} = y_1 - \sigma p_c q_{2c}$$
$$p_d q_{2d} + p_c(1-\sigma)q_{2c} = y_2. \tag{3.22}$$

3.2.1 *Large subsidy*

Here again 'large' means sufficient to induce the poor country to use only clean goods. And again, the rich want to barely induce this shift. If σ is such that:

$$\frac{1-m}{m}\mu(\sigma)\frac{y_2}{p_c(1-\sigma)} \geq A - \frac{\beta y_2}{p_c(1-\sigma)}, \tag{3.23}$$

where the slope is now $\mu(\sigma) = \frac{\alpha(1-\sigma)p_c - \beta p_d}{(1-\sigma)p_c - p_d}$ (we use $\mu(\sigma)$ to differentiate this slope from the one in the previous section, noting that now it depends on the magnitude of the subsidy), then the poor country will switch to using only clean goods. As the rich country wishes (3.23) to be an equality, a large subsidy must satisfy:

$$\frac{1-m}{m}\mu(\sigma)y_2 = Ap_c(1-\sigma)-\beta y_2 \tag{3.24}$$

This is a second-order equation in σ . Instead of solving it explicitly, we denote by σ_L^* the value of the subsidy that solves the equation. Since the above equation does not depend on y_1 , we have:

$$\frac{\partial \sigma_L^*}{\partial y_1} = 0 \tag{3.25}$$

Concerning y_2 , one cannot determine whether an increase in the poor country's income will cause the subsidy to increase or decrease:

$$\frac{\partial \sigma_L^*}{\partial y_2} = -\frac{(1-m)\mu(\sigma_L^*)+\beta}{(1-m)y_2\frac{\partial \mu(\sigma_L^*)}{\partial \sigma}-Ap_c} 0, \tag{3.26}$$

where

$$\frac{\partial \mu(\sigma_L^*)}{\partial \sigma} = \frac{(\alpha-\beta)p_c p_d}{[(1-\sigma_L^*)p_c - p_d]^2} > 0.$$

The level of the environmental amenity is given by:

$$a_{\sigma_L^*}(y_1, y_2) = Ap_c - \frac{\beta y_2}{(1-\sigma_L^*)p_c}. \tag{3.27}$$

Since the impact of y_2 on σ_L^* is ambiguous, for $a_{\sigma_L^*}$ that ambiguity also exists. Finally, as a result of the optimal subsidy, the utility level for the rich country is:

$$u_1(\sigma_L^*) = \left(\frac{1}{p_c}(y_1 - \frac{\sigma_L^* y_2}{1-\sigma_L^*})\right)^m \left(A - \frac{\beta y_2}{(1-\sigma_L^*)p_c}\right)^{1-m}. \tag{3.28}$$

3.2.2 Intermediate subsidy

Analogous to the intermediate transfer, an intermediate subsidy large enough so that the poor country uses some of (but not only the) clean good satisfies:

$$\frac{1-m}{m}\mu(\sigma)y_2 < Ap_c(1-\sigma)-\beta y_2 \tag{3.29}$$

and

$$\frac{1-m}{m}\mu(\sigma)\frac{y_2}{p_d} > A - \frac{\beta y_2}{p_d} \tag{3.30}$$

For such values of σ the interior solution for the poor country generates

$$a(\sigma) = (1-m)\left(A + \frac{y_2}{p_d}(\mu(\sigma) - \beta) \right). \tag{3.31}$$

Since

$$s_1(\sigma) = \frac{y_1}{p_c} - \sigma q_{2c}(\sigma), \tag{3.32}$$

we have to determine q_{2c} as well. After some algebraic manipulation, we can show that the poor country's consumption of the clean good is given by:

$$q_{2c}(\sigma) = \frac{1}{\Delta}\left((\mu - \alpha)A - (\alpha m + (1-m)\mu)\frac{y_2}{p_d}(\mu - \beta) \right) \tag{3.33}$$

where $\Delta = \mu(\beta_2 - m) - \alpha\mu$. We can write the utility of the rich country as:

$$s_1(\sigma)^m a(\sigma)^{1-m}.$$

As was true for income transfers, the intermediate and large subsidy cases differ. A large subsidy shifts the poor to barely using only clean goods, while an intermediate subsidy shifts the poor to a point between only-dirty and only-clean that is optimal from the perspective of the rich country and depends on the income of the rich. Thus the optimal subsidy is found by maximizing the utility of the rich country with respect to σ. Taking derivatives with respect to σ, and rearranging, we find that σ_I^* must satisfy:

$$\mu\left[q_{2c} + \sigma_I^* \frac{\partial q_{2c}(\sigma_I^*)}{\partial \sigma} \right] - (1-m)\frac{y_2}{p_d}\frac{\partial \mu(\sigma_I^*)}{\partial \sigma} = 0 \tag{3.34}$$

where $\frac{\partial q_{2c}(\sigma_I^*)}{\partial \sigma}$ is in general ambiguous and

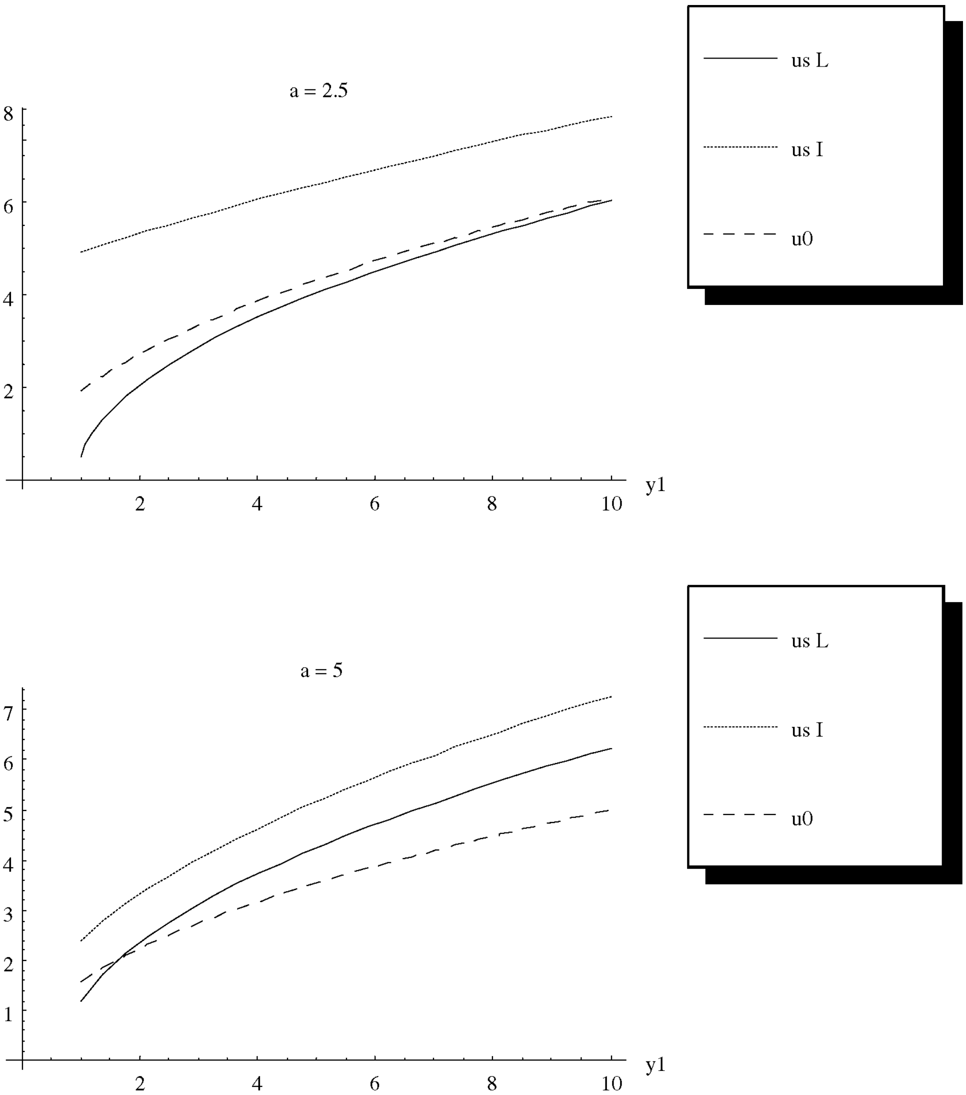
$$\frac{\partial \mu(\sigma_I^*)}{\partial \sigma} = \frac{(\alpha - \beta)p_c p_d}{[(1-\sigma_I^*)p_c - p_d]^2} > 0.$$

3.2.3 Comparing subsidy options

Finally, as was true for the transfer case, the rich country might find it better not to put funds into inducing the poor country to be cleaner, that is, it might choose not to give a subsidy at all. And as before, the resulting utility would be:

$$u_1(0) = \left(\frac{y_1}{p_c} \right)^m \left(A - \frac{\alpha y_2}{p_d} \right)^{1-m}. \tag{3.35}$$

Figure 3 Comparing subsidy options



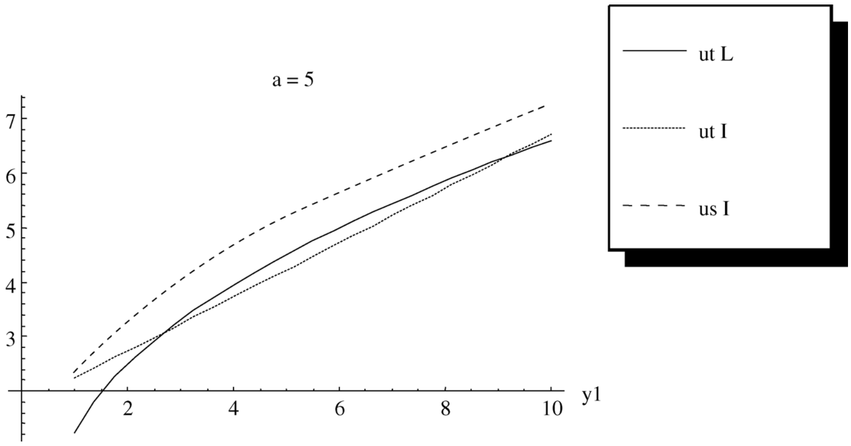
Comparing the utilities obtained by the rich country in each of these possible subsidy cases, we see in Figure 3 that $u_1(\sigma_L^*)$ is always less than $u_1(\sigma_I^*)$, that is, the intermediate subsidy seems to be the best environmental subsidy option for the rich country. Further, in contrast to the transfer case, the rich country is always better off (with low or high α) providing some subsidy than none at all.

Clearly such statements depend upon all of the parameters. Here, for instance, the value of α is large compared to the endowment A, so that the rich country stands to lose a lot by not providing incentives to the poor country to switch (at least partially) to the clean good. However, because we have used the same parameters for all our simulations, while either of the aid policies could be used to alter the default income-environment paths we can see here that the environmental subsidy policy clearly differs from the income transfer policy.

3.2.4 Comparison of subsidy and transfer options

The fact that the subsidy is better than providing no aid at all, which, in turn, is relatively often preferred to any positive level of income transfer, suggests that the subsidy is likely to be the better environmental aid policy. Figure 4 shows that this is indeed the case. It shows the level of the rich country's welfare for the two transfer cases and the intermediate subsidy case. The latter, that is, the $u_1(\sigma_I^*)$, is always above the other two cases. Not surprisingly, then, the more targeted environmental subsidy, that is, conditional aid, is the more efficient and preferred aid policy.

Figure 4 Comparing subsidy to transfers



As the subsidy appears to often be attractive for the rich country, relative to no aid, we may expect environmental outcomes for poor countries to be influenced by the presence of richer countries. The income transfer case helps to make the point that the presence of rich countries matters for income-environment paths. It is employed in this fashion for modelling extensions below concerning the effects of degradation by the rich. But a subsidy policy seems more realistic. Given the importance of innovation for environmental sustainability, also recall that a subsidy could be one way to implement technological transfer.

4 Two countries, degradation by rich and poor

Once again a rich and a poor country value a global public good, but now the use of marketed goods by the rich also degrades this amenity. As noted, an example of such an amenity is the degradation of an atmospheric service due to emissions of greenhouse gases that mix globally. This provides a second interaction between rich and poor, one distinct from but relevant for environmental aid.

Specifically, now $a = A - e_1 - e_2$ and $e_i = \alpha q_{id} + \beta_i q_{ic}$, that is, both countries degrade a and their respective uses of clean goods could differ in their impacts on a (we need not do the same for dirty goods since the rich country will not use them). Again assume $y_1 > y_2$ in such a way that $q_{1d} = 0$ and $q_{2c} = 0$, and again allow that the richer country might induce the poorer country to switch to clean goods by transferring income τ to the poorer country, yielding the budget constraints:

$$p_d q_{1d} + p_c q_{1c} = y_1 - \tau$$

$$p_d q_{2d} + p_c q_{2c} = y_2 + \tau. \quad (4.1)$$

4.1 Large transfer and degradation versus transfers

To induce the poor country to use only clean goods, the transfer τ must satisfy:

$$\frac{1-m}{m}\mu\frac{y_2+\tau}{p_c} \geq A - \frac{\beta_1}{p_c}(y_1-\tau) - \frac{\beta_2}{p_c}(y_2+\tau), \quad (4.2)$$

where $\mu = \frac{\alpha p_c - \beta_2 p_d}{p_c - p_d}$. The rich will choose a transfer to make this an equality:

$$\tau_L^* = \frac{mp_c A - m\beta_1 y_1 - [(1-m)\mu + m\beta_2]y_2}{(1-m)\mu + m(\beta_2 - \beta_1)}. \quad (4.3)$$

Note the perhaps surprising property that the transfer falls with the rich income.

The level of environmental amenity obtained with the optimal transfer is:

$$a_{\tau_L^*}(y_1, y_2) = \frac{1}{p_c}(p_c A - \beta_1 y_1 - \beta_2 y_2 - (\beta_2 - \beta_1)\tau_L^*) \quad (4.4)$$

and since τ_L^* is decreasing in y_i, as just noted, so is $a(y_1, y_2)$ (for $\beta_2 - \beta_1 \geq 0$):

$$\frac{\partial a_{\tau_L^*}(y_1, y_2)}{\partial y_1} = -\frac{\beta_1}{p_c[(1-m)\mu + m(\beta_2 - \beta_1)]} < 0 \quad (4.5)$$

$$\frac{\partial a_{\tau_L^*}(y_1, y_2)}{\partial y_2} = -\frac{(1-m)\mu\beta_1}{p_c[(1-m)\mu + m(\beta_2 - \beta_1)]} < 0, \quad (4.6)$$

and one particularly useful case to consider is when $\beta_1 = \beta_2 = \beta$, such that:

$$a_{\tau_L^*}(y_1, y_2) = \frac{1}{p_c}(p_c A - \beta_1 y_1 - \beta_2 y_2) = A - \frac{1}{p_c}\beta(y_1 + y_2). \quad (4.7)$$

In this latter case in (4.7), the environment does not depend on τ_L^*, since the two countries have the same impact on the environment. Shifting income between them is irrelevant to a. This result also emphasises that in this modelling framework, innovation is needed for sustainability. While the intermediate transfer can permit ranges of income in which economic growth proceeds alongside rising quality of the environment (as in

Section 2.2), as rich-country income rises for a given level of poor-country income, eventually the case of the large transfer will dominate and without innovation growth will inevitably lower environmental quality.

Rewriting the more general expression for environmental quality in (4.4) helps to make clearer what is happening, that is, how degradation by the rich matters:

$$a_{\tau_L^*}(y_1, y_2) = A - \frac{1}{p_c}(\beta_1(y_1 - \tau_L^*) + \beta_2(y_2 + \tau_L^*)). \tag{4.8}$$

Recall that the $(y_2 + \tau_L^*)$ term in (4.8) will remain constant because the rich country will continue to induce the poor country to be just willing to use only the clean goods. Thus for given y_2, increasing y_1 yields only increased consumption of services by the rich and thus also increased degradation of the environment. Increasing y_2 has the same effect because it reduces the transfer chosen by the rich country, leaving the rich with more effective income for consumption and thus more degradation.

The result of most interest, though, is above in (4.3) concerning the optimal transfer: it falls with rich-country income. This too follows from the degradation by the rich (which explains why it was not found in the previous section, in which $\beta_1 = 0$). In essence, degradation by the rich is a substitute for transfers in the inducement of pro-environmental choices in the poor country. While a transfer is one way to induce more use of clean goods, greater degradation of a by the rich will also induce more use of clean goods by the poor, lessening the need for transfers to keep the poor using clean goods as desired by the rich (as can be seen in (4.2)). In this somewhat perverse result, instead of 'taking responsibility for' its degradation by paying compensation, for example, the rich country views this degradation as a lever that, from its perspective, lessens the need for aid.

4.2 Durable degradation

The result just discussed is magnified when degradation of the environment is durable. Above, we implicitly modelled the degradation of *flows* of environmental services within a given period, in which only current incomes and behaviours affected environmental quality. However, for many types of degradation, including from greenhouse gas emissions, *stocks* are the relevant issue and past degradation will have impact as well. While a dynamic model could spell this out explicitly, here it suffices to note using our existing expressions that such durable effects of behaviours on environmental quality would strengthen the result just discussed.

Durable degradation implies that, conditional on current rich-country income, the total degradation of a caused by the choices of the rich is greater than the degradation of flows modelled above. That is tantamount to an increase in β_1. We have already modeled such a shift, as in Section 3 we set $\beta_1 = 0$, while in Section 4, we permitted $\beta_1 > 0$. Thus, we know qualitatively the effect: greater degradation by the rich will reduce the aid offered to induce the poor to use clean goods. Thus, in stark contrast to statements that responsibility for past environmental degradation implies that rich countries should *pay more* than they might otherwise (for example, in a Clean Development Mechanism), per

(4.2) and (4.3) the rich country itself would elect to take its past degradation into account by *reducing aid*.

5 Discussion

This paper demonstrated that the presence of richer countries who value the environment and offer environmental aid will affect poor countries' choices and environmental quality conditional on poor-country income. This is the case whether or not the rich countries' activities degrade the environmental public good. It complicates the search for a stable 'EKC' linkage of poor countries' incomes per capita with environmental outcomes.

For the case in which both rich and poor countries degrade the global public good, we find that despite being responsible for some of the degradation, the rich countries reduce their environmental aid. The reason is that degradation of the environmental amenity by the rich by itself pushes the poor countries towards the use of clean goods. This can substitute for environmental aid in inducing the shift to clean goods in poor countries that the rich desire. This somewhat perverse result is stronger when degradation is durable, that is, when historical consumption and degradation by rich countries affect over time the level of the environmental amenity enjoyed by the poor countries.

Optimal aid levels are more likely to be non-zero when aid takes the form of subsidies to existing clean goods, versus income transfers. While the optimal income transfer may be zero, that is, no aid, for the same simulation parameters the best positive subsidy level is always preferred to no aid. Thus the presence of richer countries that value the environment may well affect poor-country outcomes, given the more realistic subsidy policy. Note further that such a subsidy policy is one form of environmental technological-transfer programme. This is relevant because at least in this modelling framework, innovation in clean goods appears to be necessary for economic growth to be environmentally sustainable in the long run.

That suggests the value of further work on technological innovation and transfer. Our modelling (following Pfaff, Chaudhuri and Nye, 2004) suggested that there will be a clear increase in demand for cleaner goods as development proceeds and a greater fraction of the population is making use of the cleanest existing goods. Formalising the linkage from this demand to endogenous innovation, as well as linking that innovation to aid programmes that make the new cleaner goods available to all countries, are extensions that we intend to pursue in future work.

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Notes

1 See (World Bank 1992; Seldon and Song, 1994; Shafik, 1994; Holtz-Eakin and Selden, 1995; Grossman and. Krueger 1995) below as well as special issues of *Environment and Development Economics* (November 1997) and *Ecological Economics* (May 1998). For more theory see, for instance, (Keeler, Spence and Zeckhauser, 1972; Plourde, 1972; D'Arge and Kogiku, 1973; Forster, 1973; Gruver, 1976; Stephens, 1976; Asako, 1980; Becker, 1982; Gradus and Smulders, 1993; Tahvonen and Kuuluvainen, 1993; Bovenberg and Smulders, 1995; Michel and Rotillon, 1995; Seldon and Song 1995; Withagen, 1995; Beltratti, 1996; Elbasha and Roe, 1996; Stokey, 1998).

2 See (Pfaff, Chaudhuri and Nye, 2004) below for a theoretical analysis at household level, which could be the basis for a political economy model. Pursuing the implications of this model empirically for fuel choice and its impacts on indoor air quality, (Chaudhuri and Pfaff, 2003) find household-level empirical support for non-monotonic paths of environmental quality as household incomes rise.