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ACID RAIN AND INTERNATIONAL ENVIRONMENTAL AID: A CASE STUDY OF TRANSBOUNDARY AIR POLLUTION BETWEEN FINLAND, RUSSIA AND ESTONIA*

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ABSTRACT: It is shown in this paper that efficient cooperation on reducing transboundary air pollution requires substantial sulphur emission cuts in Estonia and in the Kola peninsula in Russia. Pareto-optimality may also entail financial transfers from Finland to Estonia because it is an important source of sulphur deposited in Southern Finland and because sulphur abatement costs are much lower in Estonia. The analysis is based on a sulphur transportation model, on estimated regional abatement cost functions and on the 'revealed-preference' approach in estimating the damage costs from pollution.

1 Introduction

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). The areas included 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. It was further decided that the parties will meet in 1993 to make a new agreement, the goal being not to exceed the critical loads, i.e. the amounts which do not considerably affect the environment.

The recent political events in Eastern Europe have made this agreement obsolete. Finland has responded to the change in international environment by seeking for cooperation with the new independent nations. An agreement with Estonia was signed in November 1991. It sets the guidelines under which bilateral cooperation will be pursued. A joint commission was also established and its first duty is to draw an agreement on reducing the emissions of air pollutants. Estonia, unlike Russia, does not recognize the agreements signed by the former Soviet Union.

The government of Finland has also recently decided on a programme of environmental aid to Eastern Europe. The plan is to support environmental investments in areas which are the sources of transboundary air pollutants deposited in Finland. Financial aid can be given up to 80 per cent of the total costs of such projects on the condition that Finnish technology or expertise is applied. The government has allocated 42 and 67 million Finnish marks for this purpose in its 1991 and 1992 budgets, respectively.

This paper sets out to evaluate the net benefits to Finland, Russia and Estonia of trilateral environmental cooperation as well as the possible need of financial transfers in achieving efficient abatement programs. Because of data problems, the analysis is confined to sulphur emissions. At present, sulphur accounts to 50–70 per cent of the aggregate acidification in Southern Finland. The next section presents the emission data, a model describing the transportation of sulphur between the regions as well as abatement costs. Section 3 contains an analysis of the optimal form of cooperation and an evaluation of the need of side payments. The current paper extends our previous one (Kaitala, Pohjola and Tahvonen 1991) by generalizing the analysis to cover three independent decision-makers.

2 The data and the model

In 1988 the Finnish-Soviet Commission for Environmental Protection established a joint programme for estimating the flux of air pollutants emitted close to the border between the countries. It consists of the estimation of emissions, model calculations of transboundary transport of pollutants, analysis of observational results from measurement stations and conclusions for emissions reductions. The emissions inventory includes sulphur, nitrogen and heavy metals.

Table 1 gives information about the depositions and emissions of sulphur in the relevant regions in the years 1980 and 1987. Depositions were calculated by Tuovinen, Kangas and Nordlund (1990) by applying the latest version of the long-range transport model for sulphur developed at the Western Meteorological Centre of the European Monitoring and Evaluation Programme (EMEP). Emission data approved by both the Finnish and Soviet parties were used as inputs in the model calculations. Finland is here divided into three subregions: Northern, Central and Southern Finland. To conform the analysis to the current political environment the areas close to the eastern border of Finland are divided into two independent units: Russia and Estonia. The Russian areas are further split into three: the Kola peninsula, Karelia and the St Petersburg region.

Both components of pollution are much higher in the Russian areas than in either

Finland or Estonia. In 1987 the emissions of the nearby Russian regions were about three times larger than the Finnish. However, the trends are declining in all areas. In making comparisons between the regions it should be kept in mind that this Russian territory is about 25 per cent larger than Finland and that Estonia is about the same size as Southern Finland. The annual sulphur deposition per square meter ranges from 0.5–0.6 grams in Northern and Central Finland as well as in Karelia to 1.2–1.3 grams in Southern Finland and Estonia.

The numbers in the parentheses in table 1 denote exogenous deposition, that is, deposition originating from emissions in other countries and the rest of Russia as well as deposition coming from unidentified (both natural and man-made) sources. About half of the total sulphur problem can be covered by the trilateral analysis.

Table 1: Sulphur emissions and depositions in 1980 and 1987
(1 000 tons per year)

	Emission E		Deposition Q			
	1980	1987	1980		1987	
Northern Finland	18	5	50	(27)	46	(26)
Central Finland	107	60	124	(66)	98	(59)
Southern Finland	167	97	89	(38)	66	(35)
Finland total	**292**	**162**	**263**	**(131)**	**210**	**(121)**
Kola	362	350	156	(36)	131	(27)
Karelia	85	85	118	(65)	95	(50)
St Petersburg	125	112	108	(57)	88	(46)
Russia total	**572**	**547**	**382**	**(158)**	**314**	**(123)**
Estonia	**120**	**104**	**71**	**(38)**	**60**	**(32)**

Source: Tuovinen, Kangas and Nordlund 1990

Tuovinen, Kangas and Nordlund (1990) have also estimated an annual sulphur budget between these seven regions for the year 1987. It can be used to formulate a sulphur transportation matrix indicating how the emission in one area is transported in the atmosphere for deposition in another. The columns of table 2 specify the deposition distribution between the regions of one unit of sulphur emitted in each area. The large numbers on the diagonal show how important own sources of pollution are for each region. The column and row sums are not equal to unity because all areas both emit sulphur to and receive it from the rest of the world.

Table 2: Sulphur transportation matrix for the year 1987

	Emitting region:						
	NFin	CFin	SFin	Kol	Kar	StP	Est
Receiving region:							
Northern Finland	.200	.017	.010	.046	.012	.000	.000
Central Finland	.000	.300	.062	.011	.047	.036	.029
Southern Finland	.000	.017	.227	.003	.000	.027	.038
Kola	.000	.017	.000	.286	.023	.009	.000
Karelia	.000	.033	.031	.017	.318	.045	.019
St Petersburg	.000	.017	.031	.003	.012	.268	.058
Estonia	.000	.000	.031	.000	.000	.018	.221

Source: Tuovinen, Kangas and Nordlund 1990

The asymmetry of the Finnish-Russian pollution problem can be seen by combining the information in tables 1 and 2. In 1987 about 16 per cent of sulphur deposited in Finland originated from the nearby Russian areas whereas only 3 per cent of their deposition came from Finland. The reason for this does not lie in the behaviour of the atmosphere (table 2) but is to be found in the asymmetry of the emissions: in 1987 the emissions of the nearby Russian areas were 3.4 times higher than the Finnish. The two other sulphur budgets, namely those between Estonia and Finland and between Estonia and Russia were approximately on balance. For example, about 3 per cent of the Estonian deposition came from the Russian areas, whereas 2.5 per cent of their deposition originated from Estonia.

A sulphur transportation model can now be constructed on the basis of tables 1 and 2. Let E_i and Q_i denote the annual emission and deposition of sulphur, respectively, in region i, and let A stand for the matrix of table 2 and B for the vector of exogenous deposition in 1987 as specified in the last column of table 1.

The model can then be expressed in vector notation as

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

For further analysis it is useful to partition the vectors according to the countries: $Q = (Q_F, Q_R, Q_E), E = (E_F, E_R, E_E), B = (B_F, B_R, B_E)$, where the subscript F refers to Finland, R to the nearby areas of Russia and E to Estonia. Matrix A can then be written as

$$A = \begin{pmatrix} A^{FF} & A^{FR} & A^{FE} \\ A^{RF} & A^{RR} & A^{RE} \\ A^{EF} & A^{ER} & A^{EE} \end{pmatrix}. \tag{2}$$

The dimensions and contents of each submatrix are easily seen from table 2. The (i,j)-component of, say, A^{FF} is denoted by a_{ij}^{FF}.

Given the sulphur transportation model, 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 in region i, $C_i(E_i)$, and the second the damage, measured in monetary units, that sulphur deposition causes to the environment, $D_i(Q_i)$. The total costs to Finland, Russia and Estonia can then be written as

$$J_F(E_F, E_R, E_E) = \sum_{i=1}^{3}\{C_{Fi}(E_{Fi}) + D_{Fi}(Q_{Fi})\}, \tag{3}$$

$$J_R(E_F, E_R, E_E) = \sum_{i=1}^{3}\{C_{Ri}(E_{Ri}) + D_{Ri}(Q_{Ri})\}, \tag{4}$$

$$J_E(E_F, E_R, E_E) = C_E(E_E) + D_E(Q_E), \tag{5}$$

respectively. The regions have here been indexed in the same way as in table 2, i.e., $F1$ denotes Northern Finland, $R1$ Kola and so on.

Both cost 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 region i in a given time period. Here we use the data provided by the Finnish Integrated Acidification Assessment

(HAKOMA) project at the Technical Research Centre of Finland and decribed in more detail in Johansson, Tähtinen and Amann (1991). The original data is in piecewise linear form but here we use quadratic approximations with the assumption that only the parts decreasing in E_i are relevant for the analysis. Let

$$C_i(E_i) = \alpha_i(\bar{E}_i - E_i) + \beta_i(\bar{E}_i - E_i)^2 + \gamma_i, \tag{6}$$

where $\bar{E}_i$ denotes the actual emissions of region i in the base year, i.e. in 1987. The parameter α_i has been chosen to be equal to the observed marginal costs at $\bar{E}_i$ and γ_i to be equal to the respective total cost. β_i is estimated by the ordinary least squares technique.

Table 3 presents the parameters of (6) for the seven regions. Because the quadratic function approximates rather poorly the sulphur abatement costs in Kola and Estonia, their cost functions are here adjusted by making them consist of two components: first, of a linear segment describing the abatement costs for initial reductions of emissions from the 1987 level and, second, of a quadratic segment.

Table 3: Abatement cost function parameters (standard deviations in parentheses)

	α	β	γ
Northern Finland	10.0	2.093 (1.181)	5.9
Central Finland	3.8	0.172 (0.012)	33.0
Southern Finland	4.6	0.068 (0.006)	53.6
Kola			
- for $98 < E_{R1} \leq 350$:	1.0	0.0	0.0
- for $0 < E_{R1} \leq 98$:	1.0	0.077 (0.005)	252.0
Karelia	4.0	0.045 (0.004)	0.0
St Petersburg	6.0	0.051 (0.003)	0.0
Estonia			
- for $60 < E_E \leq 104$:	2.0	0.0	0.0
- for $0 < E_E \leq 60$:	2.0	0.191 (0.009)	88

It is much harder to obtain information about the damage functions $D_i(Q_i)$. Instead of direct measurements we here apply an indirect way, suggested by Mäler (1990). 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 policy authorities of Finland, Russia and Estonia 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 in each region equals the marginal damage to the whole nation from further deposition in the specific region.

The problem here is that our data are from the period in which Estonia was part of the Soviet Union and was not able to pursue her own environmental policies. We deal with this by assuming first that Estonia is a member state of the Soviet Union and then by making a sensitivity analysis for the estimated damage costs.

Consequently, suppose that the emission levels in Finland are chosen in such a way that

$$-C'_{Fi}(E_{Fi}) = \sum_{j=1}^{3} a_{ji}^{FF} D'_{Fj}(Q_{Fj}) \tag{7}$$

for $i = 1, 2$ and 3 and in the Soviet Union so that

$$-C'_{Si}(E_{Si}) = \sum_{j=1}^{4} a_{ji}^{SS} D'_{Sj}(Q_{Sj}) \tag{8}$$

for $i = 1, 2, 3$ and 4. Here A^{SS} is the submatrix of A containing the Russian and Estonian transportation coefficient and $S4$ stands for Estonia. These emission levels minimize in each country — Finland and the Soviet Union — the national cost function ((3) or the sum of (4)and (5)) subject to the constraints given by the transportation model (1) and the fixed emissions of the neighbouring nation. Acting in isolation each country pays attention to the deposition of sulphur in its own area only. The externalities between the regions are internalized within but not between the countries.

The estimation of the damage functions can be completed easily if — again following Mäler (1990) — we make the simplifying assumption that these functions are linear, i.e.

$$D_i(Q_i) = \delta_i Q_i, \tag{9}$$

where δ_i is positive. Knowing the marginal abatement costs (the α's of table 3) and the transportation coefficients (matrix A in table 2), the first-order conditions (7) and (8) then immediately provide estimates for the δ_i's if the observed emission vector $(\bar{E}_F, \bar{E}_S) = (\bar{E}_F, (\bar{E}_R, \bar{E}_E))$ in 1987 is assumed to be the Nash equilibrium of this acid rain game:

$$\delta_F = (A^{FF})^{-1}\alpha_F, \tag{10}$$

$$\delta_S = (A^{SS})^{-1}\alpha_S. \tag{11}$$

The numerical values of these marginal damage vectors are given in table 4 which for comparison also displays the marginal abatement costs.

Table 4: Marginal abatement (MC) and damage (MD) costs (FIM/kilogram of sulphur)

	MC $\underline{\alpha}$	MD $\underline{\delta}$
Northern Finland	10.0	50.0
Central Finland	3.8	8.9
Southern Finland	4.6	15.6
Kola	1.0	2.6
Karelia	4.0	11.6
St Petersburg	6.0	20.2
Estonia	2.0	2.8

Sulphur abatement costs are the lowest in Kola and Estonia — 1 and 2 Finnish marks per kilogram of sulphur, respectively — and the highest in Finnish Lappland — 10 marks per kilo. The marginal damage cost is the highest in Northern Finland — 50 marks per kilogram of sulphur deposited — and the lowest in Kola and Estonia — about 3 marks per kilo. This approach reveals that the Soviet decision-makers regarded additional sulphur deposition to be about eight times more harmful in the Leningrad, i.e. St Petersburg, area than in Kola or Estonia.

Armed with the damage costs we can now turn to consider the potential benefits of environmental cooperation between the countries as well as to assess its optimal form. Here we return to our original assumption that Estonia and Russia are now independent decision-makers and can thus pursue their own policies.

3 Optimal cooperation and environmental aid

A Pareto-optimal sulphur abatement contract between the countries can be derived by minimizing the joint costs

$$J(E_F, E_R, E_E) = J_F(E_F, E_R, E_E) + J_R(E_F, E_R, E_E) + J_E(E_F, E_R, E_E) \tag{12}$$

with respect to the emissions in the Finnish areas (vector E_F), in the Russian regions (vector E_R) and in Estonia (E_E) under the constraints set by the transportation model (1). The optimal emission vector (E_F^*, E_R^*, E_E^*) is obtained by solving the first-order conditions

$$-C'_{Fi}(E_{Fi}) = \sum_{j=1}^{3} a_{ji}^{FF} \delta_{Fj} + \sum_{j=1}^{3} a_{ji}^{RF} \delta_{Rj} + a_i^{EF} \delta_E, \; i = 1,2,3, \tag{13}$$

$$-C'_{Ri}(E_{Ri}) = \sum_{j=1}^{3} a_{ji}^{FR} \delta_{Fj} + \sum_{j=1}^{3} a_{ji}^{RR} \delta_{Rj} + a_i^{ER} \delta_E, \; i = 1,2,3. \tag{14}$$

$$-C'_E(E_E) = \sum_{j=1}^{3} a_j^{FE} \delta_{Fj} + \sum_{j=1}^{3} a_j^{RE} \delta_{Rj} + a^{EE} \delta_E. \tag{15}$$

Table 5 displays the optimal emissions, the resulting depositions in all areas as well as the monetary benefits from cooperation to the three countries. The exogenous deposition (vector B) is assumed to remain at the 1987 level. It does not affect the optimal emission levels but has an impact on the depositions and the total costs. The monetary benefit has been calculated for each country by subtracting the optimal cost from the non-cooperative cost: benefit to country I equals $J_I(\bar{E}_F, \bar{E}_R, \bar{E}_E) - J_I(E_F^*, E_R^*, E_E^*)$, $I = F, R, E$.

Table 5: The consequences of cooperation and its annual monetary benefits

	Emissions (10^3 tons) E^*	Emission reduction (%)	Depositions (10^3 tons) Q^*	Deposition reduction (%)	Benefit (10^6 FIM) $\bar{J} - J^*$
Northern Finland	5	0.0	34	26.1	
Central Finland	58	3.3	92	6.1	
Southern Finland	89	8.2	61	7.6	
Finland	**152**	**6.2**	**187**	**10.9**	**700**
Kola	82	76.6	54	58.8	
Karelia	74	12.9	85	10.5	
St Petersburg	104	7.1	82	6.8	
Nearby Russia	**260**	**52.5**	**221**	**29.6**	**42**
Estonia	**58**	**44.2**	**49**	**18.3**	**-64**

The joint cost minimization requires Russia to cut her sulphur emissions by more than 50 per cent from the 1987 level in the areas near the Finnish border. The greatest reductions should be carried out in the Kola peninsula. Two nickel smelteries are the main sources of sulphur there. Emissions should also be cut by about 45 per cent in Estonia where oil-shale-based electricity production is the principal source of sulphur. The abatement activities should be concentrated on these regions for two reasons: first, their sulphur abatement costs are rather low and, second, their emissions contribute significant amounts to deposition in Northern and Southern Finland as well as in the St Petersburg area where the marginal damage of pollution is rather high. The Finnish emissions were quite close to the optimal level in 1987 — they should have been 8 per cent lower in the southern area and 3 per cent smaller in the central part of the country. This asymmetry in the abatement requirements between the countries can be explained by the asymmetries in marginal abatement costs (table 3) and in observed emission levels (table 1).

Table 5 also reveals that both Finland and Russia benefit from the cooperation but Estonia loses. The Finnish benefit is rather large, 700 million Finnish marks a year, and it comes from the sizeable reductions in the sulphur damage costs. The greatest gain accrues to Northern Finland. The Russian benefit is more modest — only 42 million a year. All its areas benefit rather equally from the decrease in sulphur depositions but Kola bears the greatest burden of the abatement costs. Estonia's net loss follows from the rather large abatement requirement and from the fact that our estimate for the marginal damage cost is quite low.

As no sovereign state can be forced into cooperation, it is reasonable to expect that in order to sign such an agreement Estonia should be compensated for at least the loss, i.e. 64 million a year. Finland is the obvious candidate for the party who finances the required side payment as Russia's net gain does not even equal Estonia's loss. It is interesting that this sum is rather close to the amount allocated in the 1991 and 1992 budgets of the government of Finland for environmental aid to Eastern Europe, namely 42 and 67 million, respectively. It should be kept in mind, however, that besides air pollution abatement this aid is also meant for other environmental investments and targeted to also other areas than Estonia.

The side payment should be even larger and given to Russia as well if sharing the net benefit from cooperation is regarded to be fair. Assuming that the net gain — 678 million marks —- is split equally between the countries, Finland should pay Estonia 290 and Russia 184 million a year.

As was mentioned earlier, the estimated sulphur damage cost for Estonia may not reflect the true preferences of the decision-makers of this new-born state. We therefore conduct a sensitivity analysis in table 6 to find out how robust are the qualitative conclusions concerning the need of Finnish transfer payments. The Estonian net benefit from environmental cooperation increases as δ_E is increased from its estimated value. For $\delta_E = 9.3$ the net benefit equals zero. No side payments are needed to induce Estonia to cooperate if the value of marginal damage is higher than this. If sulphur deposition were regarded to be as harmful as in Southern Finland, the net annual benefit to Estonia would be FIM 68 million. Here the benefits from reduced sulphur deposition outweigh the costs of the large emission reductions required by cooperation.

Table 6: Estonian damage costs and the benefits from cooperation

Marginal damage in Estonia (FIM/kg)	Emission reduction in Estonia (%)	Net gain from cooperation (10^6 FIM)		
		Finland	Russia	Estonia
2.8	44.2	700	42	- 64
6.0	46.2	702	45	- 33
9.3	48.1	703	48	0
12.0	49.6	704	50	28
15.6	51.6	705	54	68

But if the Estonian damage coefficent were so high that its net benefit from cooperation were positive, then we should observe considerable cuts in Estonian sulphur emissions even without any international cooperation. For $\delta_E = 9.3$ the non-cooperative emission level should be 42.5 per cent lower than it was in the year 1987. Nothing indicates that measures as drastic as this are currently planned, and we may be rather confident about the robustness of our qualitative results concerning the need of side payments.

4 Conclusions

We have here conducted a case study of optimal cooperation on transboundary air pollution abatement between Finland, Russia and Estonia. Acid rain is an example of a regional reciprocal externality in which countries are both sources and victims of an environmental problem. The economics of such cases was pioneered, among others, by d'Arge (1974), Scott (1972) and Walter (1975). More recent work can be found, for example, in the survey papers of Mäler (1990) and Newbery (1990).

Our approach was practical, the aim being to demonstrate how the basic concepts of game theory, namely, Nash equilibrium and Pareto optimum, can be used to devise optimal sulphur abatement programs. It was shown that it is rational to abate sulphur more in the Russian and Estonian territories than in Finland simply because this is much less expensive there. The reason is the fact that considerable emission reductions were already carried out in Finland in the 1970s and the 1980s whereas not much happened in this respect in the Soviet Union.

Optimal programs may, however, entail transfer payments from Finland to Estonia because the former benefits but the latter loses from cooperation. Transboundary air pollution is a game in which those who gain have to devise incentives to those who lose to ensure their participation. Agreements may not be enforceable without side payments as there is no supernational authority having the power to enforce them. The case for transfer payments is even more relevant when — as is the case here — the polluting parties are rather poor and lack the financial resources for investments in abatement technology.

Our analysis in this paper was based on a restrictive set of assumptions, but it has been qualified in a number of respects in our companion papers. In Tahvonen, Kaitala and Pohjola (1992) we have replaced the damage cost functions by upper limits on sulphur depositions and assumed joint minimization of abatement costs. In Kaitala, Pohjola and Tahvonen (1990) we have investigated the long-run aspects of acidification in a dynamic game framework. These generalizations do not, however, change the qualitative results of the present paper concerning emissions cuts and side payments.

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