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**TRANSFRONTIER POLLUTION AND GLOBAL
ENVIRONMENTAL MEDIA**

by
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The Kiel Institute of World Economics

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Transfrontier Pollution and Global Environmental Media

Horst Siebert*

Environmental allocation has important international implications. One aspect is the impact of environmental scarcity on competitiveness and trade (Siebert et al 1980). In this approach, among other issues such as environmental policy and the terms of trade or environmental policy as a device for protection (Siebert 1991), the repercussions of a country's environmental policy on the environmental quality of another country through the international division of labor are (will be?) studied. But countries may be interlinked more directly via environmental media, for instance through river systems or atmospheric media or they may use an international public good jointly. Then the issue arises how the economic decisions in one country affect environmental quality in the other country or the jointly-used public good. In this paper, transfrontier and global environmental issues are analyzed. The non-cooperative and cooperative solution of transfrontier pollution and global environmental media are discussed. Policy measures are reviewed.

Transfrontier pollution and global issues have the common feature that countries are directly linked to each other via environmental media. For analytical purpose it is worthwhile, however, to distinguish transfrontier pollution and global environmental systems (Siebert, 1985). Transfrontier pollution is characterized by a diffusion function T with environmental quality U^j in one region j being determined by emissions E^k not only of region j , but - via the diffusion function T - also by emissions of region i .

$$U^j = G (E^j, T(E^i)) \quad (1)$$

For instance, T may be uni-directional. In contrast, for an international public good k , the diffusion function cannot be explicitly defined. The

*Critical comments to this paper by Gernot Klepper and Ernst Mohr are appreciated. I owe figure 3 to Ernst Mohr.

international public good k is used in equal amounts by all, its quality being determined by emissions in j and i and we have

$$U^k = G (E^j, E^i) \quad (2)$$

Apparently, the international public good can be interpreted as a special case of transfrontier pollution¹⁾ where the diffusion function T is not explicitly considered. In order to give the problem more structure and to discuss different policy solutions for the two cases, it is worthwhile to explicitly distinguish the cases of transfrontier pollution and global environmental media.

1. Transfrontier Pollution

Transfrontier pollution represents an externality between countries and implies a distortion. The upstream or the upwind country sends pollutants via the environmental media to the downstream or downwind country. This implies a distortion. The polluting country reduces its ambient level of pollution by sending pollutants abroad, thus reducing the opportunity costs of environmental policy and increasing its comparative advantage for pollution-intensive activities. In the pollution-receiving country, the ambient level of pollution is increased and the comparative advantage of pollution-intensive activities is reduced. Thus, the distortion refers to environmental allocation as well as to sectoral structure.

Without a solution to transfrontier environmental problems, national environmental policy operates under the conditions of an international distortion. This has several implications. The opportunity costs of protecting the environment in the downstream or downwind country are too high. This limits the scope of environmental policy and reduces the optimal environmental quality strived for. Moreover, the obstacles to environmental policy may be increased by pointing to transfrontier pollution; environmental policy has to find its reason in being the forerunner for other countries, as in the German case, hoping for an international demonstration effect and for other countries to follow.

The Non-cooperative Solution to Transfrontier Pollution

In the non-cooperative solution each country maximizes its utility (or minimizes its costs) separately; the upstream country does not take into account transfrontier pollution. Note that the two countries are interpreted as separate units with their own preference functions and their own abatement functions. The countries are linked via transfrontier pollution. Let environmental damage depend on pollutants ambient in the environment with S_o^1 denoting gross emissions before diffusion and abatement, T pollutants transferred from region 2 to region 1, S_r^1 pollutants abated and C^1 costs of abatement. Then, the upstream country 2 minimizes its total cost

$$\text{Min } G^2(S_o^2 - T(S_r^2) - S_r^2) + C^2(S_r^2). \quad (3)$$

It is assumed that the initial levels of pollution, S_o^1 and S_o^2 , are given²⁾ with the transfer of pollutants not being considered, the optimality condition requires

$$\frac{dG^2}{dS_r^2} = \frac{dC^2}{dS_r^2} \quad (4)$$

The downstream country minimizes

$$\text{Min } G^1(S_o^1 + T(S_r^2) - S_r^1) + C^1(S_r^1) \quad (5)$$

where pollutants ambient in the environment of region 1 are influenced by transfrontier pollution. Optimality requires

$$\frac{dG^1}{dS_r^1} (S_o^1 + T(S_r^2) - S_r^1) = \frac{dC^1}{dS_r^1} \quad (6)$$

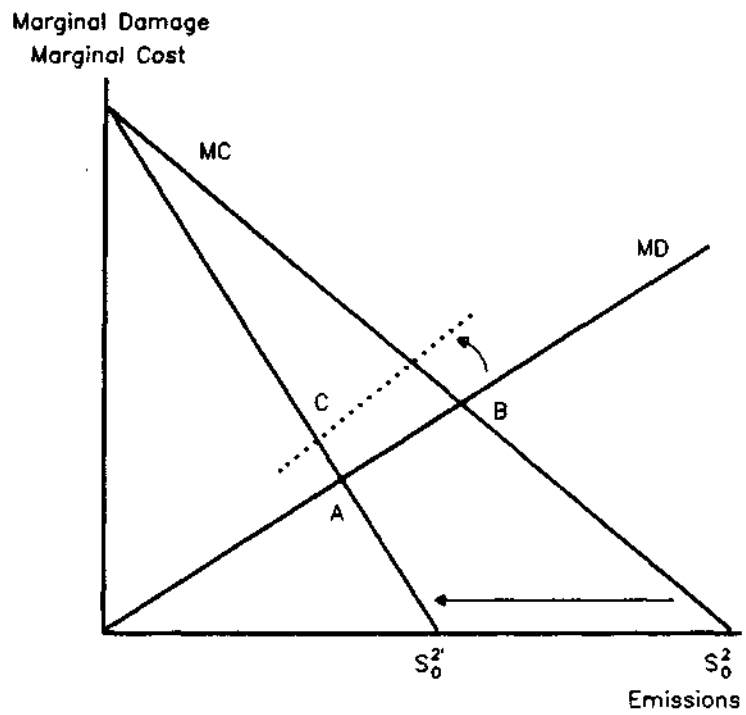
The optimality conditions 4 and 6 mean that prevented marginal damage is equal to marginal cost of abatement. In a non-cooperative solution with each country optimizing separately, the optimality condition implies that the upstream country considers pollutants transferred abroad as a substitute for abatement. Consequently, its incentive to abate is relatively low as shown by point A in figure 1. For the upstream country,

the transfer of pollutants $S_o^2 S_o^{2'}$ can be interpreted as a leftward shift in the abatement function. If country 2 abstains from abatement, i.e. if $S_r^2 = 0$, diffusion depends on the initial level of pollution $T = T(S_o^2)$. Abatement reduces the concentration of the pollutant in the ambient and hence transfrontier diffusion declines ($dT/dS_r^2 < 0$). If all emissions are abated, such as under the application of a perfect filter system, there is no diffusion across borders. It can be argued that pollutants transferred abroad are proportional to pollutants ambient and, consequently, of pollutants abated. Therefore, the marginal cost curve in the reference case of abatement and in the case of transfrontier pollution intersect on the cost axis. Comparing the two marginal cost curves for country 2 in figure 1 an international transfer of pollutants can be interpreted as a costless reduction in the initial level of pollution.

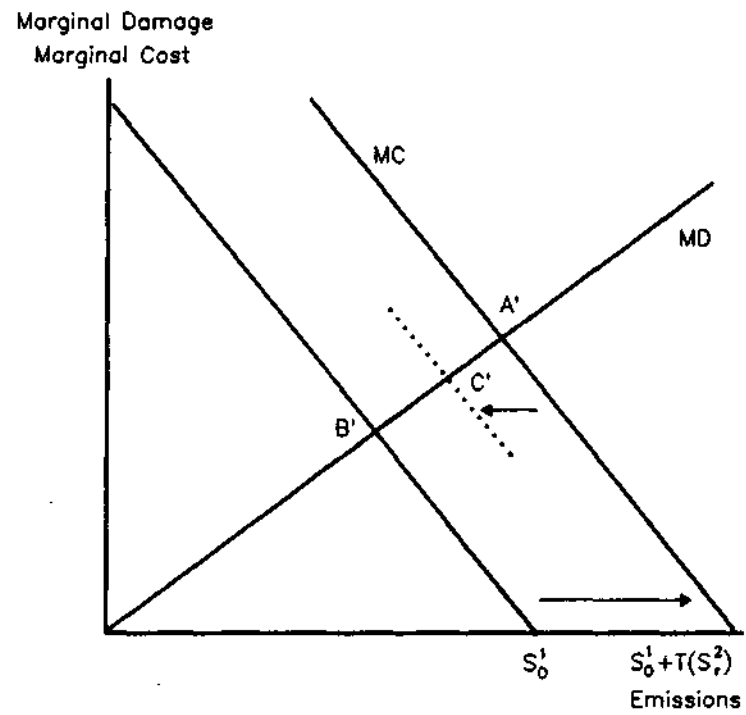
For the downstream country, however, the import of pollutants via environmental media increases the "initial" level of pollution and shifts the cost curve to the right. Optimal abatement is at point A' in figure 1.

An alternative illustration with reaction functions is shown in the $S_r^1 - S_r^2$ - space in figure 2. Equations 4 and 6 implicitly define the reaction functions of the two countries. For the downstream country, 1, there is an implicit relation $R^1(S_r^2)$ between emissions abated in country 2 and in country 1. The slope is negative. This can be seen from figure 1. The less country 2 abates, the more the marginal cost curve of country 1 shifts to the right. As the marginal damage is increasing in emissions (concentration), country 1 will react with an increase in its abatement efforts.

I_o^1 and I^1 are indifference curves of country 1. These indifference curves must have an extremum on the reaction function R^1 by the definition of the reaction function. A departure from the reaction curve R^1 violates optimality. Indifference curves further to the north represent higher utility levels for country 1 as for given S_r^1 higher abatement activities in country 2 imply a smaller import of pollutants into country 1.



Upstream Country 2



Downstream Country 1

Figure 1. Transfrontier Pollution

For the upstream country 2, pollutants in the other country do not influence the level of abatement. Its reaction function R^2 is independent of the abatement level in country 1. Note that R^2 is also an indifference curve of country 2 when the transfer of pollutants is not explicitly taken into account. Other indifference curves of country 2, not depicted in figure 2, are parallel to R^2 . An indifference curve further away (both north and south) indicates lower utility levels.

The non-cooperative solution is given by the intersection of the reaction functions in point A of figure 2. It follows straightforwardly from figure 2 that the non-cooperative solution in the transfrontier case does not represent a situation in which one or both of the countries has an incentive to change its position. In point A, country 1's indifference

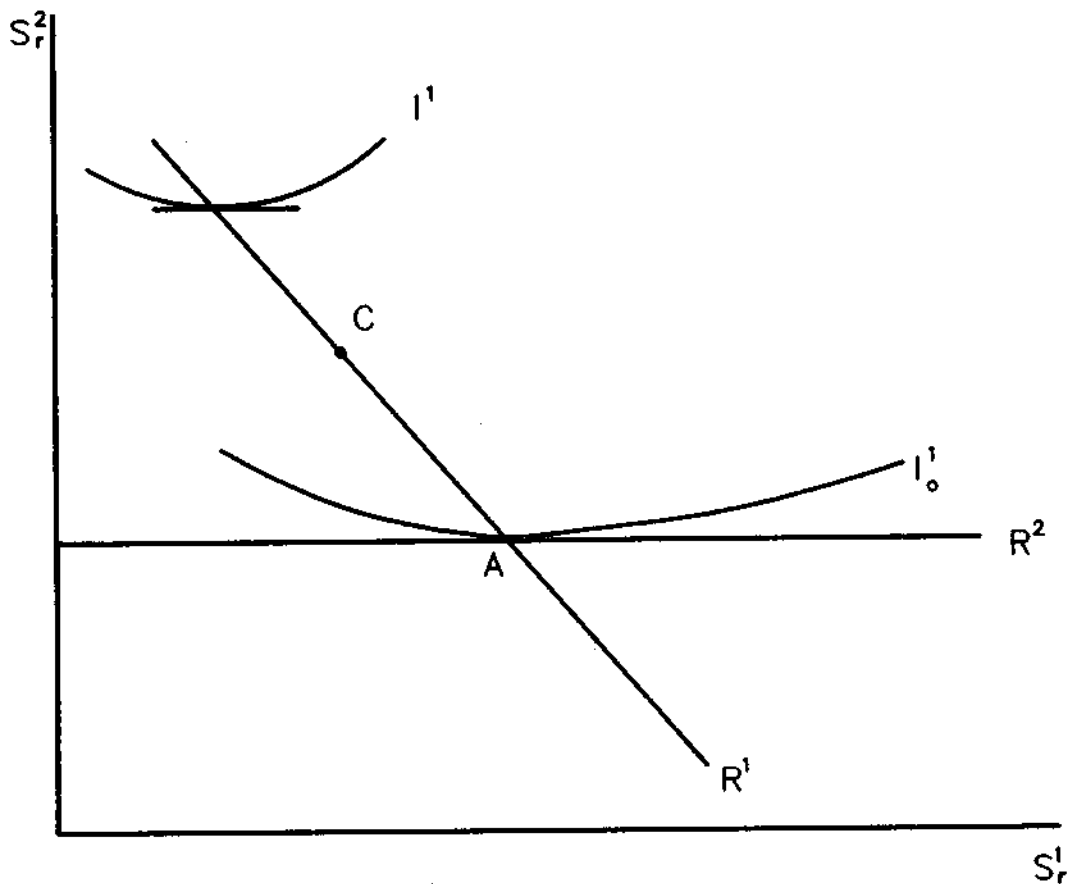


Figure 2. Non-Cooperative and Cooperative Solution of Transfrontier Pollution

curve I_0^1 is tangent to country 2's indifference curve R^2 . Intuitively, any isolated change in abatement efforts of country 1 would necessarily worsen the utility of the downstream country and any isolated or coordinated change in abatement efforts of the upstream country would necessarily worsen that country's utility. A Pareto-improving reallocation of abatement activities is therefore impossible under the given conditions. Nevertheless, there is scope for improvement if the institutional arrangement changes.

The Cooperative Solution in Transfrontier Pollution

If we allow side payments, at least one country can reach a higher utility level. In a cooperative solution both countries optimize jointly. Such payments then redistribute the increase in utility (Kuhl 1987, Mohr 1990). Joint minimization of costs³⁾

$$\text{Min } G^1(s_o^1 + T(s_r^2) - s_r^1) + G^2(s_o^2 - T(s_r^2) - s_r^2) + C^1(s_r^1) + C^2(s_r^2) \quad (7)$$

yields⁴⁾

$$-\frac{dG^1}{ds_r^1} = \frac{dC^1}{ds_r^1} \quad (8)$$

$$-\frac{dG^1}{ds_r^2} - \frac{dG^2}{ds_r^2} = \frac{dC^2}{ds_r^2} \quad (9)$$

As before, abatement in the downstream country 1 benefits only that country. Hence, as before, joint cost minimization requires that the downstream country's marginal abatement equals its marginal damage costs (equation 8).

However, contrary to the non-cooperative case, under joint cost minimization it is taken into account that abatement in the upstream country benefits both. Joint cost minimization therefore requires that marginal abatement cost equals the sum of marginal damage costs in both countries (equation 9). Taken together, equations 8 and 9 imply that

under joint cost minimization marginal abatement costs in the downstream country must necessarily be larger than those upstream. This need not surprise in the face of the downstream "windfall" associated with upstream abatement.

Comparing equations 4 and 9 and taking into account that $dG^1/dS_F^2 < 0$, it follows that under joint cost minimization the abatement effort upstream exceeds that under the non-cooperative solution. Hence in figure 2 the joint cost minimum is located above R^2 . Furthermore, the joint cost minimum must be located on R^1 as R^1 represents the optimality condition 6 which is identical to 8. In figure 2 joint cost minimization is located in a point like C. Hence, compared to the non-cooperative solution A it requires greater abatement efforts upstream and smaller efforts downstream. In figure 1, the marginal damage curve of the upstream country shifts upward because the negative impact of transfrontier pollution on the downstream country is taken into account. Relative to A, more pollutants are abated (point C). In the downstream country 1, pollution to be abated is reduced.

Side Payments

An immediate question arises as to how this cost-reducing reallocation can be brought about. After all, we know that any movement from A in the direction of C by a pure reallocation of efforts reduces utility in the upstream country. The answer to this is "side payments". The role of side payments can be illustrated in figure 3 (Kuhl 1987).

Costs associated with the non-cooperative solution A in figure 2 are represented by the origin in figure 3. A movement along R^1 in the upward-left direction in figure 2 corresponds to a movement from A in the direction of K in figure 3. Such a movement reduces costs to country 1 but increases costs to country 2. Note that contrary to the case of a global environmental good there is no lense of mutual advantages for both countries in figure 3 (compare figure 5).

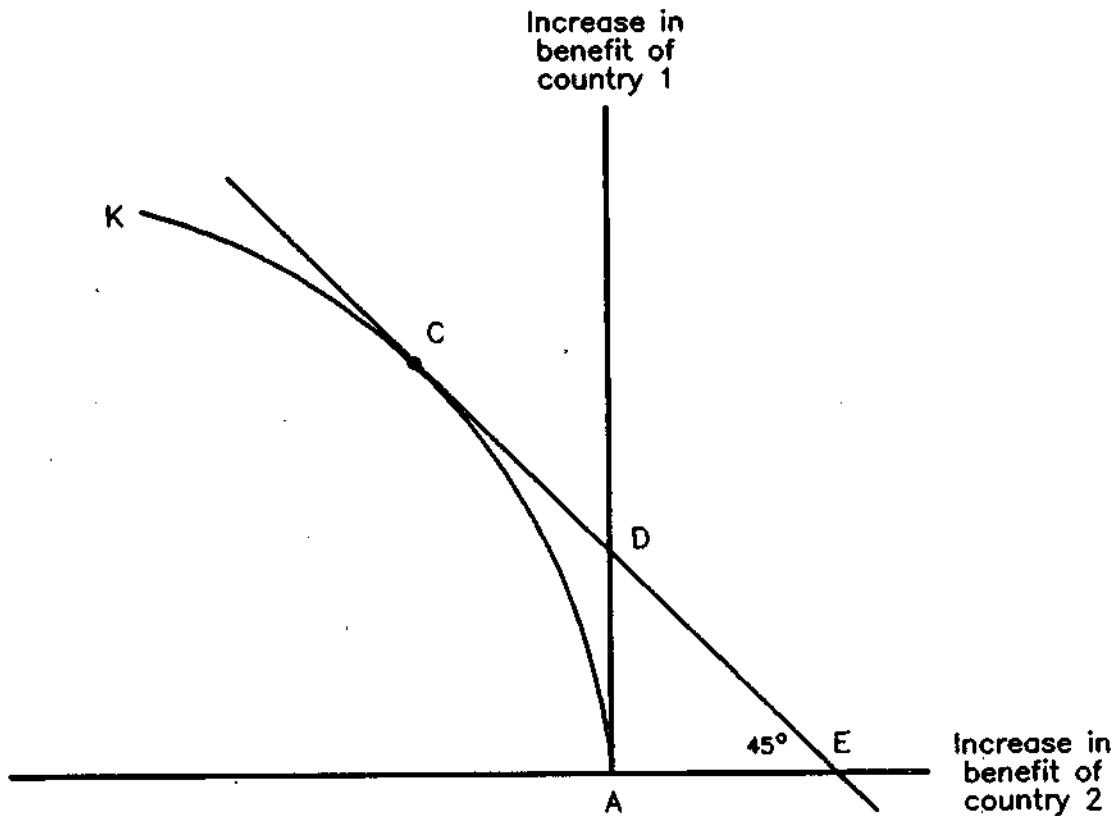


Figure 3. Reallocation of Abatement Efforts and Side Payments

Side payments from 1 to 2 can be represented by a line with slope -1 starting on the curve A-K in figure 3. For example, suppose actual abatement is represented by C in figure 3. Without side payments costs would be represented by C, too. Obviously such an agreement on cost minimization could never materialize as 2 loses compared to non-cooperation in A. This disincentive to cooperate can be mitigated by side payments from 1 to 2, separating the location which represents actual abatement costs from the costs (gains) associated with cooperation. While abatement costs still remain in C, the gains of cooperation are represented by points on the line through C in the direction of E. Larger side payments are represented by points on the line C - E closer to E.

Interestingly, there is a range of side payments for which both countries can gain. In D, cooperation benefits only the downstream country while higher abatement costs upstream are exactly set off by the side payments

country 2 receives. In E, only country 2 gains while the side payments that country 1 pays exactly set off its gains from lower environmental costs. In between D and E both benefit from cooperation.

Joint cost minimization is represented by C in figure 3, at the tangential point of the utility transformation line and the cost reduction function. Cost minimization is optimal under side payments for a simple reason. It maximizes the cake generated by cooperation in a first step. This "largest-sized" cake can then, in a second step, be distributed amongst the parties.

The Bargaining Approach to Transfrontier Pollution

While the use of side payments in a cooperative solution uniquely determines the abatement efforts of the parties to an agreement (point C in figure 3), the distribution of gains remains only vaguely determined (between D and E). This non-uniqueness can be resolved by applying particular cooperative solution concepts or by investigating the negotiation process which brings about cooperation. Whatever the solution concept or the particular bargaining situation, any solution to the cooperation problem is constrained by the outside opportunities of the parties. In terms of figure 3, these outside opportunities are represented by a recourse to non-cooperative behavior in A. These outside opportunities are represented in the solution space to the distribution problem by points D and E which act as threat points in the negotiations between the two countries. The voluntary nature of international environmental agreements guarantees that the solution will be located somewhere on or in between these limiting points of the bargaining solution.

In the bargaining process between autonomous countries, we meet all the problems of environmental policy "in nuce". The environmental media are used as common property resources, consequently the downwind region has no property title to force in the polluting area to abate pollutants; it is not possible to exclude the polluting area from using the environment as a receptacle of waste. The polluting area can behave as a free rider.

Without clearly defined property rights, both countries have to determine the tolerable level of pollution in a bargaining process.

In a scenario with a one-directional spillover and in which the upwind country uses the environment as a free good bargaining implies that both countries can only benefit if the pollutee compensates the polluter to reduce pollution in the upwind country (victim-pays-principle). Thus, a side payment is necessary. When bargaining costs are neglected, a solution of the game according to equation 8 and 9 can be found. This bargaining result represents a Coase solution (1960) and a Nash solution (1950) in a cooperative game.

A Nash equilibrium requires that the solution cannot be improved to the advantage of both regions. This implies individual rationality, i.e. the solution must be at least as favorable as the initial situation for each participant. When spillovers are multi-directional, each region has a threat potential irrespective of compensation.

The bargaining situation is often characterized by information asymmetries. In the bargaining process, the polluter will exaggerate the costs of pollution abatement in order to reduce the demands of the other country. Similarly, it is expected that the victim will exaggerate the extent of the incurred damages, in order to maximize the assessment of corrective measures needed. In order to avoid this deliberate falsification of information about the damages and costs of the respective abatement, the reciprocal-compensation principle has been proposed (OECD 1973). It has been suggested that an international fund be established to which the polluting country would pay according to its assessment of the damages and victimized land would pay according to its assessment of the costs of abatement. This approach is designed to guarantee that the factors determining the emission tax are set as realistically as possible. The funds collected from the two parties would then be redistributed to them for the implementation of the environmental-protection measures. It is essential that the countries do not know the rate by which the tax receipts will be redistributed because this information would distort their estimates of the costs and damages.

Policy Instruments for Transfrontier Pollution

The solution to the transfrontier pollution problem requires some commitment of national governments to an international agreement. This commitment may include ceding national sovereignty in the area of environmental policy to an international agency, cost-sharing rules, agreeing on diffusion norms or uniform reductions in national emissions. In the sense of a causal therapy, a solution should explicitly address the quantities transmitted, i.e. $T(E^i)$ in equation 1. Practical solutions may affect the quantities transmitted only in an indirect way.

Cost Sharing. In such a transfrontier agency, the costs of pollution abatement could be shared by the countries involved. The costs of attaining and maintaining an acceptable level of quality in the transfrontier environmental medium would be added and distributed among the countries according to a set rate. Once again, many problems arise with this proposal. Since costs are determined by the desired level of environmental quality, how much environmental quality should be strived for? By what criteria can abatement costs be attributed to different countries? (See reciprocal compensation procedure.)

A transfrontier agency defined according to the boundaries of a river system should be clearly distinguished from an approach in which emissions in the two countries are controlled in general. Reducing the general level of emissions in a two-country system only affects transfrontier pollution indirectly and does not solve the basic reason of distortion. By cutting the level of pollution in the country of origin, the externality is reduced in importance, but it continues to exist.

Transferable Discharge Permits. If a transfrontier environmental system can be clearly delineated, marketable discharge systems may be used for the transfrontier system. It then can be left to the market to find the price for emissions. In most cases, however, the approach of marketable discharge permits requires an explicit account of diffusion in order to determine the price of a unit of pollutants at different points in space.

Using transferable discharge permits for the two-country system and thus limiting the total quantity of emissions in two countries is not the appropriate approach to solve the transfrontier pollution issue because it only reduces the general level of pollution in the two-country system, but does not solve the transfrontier distortion. The same argument applies to uniform emission reductions in all countries by a given percentage.

Transfrontier Diffusion Norms. A transfrontier diffusion norm defines the ambient level of pollution of an environmental medium at the border, for instance of a tributary to a river or of air quality at the border. Such diffusion norms have been used in national water management.

A transfrontier diffusion norm allows a decentralized approach to environmental policy in the countries involved. The upstream or upwind country having agreed on a diffusion norm, probably not without a side payment, will internalize the costs of transfrontier pollution to the individual polluters. In such an approach, it can be left to the individual countries by which policy instruments they make sure that the diffusion norm is not violated, and emission tax sales may very well differ between countries. Transfrontier diffusion norms could be instrumental in implementing the polluter-pays-principle for the individual polluter, albeit not for the polluting country possibly receiving a side payment.

International Liability Rules. Making countries liable for the damages caused by transfrontier pollution would also permit decentralizing environmental policy among countries. The upstream or upwind country then would anticipate the compensation it would have to pay. This would imply an internalization of environmental costs arising in the downstream country.

Liability rules, however, imply high transaction costs, more specifically time-consuming debates in the international court system. Consequently, liability rules do not represent a dominant solution to transfrontier pollution.

Positive International Spillovers as a Special Case: The Equatorial Rain Forest

Whereas in the case of transfrontier pollution we have negative externalities between countries, there are also positive spillovers. A case in point is the equatorial rain forest. The equatorial rain forest in Brazil and in other countries has a positive value in absorbing CO₂, producing oxygen and allowing biodiversity. Cutting down the rain forest would represent a negative externality to other countries.

Similarly, as side payments are required in a solution to reduce transfrontier pollution, one can argue for side payments to the countries with a rain forest to induce them not to destroy it. For the bargaining, however, one difference with the case of transfrontier pollution must be stressed. It might very well be that it is in the long-run interest of the rain forest country to maintain the forest for its own advantages including tourism in the future and that the country has not been aware of its own interests. A major issue is monitoring. An international agreement on the protection of the rain forest can be interpreted as a principal-agent problem where the international community is the principal and the rain forest country is the agent.

2. Global Environmental Media

In the case of global environmental media, two or more countries jointly use the environmental system as a public good, and diffusion processes are not too important. Examples are the ozone layer and the global warming of the atmosphere. In principle, each country can take the free rider position, hoping that the other countries will care for the public good.

In addition to the free rider position other features complicate the solution to the problem:

- Countries or their people may have different preferences with respect to global environment media and they may have different risk attitudes.

- Even assuming identical preferences and risk attitudes, the income per head varies considerably among the countries of the world; this implies a different evaluation of the global environment.
- Although global environmental problems can be interpreted as a public good for humanity, countries may be affected differently if the public good changes. This indicates that in spite of Samuelson's definition (1954) that the public good "is used in equal amounts by all" the user intensity varies for countries. For instance, global warming and the resulting melting of the ice caps would negatively affect the low lands of the earth such as Bangla Desh and the Netherlands.

The Non-cooperative Solution to Global Media

In contrast to the transfrontier problem, the damage prevented for a specific country i now depends on reductions of emissions in country i and j $G^i(S_r^j + S_r^i)$ or more explicitly $G^i(S_o^i + S_o^j - S_r^i - S_r^j)$, whereas costs of abatement are country specific $C^i(S_r^i)$.

Each country minimizes its total cost⁵⁾

$$\text{Min } G^i(S_r^i + S_r^j) - C_r^i \quad (10)$$

yielding the optimality conditions

$$- \frac{dG^1}{dS_r^1} (S_r^1 + S_r^2) = \frac{dC^1}{dS_r^1} \quad (11)$$

and

$$- \frac{dG^2}{dS_r^2} (S_r^1 + S_r^2) = \frac{dC^2}{dS_r^2} \quad (12)$$

In the non-cooperative solution, each country abates pollutants up to the point where its marginal benefit is equal to its cost of abatement. In figure 4 these optimal points of the non-cooperative solution are

illustrated by A^1 and A^2 respectively. In figure 4, OS_o^1 is the quantity of emissions contributed to the global public good by country 1; likewise OS_o^2 for country 2. OS_o is the total quantity of emissions by both countries. Abatement in the non-cooperative solution by country 1 (S_o^1D) and country 2 (S_o^2E) add up to S_oA .

Equations 9 and 10 implicitly define the reaction functions $R^1(S_r^2)$ and $R^2(S_r^1)$ of both countries. In figure 5, the reaction functions are shown in the $S_1^r - S_2^r$ -space. A is the solution to the non-cooperative game.

The Cooperative Solution to Global Media

As in transfrontier pollution, the non-cooperative solution can be improved. This is indicated by the lense formed by the indifference curves I^1 and I^2 . Thus, there is room for improvement for at least one of the countries.

In a cooperative solution, side payments allow to reach a more efficient solution. In a joint optimization problem, total costs for both countries are minimized. The problem is stated as follows

$$\text{Min } G^1(S_r^1+S_r^2)+G^2(S_r^1+S_r^2)+C^1(S_r^1)+C^2(S_r^2) \quad (13)$$

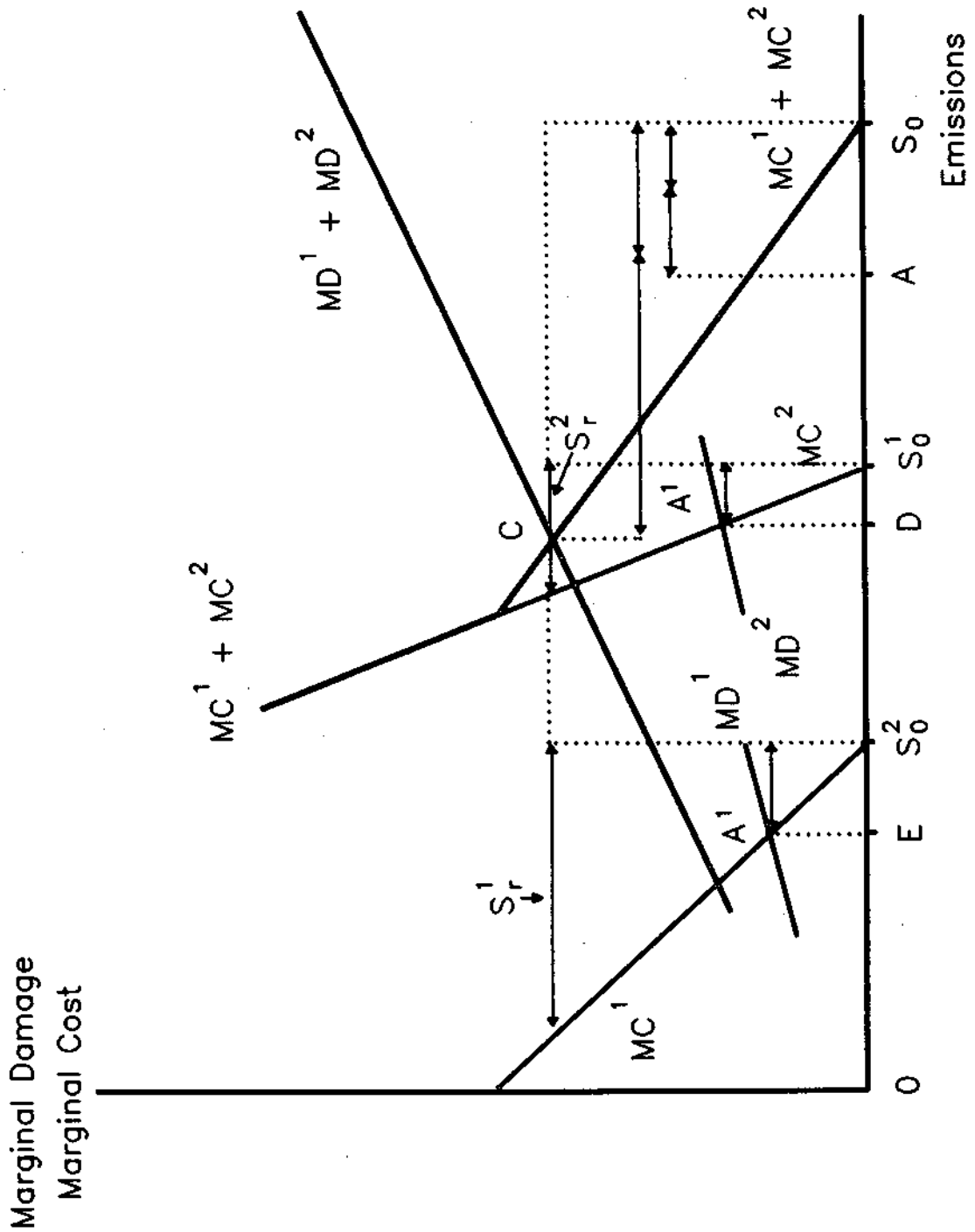
The optimal solution requires

$$-\frac{dG^1}{dS_r^1}(S_r^1+S_r^2) - \frac{dG^2}{dS_r^2}(S_r^1+S_r^2) = \frac{dC^1}{dS_r^1} = \frac{dC^2}{dS_r^2} \quad (14)$$

Joint maximization requires that the aggregated prevented marginal damage is equal to the marginal cost of abatement in country 1 which again must be equal to the marginal cost of abatement in country 2. The equality in the marginal cost of abatement implies efficiency in abatement. The condition that the sum of marginal prevented damage is equal to the marginal cost of abatement is Samuelson's summation condition for the optimal provision of public goods. This implies the vertical addition of the willingness to pay. For joint maximization the optimal supply is

given by point C in figure 4 (where the (vertically) aggregated willingness to pay, i.e. the aggregated marginal prevented damage ($MD^1 + MD^2$), and the (horizontally) aggregated cost function ($MC^1 + MC^2$) intersect).

Figure 4. Global Environmental Media



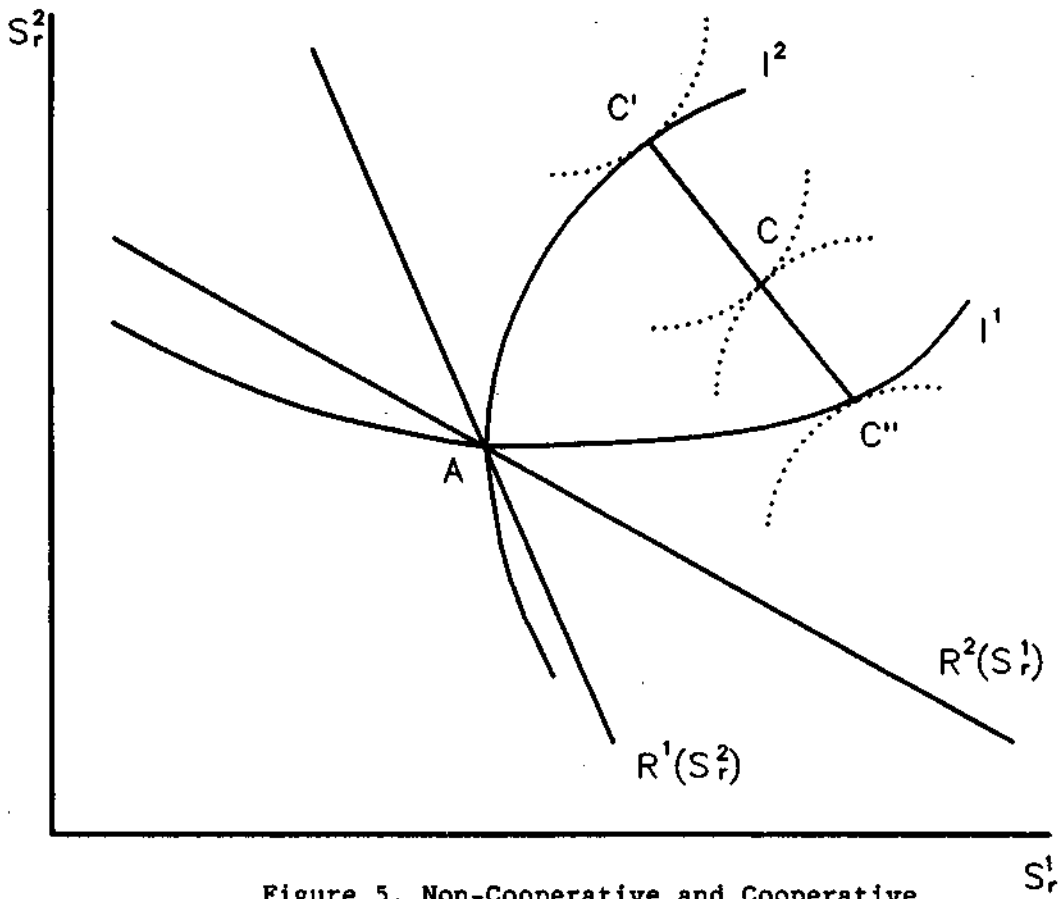


Figure 5. Non-Cooperative and Cooperative Solution for Global Environmental Media

In figure 5, the cooperative solution lies on a line $C''C'C'$ where the indifference curves of the two countries are tangent to each other. Point C is a possible Pareto optimal solution. Any point in the lense $I^1 - I^2$ represents an improvement relative to point A . The set of points in the lense is given by the points on and under the curve $C''C'C'$ in figure 6. The curve $C''C'C'$ denotes possible improvement in the welfare of both countries without side payments. If side payments along the 45° line DE are arranged, total welfare of both countries may be increased. Figure 6 depicting the cooperative solution in the case of a global good can be compared with the cooperative solution in the case of transfrontier pollution (figure 3).

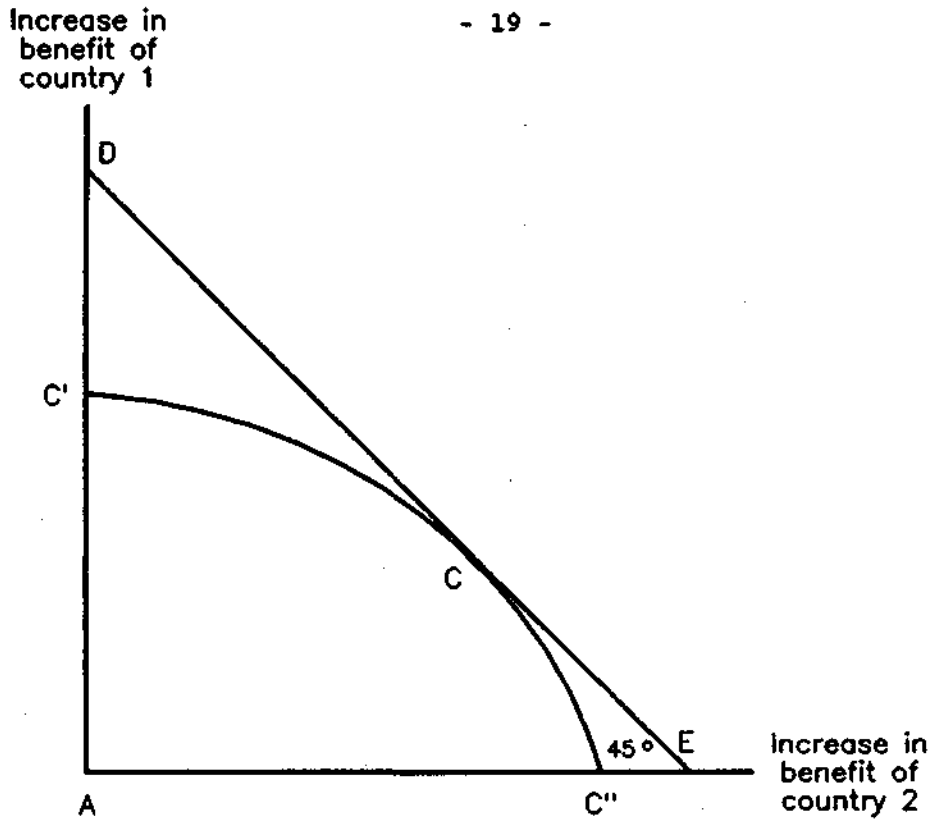


Figure 6. Welfare Improvements
in the Cooperative Solution

Transferable Discharge Permits

A solution to global environmental issues consists in agreeing on a limit for the total quantity of emissions and then allocating the tolerable level of emissions to the individual countries. In contrast to the transfrontier pollution problem, now the total quantity of emissions is the decisive variable in the sense of a causal therapy.

Allocating the tolerable quantity of worldwide emissions by a uniform reduction rate of x-percent in each country is not efficient. Some countries may be able to reduce emissions at much lower costs. Moreover, uniform reduction rates do not protect against renegeing and thus endanger the stability of the institutional arrangement.

Transferable discharge permits prevent the inefficiency of uniform reduction schemes. They make sure that the reduction of emissions occurs in the most efficient country. This means that the costs of environmental

protection are minimized for a given target level of environmental protection. Moreover, global environmental media are especially suited for transferable discharge permits because diffusion problems ("hot spots") are not relevant. In figure 4, point C denotes the global environmental quality to be attained. A market for emissions rights will establish the price corresponding to point C.

Allocating the initial endowment with discharge permits according to the size of population may contribute to the stability of a worldwide system of discharge permits (Grubb 1989). A country like China would then receive a large share of global emission rights which it could sell to the other countries. The other countries might also lease the emission rights so that China may use them later. Allocating emission rights on a per head basis may be a mechanism that contributes to the stability of the institutional arrangement.

3. An International Order for the Environment

When international public goods are involved and when nations can behave as a free rider or strategically, an institutional arrangement is called for. Such an order defines the rules for the behavior of individual countries. Each country has to commit itself to these rules. In analytical structure, the problem is similar to the rules for multilateral trade. This institutional arrangement is intended to prevent strategic behavior of individual countries to improve its terms of trade. The world as a whole can benefit from a cooperative solution, both in the trade and in the environmental case. Some impetus is necessary to brake the deadlock of a prisoner's dilemma, for instance a hegemon in the trade case or, possibly, the pace setting of a country moving first in environmental policy. Moreover, the stability of the institutional arrangement poses a similar problem in the trade policy and in the environmental case. Over time, the national interest of a country may change; it may renege on the institutional arrangement which then becomes instable⁶⁾. Like any international agreement, institutional arrangements must therefore contain mechanisms that make them stable and prevent renegeing.

Notes:

1) In a formal sense, one can always find a function H so that $G(E^j, T(E^2)) = H(E^j, E^i)$.

2) Explicitly, the diffusion function is $T = T(S_r^2 - S_o^2)$.

3) For the case of a global public good without an explicit diffusion function compare Hoel 1990. For an explicit transfrontier model compare Kuhl 1987.

4) Equation 9 may also be written as

$$\frac{dG^2}{dS_r^2} + \frac{dG^2}{dT} \frac{dT}{dS_r^2} - \frac{dG^1}{dT} \frac{dT}{dS_r^2} = \frac{dC^2}{dS_r^2}$$

5) Compare Hoel (1990)

6) On the stability of investment contracts compare Thomas and Worrall (1990), Mohr (1990).

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