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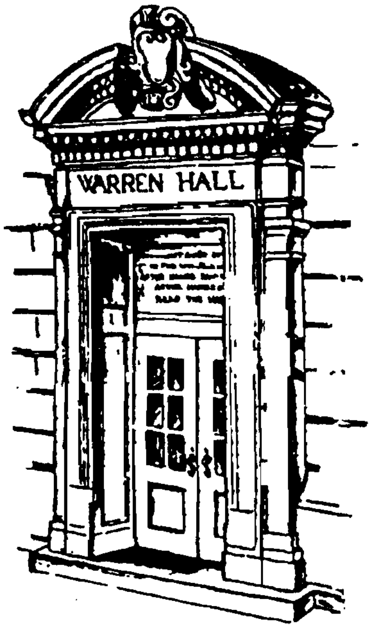

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INTERNATIONAL PUBLIC GOODS AND THE CASE FOR FOREIGN AID

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Abstract

In the presence of international public goods, donors are faced with two instruments whereby recipient utility may be altered — contributions towards the international public good and direct transfers (conventional foreign aid). The self-interested donor's optimal choice of transfer-contributions combinations will typically depend upon the public goods technology. Some technologies call for a corner solution, with either transfers or contributions set to zero, and others are characterised by interior solutions, where the donor's optimal strategy calls for a positive transfers and positive contributions. Whether or not the presence of an international public good strengthens the case for conventional foreign aid transfers is therefore not always obvious.

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1. Introduction

Public discourse and debate on foreign aid, defined as official flows of resources to developing countries, has undergone an interesting transformation since the fall of the Berlin wall and the collapse of the cold war. Twenty years ago, the rationale for foreign aid was seen either in terms of security or solidarity. On the one hand, official flows served to keep countries in one of the two main global blocs--this was obviously true of military assistance, but it was also true of flows intended for development purposes. On the other hand, there was also a strong sentiment in developed countries that resource transfers from rich countries to poor countries were a moral obligation. The combination of these two influences led to high and increasing levels of aid flows.

In the last decade, the cold war rationale has obviously disappeared. At the same time, however, "aid fatigue" has gripped the other major rationale for foreign aid, as the result of budgetary pressures in donor countries but also, equally importantly, as the result of considerable scepticism about the efficacy of foreign aid in actually helping poor countries, and in particular the poor in these countries. This scepticism is unusual in that it is to be found both on the political right and on the political left. On the right, there has been a revival of old arguments (e.g. Bauer and Yamey, 1981) that foreign aid, since it consists of flows to governments from governments, simply serves to increase the size of a bloated and inefficient public sector; an argument which has gained strength as private capital flows have vastly outstripped public flows in the aggregate. On the left, there have been similar concerns about flows going to corrupt elites in the South and in the North, about the use of flows to leverage market oriented development strategies, and a preference for channelling flows through the newly resurgent civil society in developing countries (e.g. Oxfam, 1995)

The analytical literature on the efficacy of aid in achieving its stated objectives has provided further grist to this mill. It seems clear that the "middle ground" has shifted in the last decade, from the relatively positive assessments of Cassen (1987) and Ridell (1987) to the scepticism evident in Boone (1996) or Burnside and Dollar (1997). The latter paper, in particular, is illustrative of the point at which the current debate finds itself. The paper concludes that there is, in general, no correlation between aid flows and development as measured by growth in per capita GNP (similar results hold in the literature for other indicators such as infant mortality rates). Further detailed econometric analysis reveals that this is the result of a combination of forces. While aid does indeed increase growth rates when it flows into good policy environments, it typically does not flow into such environments and does not induce such environments to emerge. While there are variations between different types of aid donors, this is a devastating critique in view of the fact that, at least since the 1980s, the international community is meant to have applied conditionality on aid flows (examples of recent theoretical analyses of conditionality are Coate and Morris, 1996, and Svensson, 1997b). It also questions somewhat the left leaning critique that the reason why aid has failed is that it is directed towards the wrong model of development (so if only the model was right, then conditional aid would help development)--but what these recent results seem to suggest is that aid cannot leverage policy change domestically. This has in turn led to the discussion and literature on "ownership", and then on to how this is to be identified and monitored (see Gwin and Nelson, 1997).

It is perhaps not surprising that at the end of this exhausting analytical and policy debate on the efficacy of conventional aid, some in the policy and in the analytical realm have turned to the newly emerging area of international public goods--almost in relief, one feels! There is of course no question that the rapidly globalizing world has thrown up major problems of cross border and global externalities, and highlighted others. As Cassen (1997) notes: "At any conference to consider the foreign policy agenda of the future, the list of key issues would include environment, population, migration and refugees, drugs and crime, and disease control--these are all factors in developing countries which can impact on industrial countries." This quote, and the sentiments in it, characterise the emergence of a newly articulated rationale for foreign aid, which is closer to the security than to the solidarity agenda. It rests much more on the direct spillovers of the lack of development in poor countries, on to the well being of those in rich countries. However, there is also a strand in this literature, which recognises that attempts to deal with cross border externalities may well have implicit transfers involved. As Schelling (1997) notes: "Any action [in rich countries] to combat global warming will be, intended or not, a foreign aid program", and he goes on to make the intriguing suggestion that, in fact, it might be more efficient for the US to undertake reduction of global warming gases and allow Bangladesh, say, a higher emission level, rather than making financial transfers in the old fashioned mode. Similarly, Jamison et.al. (1997) argue that: "Much of [health] aid should be redirected away from service delivery and toward activities that require international collective action, such as research and development and control of global health risks."

Through an interesting dynamic, therefore, we find ourselves at the intersection of two literatures--that on conventional foreign aid, and that on global externalities and public goods. Could international public goods and cross border spillovers provide a revived rationale for old fashioned transfers intended to spur development in poor countries? When faced with the choice of making transfer or contributing to an international public good, what should a donor country do, even if its objectives were governed by self interest rather than solidarity? And what happens to the many issues (like conditionality and ownership) in old fashioned solidarity driven aid, so exhaustively and exhaustingly debated over the last twenty years or more, in this new world of international public goods? The objective of this paper is to begin the discussion of these questions, which seem to us to have been neglected in the rush to embrace international public goods as a new rationale for maintaining international development cooperation and even traditional aid flows. Section 2 sets out a simple model of interaction between two countries which share a common public good, and poses the problem of the richer "donor" country deciding between making a transfer or contributing to a public good, while being concerned only about the impact of outcomes on its own well being. Section 3 carries out an analysis of the problem with different specifications of the public good. Section 4 concludes the paper with a discussion of the implications and of areas for further research.

2. The Basic Model and the Neutrality Result

In order to think systematically about the interaction between international public goods and conventional aid transfers, in light of the literature on donor-recipient interactions (e.g. Svensson, 1997a, b) and the literature on contributions to public goods (e.g. Cornes and Sandler, 1996), the simplest model will need the following components: two agents with differing endowments; the possibilities of direct transfers from one (the richer, say the donor) to the other (the poorer, say the recipient); a public good formed out of contributions of the two parties but which both parties enjoy; and a set up where the donor is the "Stackelberg leader" and the decision on transfers versus contribution to the international public good is made to maximise the donor's objective function, taking into account the recipient's reaction function. In fact, the literature on private contributions to public goods provides us with a model which comes very close to the above specification, except that instead of a Stackelberg leader-follower set up a Nash equilibrium between the two players is used as the main tool of analysis. We will start with a brief statement of the Nash equilibrium framework. This will allow us to introduce notation and will also serve as a benchmark for the more appropriate Stackelberg formulation.

In the basic Nash model, two goods enter each agent's utility function. One is a private good and the other is an international public good. Given their incomes, countries play a noncooperative game in contributions towards a single international public good – in other words a good whose consumption is non-excludable and non-rival. This is a seemingly natural way to model the interaction between the donor and the recipient. It allows for an analysis of the effect of an income transfer from one agent to another, and it captures the essence of the international public goods problem. Each agent optimises his or her objective function taken other agents' strategies as given. Contributions to the public good are made simultaneously by each country. The Nash equilibrium is then characterised by the intersection of the best response functions of each player. For the sake of clarity, analysis will be restricted to the case where there is one "donor" and one "recipient". Without loss of generality, suppose hereafter that agent 1 is the donor and agent 2 is the recipient. The two-player game can be described as follows:

Game 1: Simultaneous contributions to an international public good.

Definition: A game P1 in voluntary, simultaneous contributions to a public good consists of a set of players (I), strategies (g_i, $\forall\ i \in I$) and payoffs (u_i, $\forall\ i \in I$) such that:

$i \in I = \{1, 2\}$
$g_i \in \Re_+$
$u_i = \max u_i(x_i, G)$
s.t. $x_i + G = w_i + g_{-i}$
$x_i \geq 0$

where:

i = 1 or 2
g_i = government i's contribution to the international public good
x_i = government i's consumption of a private good
w_i = government i's wealth
u_i = government i's value function
G = $g_1 + g_2$ = the public good, enjoyed by both parties
g_{-i} = $G - g_i$

Assumption 1: Utility is continuous, increasing in both arguments and strictly concave.

Denote agent i's demand function for the public good by $f_i(m)$, where $m = g_{-i} + w_i$ is *i*'s full income.

Assumption 2:[1] $0 < f_i'(m) < 1$

[1] This assumption simply requires that both the private and the public goods be normal goods and follows Andreoni (1988) and Bergstrom et al. (1986).

Definition: A Nash equilibrium (NE) of P1 is a vector (g_1, g_2) such that for i = 1, 2 (g_i^*, x_i^*) solves

$$\max_{x_i, g_i} \; u_i(x_i, g_i + g_{-i}^*)$$

$$\text{s.t. } x_i + g_i = w_i$$

$$x_i, g_i \geq 0$$

A key assumption is made in the specification that the public good is simply the sum of the two contributions. As will be seen, this additive formulation drives many of the basic results, and departures from additivity change the results considerably.

Let us, for the purpose of P1, restrict our attention to the case where both governments contribute a positive amount to the public good in equilibrium, i.e. the NE is an interior one.[2] Within this framework, foreign aid might be conceptualised, as has been done by Sandler (1997) and others, as a transfer of Δw from government 1 (the donor) to government 2. Consider the following comparative statics exercise. Suppose we are originally at an interior NE. Now, suppose a "world government" mandates the donor to make a transfer $\Delta w < g_1^*$ to the recipient. After the redistribution, it can be shown that there is a new NE in which both the recipient and the donor change their contributions to the public good by precisely the same amount by which their wealth has changed. Consumption of both the public and private goods, and hence indirect utilities, are therefore unaltered in the new NE. This is the so-called "neutrality theorem".[3] What it means for our purposes is that aid in the form of a wealth transfer from donor to recipient has no effect on international public goods provision, or donor and recipient well being. Furthermore, the recipient views any increase in the donor's contribution towards the public good say Δg_1 as identical to a wealth transfer of $\Delta w = \Delta g_1$. There is a second sort of neutrality result here, in that agents are indifferent between aid in the form of public good contributions and aid in the form of transfers.

The Nash framework is a useful means of conceptualising how the presence of an international public good alters the case for conventional resource transfers. However, the Nash approach, standard in the literature on public goods, is problematic in our present context for at least two reasons. First, in the foreign aid arena, it is natural to think of the "donor" as a "leader". The notion of a world government which "orders" a transfer from donor to recipient, thereby rationalising the Nash comparative static exercise, does not sit well with the aid literature, and indeed almost all of the theoretical literature on conditionality and so on is in the Stackleberg leader-follower framework. Second and related, it was argued earlier that conventional resource transfers and public good contributions could be regarded as dual instruments. Therefore, they should ostensibly be considered simultaneously as part of a coherent strategy if we are to be capable of addressing the question of balance between contributions and direct transfers. These features can better be captured in a Stackleberg leadership game in which the recipient plays the best response to the donor's transfer and contribution level, and the donor chooses transfer and contribution levels that maximise his own welfare, taking into account the recipient's reaction function.[4] The Stackleberg game in contributions may be modelled as follows.

Game 2: Stackleberg – donor is the leader and recipient is the follower

$P2 = (I, \{g_i, u_i\}_{i=1,2})$ where:

The recipient (follower) solves:

$$\max_{x_2, g_2} \; u_2(x_2, g_1 + g_2)$$

$$\text{s.t. } x_2 + g_2 = w_2$$

$$x_2, g_2 \geq 0$$

[2] The literature also considers corner solutions (see for instance, Cornes and Sandler, 1996 and Bergstrom et al., 1986). These will be mentioned later but not be considered in detail in the Nash framework.
[3] See Warr (1983) and Bergstrom et. al. (1986)
[4] See for example Pedersen (1996) who models foreign aid as a Stackelberg game.

Denote the recipient's reaction function by:

$g_2(g_1) = \text{argmax}\ u_2(x_2, g_1 + g_2)$

Then, the donor (leader) solves:

$$\max_{x_1, g_1} \quad u_1(x_1, g_1 + g_2(g_1))$$

$$\text{s.t. } x_1 + g_1 = w_1$$
$$x_1, g_1 \geq 0$$

Definition: A Stackleberg equilibrium (SE) of P2 is a contribution g_1 and a reaction function $g_2(.)$ such that (g_1^*, x_1^*) solves the donor's problem and $(g_2(g_1^*), x_2^*)$ solves the recipient's problem.

We have argued that P2 is a more appropriate formulation for foreign aid than P1. But formulating the problem in this manner does not get rid of the neutrality outcome. Provided that the same conditions mentioned in the NE neutrality theorem are satisfied, the SE is also characterised by neutrality following an aid transfer.[5] In particular, starting from an interior SE to P2[6]: (i) a comparative static redistribution of income from 1 to 2 will leave public goods provision as well as welfare unaltered and (ii) agents will be indifferent between aid in the form of increased public goods contributions and direct income transfers. In particular, the donor will not care, in his own interests, whether he gives "conventional" aid or contributes to international efforts to mitigate cross-border externalities.

The neutrality result is a sobering one for those who would advocate a transition from conventional aid to international public goods contributions, or those who would strengthen the case for conventional aid in the name of cross border spillovers. It says that the two are perfect substitutes. Clearly, therefore, we must explore deviations from this benchmark if we are to obtain interesting insights into the relationships between conventional aid and contributions to international public goods. The next section takes up this story.

3. Types of International Public Goods and the case for Foreign Aid

As noted above, the neutrality result renders moot the choice between conventional aid and contributions to international public goods. However, as is well known from the public goods literature (see Cornes and Sandler, 1996) neutrality can be overturned when the technology for the public good is not simply an additive one.[7] Following the literature, we will consider three special cases. The first case considers outcomes when there are differing efficiencies in the production of the public good. An example would be pollution abatement – it may be cheaper for country 1 to "produce clean air" than it is for country 2. This can be captured in the simplest possible manner by supposing that the total public goods provision is still $G = g_1 + g_2$, but that each country's budget constraint is of the form: $x_i + \pi_i g_i = w_i$, where $\pi_i \neq \pi_j$. In particular, $\pi_i < \pi_j$ means that country *i* produces the public good more efficiently than country *j*. The second case is a "min" technology, where $G = \min\{g_1, g_2\}$. This relates directly to Hirshleifer's (1983) notion of a "weakest link" technology in public goods provision, with a good example in the international public goods arena being infectious disease control. The third case is a "max"(or "best-shot") technology, where $G = \max\{g_1, g_2\}$. This type of view would be pertinent to high-tech R&D (with the obvious caveat that the R&D in question is in fact a public good).[8]

Non-neutrality results in the Nash game for alternative public goods production technologies have been documented elsewhere, most notably in Cornes and Sandler (1996) and in Sandler (1997). We summarise simplified versions for the three cases mentioned above here – formal statements of the propositions as well as proofs can be found in Appendix I. (i) When two countries produce a public good with an additive technology (e.g. clean air) with differing efficiencies, non-neutrality results. Furthermore, a transfer from 1 to 2 increases (decreases) public goods provision and indirect utility of the donor and recipient if and only if the recipient

[5] For a proof see Bruce (1990) or Sandler (1992)

[6] And provided the conditions from the Nash neutrality result are also satisfied.

[7] Even a technology of the form $f(\Sigma g_i)$ generates the neutrality result.

[8] Note that in the "max" and "min" technology cases, assumption 2 must be modified slightly to $0 < f_i'(w_i) < 1$.

produces clean air more (less) efficiently than the donor. (ii) Suppose agents are identical, differing only in wealth levels, where $w_1 > w_2$. Then, in the case of a weakest-link technology, a transfer from donor to recipient, which does not fully equalise incomes increases public goods provision and makes the recipient unambiguously better off. It also makes the donor better off provided the increased utility resulting from increased public goods provision more than offsets the reduction in utility following the donor's diminished private goods consumption. (iii) Suppose agents are identical, differing only in wealth levels, where $w_1 > w_2$. Then, in the case of a best-shot technology, a transfer from donor to recipient, which does not fully equalise incomes reduces public goods provision and makes the donor worse off. However, the recipient will be better off provided the increased utility resulting from increased private goods consumption more than offsets the reduction in utility following the diminished public goods provision.[9]

The fact that in the Nash case we can talk about whether the donor is better off or not following a transfer highlights the problem with the Nash approach--why should a donor make a transfer if it makes him worse off? We therefore really do have to move to a Stackleberg framework. The Nash excursion turns out to have been useful, however, since the results in the Stackleberg case basically follow the Nash intuitions.

Analogous to the Nash case, non-neutrality arises in the Stackleberg case when the public good technology is non-additive or efficiencies vary. As before, we will consider three cases: differing efficiencies, weakest-link and best shot technologies, but this time in a Stackelberg framework. The game is a little more complex than that described in P2 above because the donor's strategy consists of an income transfer t to agent 2 (the recipient) as well as his contribution to the international public good. However, in some cases, rather than have the donor maximise directly over t, we will deduce the optimal transfer from the best response function of the recipient and the indirect utility function of the donor. In the presence of corner solutions in the transfer-contributions strategy of the donor, this approach simplifies the analysis considerably. The recipient is the follower, and his strategy then simply comprises of a contribution to the public good given the donor's transfer and contribution level. Here, we summarise the results in three propositions and briefly outline the intuition behind the results. Proofs of these propositions are available in Appendix II.

Differing efficiencies $(\pi_1 \neq \pi_2)$, $\pi_i \in (0, 1)$, $G = g_1 + g_2$

Proposition 1: In a Stackleberg game with differing efficiencies any transfer ($t < g_1^*$) from agent 1 to agent 2 will be characterised by non-neutrality. Furthermore, faced with a choice between income transfers and contributions towards the public good, the donor will set $t = 0$ when $\pi_2 > \pi_1$, and $g_1 = 0$ when $\pi_2 < \pi_1$.

Thus, when the donor and the recipient produce the public good with differing efficiencies, a corner solution in "transfers" will result. More specifically, the basic intuition is that if the donor is more efficient, then he should set direct transfers equal to zero and concentrate solely on public goods provision as a means of enhancing welfare. Inasmuch as the recipient directly benefits from the public good, such contributions on the part of the donor may be regarded as a more efficient form of foreign aid, thereby echoing the sentiment expressed by Schelling (1997).

Weakest link $G = min\{g_1, g_2\}$

Proposition 2: In a Stackleberg framework with identical preferences, characterised by a weakest link technology, there are conditions under which there exists a new equilibrium with positive transfers and increased public goods provision which pareto dominates the pre-transfer equilibrium.

Thus when the technology is of the weakest-link variety, the donor will want to use a combination of direct resource transfers and contributions to the public good. The reasons for this should be quite intuitive. If the public good is a normal good, then contributions to the good increase with income. The "min" technology means that in order to ensure a given level of contributions, both countries must contribute towards public goods provision. Therefore, if the donor wishes to attain a given level of provision, he must encourage the recipient to contribute via income transfers to him, and must himself make contributions – complementarity of contributions is what drives this result.

[9] For proofs of these propositions see Appendix.

Best-shot: $G = max\{g_1, g_2\}$

Proposition 3: In a Stackleberg framework with a best-shot technology and identical agents, the SE will be characterised by zero direct income transfers.

The outcome here is no different than that in the NE. It is clear that with a "max" technology, the donor is better off making no direct income transfer to the recipient, but rather, devoting his resources to public goods investments. Given the technology, this result should be relatively intuitive. Even with identical preferences, the degree of difference in income levels between donor and recipient typically implies that public goods provision is likely to be determined by donor rather than recipient contributions, even when some income transfer is made. The donor therefore has no reason to believe that the recipient will devote any direct income transfers towards public goods contributions, and therefore has no self-interest in making such transfers.

4. Discussion and Conclusion

To those who might have thought that cross border externalities and international public goods would lead to a significant strengthening of the argument for conventional aid, not by relying on solidarity but by appealing to the self interest of the donor, the results of this paper are only half comforting. It turns out that for international public goods to come to the rescue of conventional aid through this channel, one of two situations must hold: (i) the public good must be an additive combination of the two contributions, and the recipient country must be more efficient at producing the public good than the donor country; or (ii) the total public good must be determined to a large extent by the lower of the two contributions. If, on the other hand, (i) the public good is additive in individual contributions but the donor country is more efficient in producing it, or (ii) the total public good is determined by the larger of the two contributions, then it is in the donor's interest to minimise the conventional transfer. These cases highlight the fact that the international public goods argument for conventional aid is more complex than meets the eye. Depending on the nature of the public good, a variety of outcomes are possible.

It is worth stressing the importance of setting out exactly the nature of the public good. Let us start with fundamental genomic research. This has the characteristics of a max technology, and there is an argument for richer countries to undertake this research and then make this freely available to poorer countries. But three issues arise. First, will the research be specific to the needs of poorer countries? Second, will the results indeed be made available freely to poorer countries? Third, even if they are, does the poorer country have the capacity to use them? These questions take us deeper into the nature of the good at hand. The fact that different types of research (on tropical versus temperate agriculture, for example) affect rich and poor countries differently caution us against lumping things together into a single "public goods" category. The second question reminds us that the publicness or otherwise of a good is technologically as well as socially and politically determined--privately conducted research into tropical crops, with private patents for seeds etc., is not what we mean by the "max technology" specification. The third question reminds us also to think about the whole process before specifying the public good.

Take infectious diseases as another example. The development of vaccines, and fundamental research into the nature and evolution of such diseases, is probably a max technology and, according to our analysis, the donor would be well advised to conduct such research himself and then make the results freely available to the recipient. But implementation of an immunisation program is probably a min technology--no matter how well developed the program is in the donor country, ultimately it will be the level of immunisation in the recipient country which will determine the global level of infection. The focus therefore should be on improving the recipient's capacity and willingness to implement an immunisation program.

Now consider a class of public goods that seem to satisfy the additive technology characterisation--clean air, or its converse the public bad, green house gases. Here, whoever reduces their emission, the whole world benefits. Is it better for the US to undertake the reduction, at some cost to its income level, or to give Bangladesh foreign aid and rely on the latter to cut its emissions as it gets wealthier? The answer depends on which of the two countries can reduce emission at least cost per unit reduction. This is an empirical question, but if it turns out that the US is more efficient, it would be rational for the US to seek to achieve emission reductions not through making Bangladesh richer and then relying indirectly on Bangladesh's choice to use some of this increase wealth to get cleaner air, but by directly reducing its (the US's) own emissions. But if the issue is bio-diversity, and the focus is on the bio-diversity present in the Amazon basin, say, then almost by definition the US is less efficient in preserving this than Brazil--the US, in its own interests, will have to rely on giving Brazil the resources with which to preserve bio-diversity in the Amazon.

Thus the presence of international public goods does not necessarily strengthen the case for conventional aid across the board. However, it should also be clear from the above that the presence of international public goods by no means eliminates the need to worry about the "conventional" problems of "conventional" aid, since it is really only in those areas where implementation is not needed in the recipient country that the donor country can go it alone. In the min technology, certainly, even optimally the donor will wish to make transfers as well as contribute itself to the public good. The efficiency of these transfers then becomes a concern of the donor, and we are back in to the depths of the literature on conditionality. For example, the way that transfers have been modelled here assumes full fungibility of resources. Clearly, the donor could get a bigger bang for its buck by trying to tie the transfers to expenditures on infectious disease control. But in order to do this there needs to be an effective contracting system with sanctions for non-compliance. The literature on conditionality has pointed, for example, to the "Samaritan's Dilemma"[10] problem of a donor who cares about the well being of the recipient, hence the inability to implement contracted sanctions, and the inefficiency of the time inconsistency which results. These issues are not avoided, indeed they are perhaps sharpened, even when the donor only cares about consequences for himself. At the same time, when current efficiency differences in public goods production dictate that the donor specializes in contributing to the public good rather than making transfers, there is still the question, not modelled in this paper, of whether it is better to try and improve the efficiency of public good production in the recipient country--but this takes us right back to implementation issues in the recipient country.

Thus the basic conclusion of this paper is to insert a note of caution into the current excitement around international public goods as a new rationale for aid. International public goods certainly provide a rationale for international co-operation based on self interest, but only in certain circumstances do they provide a rationale for donors to continue conventional transfers based on self interest. At the same time, in the actual implementation of many public goods interventions, the old issues of conditionality, fungibility, monitoring. sanctions, etc. are ever present. In order to investigate these issues, further research will have to develop richer models which incorporate (i) a combination of altruistic and self interested motives in making transfers, (ii) choices between contributing to different types of public goods, (iii) contractual agreements on the transfers and on the public goods contributions, and enforcement mechanisms. This will allow us, among other things, to address the question of whether, even when there is altruism involved, it is better for the donor country to express it through contributions to the types of public goods which do not lead it into the tangle of conditionality--essentially, by supplying public goods which it can produce and then make freely available.

[10] See Buchanan (1975) and Coate (1995).

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APPENDIX I: Nash Propositions and Proofs

Case 1: Differing efficiencies ($\pi_1 \neq \pi_2$) – $G = g_1 + g_2$

Proposition A1 : When two countries produce a public good with an additive technology with differing efficiencies, non-neutrality results. Furthermore, a transfer (t) from 1 to 2 increases (decreases) public goods provision and indirect utility of the donor and recipient if and only if the recipient produces clean air more (less) efficiently than the donor.

Proof:

Neutrality implies that public goods provision and indirect utilities will be unaltered following the transfer. By the strict convexity of preferences, this can only be the case if private goods consumption is also unaltered. Consider the budget constraint of agents 1 and 2. They are, respectively:

$x_1 + \pi_1 g_1 = w_1 - t$ (1)
$x_2 + \pi_2 g_2 = w_2 + t$ (2)

(1) => in order to keep x_1 constant, the donor has to reduce his contribution by t/π_1.
(2) => in order to keep x_2 constant, the donor has to increase her contribution by t/π_2.

Neutrality requires that $\Delta g_1 + \Delta g_2 = 0$. But differing efficiencies => $t/\pi_1 + t/\pi_2 \neq 0$. This contradiction completes the first part of the proof.

Following G1, denote agent 1 and agent 2's demand functions for aggregate public goods by $f_1(m)$ and $f_2(m)$ respectively, where m denotes each agent's full income. In any NE following the transfers, we know that the following equality must hold:

$G = f_1((w_1 - t)/\pi_1 + g_2) = f_2((w_2 + t)/\pi_2 + g_1)$.

Then, the total supply of the public good will increase (G'>G*) following the transfer iff:

$f_1((w_1 - t)/\pi_1 + g_2') > f_1((w_1)/\pi_1 + g_2^*)$ **and** (3)

$f_2((w_2 + t)/\pi_2 + g_1') > f_2((w_2)/\pi_2 + g_1^*)$ (4)

where "primes" denote the NE contributions following the transfer and "stars" denote pre-transfer contributions.

Assumption 2 means that conditions (3) and (4) can be satisfied if and only if:

$g_2' > g_2^* + t/\pi_1$ **and** (5)

$g_1' > g_1^* - t/\pi_2$ (6)

For the "only if" part of the proposition, we have to show $\pi_2 > \pi_1$ implies that G'<G* and $u_1' < u_1^*$. Suppose $\pi_2 > \pi_1$. Then, for fixed $x = (x_1, x_2) = (x_1^*, x_2^*)$ it is easy to see that conditions (5) and (6) are not feasible. This implies that G'<G*. Furthermore, since utility is increasing in both goods and x is unchanged, it must also be the case that $u_1' < u_1^*$.

For the "if" portion of the proposition, we must show that $\pi_2 < \pi_1$ implies that G'>G* and $u_1' > u_1^*$. Again, from the budget constraint, keeping x fixed at the pre-transfer NE level (x_1^*, x_2^*), $\pi_2 < \pi_1$ implies that conditions (5) and (6) are feasible. We know from the proof of neutrality that when $\pi_2 = \pi_1$, there exists a new equilibrium in which each agent reduces his contribution by precisely the amount of the transfer. Here, we know that agent 1 will reduce his contribution by at least t/π_1 and agent 2 will increase his contribution by at least t/π_1, in order to compensate for agent 1's reduction. However, $\pi_2 < \pi_1$ means that agent 2's income gain outweighs agent 1's income loss. Assumption 2 then guarantees that conditions (5) and (6) will hold. This in turn implies that $G' > G^*$. We conducted this exercise holding x fixed at x^*, so it must also be the case that $u_1' > u_1^*$. #

Case 2: Weakest link – $G = min\{g_1, g_2\}$

Proposition A2: Suppose agents are identical, differing only in wealth levels, where $w_1 > w_2$. Then, in the case of a weakest-link technology, a transfer from donor to recipient, which does not fully equalise incomes increases public goods provision and makes the recipient unambiguously better off. It also makes the donor better off provided the increased utility resulting from increased public goods provision more than offsets the reduction in utility following the donor's diminished private goods consumption

Proof:

Since utility is strictly increasing in wealth, the recipient is obviously made better of by any positive wealth transfer. To see the effect of the transfer on public goods provision, notice first that with identical preferences and $w_1 > w_2$, the NE will be determined by the recipient's demand for the public good: $G^* = f_2(w_2)$. Clearly, if $w_1 - w_2 > t$, i.e. the transfer is non-equalising, it will continue to be the case that the recipient's demand function for the public good will determine the aggregate level of public goods provision. So, $G' = f_2(w_2 + t)$. By assumption 2, $f_2(w_2 + t) > f_2(w_2)$ for $t > 0$.

To see what happens to the donor's welfare following a positive transfer notice that the donor's best response will simply be to match agent 2's contributions unit for unit. Following the transfer, donor's value function following the may be denoted:

$$u_1(w_1 - t - f_2(w_2 + t), f_2(w_2 + t))$$

Taking the derivative of this function with respect to transfers we see that the donor's utility will increase following a positive transfer provided:

$$[\delta u_1(w_1 - f_2(w_2 + t), f_2(w_2 + t))/\delta x_1]/ [\delta u_1(w_1 - f_2(w_2 + t), f_2(w_2 + t)) /\delta G] < [f_2'(w_2 + t)]/[1 + f_2'(w_2 + t)]$$

The donor will be strictly worse off when this inequality is reversed.#

Case 3: Best-shot – $G = max\{g_1, g_2\}$

Proposition A3 : Suppose agents are identical, differing only in wealth levels, where $w_1 > w_2$. Then, in the case of a best-shot technology, a transfer from donor to recipient, which does not fully equalise incomes reduces public goods provision and makes the donor worse off. However, the recipient will be better off provided the increased utility resulting from increased private goods consumption more than offsets the reduction in utility following the diminished public goods provision.

Proof:

When preferences are identical and w_1 - w_2, the NE will be characterised with agent 2 contributing nothing towards the public good and the agent contributing a positive amount, i.e.:

$$G^* = f_1(w_1)$$

When $t < w_1 - w_2$, $G' = f_1(w_1 - t)$. From assumption 2, $G' < G^*$. Clearly, the donor is made strictly worse off by such a transaction since $(x_1', G') < (x_1^*, G^*)$. The recipient's indirect utility following the transfer will be:

$$u_2(w_2 + t, f_1(w_1 - t))$$

Taking the derivative of this function with respect to t reveals that the recipient will be better off following the transfer provided:

$$[\delta u_2 (w_2 + t, f_1(w_1 - t))/\delta x_2] / [\delta u_2 (w_2 + t, f_1(w_1 - t))/\delta G] > f_1'(w_1 - t)$$

The recipient will be strictly worse off when this inequality is reversed. #

APPENDIX II: Proofs of Stackleberg Propositions

Proof of Proposition 1: Differing efficiencies

Assume:
$(\pi_1 \neq \pi_2)$, $(\pi_i \in (0, 1))$, $G = g_1 + g_2$

Denote agent 2's reaction function in the Stackleberg game by $G = f((w_2 + t)/\pi_2 + g_1)$. Then agent 1's (the leader's) problem is the following:

$$\max_{x_1, g_1} \quad u_1(x_1, f((w_2 + t)/\pi_2 + g_1))$$

$$\text{s.t.} \quad x_1/\pi_1 + g_1 = (w_1 - t)/\pi_1$$
$$x_1, g_1 \geq 0$$

Let "stars" denote pre-transfer SE levels and "primes" denote post-transfer SE levels.

Neutrality requires that $G' = G^*$, i.e. that aggregate public goods provision remain unaltered following the transfer, and that consumption of the private goods remain unaltered (i.e. that individuals' indirect utilities are unaltered). The first of these conditions implies that:

$$G' = f((w_2 + t)/\pi_2 + g_1') = f((w_2)/\pi_2 + g_1^*) = G^*$$

By the strict convexity of preferences, this can only hold if:

$$g_1' = g_1^* - t/\pi_2$$

Note however, differing efficiencies implies that $t/\pi_2 \neq t/\pi_1$. Therefore, when the above equality holds, the donor is strictly better off when $\pi_2 < \pi_1$ and strictly worse off when $\pi_2 > \pi_1$. This contradiction completes the proof of non-neutrality.

For the second half of the proposition, consider the utility of the donor, keeping G fixed at G^*.

Before the transfer the donor's indirect utility is:

$$u_1(w_1 - \pi_1 g_1^*, f(w_2/\pi_2 + g_1^*))$$

Following the transfer, it is:

$$u_1(w_1 - \pi_1 g_1^* + (\pi_1 t)/\pi_2 - t, f(w_2/\pi_2 + g_1^*))$$

Suppose $\pi_2 > \pi_1$. Then it should be clear from the expression above that a utility-maximising donor will wish to set $t=0$. Suppose, alternatively, that $\pi_2 < \pi_1$. Then, analogously, the donor should set $g_1=0$. #

Proof of Proposition 2: Weakest link $G = \min\{g_1, g_2\}$

Suppose agents 1 and 2 have identical preferences and differ only in wealth levels, where $w_1 > w_2$. Then, clearly:

$$G^* = \min\{g_1^*, g_2^*\} = \text{argmax } u_2(w_2 - g_2, g_2)$$

Now, suppose there was a transfer from 1 to 2 which was not perfectly equalising, i.e. $w_1 - w_2 > t$. Then, clearly:

$$G' = \min\{g_1', g_2'\} = \text{argmax } u_2(w_2 + t - g_2, g_2)$$

Clearly, agent 2 is better off following a transfer and by assumption 2, G' > G*.

As before, denote agent 2's demand for the public good by $f(w_2 + t)$. Then, agent 1's problem is the following:

$$\max_{t \geq 0} u_1(w_1 - t - f(w_2 + t), f(w_2 + t))$$

In order to see when it would be expedient for the donor to make a transfer to the recipient, consider the first order condition to the donor's maximisation problem.

$$-[\delta u_1(w_1 - t - f(w_2 + t), f(w_2 + t))/\delta x_1][1 + f'(w_2 + t)] + [\delta u_1(w_1 - t - f(w_2 + t), f(w_2 + t))/\delta G][f'(w_2 + t)] \leq 0$$

$$\lim_{t \to 0} -[\delta u_1(w_1 - t - f(w_2 + t), f(w_2 + t))/\delta x_1][1 + f'(w_2 + t)] + [\delta u_1(w_1 - t - f(w_2 + t), f(w_2 + t))/\delta G][f'(w_2 + t)]$$
$$= -[\delta u_1(w_1 - f(w_2), f(w_2))/\delta x_1][1 + f'(w_2)] + [\delta u_1(w_1 - f(w_2), f(w_2))/\delta G][f'(w_2)]$$

Agent 1 will therefore find it worthwhile making a positive transfer if and only if:

$$[\delta u_1(w_1 - f(w_2), f(w_2))/\delta x_1]/ [\delta u_1(w_1 - f(w_2), f(w_2))/\delta G < [f'(w_2)]/[1 + f'(w_2)]$$

Therefore, when this condition is satisfied, both agents are made better off by the transfer.#

Proof of Proposition 3: *Best-shot:* $G = \max\{g_1, g_2\}$

When agents are identical, differing only in terms of income, we know that in equilibrium $g_2 = 0$.
Then, agent 1's problem becomes:

$$\max_{g_1, t} u(w_1 - t - g_1, g_1)$$
$$\text{s.t.} \quad g_1 \geq 0$$
$$t \geq 0$$

It is clear that the second constraint will be binding. So, g_1 will solve the first order condition:

$\delta u_1 (x_1, g_1)/\delta x_1 = \delta u_1 (x_1, g_1)/\delta g_1$ #

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