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# AN ECONOMIC ANALYSIS OF TRANSBOUNDARY AIR POLLUTION BETWEEN FINLAND AND THE SOVIET UNION

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ABSTRACT: This paper evaluates the net benefits to both parties of bilateral cooperation between Finland and the Soviet Union on reducing sulphur emissions. The analysis is based on a sulphur transportation model and on estimated abatement cost functions. t is shown that efficient cooperation may entail financial transfers from Finland to the Soviet Union because it is cheaper to abate suphur there. It is further demonstrated that the recently signed agreement aiming at reductions in air pollutants is not rational from the Soviet Union's viewpoint and may not, therefore, be carried out without monetary support from Finland.

Research on this topic was initiated while Pohjola was with the University of Helsinki and the Labour Institute for Economic Research and Tahvonen with the University of Helsinki. We are grateful to Ilkka Savolainen and Markus Tähtinen from the Technical Research Centre of Finland for providing us with unpublished data on sulphur abatement costs in Finland and the Soviet Union. Kaitala and Pohjola acknowledge financial support from the Yrjö Jahnsson Foundation.

# 1 Introduction

Acid rain is one of the major environmental concerns in Europe. Its primary sources are emissions of sulphur dioxide and nitrogen oxides. The former is emitted when fossil fuels are burnt, whereas the latter originate not only from nitrogen in fuel but also from nitrogen in air. In the atmosphere these oxides can be transported by the winds for distances ranging from 50 to 2000 kilometers. Ultimately, however, they are removed from the atmosphere by rain — wet deposition or acid rain — or by contact with plants and surface water — dry deposition. As a result, the acidity of the soil and surface water is increased. This damages forests, kills fish and spoils the ground water. Acid rain also damages man-made structures (like buildings) and can affect human health.

The use of the atmosphere as a dump for pollutants makes the environmental problem transnational. Emitting countries bear only a fraction of the costs in the form of harmful deposition, because considerable amounts of deposition can be transported by the winds to other nearby countries. A regional externality is thus created, and the conventional prediction is obtained that non-cooperation between the countries on environmental protection results in too high emissions evaluated from their collective viewpoint. The reason is that in balancing the marginal costs of abatement against the marginal damage from deposition each country takes into account the damage to its own environment without any regard to the consequences for the others (see, for example, Mäler 1990).

The incentives for cooperation among the countries concerned are strong, but which form should cooperation take? As there is no international body with the power to enforce a solution, environmental problems have to be solved by the concerned countries on a voluntary basis. But cooperation among a large number of countries is made difficult by the presence of the free-rider problem, i.e. by the fact that each country would gain by reneging on the cooperative agreement if all others adhered to it. Furthermore, as Mäler (1990) has demonstrated, cooperation may entail financial transfers between some of the countries because they are not in a symmetrical position. Some are more upwind than others, and the upwind countries may even lose from the cooperative reduction of emmissions if they are not compensated for the costs of required abatement measures.

Given the problems associated with efficient full-scale cooperation between the European countries affected by the acid rain, some nations have taken direct steps towards bilateral agreements on environmental protection. In the autumn of 1989 the governments of Finland and the Union of Soviet Socialist Republics signed an action plan for the purpose of limiting and reducing the deposition and harmful effects of air pollutants emanating from areas near their common border (Action Programme 1989). These areas include the whole territory of Finland and the following regions in the Soviet Union: Kola, Karelia, Leningrad and Estonia. The parties agreed that, in addition to active participation in international cooperation, they will reduce the total annual sulphur emissions by 50 per cent in these areas as soon as possible but by the end of 1995 at the latest. The reductions will be calculated on the basis of the 1980 levels. Nitrogen emissions were agreed to be reduced in such a way that after 1994 they will not exceed the 1987 levels. In 1993 the parties will agree on further reductions, the goal being not to exceed the critical loads, i.e. the amounts which do not considerably affect the environment.

This paper sets out to evaluate the net benefits to both parties of this kind of cooperation. Because of data problems, the analysis is confined to sulphur emissions. The next section presents a model describing the transportation of sulphur between Finland and the nearby areas of the Soviet Union. It relates the annual sulphur deposition in each country to emissions in both of them as well as in the third countries. Pollution costs are assumed to consist of two components: abatement costs and the monetary value of the damage from sulphur deposition. Abatement cost functions are obtained for the two regions from the estimates provided by the HAKOMA project at the Technical Research Centre of Finland, and the damage functions are estimated from actual emissions in the way suggested by Mäler (1990).

Section 3 is devoted to answering the question whether there exist more efficient forms of cooperation than the equal proportional reduction of the emissions by 50 per cent. The analysis is aimed at contributing to the timely debate in Finland on the need of providing the Soviet Union with financial or material support for investments in environmental protection in the nearby areas. This 'victim pays principle' seems to be receiving increasing support from politicians and environmentalists, although the official policy of the government adheres to the 'polluter pays principle' adopted by the OECD countries in 1972. But, interestingly enough, the goverment budget for the year 1990 contains a payment of FIM 30 million to Poland towards the costs of environmental investments with the promise of 60 million more for the period 1991-92.

Section 4 presents an alternative framework in which the countries are assumed to minimize abatement costs subject to constraints specifying upper limits on the deposition of sulphur in each country. Target-oriented environmental policy raises some interesting questions when considered in the context of transboundary air pollution. What are the benefits of cooperation if concerned countries aim at critical deposition levels knowing the transportation of sulphur? In the absence of cooperation each country reduces its own emissions so as to minimize abatement costs under its own deposition constraint and given the behaviour of the others. This generates equilibrium emission levels and associated abatement costs. Does the sum of these costs over the countries always exceed the minimum cost obtained under cooperation when total costs are minimized under joint pollution constraints? We analyze the general economic logic behind these problems and calculate whether there are potential benefits from cooperation between Finland and the Soviet Union in the case of abating sulphur emissions.

Section 5 concludes the paper.

# 2 The Model

Let $Q_i$ denote the annual deposition of sulphur in country $i$, $i = 1, 2$, country 1 being Finland and 'country' 2 the nearby areas (i.e. Kola, Karelia, Leningrad, Estonia) of the Soviet Union. It has three sources: the emission $E_i$ of sulphur in the home country, the emission $E_j$ in the other country and the emissions in third countries. Let the transportation matrix $A = (a_{ij})$ indicate how the emission in country $j$ is transported in the atmosphere for deposition in country $i$, and let $B_i$ be the corresponding deposition from emissions in the rest of the world. Then the transportation model can be expressed in vector notation as

$$Q = AE + B. \tag{1}$$

The parameters can be estimated from the sulphur budget between Finland and the Soviet Union for the year 1987. This budget has been constructed at the Finnish Meteorological Institute by Tuovinen, Kangas and Nordlund (1990) by applying the long-range sulphur transport model developed at the Western Meteorological Centre in Oslo. The parameters are as follows:

$$A = \begin{pmatrix} 0.321 & 0.061 \\ 0.080 & 0.316 \end{pmatrix}, \qquad B = \begin{pmatrix} 118 \\ 155 \end{pmatrix}. \tag{2}$$

Table 1 gives information about the depositions and emissions of sulphur in the two regions in the years 1980 and 1987. Both components of pollution are much higher in the nearby areas of the Soviet Union than in Finland. However, the trends are declining in both areas.

*Table 1:* Deposition ($Q$) and emission ($E$) of sulphur
( 1 000 tons per year)

| | | 1980 | 1987 |
|---|---|---|---|
| Finland | $Q_1$ | 262 | 210 |
| | $E_1$ | 292 | 162 |
| Nearby Soviet Union | $Q_2$ | 453 | 374 |
| | $E_2$ | 692 | 651 |

Source: Tuovinen 1990

Let us next consider the costs of air pollution. Following Mäler (1990), these can be thought of as having two components: the first is the cost of abating sulphur emissions, $C_i(E_i)$, and the second the damage, measured in monetary units, that sulphur deposition causes to the environment, $D_i(Q_i)$. The total costs to country $i$ can then be written as

$$J_i(E_i, E_j) = C_i(E_i) + D_i(Q_i). \tag{3}$$

Both components are assumed to be continuous, convex functions of their arguments. It is reasonable to regard $C_i(E_i)$ as decreasing in $E_i$, and $D_i(Q_i)$ as increasing in $Q_i$.

The cost function $C_i(E_i)$ is defined as the minimal cost envelope encompassing the entire range of sulphur abatement options for country $i$ in a given time period. The costs can be calculated for various sulphur reduction requirements ranging up to the maximal technologically feasible removal. The HAKOMA project at the Tehnical Research Centre of Finland has produced such national cost functions by applying an engineering approach in estimating the direct costs of sulphur reductions in both combustion processes in energy production and non-combustion processes in industries using inputs containing sulphur. The annual costs, measured in million Finnish marks, have been estimated on the basis of expected energy demands for the year 2 000, and they include both capital and operating costs. The former have been obtained by assuming that the plants are operated for 25 years and that the annual nominal interest rate is 5 per cent. Two main options to reduce emissions in energy production have been considered in constructing the cost functions. The first one is sulphur abatement through in-furnace lime injection and flue gas desulphurization. The second is switching to the use of low sulphur heavy fuel oils in combustion systems. In calculating costs for non-combustion processes industry-specific costs per abated amount of sulphur have been applied.

Here we use quadratic approximations of the piecewise linear functions, depicted in figures 1 and 2, with the assumption that only the parts decreasing in $E_i$ are relevant for the analysis. Let

$$C_i(E_i) = \alpha_i(\bar{E}_i - E_i) + \beta_i(\bar{E}_i - E_i)^2 + \gamma_i, \tag{4}$$

where $\bar{E}_i$ denotes the actual emissions in the base year, i.e. in 1987. The parameter

FIGURE 1. Abatement costs (the dashed curve) and the estimated cost function (the solid curve) for Finland

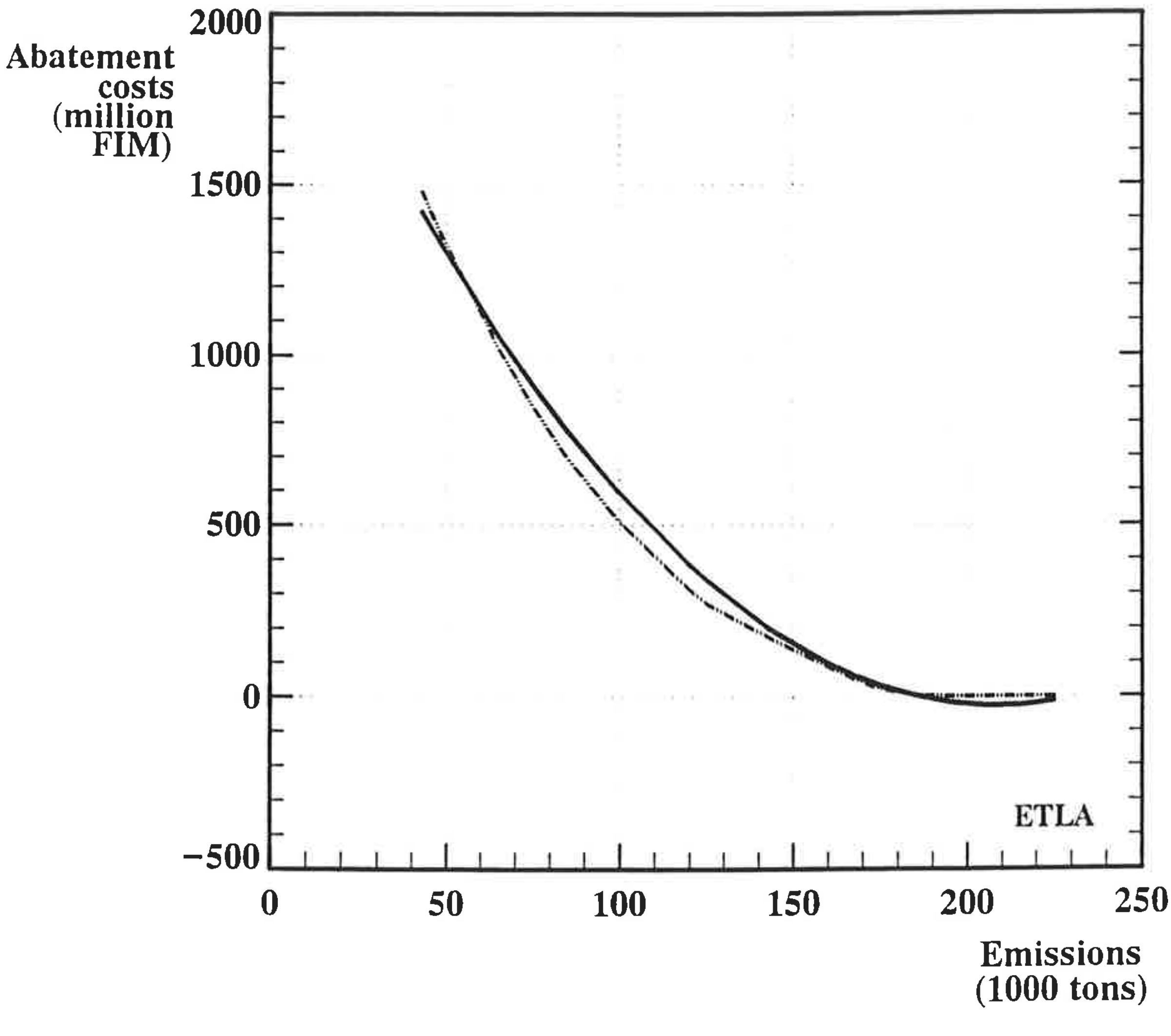
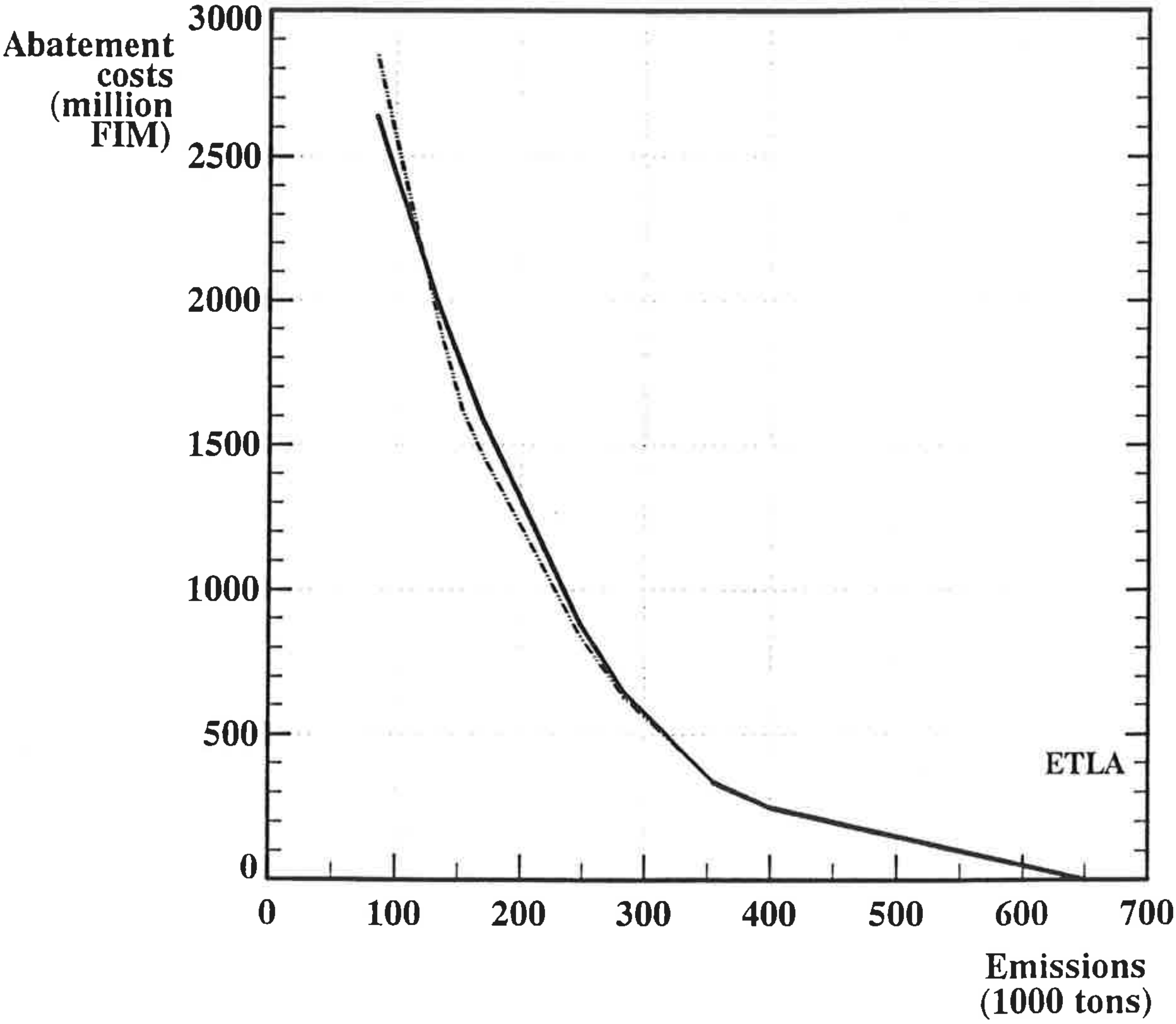


FIGURE 2. Abatement costs (the dashed curve) and the estimated cost function (the solid curve) for the nearby areas of the Soviet Union



$\alpha_i$ has been chosen to be equal to the estimated marginal costs at $\bar{E}_i$ and $\gamma_i$ to be equal to the respective total cost. $\beta_i$ is estimated by the ordinary least squares technique.

Table 2 presents the parameters of (4) for the two regions. Because the quadratic function approximates the Soviet costs rather poorly, it is here adjusted by making it consist of two components: first, of a linear segment describing the abatement costs for initial reductions of emissions from the 1987 level down to $E_2 = 399$ and, second, of a quadratic segment at $\bar{E}_2 = 399$ (see figure 2).

*Table 2:* Abatement cost function parameters (standard deviations in parentheses)

| | $\alpha_i$ | $\beta_i$ | $\gamma_i$ |
|---|---|---|---|
| Finland | 4.9 | 0.05312 (0.00166) | 86.9 |
| Nearby Soviet Union | | | |
| for $399 < E_2 \leq 651$: | 1.0 | 0.0 | 0.0 |
| for $0 < E_2 \leq 399$: | 1.0 | 0.02097 (0.00077) | 252 |

It is much harder to obtain information about the damage functions $D_i(Q_i)$. In principle, one could estimate the impacts of sulphur deposition on, say, the growth of forests and then assess the monetary value of the damage caused. Although interesting research is in progress on the effects of changing environmental factors on forest growth (Hari, Holmberg, Raunemaa and Nikinmaa 1990), the results are not yet in a form which can easily be subjected to an economic analysis (see, however, Kaitala, Pohjola and Tahvonen (1990) for some initial modelling experiments). Therefore, we here apply an indirect way, suggested by Mäler (1990), of estimating the damages resulting from sulphur deposition. The idea is a simple one: it is assumed that actual sulphur emissions are the results of rational choices by nations acting in isolation and, therefore, reveal to an outside observer the implicit cost resulting from sulphur deposition.

More specifically, suppose that the two regions, Finland and the nearby Soviet Union, act independently from each other in carrying out their environmental policies. Then, acting rationally, it is optimal for each country to allow sulphur emissions up to the amount at which the marginal abatement cost equals the marginal damage from further deposition in the own country, i.e. to the level at which

$$-C_i'(E_i) = a_{ii}D_i'(Q_i). \tag{5}$$

This condition is obtained by assuming that country $i$ minimizes its costs (3) subject to the transportation model (1) and a given level of emissions by the neighbouring country. Acting in isolation each country pays attention to the deposition of sulphur in its own region only — the marginal damage is multiplied by $a_{ii}$, the share of deposition originating from domestic sources.

The estimation of the damage function can be completed easily if we make the simplifying assumption that this function is linear, i.e.

$$D_i(Q_i) = \delta_i Q_i, \tag{6}$$

where $\delta_i$ is positive. The marginal conditions (5) then immediately provide estimates for the $\delta_i$'s if the observed emissions $(\bar{E}_1, \bar{E}_2)$ in 1987 are assumed to be the Nash equilibrium of the acid rain game. This procedure yields

$$\begin{aligned} \delta_i = \alpha_i / a_{ii} &= 15.265 \quad \text{for Finland,} \\ &= 3.165 \quad \text{for the nearby Soviet Union.} \end{aligned} \tag{7}$$

Note that the Soviet cost function has a kink at $\bar{E}_2 = 651$ if it is assumed that the abatement costs are zero for $E_2 > 651$. This causes the problem that $\delta_2$ is not uniquely determined by the procedure outlined above but $\delta_2 \in [0, 3.165]$. We have chosen the largest value as the basis of our calculations. This minimizes the differences between the countries in their valuations of the environment. Smaller values would not change our qualitative conclusions except in the unlikely case of $\delta_2$ close to zero.

Armed with these cost functions and the transportation model we can now turn to consider how the externalities created by the winds can be internalized through efficient environmental cooperation. The framework can also be applied in assessing the cost efficiency of the recently signed agreement between Finland and the Soviet Union.

# 3 Environmental cooperation

Suppose that the two countries want to make a collectively rational binding agreement on reducing sulphur emission. Such an agreement has to take into account the reciprocal externalities arising from the use of the athmosphere as a dump for air pollutants. A straightforward way of devising a contract is to assume that the parties maximize the total net gain from sulphur abatements, i.e. that they minimize the total cost

$$J(E_1, E_2) = J_1(E_1, E_2) + J_2(E_1, E_2) \tag{8}$$

with respect to both $E_1$ and $E_2$ and subject to the transportation model (1). This results in the first-order conditions

$$-C_i'(E_i) = a_{ii}D_i'(Q_i) + a_{ji}D_j'(Q_j) \tag{9}$$

for $i, j = 1, 2, i \neq j$. In balancing abatement costs against the damage from deposition in country $i$ it is now rational from the collective viewpoint to take into account the fact that the share $a_{ji}$ of $i$'s emissions is deposited in country $j$ resulting in an increase in damage costs at the rate $D_j'(Q_j)$. As the right-hand side of (9) is greater than that of equation (5) at $(\bar{E}_1, \bar{E}_2)$, cooperation calls for reductions in the emissions of both countries. Sulphur emissions in third countries are assumed to be unaffected by the Finnish-Soviet cooperation.

Given the data of equations (2) and (7) and of table 2 it is possible to derive the optimal cooperative solution $(E_1^*, E_2^*)$ from equations (9). These emission levels, the resulting depositions as well as the monetary benefits from cooperation are shown in table 3. The cooperative program requires emission reductions in Finland by 1.2 per cent. In the nearby areas of the Soviet Union emissions should be cut by 42.1 per cent. This asymmetry is explained by the marginal abatement costs. As table 2 reveals they are about 5 times greater in Finland than in the nearby Soviet

Union when evaluated at the 1987 emission levels. Another way of expressing this fact is that, given the rough symmetry of the transportation matrix (2), the marginal damage from sulphur deposition is regarded by the Finnish policy-makers to be about 5 times greater than the marginal damage cost as seen by the Soviet decision-makers. These views are quantified in the estimated $\delta_i$-parameters in equation (7).

*Table 3:* The consequences of and benefits from cooperation

| | Emissions $E_i^*$ | Emission reduction % | Depositions $Q_i^*$ | Deposition reduction % | Benefit (million Fmk/a) $J_i^* - \bar{J}_i$ |
|---|---|---|---|---|---|
| Finland | 160 | 1.2 | 192 | 8.6 | 259 |
| Soviet Union | 377 | 42.1 | 287 | 23.3 | - 9 |

As table 3 reveals, the Soviet Union loses from the Pareto-optimal environmental cooperation. The net benefit is negative by FIM 9 million a year. The total loss is 225 million over the 25 year period used in the abatement cost calculations. It is reasonable to expect that in order to sign the agreement the Soviet Union has to be compensated for at least the loss. This outcome is an example of the 'victim pays principle' and its explanation is very simple: given that the marginal costs of abating sulphur in Soviet Union are only about a fifth of those in Finland, it is optimal for Finland to use monetary compensation to induce its neighbour to invest in environmental protection.

The specified compensation is rather small because it is assumed that Finland has all the bargaining power and is thus able to keep all the total net gain of 250 million marks per year to herself. A more realistic assumption might be that of equal bargaining power, in which case the monetary net gain is split equally between the countries. In this case Finland should pay 134 million per year to the Soviet union. This amounts to 3.35 billion marks over the 25 year period.

It may be of some interest to enquire how closely the actual agreement between the two countries, signed in November 1989, approximates the Pareto-optimal solutions derived above. The parties agreed on the reduction of sulphur emissions by at least 50 per cent from the 1980 levels. Let us assume that these new limits will be realized and calculate the consequences for deposition and monetary costs. These are shown in table 4.

*Table 4:* An evaluation of the Finnish-Soviet agreement

| | Agreed emissions | Emission reduction % | Depositions | Deposition reduction % | Benefit (million Fmk/a) |
|---|---|---|---|---|---|
| Finland | 146 | 9.9 | 186 | 11.4 | 275 |
| Soviet Union | 346 | 46.9 | 276 | 26.2 | - 54 |

The agreement implies greater emission reductions in both areas than what is optimal according to our calculations. The total annual net benefit is 221 million marks, which is, however, quite close to the optimal sum of 250 million. The agreement seems to benefit Finland more than the Soviet Union. In fact, it seems that Finland had already in 1987 cut down her emissions by almost the required amount whereas not much had yet happened in the nearby Soviet Union. Our results raise the following conclusions. First, our estimates of the decision-makers' concerns for the environment, as reflected in the estimated marginal damage from sulphur deposition, may be too low. The public concern for the environment may have had an impact on the behaviour of the policy-makers which is reflected in the signed agreement but not yet in the observed emission levels. Second, but if our estimates are reasonable approximations of the true costs and preferences, then the signed agreement is not individually rational for the Soviet Union. This may have the consequence that the agreed emission reductions will not be carried out without monetary support from Finland.

Our conclusions can be criticized on the grounds that the countries may not have been as rational, selfish and non-cooperative as is assumed in the application of the revealed-preference approach to the estimation of the marginal damages from sulphur deposition. Other, more direct ways to assess the damages should, therefore, be used. In a recent paper, Newbery (1990) has done this by assessing the damage from acid rain to property, population and welfare (measured in terms of willingness to pay for reductions in pollution) in the context of European air pollution. From the viewpoint of our conclusions it is quite a relief to see that Newbery's results concerning optimal sulphur abatements in various European countries are not substantially different from Mäler's (1990) conclusions based on the revealed-preference approach.

However, the possible sensitivity of the conclusions to the estimated damage functions calls for other approaches to the problem of designing optimal environmental contracts. We shall next consider an alternative which is based on abatement cost minimization subject to constraints of sulphur deposition levels. This allows us to assess the cost effectiveness of various cooperative policies expressed in terms of target deposition levels without any need to estimate damage costs.

# 4 Abatement cost minimization under upper limits on pollution

Let us assume that the decision-makers are interested in minimizing sulphur abatement costs subject to constraints specifying acceptable pollution levels. This is usually the explicit form of environmental policy in many different contexts. The approach is often preferred to other alternatives, like the one considered in the previous section, because no explicit consideration has to be given to the difficult problem of evaluating environmental damages. It must, however, be noted that this method does not completely circumvent the valuation problem. The cost minimization procedure yields a shadow price for the maximum acceptable deposition level. Its value indicates the decision-maker's marginal valuation of environmental damages at the target level of pollution.

Critical pollution levels are explicitly mentioned in the Finnish - Soviet action plan. The parties have agreed that "they shall strive to reduce transboundary fluxes of air pollutants between the two countries so that the depositions, including those emanating from other European countries, shall not exceed the critical loads in areas near the common border" (Action Programme 1989). The aim of Finnish policy is to reduce annual sulphur deposition to a level not exceeding 0.5 grams per square meter.

We are here interested in comparing the optimal cooperative allocation of abatement activities between Finland and the Soviet Union to the allocation which will be attained if no cooperation takes place. Let $\hat{Q}_i$ denote the highest acceptable level of sulphur deposition in country $i$. Then the optimal emission levels in the two countries are found as the solution to the following joint cost minimization program: minimize with respect to $E_1$ and $E_2$ the total cost function

$$C(E_1, E_2) = C_1(E_1) + C_2(E_2) \tag{10}$$

subject to

$$\hat{Q} \geq AE + B \tag{11}$$

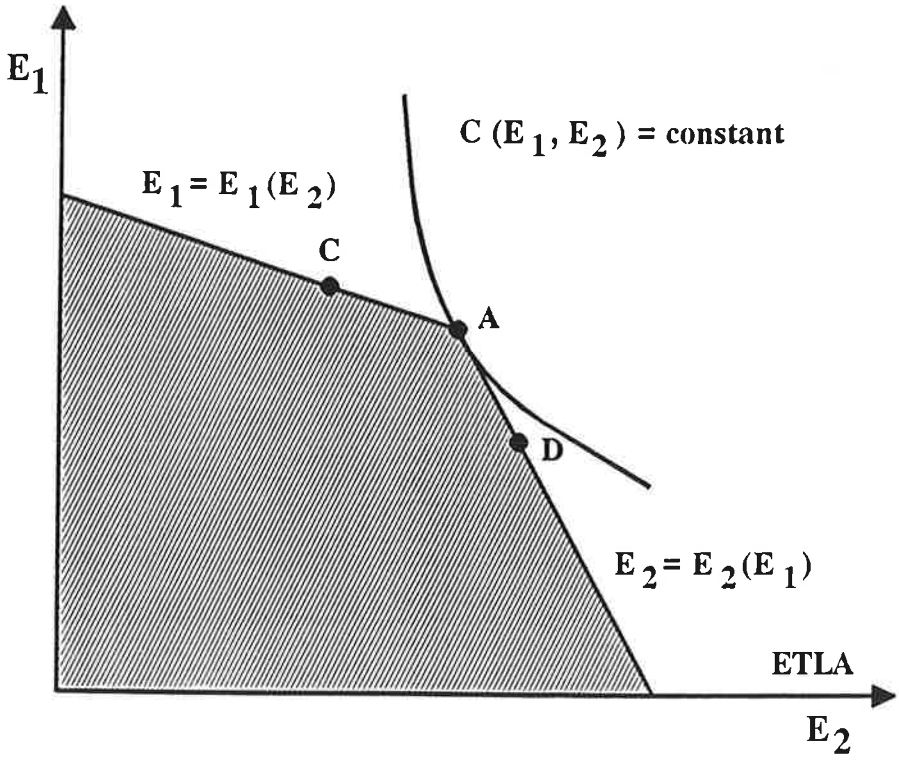
and

$$0 \leq E \leq E^{max}. \tag{12}$$

Here the country-specific cost functions and the sulphur transportation parameters are as specified in equations (4) and (2), respectively. The upper limits on admissible emissions are denoted by the vector $E^{max}$. These are taken to be those emission levels for which the abatement costs equal zero. For Finland we have $E_1^{max} = 186$ and for the nearby Soviet Union $E_2^{max} = 651$.

Let us study the solution of this programming problem graphically. Assume that emissions are lower than the maximum admissible levels and consider the constraint (11). The two inequalities define the region of feasible solutions given by the shaded area in figure 3. The line $E_1 = E_1(E_2)$ specifies the maximum emissions in Finland satisfying its deposition constraint for given emissions in the nearby Soviet Union. The slope of this line is $dE_1/dE_2 = -a_{12}/a_{11}$. The line $E_2 = E_2(E_1)$ is defined in an analogous way for the Soviet Union. Its slope $dE_1/dE_2$ is $-a_{22}/a_{21}$ in the figure. Because the cost functions are assumed to be convex, the isocost curves are convex and downward sloping. Abatement costs decrease when higher isocost curves are reached. The optimal solution is the point in the feasible region which lies on the highest isocost curve.

**FIGURE 3. Optimal sulphur abatement under pollution targets**



The intersection of the 'reaction' functions $E_1 = E_1(E_2)$ and $E_2 = E_2(E_1)$ is denoted by A in figure 3. This point will be reached when the two countries minimize in isolation, that is without any cooperation, their own sulphur abatement costs under upper limits $\hat{Q}_1$ and $\hat{Q}_2$, respectively, on pollution levels. Let $\hat{E}_1$ and $\hat{E}_2$ be the resulting emissions. It is interesting to see that under certain conditions these emissions may be the optimal solution to the cooperative problem defined in equations (10)-(12). This is the case when the slope of the isocost curve, going through A, of the joint cost function (10) is between the slopes of the reaction functions, i.e. when

$$-a_{22}/a_{21} \leq -C_2'(\hat{E}_2)/C_1'(\hat{E}_1) \leq -a_{12}/a_{11} \quad (13)$$

holds. A reallocation of the non-cooperative abatement activities is thus not optimal.

But if $-C_2'(\hat{E}_2)/C_1'(\hat{E}_1) < -a_{22}/a_{21}$ it is optimal from the collective viewpoint to move to a point like C in figure 3 by increasing emissions in the nearby Soviet Union and by decreasing in Finland. Exactly opposite reallocation would be required if it were the case that $-a_{12}/a_{11} < -C_2'(\hat{E}_2)/C_1'(\hat{E}_1)$. A point like B would be reached.

It can also happen that the reaction functions do not intersect. Suppose that one of the countries, say Finland, has so low a target for sulphur deposition that its entire reaction function $E_1 = E_1(E_2)$ lies to the left of the neighbour's function in figure 3. Then it is immediately clear that non-cooperation does not result in optimal emissions and, consequently, coordination is required.

Let us next investigate which one of these cases prevailed in the context of transboundary air pollution between Finland and the Soviet Union in 1987. Given the sulphur transportation coefficients of equation (2) and the cost function parameters of table 2, we have

$$-a_{22}/a_{21} = -3.950 < -C_2'(651)/C_1'(162) = -0.204 < -a_{12}/a_{11} = -0.190.$$

This means that it would not have been possible to attain the 1987 sulphur deposition levels with lower abatement costs by cooperatively reallocating the abatement activities. The conclusion may be somewhat surprising. Its explanations lies in the fact that only 6.1 per cent of sulphur emissions in the nearby Soviet Union are transported by the winds into deposition in Finland, whereas 32.1 per cent of Finnish emissions fall on its own territory. Consequently, the marginal abatement costs in Finland should have been over five times higher than in the Soviet Union for it to have been optimal to reallocate the emissions. According to the estimates of table 2, the ratio of the marginal costs was just below five.

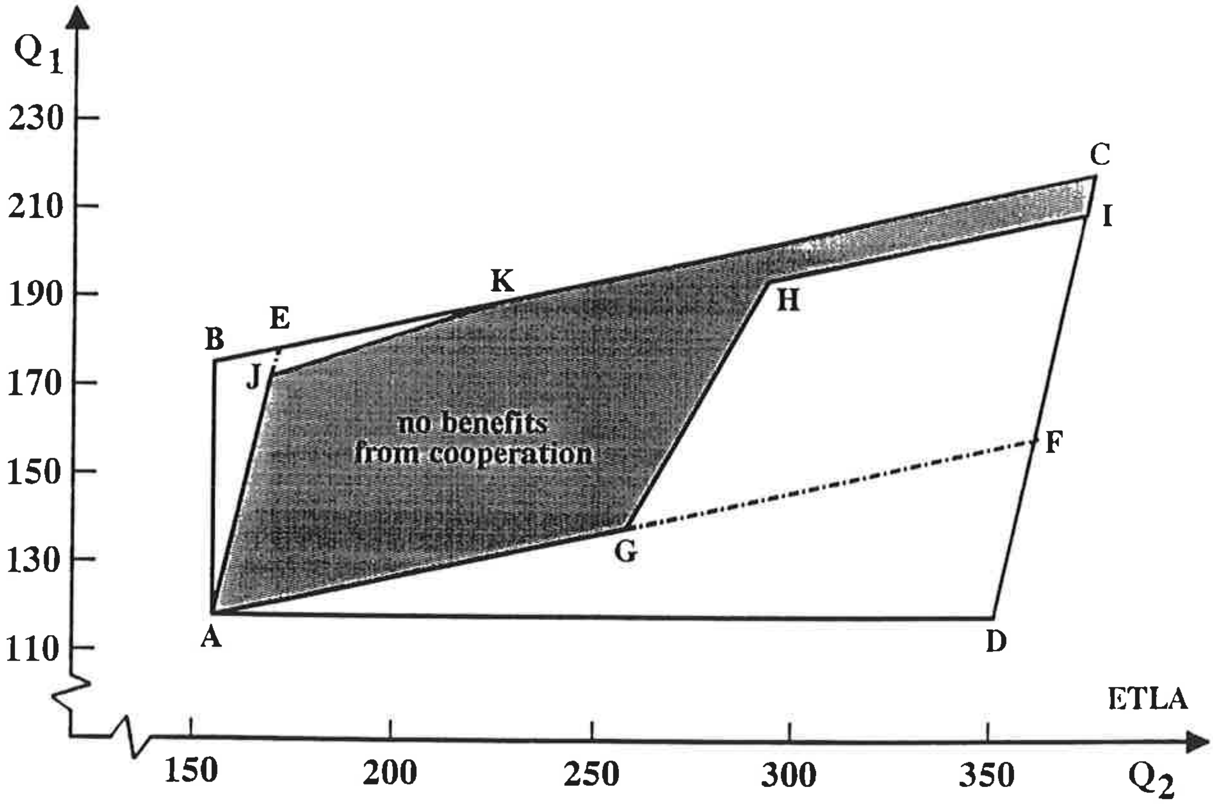
Intuition suggests that these results crucially depend on the target deposition levels of both countries. If for example the Finnish target is reduced, the curve $E_1 = E_1(E_2)$ shifts toward the origin in figure 3. Let us therefore consider what pollution levels can be achieved in the two countries given the transportation model $Q = AE + B$ and the constraints $0 \leq E \leq E^{max}$ where $A$ and $B$ are as defined in (2) and $E^{max} = (186, 651)'$. The outcome depends on whether the countries act in concert or not. Under cooperation the depositions defined by the set ABCD $= \{(Q_2, Q_1) | Q = AE + B, 0 \leq E \leq E^{max}\}$ in figure 4 can be achieved. Because binding contracts can be signed, any feasible deposition level is obtainable if desired. But if the countries act in isolation, then only those pollution levels are attainable which correspond to individually rational, i.e. own cost minimizing emissions. These depositions are specified in figure 4 by the set AECF of points $(Q_2, Q_1)$ for which $Q = AE + B$ where $E_i$ minimizes $C_i(E_i)$ when $E_j \in [0, E_j^{max}]$ is given, $i, j = 1, 2, i \neq j$. This set is smaller than the cooperative one implying that by acting in concert the countries can satisfy lower deposition targets. Thus pollution limits $(\hat{Q}_1, \hat{Q}_2)$ belonging to the sets ABE and AFD are not attainable if the mode of the game is non-cooperative.

Let us next consider the deposition targets attainable without cooperation, i.e. the set AECF in figure 4 and ask whether the corresponding emissions qualify as the optimal solution to the cooperative abatement problem defined in equations (10)-(12) and characterized in (13). Only those emissions do which correspond to the pollution targets in the shaded area. The set GHIF specifies those levels whose achievement under optimal cooperation requires increases in Finnish and reductions in Soviet emissions when compared the the case of non-cooperation. The set EKJ denotes those pollution targets whose cooperative attainment needs decreases in Finnish and increases in Soviet emissions. This set is much smaller that the former one because the marginal abatement costs are higher in Finland than in the nearby Soviet Union.

We are now in a position to be able to assess the benefits of cooperation. Figure 4 reveals, as was argued earlier, that no benefits exist if the targets are the actual 1987 depositions levels $Q_1 = 210$ and $Q_2 = 374$. These targets are quite close to the highest attainable combination which is explained by the way in which the abatement cost functions have been constructed. In the action plan between Finland and the Soviet Union the parties have agreed to reduce their sulphur emissions by 50 per cent from the levels which prevailed in 1980. The agreed emissions imply $Q_1 = 186$ and $Q_2 = 276$. We can now see from figure 4 that if these depositions are regarded as the target levels in the respective countries, then the action programme could be implemented as a non-cooperative game without any need for binding contracts on emission reductions. There is no incentive to deviate from the cooperative emission levels.

According to the action plan the parties shall agree in 1992 on critical loads of air pollutants and shall approve a new programme for further reductions of emissions, the goal being not to exceed the critical loads (Action Programme 1989). The current agreement specifies the critical load for annual sulphur deposition to be 0.5 grams per square meter in Finland. Assuming uniform distribution over the whole territory this corresponds to the total annual deposition of 168.5 (in 1 000 tons). Whether Finland can achieve this level without the cooperation of the nearby Soviet Union depends on the pollution target there.If it is very low, in the range $155 \leq Q_2 \leq 167.7$, then according to figure 4 optimality requires cooperation to reduce Finnish emissions below the level implied by the non-cooperative solution of the game. But if the Soviet target lies in the range $167.7 < Q_2 \leq 276.9$, the non-cooperative equilibrium qualifies as the cooperative solution. Higher target levels again call for cooperation to reduce Soviet emissions from the non-cooperative

**FIGURE 4. Comparison of cooperative and non-cooperative abatement policies**



level.

It may well be the case that the Soviet target will be near $Q_2 = 370$. The corresponding non-cooperative emissions are then $\hat{E}_1 = 33.6$ and $\hat{E}_2 = 651$ and the optimal ones $E_1^* = 88.0$ and $E_2^* = 364.9$, respectively. Cooperation benefits Finland by 539 million marks a year but yields the Soviet Union an annual loss of 312 millions. Consequently, Finland should pay her neighbour at least the sum covering this loss as an incentive for cooperation. If the net gain from environmental cooperation is split equally, the monetary transfer payment comes to 425 million marks.

The approach used in this section was motivated by the likely sensitivity to the damage cost specification of the results obtained by applying the revealed-preference method. And, indeed, if pollution targets are exogenously given, the 'victim pays principle' does not come out of the analysis as prominently as it did in the previous section. Finland should provide the Soviet Union with monetary incentives only if her target deposition is rather low and Soviet Union's relatively high. But the approach adopted here is also subject to criticism concerning the exogeneity of the targets. As the action plan between Finland and the Soviet Union indicates, countries tend to negotiate concerning acceptable pollution levels. This means that they are not exogenously given but depend on the mode of the acid rain game. Non-cooperation may imply higher deposition targets which should be taken into account in assessing the benefits from cooperation.

# 5 Conclusions

We have demonstrated in this paper that optimal bilateral cooperation on reducing transboundary air pollution between Finland and areas nearby in the Soviet Union may entail transfer payments from Finland to her neighbour. We have also shown that the recently signed action plan aiming at reductions in sulphur emissions is rather costly to the Soviet Union. This leads us to suspect that the terms of the agreement will not be carried out without monetary support from Finland. The basic explanation for these findings is the fact that abating sulphur in Finland is much more expensive than in the Soviet Union, at 1987 emission levels five times more expensive at the margin. The reason is that considerable emission reductions were already carried out in Finland in the 1970s and 80s whereas not much has yet happened in the Soviet Union. By 1987 Finland had cut her emissions by 44 per cent from the 1980 level, the regions nearby in the Soviet Union by only 6 per cent. Thus Finland has already achieved the emission reduction specified in the action plan.

It is interesting and rather surprising to observe that according to our calculations based on the revealed-preference approach optimal emissions reductions are not wide of the 50 per cent mark agreed on in the action plan. In both countries sulphur emissions should be cut by 45 per cent from the 1980 levels. The problem lies in the fact that one of the parties has already carried out her part of the deal whereas the other has not. To meet the reduction requirements it would be sufficient for the Soviet Union to renew the technologies used in two nickel smelteries situated in the Kola peninsula and in the power stations in Estonia using oil shale.

This paper has demonstrated a case for the 'victim pays principle'. Transboundary air pollution is a game in which those who gain from cooperation must devise incentives to those who lose to ensure their participation. This is a stark reality in international environmental cooperation because there is no supernational authority having the power to enforce agreements. The case for monetary incentives is even stronger when the polluting party is poor and lacks the resources to finance the required investments in abatement technology.

There are at least three obvious and important ways to extend the analysis presented in this paper. The first one is the recognition of the fact that suplhur is a stock pollutant as well as a flow pollutant. This means that the damage caused by sulphur deposition depends on the stock of acid in the environment as well as on the rate of deposition. Some initial experiments to model the stock dynamics in the context of Finnish-Soviet air pollution have been reported in Kaitala, Pohjola and Tahvonen (1990). It is shown that the recovery of the soil from acid rain is a slow process. Consequently, ecological conditions can deteriorite for some time even if emissions are decreasing. Benefits from emission reductions are measured in that paper by the impact on the value of forest growth of lower acidification of the soil. The qualitative policy conclusions are the same as in the current paper.

The second extension needed is a more disaggregated regional analysis. We have here regarded Finland and the nearby regions of the Soviet Union as homogenous areas with respect to air pollution. No attention has been paid to the fact that pollution is very much concentrated in certain areas, namely southern Finland and Estonia as well as north-eastern Lapland and Kola peninsula. The long border between the countries and the direction of the winds make it impossible to reduce sulphur deposition in southern Finland by decreasing emissions in Kola. A more disaggregated sulphur transportation model and more refined abatement cost functions are needed before these aspects of the pollution problem can be given proper attention. We do not think that the qualitative insights of the current paper would change as a result of such an extension but the quantitative estimates certainly would.

The last extension we propose is a theoretical one. The incentive effects of the 'victim pays principle' should be investigated. These may be adverse in the long-run. By refusing to sign any agreements on emission reductions a country may increase its bargaining power in future negotiations concerning the size of the side-payment. This kind of question has already been considered by Kaitala and Pohjola (1988) in the context of regulating transboundary fisheries.

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