Pollution Abatement and Tied Foreign Aid

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Abstract.

There exists in the literature a presumption that foreign aid (especially if it is tied) can be used effectively to reduce cross border pollution. Focussing on the interaction of private and governmental pollution abatement in the recipient country and tied foreign aid we identify three main reasons why the optimism of the literature may not be justified: (a) foreign aid crowds out private and/or governmental pollution abatement in the recipient country, (b) foreign aid creates incentives to increase output and emissions and (c) foreign aid induces capital accumulation because it raises the rental of capital.

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I Introduction

The main issue addressed in this paper is practical and very topical. The European Union and several member countries (especially Germany) provide considerable amounts of tied foreign aid to Eastern European countries in order to achieve a reduction in pollution (mainly emissions)[1]. Is this type of foreign aid effective in lowering pollution if we allow for a policy reaction in Eastern European countries?

Generally, as is well known, pollution abatement may be undertaken by governments and private firms or by governments alone. It is therefore essential to model the interaction between governments and private firms in the provision of pollution abatement. There exists a presumption that pollution abatement will be undertaken by private firms if the appropriate pollution abatement technology is available and the emissions of dirty firms are taxed at a high enough rate.

Tied foreign aid, which by assumption is used only for pollution abatement, is bound to affect the interaction between the governmental and private provision of pollution abatement in Eastern Europe. The interaction between the government and the private sector can, of course, assume many forms. To obtain clear-cut insights we focus on simple forms. The focus on simple forms notwithstanding, we shall see that there are many possible scenarios. Which of these scenarios is more relevant to the real world can finally only be decided in the light of empirical analysis.

Whether tied foreign aid reduces emissions in the aid receiving country essentially depends on three effects: (1) ceteris paribus emissions per unit of output fall (however see Proposition 1, the invariance theorem); (2) total emissions may still rise because net (after tax) value added increases which creates incentives to raise output; and finally (3) there is a hike in the rental of capital which generally makes for capital accumulation in the long run. This again counteracts the initial ceteris paribus emission reducing effect of tied foreign aid.

The paper makes use of a simple model. We refer to it as a pilot model. It will be obvious to the reader that many of the results hold under more general assumptions. A simple model has been chosen because we want to make the analysis and the derivation of the results as transparent as possible. To this end we have assumed that the governments in the aid receiving countries finance their contribution to pollution abatement only from the proceeds of a tax which is levied

[1]See, for example: Umweltpolitische Zusammenarbeit in Mittel- und Osteuropa (environmental policy cooperation in Middle and Eastern Europe), German ministry for the environment, protection of nature and reactor safety, March 2003, 3rd edition.

upon emissions. It is often alleged that there exists some empirical evidence for this earmarking of tax revenue [2]. Furthermore, we concentrate exclusively on the scale and technique effects of foreign pollution abatement[3]. Therefore there exists only one industry with all firms identical. In more general models foreign pollution abatement also has composition effects, i.e.: changes the allocation of factors between different industries, see e.g. Hatzipanayotou et al (2002).

Throughout the paper the tax on emissions levied by the government is fixed. We realize, of course, that the tax rate is a potential policy instrument; however in this paper our main aim is to highlight the effects of pollution abatement policy. The latter is easier to change than emission tax rates. It is well known that tax rates are enacted through laws. It may take considerable time to change the laws because of the existence of well organized vested interest groups in many countries.

The paper is structured as follows. The "generic" model is formally stated in the following part II. It consists of four expressions which describe the effects of foreign pollution abatement on the endogenous variables. Following a standard practice of the huge literature on transfers, see e.g. Kemp (1992) for a survey, foreign pollution abatement (tied foreign aid) is taken to be exogenous. The endogenous variables are: employment in production and pollution abatement, the governmental as well as the (possibly) private provision of pollution abatement, tax revenue and the level of emissions.

As pointed out before one of our key concerns is the modelling of the interaction between the government and private firms in the provision of pollution abatement. All our results are driven by the assumption that there is a lack of perfect coordination of pollution abatement provided by the government, the private sector of the recipient country and foreigners. Parts III and IV are based upon the assumption of a parametric treatment of the government provision by the private sector. However in part V we adopt a more political economy perspective; we allow for the governmental provision to be manipulated by the private sector. This leads to additional insights which seem to be of great real world relevance.

Last but not least an important novel feature of the present paper is its distinction between the short and long run effects of foreign pollution abatement. As pointed out before, foreign pollution abatement generally affects the profitability of the industry, or to put it more precisely,

[2] Brett and Keen (2000) note that in the USA the proceeds of environmental taxes are often earmarked for pollution abatement.

[3] On the distinction between scale, technique and composition effects, see Copeland and Taylor (2003), pages 2 - 4. There exists empirical evidence that the composition effect is very small, see again Copeland and Taylor (2003), page 250 ff, especially page 258.

the rental of capital, see part III, Proposition 1. This has long run effects, in the sense, that an increase in the rental of capital may call forth either domestic and/or foreign direct investment. This in turn has secondary effects on employment in production, pollution, pollution abatement and tax revenue. Long run effects may either reinforce short run effects or counteract them. The emphasis on secondary effects due to foreign investment seems to us of special importance in the context of the relationship between the European Union (and in particular Germany) and the private sector in Eastern European countries.

It seems to be widely accepted that many forms of foreign aid (public and private) are tied to certain conditions. Accordingly one generally distinguishes between three different types of tying (Chao and Yu, 1999). First, aid may be tied to the consumption of certain goods; see for example, Kemp and Kojima (1985), Lahiri and Raimondos (1995), Schweinberger (1990), (2002), and Hatzipanayotou and Michael (1995). Secondly, foreign aid may be tied to the financing of certain projects such as pollution abatement (Chao and Yu, 1999) and the present paper. Finally, there is policy tying. Lahiri and Raimondos-Møller (1997) consider, for example, the tying of aid to tariff reductions.

The literature on cross border pollution is substantial, for useful surveys see, for example, Hatzipanayotou et. al (2002) or Copeland and Taylor (1995). In the latter article a model of a world economy consisting of two regions is considered: North and South. Each region is composed of many countries. The governments set pollution quotas. Copeland and Taylor derive conditions under which coalitions of countries which agree on a reduction of pollution bring about a Pareto improvement. They also derive the surprising result, see Proposition 7, on page 731, that untied aid has no effect on global pollution and welfare in the various countries. This result bears a striking resemblance to the first result of the present paper, see Proposition 1, the invariance theorem. However the resemblance is misleading because Copeland and Taylor are considering untied aid and the latter changes pollution in the donor and recipient countries.

The present paper is most closely related to two articles on foreign aid and pollution abatement: Chao and Yu (1999) and Hatizpanayotou et al (2002). Our paper shares with Chao and Yu (1999) the assumption of tied aid; however it should be noted that Chao and Yu are only concerned with national pollution. Hatizpanayotou et al (2002) in common with the present paper focus on the effects of cross border pollution but foreign aid is not tied to pollution abatement. Chao and Yu (1999) make use of a two country general equilibrium model (with public and private pollution abatement) to analyze the welfare effects of tied aid. One of their results is of special interest: even in the presence of terms of trade deterioration tied foreign aid can bring about a Pareto improvement.

The main result in Hatzipanayotou et al (2002) concerns the finding that even in the absence of international cooperation trans-border pollution can be a blessing in disguise because it may induce an increase in foreign aid and therefore a reduction in world wide pollution.

The key results of the present paper are summarized in the conclusions. First and foremost we show that foreign aid, even if it's tied to pollution abatement, may lead to a rise in the world wide pollution in the short and long run.

Most of our results differ significantly from the received literature for the following four main reasons. Firstly, there is a lack of coordination of the provision of pollution abatement between the government, the private sector of the recipient country and foreigners. Secondly, we allow (in contrast to the literature) for employment effects in the short and long run analyses. Employment effects of environmental policies seem to play a key part in all actual policy discussions. Thirdly, the distinction between short and long run effects appears to be novel. Foreign aid changes the rental of capital and this may call forth either domestic or foreign direct investment. Last but not least, we allow in section V for manipulable governments. This opens up perspectives, which, in the present context, cannot be found in the received literature.

II The Model

We consider a model comprising a production sector that produces a single product using labour and capital according to a production function $f_1(K_1, L_1)$, where L_1 is the quantity of labour used in production and K_1 is the capital stock. In this production activity, pollution is also generated but the amount of pollution depends upon how much labour is devoted to pollution abatement. We assume that the amount of labour engaged in pollution abatement is $L = L_A + L_G + L_F$, where L_A is the quantity of labour employed in pollution abatement by the private sector, L_G is the employment of labour in pollution abatement financed by the government of the foreign-aid-receiving country and L_F is employment of labour in pollution abatement financed from tied foreign aid. Total emissions are given by $z_1 = \alpha(L)x_1$, where $x_1 = f_1(K_1, L_1)$ stands for the output of the private sector and $\alpha(L)$ represents a pollution abatement function with the properties that $\partial\alpha/\partial L < 0$ and $\partial^2\alpha/\partial L^2 > 0$.[4]

[4]It is common practice in the bulk of the received literature to assume that the pollution abatement function is continuously differentiable. However note that threshhold effects (implying step functions) may be important; see, for example, Copeland and Taylor (2003), pp. 87 -

The production and pollution abatement decisions by the private sector are modelled by means of the profit function

$$\Pi = \max_{L_A, L_1} \{(p_1 - \alpha(L)t) f_1(K_1, L_1) - L_1 - L_A : L = L_A + L_G + L_F\}, \tag{1}$$

where p is the price of the output, t is the tax levied per unit of emissions and where it is assumed that the wage rate for labour is normalized to unity.[5] The production function $f_1(.)$ is a standard neoclassical production function (as widely used in sector specific factor models). Thus, according to (1), the private sector chooses the quantities of labour used for production and for pollution abatement to maximize the sector's after-tax profits, given the capital stock. This is a short-run profit maximization problem since it takes the capital stock, K_1, as given.

The first order necessary conditions for a solution (L_1, L_A) to the profit maximization problem in (1) are

$$[p_1 - \alpha(L)t] \frac{\partial f_1}{\partial L_1} - 1 \leq 0 \leq L_1 \quad (CS) \tag{2}$$

and

$$-\frac{\partial \alpha(L)}{\partial L} t f_1(K_1, L_1) - 1 \leq 0 \leq L_A \quad (CS), \tag{3}$$

where CS denotes "complementary slackness".[6]

We now specify the government's budget constraint. We assume that the provision of L_G is financed exclusively from emission tax revenue. Therefore, the government's budget constraint may be expressed as

$$L_G = t\alpha(L) f_1(K_1, L_1) > 0. \tag{4}$$

Finally, total emissions are specified as

$$z = \alpha(L) x_1 = \alpha(L) f_1(K_1, L_1), \tag{5}$$

where $x_1 = f_1(K_1, L_1)$ is the level of production.

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[5] As pointed out before, employment effects are important in all policy discussions. Employment effects can also be found in a different context in the received literature on transfers (Beladi (1990) and Chao and Yu (1987)).

[6] Complementary slackness is expressed in the form $x \geq 0 \leq y$ (CS), which means that $x \geq 0$, $y \geq 0$ and $xy = 0$.

The expressions (2) to (5) are referred to as the generic model. We make use of this generic model to generate three different and more special models.

To this end, we first assume that the production function $f_1(.)$ satisfies the Inada condition.[7] Hence expression (2) always holds as an equation and $L_1 > 0$. In part III we additionally assume that the pollution abatement function, $\alpha(L)$ also satisfies the Inada condition or, more generally, that the emission tax rate t is high enough so that pollution abatement will be undertaken by the private sector and the government. This assumption is relaxed in part IV, where pollution abatement is only undertaken by the government.[8] Therefore in part IV, the model consists only of expression (1) as an equation and equations (4) and (5). We shall see that this entails striking changes in the results of the short and long run analyses. Finally, in part V we model a government that is manipulated by the private sector.

III GOVERNMENTAL, PRIVATE AND FOREIGN POLLUTION ABATEMENT

(A) Short run analysis

If the private sector, the government of the aid receiving country and foreigners engage in pollution abatement we obtain a surprising result regarding the effectiveness of the provision of tied foreign aid. We refer to it as the *invariance theorem.*

Proposition 1. (the invariance theorem) *Consider an increase in tied foreign aid. Assume that, both before and after the increase in tied foreign aid, the government and the private sector in the aid receiving country provide pollution abatement. Then: (a) An increase in tied foreign aid crowds out private pollution abatement on a one to one basis. Total employment of labour in production and pollution abatement remain unchanged. The same applies to total emissions. (b) The increase in tied foreign aid raises the return to capital in the private sector and therefore creates incentives for domestic and/or foreign direct investment (in the long run).*

Proof. Proposition 1 follows directly from an inspection of equations (2) to (5). If the private sector engages in pollution abatement one can solve equations (2) and (3) for L and L_1. Equation (4) pins down L_A and equation (5) total emissions z. From equation (4) it is obvious that we must have $\triangle L_A + \triangle L_F = 0$. This proves Proposition 1(a). Proposition 1(b) simply follows from

[7] The Inada conditions on the per-capita production function $f(k)$ are that $f(0) = 0$, $f'(0) = \infty$, $f'(\infty) = 0$, and $f(\infty) = \infty$, in addition to being strictly increasing ($f'(k) > 0$) and strictly concave ($f''(k) < 0$).

[8] It is often argued that in many developing countries effluent taxes are very low, see Beghin et al (1997). In this case pollution abatement is confined to governments.

the fact that: $v_1 f_1(.) - L_1 - L_A = rK_1$, where r stands for the rental of sector specific capital K_1 and $v_1 = p_1 - \alpha(L)t$. Since $\triangle L_A < 0$ we know that $\triangle r > 0$. Q.E.D. ■

It cannot be emphasized strongly enough that the *invariance theorem*, Proposition 1(a), holds under much more general assumptions. Also (to the best of our knowledge) it is an entirely novel result.[9]

It is shown in Appendix A that the *invariance theorem* can be generalized. An essential implicit assumption in this context is that governmental, private and foreign pollution abatement are perfect substitutes. The version of the *invariance theorem* stated in Proposition 1 is based upon the assumption of a fixed wage in order to focus on the total employment effects of foreign aid provision. This seems appropriate since employment effects of pollution abatement policies loom large in actual policy discussions. However it is straightforward to allow for flexible wages and full employment, see again Appendix A.

For our purpose, the significance of the *invariance theorem* is twofold. Firstly, it represents a very general and novel result regarding the effects of foreign pollution abatement if the government and the private sector engage in pollution abatement. Secondly, it plays a crucial role as a benchmark for all the following results.

We now turn to the long run analysis. Taking into account the effects induced by domestic or foreign direct investment, it will be seen that foreign pollution abatement may not be ineffective after all.

(B) The long run analysis

The long run analysis of the effects of an increase in foreign pollution abatement is based upon the following assumptions:

(a) an increase in the rental of capital induces an increase in either domestic and/or foreign direct investment,[10]

(b) the profit function of the private sector is concave in L_A(total labour used in pollution abatement) and L_1 (labour used in production),

[9] Copeland and Taylor (1995) derive their Proposition 7, a result which may be regarded as an application of the neutrality theorem (familiar from the theory of public goods). Copeland and Taylor are concerned with the effects of untied aid whilst our result is based upon the assumption of tied aid. In our model there is no change in emissions in the aid receiving country as a result of foreign aid. However, in Copeland and Taylor the amount of pollution is lowered in the recipient country.

[10] Changes in factor prices may, of course, give rise to technical progress in the long run. Technical progress may mitigate or exacerbate pollution through scale and composition effects. Due to space limitations these important issues are beyond the scope of this paper.

(c) own effects on marginal profitability of L_1 and L_A dominate cross effects, i.e.:

$$\left|\frac{\partial^2\pi}{\partial L_1^2}\right| > \left|\frac{\partial^2\pi}{\partial L_1 \partial L_A}\right| \quad \text{and} \quad \left|\frac{\partial^2\pi}{\partial L_A^2}\right| > \left|\frac{\partial^2\pi}{\partial L_A \partial L_1}\right| \tag{6}$$

We shall refer to this set of assumptions as set A. Note that from (b) it follows that we have assumed that $\partial^2\alpha/\partial L^2 > 0$.

Our immediate aim is to derive the long run effects on employment of an increase in the capital stock. To this end we differentiate expressions (2) and (3), which hold as equations, with respect to K_1. This yields:

$$v_1\frac{\partial^2 f_1}{\partial L_1^2}dL_1 - t\frac{\partial\alpha}{\partial L}\frac{\partial f_1}{\partial L_1}dL = -v_1\frac{\partial^2 f_1}{\partial L_1 \partial K_1}dK_1 \tag{7}$$

$$-\frac{\partial\alpha}{\partial L}\frac{\partial f_1}{\partial L_1}dL_1 - \frac{\partial^2\alpha}{\partial L^2}f_1 dL = \frac{\partial\alpha}{\partial L}\frac{\partial f_1}{\partial K_1}dK_1 \tag{8}$$

Subject to the set of assumptions A, the effect of increases in K_1 on L and L_1 can be illustrated by means of the following Figure 1. In Figure 1, FE represents the equilibrium locus derived from expression (2) and PA is the equilibrium locus from expression (3).

It follows from the assumption of a concave profit function that the Jacobian determinant of equations (2) and (3) is positive, i.e.,

$$D = -v_1 f_1 \frac{\partial^2 f_1}{\partial L_1^2}\frac{\partial^2\alpha}{\partial L^2} - t\left(\frac{\partial\alpha}{\partial L}\frac{\partial f_1}{\partial L_1}\right)^2 > 0. \tag{9}$$

Having established that domestic or foreign direct investment has positive employment effects we now address the all-important question of the long run effects of capital accumulation on emissions z.

Differentiating totally equation (5) we obtain:

$$dz = \frac{\partial\alpha}{\partial L}f_1 dL + \alpha(L)\frac{\partial f_1}{\partial L_1}dL_1 + \alpha\frac{\partial f_1}{\partial K_1}dK_1. \tag{10}$$

The attention of the reader is now drawn to the following Figure 2. The schedules FE and PA are the same in Figures 1 and 2. The schedule $\overline{Z}^0 - \overline{Z}^0$ is derived from expression (5). It is defined as the locus of L and L_1 that yield the same level of emissions as <u>for the initial value of K_1</u>.

Setting $dz = dK_1 = 0$ in expression (10), it is straightforward to derive the slope of the schedule $\overline{Z}^0 - \overline{Z}^0$. Note that $\overline{Z}^0 - \overline{Z}^0$ passes through A; i.e., we keep the emissions fixed at the original equilibrium level. The schedule $\overline{Z}^0 - \overline{Z}^0$ divides the space into two halfspaces; to the right emissions are higher, to the left lower. Let us assume that the slope of $\overline{Z}^0 - \overline{Z}^0$ is higher than the slope of FE; i.e.,

$$\frac{-\alpha(L)\frac{\partial f_1}{\partial L_1}}{\frac{\partial \alpha}{\partial L} f_1} > \frac{v_1 \frac{\partial^2 f_1}{\partial L_1^2}}{t \frac{\partial \alpha}{\partial L}\frac{\partial f_1}{\partial L_1}}. \tag{11}$$

Then it follows that

$$f_1 \frac{\partial^2 f_1}{\partial L_1^2} + \frac{\alpha t}{v_1}\left(\frac{\partial f_1}{\partial L_1}\right)^2 > 0. \tag{12}$$

How will the $\overline{Z} - \overline{Z}$ schedule shift as K_1 increases? Clearly, there must be a leftward shift because ceteris paribus the increase in K_1 raises emissions. We are now in a position to state Proposition 2:

Proposition 2. *(a) Taking into account the long run effects of an increase in foreign pollution abatement, employment in production and in pollution abatement rises (subject to the set of assumptions A). (b) There is an increase in total emissions in the long run due to an increase in foreign pollution abatement if:*

$$f_1 \frac{\partial^2 f_1}{\partial L_1^2} + \frac{\alpha t}{v_1}\left(\frac{\partial f_1}{\partial L_1}\right)^2 > 0 \tag{13}$$

(c) Assume that the pollution abatement function $\alpha(L)$ satisfies the Inada condition and therefore private pollution abatement takes place even for very small values of t. Then there exist very small values of t such that an increase in foreign pollution abatement in the long run raises emissions if and only if:

$$\left(\frac{\partial \alpha}{\partial L}\right)^2 - \alpha \frac{\partial^2 \alpha}{\partial L^2} < 0. \tag{14}$$

Proof. Proposition 2(a) follows from Figure 1, Proposition 2(b) from the derivation of expression (12). Proposition 2(c) is proven in Appendix B. Q.E.D.

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Proposition 2(b) seems of particular interest because it depends only upon properties of the production function. It is a fact that much more is known about the properties of production than pollution abatement functions. It represents, of course, only a sufficient condition but it highlights that an increase in K_1 raises (ceteris paribus) the marginal value product of labour used in production as well as in pollution abatement. Whether emissions rise or fall depends upon the relative increases in L_1 and L. The first term in expression (12) shows that L_1 will rise by relatively less if the production function is more concave. An analogous interpretation applies to the second term in expression (12).

Proposition 2(c) is interesting because it highlights that if the tax rate t assumes very small values then the result depends only upon the properties of the pollution abatement function $\alpha(L)$. The problem is, of course, that empirically apparently very little is known about the specific form of pollution abatement functions[11]. If we are willing to assume a simple form $\alpha = AL^{-\beta}$, where $0 < \beta < 1$ it is easy to show that the condition of Proposition 2(b) is satisfied.

In any case, the upshot of Proposition 2 is clear-cut. Foreign pollution abatement can be expected to have positive employment effects in the long run and may therefore be desirable from the point of view of the aid receiving country. However it is by no means certain that the purpose of the donor countries, namely the reduction of emissions, can be achieved either in the short or in the long run. The latter can only be determined on the basis of a thorough empirical analysis which can take as a starting point the testing of the results of our theoretical pilot model.

IV Public and Foreign Pollution Abatement.

(A) Short run analysis

We have seen in part III that neither the aid receiving nor the aid providing country benefit in the short run from foreign aid if the government and private firms in the aid receiving country engage in pollution abatement. This follows from the *invariance theorem*. We now drop the assumption that the pollution abatement function satisfies the Inada condition. The emission tax rate is assumed to be relatively low so that private firms have no incentive to provide pollution abatement. As we shall see, this relatively small change in assumptions entails drastic changes in the results. Firstly, we shall prove that foreign pollution abatement benefits the recipient country because, subject to standard assumptions, employment in production and in pollution abatement rise. Furthermore there now exists, in the short run, the possibility that emissions fall and therefore the aid providing as well as the aid receiving country gain from foreign aid.

[11] As pointed out before, pollution abatement functions may not be differentiable. However the assumption of continuous differentiability seems to be standard in most of the literature.

To prove this we differentiate expression (4), the government budget constraint, having set L_A equal to zero. We readily obtain

$$\left(1 - \frac{\partial \alpha}{\partial L} t f_1\right) dL - t\alpha(L) \frac{\partial f_1}{\partial L_1} dL_1 = dL_F + t\alpha \frac{\partial f_1}{\partial K_1} dK_1 \tag{15}$$

The short run employment effects can be determined from expressions (7) and (15) having set $dK_1 = 0$. The Jacobian determinant of equations (7) and (15) is equal to

$$D^{'} = \left(1 - \frac{\partial \alpha}{\partial L} t f_1\right) v_1 \frac{\partial^2 f_1}{\partial L_1^2} - t^2 \frac{\partial \alpha}{\partial L} \alpha \left(\frac{\partial f_1}{\partial L_1}\right)^2 < 0 \tag{16}$$

As can be seen, we have assumed that the Jacobian determinant is negative. This seems reasonable in the light of the fact that in this part no private pollution abatement is undertaken (because t is too small).

We are now in a position to state and prove Proposition 3.

Proposition 3. *Assume that only the government of the aid receiving country and foreigners provide pollution abatement and $D^{'}$(see expression (16)) is negative. Then (in the short run): (a) an increase in foreign pollution abatement raises employment in production and pollution abatement. It may also crowds out (partly) the pollution abatement undertaken by the aid receiving country, if t is very small. (b) an increase in foreign pollution abatement lowers emissions if and only if:*

$$f_1 \frac{\partial^2 f_1}{\partial L_1^2} + \frac{\alpha t}{v_1} \left(\frac{\partial f_1}{\partial L_1}\right)^2 < 0.$$

Proof. Consider the following Figure 3. Figure 3 shows two schedules: the FE schedule which is derived from expression (2), as an equation, and the GB schedule derived from expression (4). If $D^{'} < 0$ as assumed, it follows at once that the GB schedule is flatter than the FE schedule. An increase in L_F shifts the GB schedule upwards. This proves that employment in production and pollution abatement rise. The result that an increase in foreign pollution abatement partly crowds out the pollution undertaken by the government of the aid receiving country can be proven as follows. Solving expressions (7) and (15) for dL/dL_F we obtain:

$$\frac{dL}{dL_F} = \frac{dL_G}{dL_F} + 1 = \frac{v_1 \frac{\partial^2 f_1}{\partial L_1^2}}{D^{'}}. \tag{17}$$

It is easy to see that $dL/dL_F < 1$, if t is very small. Hence Proposition 3(a) has been proven. To prove Proposition 3(b) we simply compare the slopes of the FE schedule and an appropriately defined schedule $\overline{Z} - \overline{Z}$, see the Figure 4, below. Note that the schedule $\overline{Z} - \overline{Z}$ is derived from expression (5) keeping the level of emission fixed at the original equilibrium level.

If the slope of the $\overline{Z} - \overline{Z}$ schedule is lower than the slope of the FE schedule, as shown on Figure 4 we can write:

$$\frac{-\alpha(L)\frac{\partial f_1}{\partial L_1}}{\frac{\partial \alpha}{\partial L} f_1} < \frac{v_1 \frac{\partial^2 f_1}{\partial L_1^2}}{t \frac{\partial \alpha}{\partial L} \frac{\partial f_1}{\partial L_1}}. \tag{18}$$

This yields:

$$f_1 \frac{\partial^2 f_1}{\partial L_1^2} + \frac{t\alpha(L)}{v_1} \left(\frac{\partial f_1}{\partial L_1} \right)^2 < 0 \qquad Q.E.D.$$

■

While Proposition 3(b) clearly is related to the result of Proposition 2(b), it should be carefully noted that Proposition 2(b) only states a sufficient condition for direct investment to raise emissions whereas the result of Proposition 3(b) represents a necessary and sufficient condition for foreign aid to lower emissions in the short run. The reason for the similarity of the results is clear-cut. In the model of part III direct investment raises the marginal product of labour employed in production as well as in pollution abatement. Subject to the (different) assumptions of part IV, the provision of foreign pollution abatement has analogous effects (in the short run).

(B) Long run analysis

It follows from the short run analysis that employment in the pollution abatement, L, rises. The latter result implies that an increase in foreign pollution abatement creates incentives for direct domestic and/or foreign investment. As in part III it is straightforward to prove that an increase in foreign pollution abatement raises the rental of capital.

The interesting question which now arises concerns the possibility of the short run effects being reinforced or more than offset by the long run effects.

It is straightforward to show that the long run effects can only reinforce the short run effects as far as employment in production and pollution abatement is concerned. However it is quite possible that, as far as the effects on emissions are concerned, the long run effects can reverse and in fact more than offset the short run effects. Therefore foreigners may find that an increase in foreign aid raises emissions in the long run even if it lowered emissions in the short run.

To analyze the long run effects we make use of expressions (8) and (15), having set dL_F equal to zero.

The reader's attention is drawn to Figure 5. The short run effects on employment and emissions are shown as a movement from A to B. The line $\overline{Z} - \overline{Z}$ represents the locus of L and L_1 such that the level of emissions is fixed corresponding to point A. It is clear that in this case emissions fall in the short run. In the long run the FE schedule shifts to the right and downward, the GB schedule upward (from GB^1 to GB^2). The long run equilibrium point is given by C. Direct foreign or domestic investment induces also an upward and leftward shift in the schedule $\overline{Z} - \overline{Z}$ (this is not shown on the diagram). It follows that in the long run emissions have risen more than they have fallen in the short run. Therefore again an increase in foreign pollution abatement may not be in the interest of foreigners.

These results are now formalized as Proposition 4.

Proposition 4. *Assume that D' is negative (i.e., condition (16) holds) and an increase in foreign pollution abatement occurs. This raises the rental of capital and therefore induces either domestic and/or foreign direct investment. Then: (a) the short run employment effects are reinforced in the long run, and (b) the short run effects on emissions may be reinforced or reversed in the long run, i.e., a short run reduction in emissions may be more than offset by a long run increase.*

The interesting general conclusion which follows from the preceding analysis is that if the aid receiving country attaches more weight to increases in employment than to increases in emissions, the increase in foreign pollution abatement may seem desirable from the point of view of the aid receiving country but contrary to the interest of the donor country.

V A Manipulable Government

We now relax the assumption that the private sector in the aid receiving country treats the pollution abatement provided by the government parametrically. Specifically, it is assumed that the private sector knows the tax revenue function and can solve it for L_G. Thus, the private sector knows how much labour the government will employ in pollution abatement and can take this into account when making private sector employment and production decisions.

To extend the model to take this new assumption into account, we rewrite the government budget constraint as

$$L_G = t\alpha(L_G + \widetilde{L})f_1(K_1, L_1) \tag{19}$$

where $\widetilde{L} \equiv L_A + L_F$. Solving equation (19) for L_G we obtain

$$L_G = L_G(\widetilde{L}; K_1, L_1). \tag{20}$$

Expression (20) is now substituted into the profit function of the private sector. This yields a new specification of the profit function given by

$$\Pi = \max_{\widetilde{L}, L_1}\{p_1 - t\alpha[L_G(\widetilde{L}; K_1, L_1) + \widetilde{L}]\} f_1(K_1, L_1) - (\widetilde{L} - L_F) - L_1 \tag{21}$$

The first order conditions of Π with respect to $\widetilde{L}$ and L_1 represent the core of the model of part V. The underlying key assumption is that the private sector knows the governmental budget constraint (observability) and that the government is credibly committed to financing its own contribution to pollution abatement from emission tax revenue. The main issue to be addressed is clear-cut: how does the assumed manipulability of the government by the private sector affect the main results derived in parts III and IV? In particular, it seems interesting to compare the level of emissions (for a given amount of tied foreign aid) in countries where governments are or are not manipulable.

The objective function of the private sector is now given by expression (21). Having assumed interior solutions we have the following first order necessary optimality conditions:

$$\frac{\partial \Pi}{\partial L_1} = v_1 \frac{\partial f_1}{\partial L_1} - f_1 t \frac{\partial \alpha}{\partial L} \frac{\partial L}{\partial L_G} \frac{\partial L_G}{\partial L_1} - 1 = 0 \tag{22}$$

$$\frac{\partial \Pi}{\partial \tilde{L}} = -t \frac{\partial \alpha}{\partial L} \frac{\partial L}{\partial \tilde{L}} f_1 - t f_1 \frac{\partial \alpha}{\partial L} \frac{\partial L}{\partial L_G} \frac{\partial L_G}{\partial \tilde{L}} - 1 = 0. \tag{23}$$

A very important and interesting issue arises at this point. Assume that there are two aid receiving countries that are the same except that in one of them the private sector manipulates the governmental pollution abatement but in the other L_G is treated parametrically. Both countries receive the same amount of foreign aid L_F. Which country produces more output, provides more or less governmental and private pollution abatement? Most importantly, can it be shown that the emissions are higher in the country with the manipulable government? Intuitively it seems probable that emissions should be higher in the country with the manipulable government.

The answers to these questions are given in the following Proposition 5, which is illustrated in Figure 6.

Proposition 5. *Assume that the private sector knows the tax revenue function of the government and the objective function of the private sector is given by expression (21) in the country with the manipulable government. Then: (a) Employment in production, L_1, is higher and private pollution abatement, L_A, lower in the country with a manipulable government. Public pollution abatement is higher in the country with the manipulable government. (b) Total emissions will be higher in the country with the manipulable government.*

Proof. To prove Proposition 5(a), we first differentiate expression (19) partially with respect to L_1 and then with respect to $\widetilde{L}$. It is then easy to see that:

$$\frac{\partial L_G}{\partial L_1} > 0 \text{ and } -1 < \frac{\partial L_G}{\partial widetildeL} < 0. \tag{24}$$

Now assume that we are in the equilibrium of part III and we have solved for L_1, L_G and L_A. Specifically, we assume that the values of L_1, L_G and L_A are such that expressions (2) and (3) are satisfied as equations. Now consider equations (22) and (23) and evaluate them at the equilibrium values for L_1, L_G and L_A implied by equations (2) and (3). Taking into account expression (24) it follows that:

$$\frac{\partial \Pi}{\partial L_1} > 0 \text{ and } \frac{\partial \Pi}{\partial \widetilde{L}} < 0.$$

If we postulate, as in parts III and IV that own effects on marginal profitability dominate cross effects we have:

$$\Delta L_1 > 0 \text{ and } \Delta \widetilde{L} < 0. \tag{25}$$

Finally, differentiating totally expression (19) with respect to L_1 and $\widetilde{L}$ and making use of expression (24), it follows at once that L_G will rise. This proves Proposition 5(a).

To prove Proposition 5(b) we totally differentiate expression (5) with respect to $\widetilde{L}$ and L_1 having substituted for $L = \widetilde{L} + L_G(\widetilde{L}, L_1, K_1)$. This yields:

$$dz = f_1 \frac{\partial \alpha}{\partial L}\left(1 + \frac{\partial L_G}{\partial \tilde{L}}\right) d\tilde{L} + \left(f_1 \frac{\partial \alpha}{\partial L}\frac{\partial L_G}{\partial L_1} + \alpha \frac{\partial f_1}{\partial L_1}\right) dL_1. \tag{26}$$

An inspection of expression (26) reveals that, contrary to intuition, the level of emissions may be lower in the country with the manipulable government. The private sector uses its input decision L_1 to manipulate the governmental provision of pollution abatement. Hence L_G may rise to such an extent that emissions are actually lower. Whether this possibility applies in the real world can only be determined in the light of a detailed empirical analysis. Q.E.D. ■

Our final task in this paper relates to the applicability of the invariance theorem (See Proposition 2) in aid receiving countries with a manipulable government. Note that we have assumed, as in part III, that the government as well as the private sector provide pollution abatement, see equations (22) and (23). This leads to the presumption that the invariance theorem can be generalized to countries with a manipulable government. To prove this we substitute: $L = L_G(\widetilde{L}, L_1, K_1) + \widetilde{L}$ into equations (22) and (23). It is then straightforward to see that the reduced form equations (22) and (23) represent a system of two simultaneous equations in the variables $\widetilde{L}$ and L_1. This insight gives rise to the following Proposition 6.

Proposition 6. *Assume that in a country with a manipulable government the private sector and the government provide pollution abatement before and after an increase in foreign pollution abatement. Then the level of emissions, as well as employment in production and pollution abatement, remain unchanged; only private pollution abatement L_A falls.*

Proof. See the argument preceding Proposition 6. ■

Proposition 6 seems interesting because it shows that an increase in foreign aid does not affect the government provision of pollution abatement L_G even though the private sector generally makes use of its input decision L_1 and L_A to manipulate the governmental provision.

In conclusion of part V, we simply point out that the fall in L_A (as in part III) implies a rise in the rental of sector specific capital and therefore creates incentives for domestic and/or foreign direct investment. This makes for long run effects on employment, pollution and emissions which are beyond the scope of this paper due to space limitations. However it may be conjectured that the "manipulation effect" $\frac{\partial L_G}{\partial \widetilde{L}}$, which figures in equation (23), could have important implications for the long run effects (entailing long run effects which have no analogues in part III).

VI Conclusions

Whether or not foreign aid can be used to reduce cross border pollution clearly is an important policy issue.[12] In the present paper we have considered the effects of foreign aid tied to pollution abatement on pollution abatement, pollution and employment. The received literature [see especially Chao and Yu (1999) and Hatzipanayatou et al (2002)], generally speaking, reaches the conclusion that foreign aid (especially if it is tied to pollution abatement) can make a significant contribution to the reduction of pollution (whether it is of the national or cross border variety).

In the present paper we put forward a number of models that cast considerable doubt on the effectiveness of foreign aid in regard to pollution control. Making use of a generic pilot model we focus on the interaction of foreign pollution abatement on the one hand and governmental and/or private pollution abatement in the recipient country on the other. In particular we prove that an increase in foreign pollution abatement crowds out private pollution abatement on a one to one basis if governmental and private pollution abatement are undertaken in the recipient country before and after the increase in foreign aid (see Proposition 1, the invariance theorem). This does not imply necessarily that an increase in foreign aid is undesirable from the point of view of the recipient country. The reason is that an increase in foreign aid creates incentives for domestic and/or foreign direct investment. The latter generally has positive employment effects in the recipient country, see Proposition 2.

The results change drastically if no private pollution abatement is undertaken, because emission taxes are very low for example. In this case an increase in foreign aid may lower emissions in the short run but the long run effects of capital accumulation may more than offset the short run reduction in emissions. Again because of positive employment effects the increase in foreign aid may be in the interest of the recipient but contrary to the interests of the donor country, see Propositions 3 and 4.

In this paper we also allow for the governments of recipient countries to be manipulable. Not surprisingly, we can prove that, in comparing countries with non-manipulable governments with countries with manipulable governments, ceteris paribus the level of pollution is higher in the countries with manipulable governments. Finally, we have extended the invariance theorem to countries with manipulable governments.

[12] Generally, there exist, of course, two approaches to control cross border pollution. They are summarised in the expression "carrot and stick approaches". For a brief survey of the relevant literature, see Hatzipanayotou et al (2002).

As pointed out in the Introduction the difference in conclusions (compared with the received literature) is due to novel features of our generic model and its derivatives. In particular we allow (in contrast to the received literature) for employment effects and explicitly distinguish between the short and long run effects of foreign aid. Another key assumption which drives our results is the lack of perfect coordination of the provision of pollution abatement by the private sector, the government of the recipient country and foreigners.

There are several possible extensions of the analysis of this paper that would be useful to pursue. Firstly, in some international agreements on tied foreign aid one can find so called quid pro quo clauses. In this case, the government of the recipient country undertakes to match any increases in foreign aid by its own provision. Secondly, there exists a rich literature on international technology transfers [for a brief survey see, e.g., Long (2002)]. It seems very plausible that foreign aid in the form of pollution abatement could be linked with a transfer of abatement technology. Finally, it should be noted that a "carrot and stick" approach to the international control of cross border pollution could be preferable to the present "carrot approach". It is well known that this more general approach has been on the agenda of the Doha round of tariff negotiations.

Appendices

Appendix A

We assume a general sector specific factor model. There are $i = 1, ..., m$ dirty industries and $j = m+1, ..., n$ clean industries. There is one mobile factor, which is fully employed and whose wage rate is endogenous. We allow for the emissions (outputs) of the dirty industries to be taxed at different rates t^i. Foreign pollution abatement in each dirty industry is exogenous as in the text.

From profit maximization in the dirty industries, the first order necessary conditions are:

$$[p_i - \alpha(L^i)t^i]\frac{\partial f_i}{\partial L_i} - w = 0 \qquad i = 1, ..., m, \tag{1}$$

$$-\frac{\partial \alpha^i}{\partial L^i} t^i f_i(K_{1i}, L_i) - w = 0, \tag{2}$$

where w denotes the price of the mobile factor. From profit maximization in the clean industries, the first order necessary conditions are:

$$p_j \frac{\partial f_j}{\partial L_j} - w = 0 \qquad j = m+1, ..., n. \tag{3}$$

The production functions are denoted by:

$$x_i = f_i(K_{1i}, L_i) \qquad i = 1, ..., m, \tag{4}$$

$$x_j = f_j(K_{1j}, L_j) \qquad j = m+1, ..., n. \tag{5}$$

The full employment equilibrium condition in the market for the mobile factor is:

$$\sum_{i=1}^{m} L_i + \sum_{j=m+1}^{n} L_j = \overline{L} \quad \text{(factor endowment)}. \tag{6}$$

Finally, the tax revenue raised from the taxation of emissions in each dirty industry is:

$$L^i - L^i_A - L^i_F = t^i \alpha^i(L^i) f_i(K_{1i}, L_i) \qquad i = 1, ..., m. \tag{7}$$

It follows from the set of equations (1A) to (7A) that the set of equations (1A) and (2A) may be solved for L^i and L_i, $i = 1, ..., m$. From (7A), it is clear that again in each dirty industry

$\triangle L_A^i + \triangle L_F^i = 0.$ Q.E.D.

APPENDIX B

We prove the result stated as Proposition 2(c).

From equation (11), having set $t = 0$, we readily obtain that

$$\frac{dL_1}{dK_1} = \frac{-\frac{\partial^2 f_1}{\partial L_1 \partial K_1}}{\frac{\partial^2 f_1}{\partial L_1^2}} \tag{8}$$

Substituting expression (8A) into equation (12) we have:

$$\frac{\partial \alpha}{\partial L}\frac{\partial f_1}{\partial L_1}\frac{\frac{\partial^2 f_1}{\partial L_1 \partial K_1}}{\frac{\partial^2 f_1}{\partial L_1^2}}dK_1 - \frac{\partial^2 \alpha}{\partial L^2}f_1 dL = \frac{\partial \alpha}{\partial L}\frac{\partial f_1}{\partial K_1}dK_1 \tag{9}$$

Solving (9A) for dL/dK_1 we obtain:

$$\frac{dL}{dK_1} = \frac{\partial \alpha}{\partial L} / \frac{\partial^2 \alpha}{\partial L^2} f_1 \left[\frac{\partial f_1}{\partial L_1}\frac{\frac{\partial^2 f_1}{\partial L_1 \partial K_1}}{\frac{\partial^2 f_1}{\partial L_1^2}} - \frac{\partial f_1}{\partial K_1} \right] \tag{10}$$

We now substitute expressions (8A) and (10A) into expression (19). This yields after rearrangement:

$$\frac{\partial^2 \alpha}{\partial L^2}\frac{dz}{dK_1} = \left[\frac{\partial f_1}{\partial L_1}\frac{\frac{\partial^2 f_1}{\partial L_1 \partial K_1}}{\frac{\partial^2 f_1}{\partial L_1^2}} - \frac{\partial f_1}{\partial K_1} \right] \left[(\frac{\partial \alpha}{\partial L_1})^2 - \alpha \frac{\partial^2 \alpha}{\partial L_1^2} \right]. \tag{11}$$

Proposition 2(c) follows from expression (11A) because we have assumed that $\partial^2 \alpha / \partial L^2 > 0$ and the first term in the square brackets on the right hand side of expression (11A) is negative. Q.E.D.

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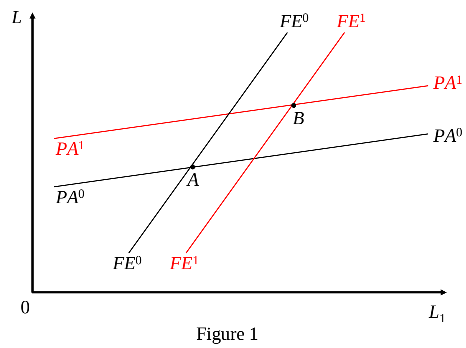

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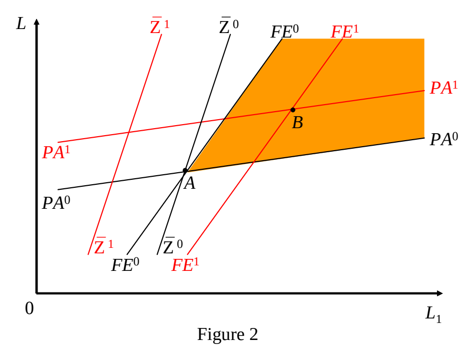

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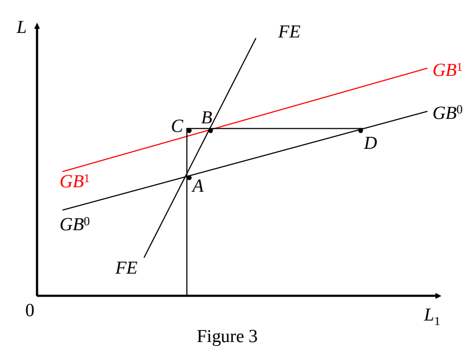

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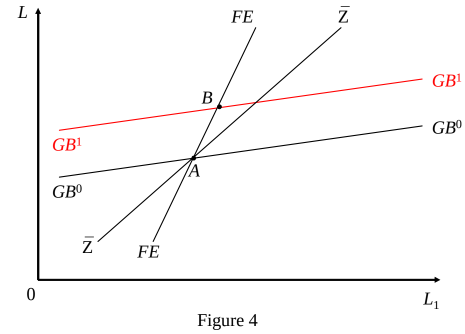

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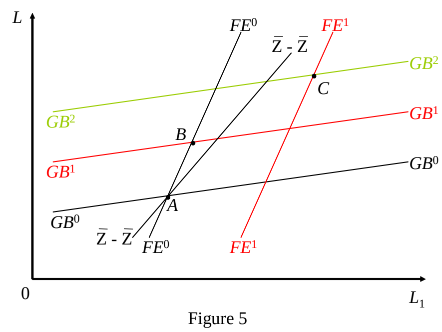

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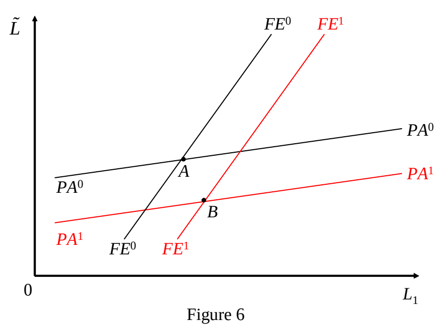

Figure 6: