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Keskusteluaiheita - Discussion papers

No. 358

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A FINNISH-SOVIET ACID RAIN GAME: "CLUB SOLUTIONS", NONCOOPERATIVE EQUILIBRIA AND COST EFFICIENCY****

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**** We are grateful to Ilkka Savolainen and Markus Tähtinen
for providing us with unpublished data on sulphur abatement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 and Olli Tahvonen from the
Foundation for Research of Natural Resources in Finland
and the Maj and Tor Nessling Foundation.

ISSN 0781-6847 22.03.1991

KAITALA, Veijo - **POHJOLA**, Matti - **TAHVONEN**, Olli, **A FINNISH-SOVIET ACID RAIN GAME: "CLUB SOLUTIONS", NONCOOPERATIVE EQUILIBRIA AND COST EFFICIENCY**. Helsinki : ETLA, Elinkeinoelämän Tutkimuslaitos, The Research Institute of the Finnish Economy, 1991. 18 p. (Keskusteluaiheita, Discussion Papers, ISSN 0781-6847; no. 358).

ABSTRACT: This study analyses the cost efficiency in sulphur abatement cooperation between Finland and the Soviet Union. It is assumed that the aim of both countries is to attain a given target deposition level at minimum possible sulphur abatement cost. Cost efficient cooperation is compared to noncooperative equilibrium and to the agreement made between these two countries. It is shown that the signed agreement does not deviate much from a cost efficient outcome or noncooperative equilibrium. The computations reveal that the main source of cooperation benefits is not asymmetrical emission transportation or difference in abatement costs but different target deposition levels of Finland and the Soviet Union.

1 INTRODUCTION

Acid deposition due to man–made emissions has serious long–term effects on the forest environment. The vitality of trees may be affected both through the direct impact on needles of increased concentration of toxic compounds and through the reduced availability of nutrients from the forest soil. Together these affect photosynthesis and the growth rate of trees (Hari, Holmberg, Reunemaa, and Nikinmaa 1990, Huttunen, Reinikainen and Turunen 1990). Because of slow growth of trees and slow recovery of forest soil, acid deposition may cause very long–term reductions in the timber supply and result in a general deterioration of the forest environment.

Sulphur dioxide emissions are a primary source of acid deposition. In the atmosphere they can be transported by winds for distances ranging from 50 to 2000 kilometers. Eventually, they are removed from the atmosphere by rain – wet deposition – or by contact with plants and surface water – dry deposition. As a consequence of the long–range transportation of emissions the countries bear only a fraction of the damage caused by their own emissions. In economic terms a transboundary, reciprocal externality is created, and the conventional prediction is obtained that noncooperation between the countries on emission control protection results in unnecessarily high emission and deposition levels evaluated from their collective viewpoint.

Mäler (1990) demonstrated that potential cooperative benefits to all European countries may be quite substantial. This result was derived by assuming that the 1984 sulphur emission levels can be characterized as a noncooperative equilibrium of an emission abatement game between the European countries. This assumption together with estimates on the interaction between countries and with country specific cost data on sulphur abatement made it possible to determine the country specific marginal damage costs. By assuming that damage cost functions are linear Mäler estimated the annual benefits from cooperation to be 6 billion Deutsch–marks per year.

Mäler also analysed different institutional arrangements to induce the countries to limit their sulphur emissions. He found that the usual form of international agreements where countries have agreed to implement uniform emission reductions leads to abatement costs much above the cost effective solution (noncooperative costs being about 76% higher than optimal cooperative costs). An interesting feature in these results is that some countries will lose from cooperation. This raises a difficult question about the implementation of an optimal or cost effective agreement. According to Mäler the uneven distribution of the cooperative benefits is mainly due to the geographic location of countries. Some countries are more upwind than others, so their net benefits will not be as great as the countries that are more downwind.

Mäler also notes that the Soviet Union is a special case in the European acid rain game. This is because of her large size and because only a small fraction of her substantial emissions affects other European countries. Finland seems also to be a special case in the sense that she will lose from optimal cooperation.

The acid rain game between these two "special case countries" is the subject of this study. The sulphur emissions of the USSR contribute crucially to the sulphur problem in Finland because about 19 per cent of the deposition in Finland originates from the Soviet areas near the common border (Tuovinen, Kangas and Norlund 1990). On the other hand, the corresponding Soviet regions receive only about 3 per cent of her deposition from Finland. The intensity of the transboundary pollution between Finland and the USSR varies, however, among the regions. Most of the public concern has been directed towards the northern part of Finland.

In this study we divide the area of Finland into three regions and take under the consideration four Soviet regions across the common border – Kola, Karelia, the Leningrad area and Estonia. Thus, the individual emission regions used here are about the size of smaller European countries. The interaction between these regions is described by a transport coefficient matrix. The data on emission abatement costs are region specific. The basic problem is how to reach cost efficiency in environmental cooperation: The countries aim at emission reductions such that region–specific target levels for depositions are reached with minimum joint investments in emission abatement in each country. We then compare this cost efficient cooperation solution with noncooperative environmental policies and the sulphur agreement signed between the countries requiring 50 per cent reductions in sulphur emissions from the 1980 levels. The sulphur agreement, below referred to as the 50 per cent Club, covers the same Soviet region that will be studied here.

Our main finding is that these three solutions do not differ much from each other because of an asymmetrical transport coefficient matrix or because of differences in marginal abatement costs but mainly because of different target deposition levels of these two countries. In most cases Finland gains from cooperation while the Soviet Union loses. The analysis of acid rain negotiations between Finland and the USSR also serves to demonstrate the nature of international environmental problems between poor and rich countries.

The paper is organized as follows. Section 2 gives an overview of the physical background and describes our data. In section 3 we define the solution concepts to be used in the computations. Section 4 analyses the sulphur abatement agreement made between Finland and the Soviet Union. In section 5 we show how the cooperative benefits vary with variations in the region specific target depositions. Section 6 considers the gains from cooperation in perhaps the most probable case where the Finnish deposition targets are low while the Soviet target depositions are higher. Section 7 concludes the paper.

2 THE PHYSICAL BACKGROUND AND DATA

Let Q_i denote the annual deposition of sulphur in the seven regions under consideration, i= Northern Finland, Central Finland, Southern Finland, Kola, Karelia, Leningrad area and Estonia. (See Fig. 1).

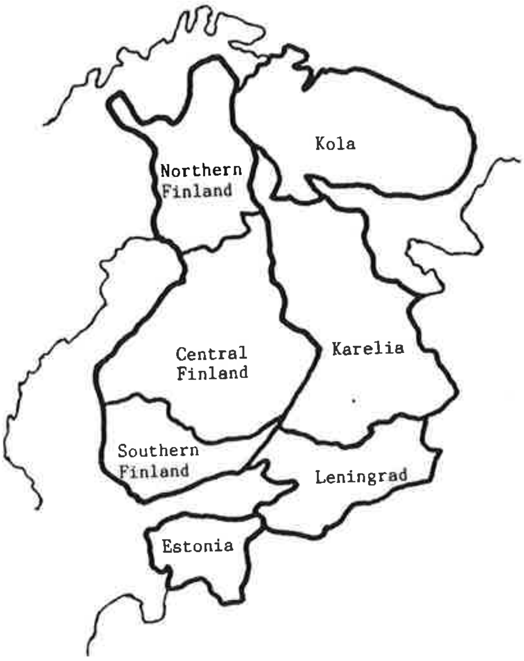

Fig. 1. Finland and the nearby regions of the Soviet Union.

The deposition in each of these seven regions has eight sources, the last being the sum of the natural backround deposition and human generated emissions from the rest of the world. Denote this exogenous deposition vector by B. Let the transport coefficient matrix A = (a_{ij}) indicate how the emission in region j is transported in the atmosphere to be deposited in region i. Now our transportation model can be expressed in vector notation as

$$Q=AE+B$$

The transport coefficient matrix has been constructed at the Finnish Meteorological Institute by Tuovinen, Kaangas and Norlund (1990) by applying the long-range sulphur transport model developed at the Western Meteorological Center in Oslo. The parameters of the matrix and the exogenous depositions are shown in Table 1.

Table 1. The transport coefficient matrix and annual exogenous deposition level (in 1000 tonnes of sulphur), $B_{8i}a^{-1}$ in 1980 and 1987.

	NFI	CFI	EFI	KOL	KAR	LEN	EST	$B_{80}a^{-1}$	$B_{87}a^{-1}$
NFI	.2	.017	0.01	.046	.012	.0	.0	27	26
CFI	.0	.3	.062	.011	.047	.036	.029	66	59
SFI	.0	.017	.227	.003	.0	.027	.038	38	35
KOL	.0	.017	.0	.286	.023	.009	.0	36	27
KAR	.0	.033	.031	.017	.318	.045	.019	65	50
LEN	.0	.017	.031	.003	.012	.268	.058	57	46
EST	.0	.0	.031	.0	.0	.018	.221	38	32

Since most of the emissions in each region are deposited in the same area the largest parameters in matrix A can be found on the diagonal. Note also the decrease in the exogenous deposition level between the years 1980 and 1987.

Table 2 gives information about the total depositions and emissions of sulphur in these seven regions.

Table 2: Annual total depositions (in 1000 tonnes of sulphur) $Q_{8i}a^{-1}$, annual depositions per square meter (in grams) $Q_{g8i}m^{-2}a^{-1}$, annual exogenous deposition per square meter (in grams) $B_{g8i}m^{-2}a^{-1}$ and annual emissions (in 1000 tonnes of sulphur), $E_{8i}a^{-1}$.

	$Q_{80}\bar{a}^{1}$	$Q_{87}\bar{a}^{1}$	$Q_{g80}\bar{m}^{2}\bar{a}^{1}$	$Q_{g87}\bar{m}^{2}\bar{a}^{1}$	$B_{g87}\bar{m}^{2}\bar{a}^{1}$	$E_{80}\bar{a}^{1}$	$E_{87}\bar{a}^{1}$
NFI	50	46	.51	.47	.26	18	5
CFI	124	98	.72	.57	.34	107	60
SFI	89	66	1.34	1.0	.53	167	97
KOL	156	131	1.12	.94	.19	362	350
KAR	118	95	.67	.53	.28	85	85
LEN	108	88	1.27	1.03	.54	125	112
EST	71	60	1.57	1.33	.71	120	104

The total deposition and also the deposition per square meter vary considerably among the regions. The deposition per square meter is highest in Kola and in the southern regions. The latter is partly explained by the high exogenous deposition from the other parts of Europe whereas in Kola the deposition is mainly due the high home emission levels.[2] The so–called critical load deposition level varies in Finland from region to region but according to some estimates it cannot hardly exceed $.3 g(S) m^{-2} a^{-1}$.

The cost functions $C_i(E_i)$ are defined as the minimal cost envelop encompassing the entire range of sulphur abatement options for region 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 Technical Research Centre of Finland has produced such regional 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 millions of Finnish marks, have been estimated on the basis of expected energy demands for the year 2000, and they include both capital and operating costs. The former have been obtained by assuming that the existing plants are operated for 15 years and that new plans for 25 years. The annual nominal interest rate used is 8 per cent. Two main options to reduce emissions in energy production have been considered in constructing the cost functions. The first is sulphur abatement through in–furnace lime injection and flue gas desulphurization. The second is switching to the use of low sulphur heavy oils in combustion systems. In calculating costs for non–combustion processes industry–specific costs per abated amount of sulphur have been applied.

The estimated cost functions are continuous, convex and piecewise linear. They are depicted in Fig. 2.

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[2] The annual deposition levels per square meter are quite low in comparison with certain parts of Central Europe. However, one has to keep in mind that the nature in the north is much more vulnerable to acid deposition (see Huttunen, Reinikainen and Turunen 1990).

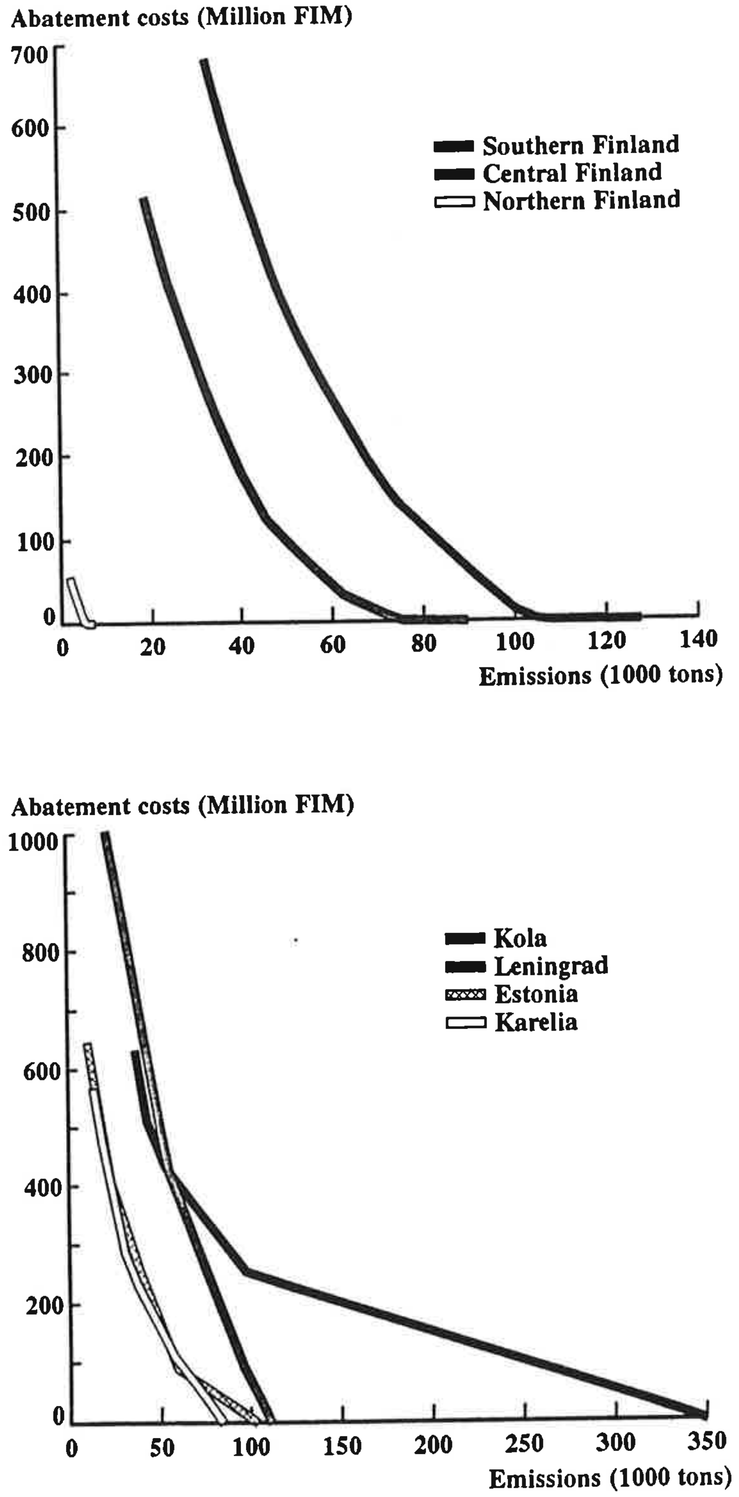

Fig. 2. The abatement cost functions in Finland and in the Soviet Union.

3 SOLUTION CONCEPTS

To study the economic logic of our problem we assume that the objective of both countries is to minimize the costs of sulphur abatement subject to region–specific deposition targets. This kind of cost efficient environmental policy is often preferred to other alternatives because no explicit consideration has to be given to the difficult problem of evaluating the damage costs of pollution. Critical deposition 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). In what follows we will analyse two explicitly mentioned environmental strategies. The first one requires that both countries must reduce the total sulphur emission levels by 50 per cent by the end of 1995 from the 1980 levels. The second one is the Finnish long–run objective which is to reduce the annual sulphur deposition below .5 grams per square meter. We will next define the solution and equilibrium concepts to be used in the analysis.

A cost effective cooperative solution is an emission vector E which solves the following problem:

$$\underset{E_f,\,E_s}{\mathrm{MIN}}\ C_{fc}+C_{sc}=\sum_{i=1}^{7} C_i(E_i)$$

$$\text{subject to}$$

$$\hat{Q}\geq AE+B,$$

$$E_{min}\leq E\leq E_{max},$$

where C_{fc} refers to the Finnish and C_{sc} to the Soviet cooperative abatement costs, E_{min} and E_{max} are region specific technically feasible minimum and maximum emission levels, and $\hat{Q}$ is the target deposition vector.

The noncooperative equilibrium is defined as the solution to the problem where both countries minimize their own abatement costs subject to their own deposition targets while taking the emissions from their neighbour as given. Formally, the noncooperative equilibrium emission vectors $\bar{E}_f=(\bar{E}_1,\bar{E}_2,\bar{E}_3)$ and $\bar{E}_s(\bar{E}_4,\bar{E}_5,\bar{E}_6,\bar{E}_7)$ solve the following minimization problems:

$$\begin{aligned}&\underset{\tilde{E}_f}{\mathrm{MIN}}\ C_{fc}=\sum_{i=1}^{3}C(E_i)\\&\text{subject to}\\&\hat{Q}_f\geq A_fE_f+B_f,\\&E_{fmin}\leq E_f\leq E_{fmax},\\&E_s=\tilde{E}_s,\end{aligned}$$

$$\begin{aligned}&\underset{\tilde{E}_s}{\mathrm{MIN}}\ C_{sc}=\sum_{i=4}^{7}C_i(E_i)\\&\text{subject to}\\&\hat{Q}_s\geq A_sE_s+B_s,\\&E_{smin}\leq E_s\leq E_{smin},\\&E_f=\tilde{E}_f,\end{aligned}$$

where the subscript $_f$ refers to Finland and $_s$ to the Soviet Union.

In addition to these two concepts we will define, by using the same notation, the agreement made between Finland and the Soviet Union. Unfortunately, the interpretation of the agreement is not unique. The agreement specifies that both countries shall reduce their total emissions by 50 per cent. One obvious interpretation is that the 50 per cent reduction strategy is assumed in each region. However, the wording of the agreement leaves room for a interpretation where emissions are not reduced uniformly in the different regions. As a consequence this strategy may create "hot spots" where the deposition per square meter may even increase. We assume here that if countries observe the agreement they reduce emissions by 50 per cent in every region.

We will call this usual form of environmental agreement as the "Club Solution" according to Mäler (1990). Formally it is defined as the solution to the following problem

$$\begin{aligned}&\underset{E_f,\,E_s}{\mathrm{MIN}}\quad C_{club}=\sum_{i=1}^{7}C_i(E_i)\ .\\&\text{subject to}\\&\hat{Q}\geq AE+B,\\&(E_{bj}-E)/E_{bj}=\alpha,\\&E_{min}\leq E\leq E_{max},\end{aligned}$$

where E_{bj} is the emission vector in the base year and α is the agreed rate of reduction.

Because of an additional constraint the club solution obviously implies abatement costs at least as high as the optimal cooperative solution. The interesting empirical question is whether the cost differences between the club solution and the optimal cooperative solution are considerable. If the difference is small, the club solution may be satisfactory as it is easier to manage and it gives a superficial sense of fairness.

4 ANALYSIS OF CLUB SOLUTIONS

To analyse the consequencies of the 50 per cent Club formed by Finland and the Soviet Union we will further assume that exogenous anthropogenic emissions will decrease by 50 per cent by the end of 1995 from the 1980 levels.[3] In what follows, we compute: (1) what are the different deposition levels in different regions, i.e. what is $\hat{Q}$, (2) whether the abatement policy of the 50 per cent Club solution deviates from the cost effective allocation of the abatement activities, (2) whether the Club solution deviates from the noncooperative equilibrium, and (3) how large are the benefits the countries can gain by cheating their neighbours, that is, by deviating unilaterally from an agreement.

The results of the computations are shown in Table 3.[4]

Table 3. A comparison of the cost efficient cooperative abatements costs with abatement costs in noncooperative equilibrium and with 50 per cent Club Solution. Exogenous anthropogenic emissions are assumed to reduce 50 per cent from 1980 levels. The first figure refers to the abatement costs in Finland and the second to the abatement costs in the Soviet Union. An asterix behind a figure means that the deposition targets of the given country are violated.

	Finland		
USSR	Noncooperation	Cooperation	50% Club Solution
Noncooperation	175.10/817.56	174.53*/817.71	175.32*/817.49
Cooperation	174.30/817.77*	174.53/817.77	X
50% Club Solution	174.96/818.0*	X	175.32/818.0

Let us first compare the noncooperative equilibrium with the cost effective cooperative solution. One notes that the Soviet Union loses and Finland gains from the optimal cooperation. The strategy pair (noncooperation, cooperation) refers to the case in which the cooperative policy has not been implemented in the Soviet Union whereas Finland has reduced emissions according the cooperative policy. As a consequence the deposition targets are violated in Finland while the Soviet Union slightly saves in the costs of abatement (FIM .06 million annually). Accordingly, Finland can slightly reduce her abatement costs (FIM .23 million annually) by applying noncooperative policy if the Soviet Union

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[3] It has been estimated that 70% of the background deposition is from anthropogenic sources (Tuovinen, Kangas and Norlund (1990)).

[4] Because our cost functions are piecewise linear and the constraints are linear the optimization problems are solved by linear programming. Noncooperative equilibria are solved by an iterative process which in all of our cases converge toward a unique equilibrium.

maintains the cooperative mode. In this case the target deposition levels are violated in the Soviet Union.

Consider next the 50 per cent Club solution. This agreement implies abatement costs in both countries that are higher than the cost efficient costs and also higher than the noncooperative equilibrium costs. Again, both parties have an incentive to cheat their partner but the differences in the abatement costs in different cases are relatively small. Thus, from the game theory point of view neither the cost efficient cooperative emission vector nor the 50 per cent Club are equilibria in a strict sence since both parties have an incentive to deviate unilaterally from the agreement and to cheat their patner. Cheating as such may be secret or public since monitoring the realization of an environmental agreement is a difficult task to carry out. However, the differences in the abatement costs between the different cases are small enough so that the temptation for not investing in sulphur abatement does not arise from this issue in practice. Consequently, this means that the 50 per cent Club solution may well be considered as a satisfactory and safe agreement. On the other hand, if one could trust that the agreed target levels $\hat{Q}$ would be used also during noncooperation then the incentive for cooperation would be relatively weak.

The analysis carried out so far does not reveal the actual nature of the problem. First, the abatement costs in the Soviet Union are quite high at the same time when the economy of the USSR has not been developing as desired. Thus, there are economic reasons to expect that the Soviet Union will not fully implement the emission reductions determined in the action plan before the end of 1995. Second, the deposition levels will remain quite high even if the agreed emission reductions will be carried out. In that case the deposition vector would be[5]: .30/.42/.74/.56/.38/.72/.92 ($g(S)m^{-2}a^{-1}$). Third, the noncooperative solution has been solved here by assuming that the regional constraints for the depositions are the same as agreed by Finland and the USSR. There is no guarantee, however, that under noncooperation these target levels are applied. The sensitivity of the environmental protection in Finland to different environmental policies applied in the USSR will be studied in sections 5 and 6.

Let us first study the second problem by assuming that the countries form a 80

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[5] If we assume that the countries minimize abatement costs subject to the constraint that the total emissions should decrease by 50% from 1980 levels we get the following deposition vector: .26/.45/.74/.40/.45/.88/.94. The deposition levels in the Southern regions are higher and in Northern regions lower. Given this deposition vector the comparison of the noncooperative equilibrium with the Club Solution and with the optimal outcome gives the result that abatement costs are nearly equal in all three cases. This holds also with the 80% Club. The assumption that the agreement requires decreases of 50% in every regions may be here preferable because it leads to slightly more uniform depositions.

per cent Club. To study this case we will further assume quite optimistically that anthropogenic emissions decrease by 70 per cent from 1980 levels. The solution of this agreement in terms of regional per square meter deposition levels is: .19/.26/.44/.29/.24/46/.58 $(g(S)m^{-2}a^{-1})$. The deposition levels in Southern Finland, Leningrad area and in Estonia are still above the critical loads. However, because there are some minimum bounds to the emission level in each region, it is impossible to reach lower deposition levels by uniform reduction agreements. The computations concerning these deposition levels are shown in Table 4.

Table 4. The comparison of cooperation abatement costs with noncooperative equilibrium and with the 80 per cent Club Solution when anthropogenic emissions decrease 70% from 1980 levels. An asterix behind a figure means that the deposition targets of the given country are violated.

	Finland		
USSR	Noncooperation	Cooperation	80% Club Solution
Noncooperation	1152.23/2289.5	1120.20*/2290.55	1165.46*/2286.47
Cooperation	1120.19/2313.34	1120.20/2313.34	X
80% Club Solution	1152.9/2287.0*	X	1165.46/2287.0

The qualitative differences between optimal cooperation and the noncooperative equilibrium are nearly the same as before. Finland gains from cooperation while the Soviet Union incurs some losses. The total benefits from cooperation are now FIM 5.69 million annually, which is, however, only .17 per cent of the noncooperative abatement costs. The difference with the previous situation is that now Finland has no incentive to cheat the Soviet Union.

Compare next the 80 per cent Club Solution with optimal cooperation. Now the Soviet Union gains FIM 26.34 million annually while Finland loses annually FIM 45.26 million. Total benefits from optimal cooperation compared with the Club Solution are again quite low, i.e. .6 per cent of the abatement costs. The Club Solution is slightly more costly than the noncooperative equilibrium.

It seems that the magnitude of the cost savings from optimal cooperation increases when lower deposition levels are aimed at. However, the cost savings received by the cost effective solution are not so dramatic. There may be several reasons for this. First, according to the transport coefficient matrix the interaction between the two countries is not so strong. The highest coefficient between regions in different countries is only .047.

With smaller size of the regions the transportation coefficients near the border would be higher. This would increase the level of interaction and the magnitude of cost savings. There are some results which strongly support this view. In another paper Kaitala et al. (1990) used only two regions, Finland and the nearby regions of the Soviet Union. With these regional units the 50 per cent Club solution coincides with both the optimal solution and the noncooperative solution. Thus, decreasing the size of the regions further may reveal higher cost savings. The second reason for low differences in equilibrium abatement costs is the arbitrary target deposition vector implied by the emissions in 1980. With some other target depositions the cost differences may be completely different.

5 TARGETS ON DEPOSITION LEVELS

We next turn to study cases where both countries define some target deposition levels and not targets on emissions. The Finnish party has defined its goals quite clearly. Her aim is to reduce the sulphur deposition in the Finnish territory to a level not exceeding $.5g(S)m^{-2}a^{-1}$. However, the Soviet party has not defined such deposition targets. Thus, in what follows we will vary the Soviet deposition target from $.5g(S)m^{-2}a^{-1}$ to $.95g(S)m^{-2}a^{-1}$ while keeping the Finnish target fixed at $.45g(S)m^{-2}a^{-1}$. We specify the Finnish target slightly below $.5g(S)m^{-2}a^{-1}$ because our regions are quite large. This means that there will be some areas with deposition below and some areas above $.5g(S)m^{-2}a^{-1}$. Especially in Northern Finland the deposition is much higher near the Soviet border than near the western border. Thus taking $.45g(S)m^{-2}a^{-1}$ as a target deposition level is an attempt to approximate the real Finnish target. Note also that there are some minimum attainable region–specific deposition levels. This follows because of the exogenous deposition level and because there are some minimum attainable emission levels in every region. Thus although we assume that the anthropogenic emissions decline by 80% from 1980 levels, we cannot reach deposition levels below $.45g(S)m^{-2}a^{-1}$ in Southern Finland and not below $.5(g)m^{-2}a^{-1}$ in Estonia. The results of our analysis are shown in Table 5.

Table 5: Noncooperative depositions [$g(S)m^{-2}a^{-1}$], optimal and noncooperative abatement costs and benefits from optimal cooperation (million FIMa^{-1}) at different Soviet deposition targets. Anthropogenic emissions (70 per cent from the exogenous deposition) are assumed to be reduced by 80% from 1980 levels.An asterix behind a figure means that the deposition targets of the given country are violated.

Target	Optimum Costs	Noncoop. Costs	Cooperative Benefits	Noncooperative Depositions
.45/.5	524.34/1299.10	521.91/1301.72	–2.43/2.62	.24.36.45.5.37.5.5
.45/.6	658.93/672.47	658.92/672.49	–.01/.02	.27.37.45.6.38.6.6
.45/.7	714.69/515.63	1194.41/243.75	479.72/–271.9	.28.29.46*.7.38.7.7
.45/.8	714.69/503.86	1194.41/87.0	479.72/–416.86	.3.29.48*.8.39.73.8
.45/.95	714.69/497.17	1194.41/0	479.72/–497.17	.31.3.49*.87.4.75.94

Note first that the sign of cooperation benefits varies with variations in the Soviet deposition targets. If the Soviet Union aims to reach the lowest attainable target level, i.e. .5g(S)m^{-2}a^{-1}, the Finnish side loses from cooperation and the Soviet side gains. However, if the deposition targets of both countries are low, the net gain from cooperation is negligible and only about .01 per cent of the noncooperative abatement costs. Note also that both countries can reach their targets without cooperation when the Soviet targets are low. Especially if the Soviet deposition target is .6g(S)m^{-2}a^{-1} the noncooperative solution and the optimal cooperative solution approximately coincide. However, if the Soviet target is .7g(S)m^{-2}a^{-1}, the picture changes considerably. Finland cannot anymore reach her target deposition in Southern Finland without cooperation. Now the Finnish party significantly gains from cooperation while the Soviet Union incurs losses. The net gain from cooperation in terms of reduced abatement costs is now about 15 per cent from the noncooperative abatement costs. When the Soviet target approaches .95g(S)m^{-2}a^{-1} the Finnish noncooperative deposition in Southern Finland approaches .49g(S)m^{-2}a^{-1}. Accordingly, the Soviet noncooperative abatement cost approaches zero and the loss from cooperation approaches about half a billion FIM annually. The net gains from cooperation are not any more realized in reduced abatement costs. The abatement costs are in fact higher in the optimal cooperative solution than in noncooperative equilibrium. The gains from cooperation are realized in the sense that Finland reaches her deposition targets.

6 BENEFITS FROM COOPERATION WITH HIGH DEPOSITION TARGETS IN THE SOVIET UNION

To conclude our analysis let us assume that the Soviet deposition targets equal the regional deposition levels of 1987. This implies that the Soviet Union does not have to spend any money on sulphur abatement if Finland maintains or decreases her emission levels and if the exogenous deposition level does not increase. Under these assumptions the noncooperative policy of the Soviet Union is simply to maintain the current emission levels. Let us assume in addition that anthropogenic emissions decrease by 70 per cent from 1980 levels. Now we can easily compare the noncooperative abatement costs to cooperative abatement costs when the Finnish target deposition varies.

The results of this comparison are shown in Fig. 3. Symbol C_{fc} refers to Finnish cooperative costs, C_{fn} to Finnish noncooperative costs and symbol C_{sc} to Soviet cooperative costs. Note first that without cooperation Finland cannot reach a deposition target below .532g(S)m^{-2}a^{-1} while with cooperation .430g(S)m^{-2}a^{-1} is attainable. Between target levels .88g(S)m^{-2}a^{-1} and .655g(S)m^{-2}a^{-1} it is optimal for Finland to abate only her own emissions and there are no potential gains from cooperation. Below target level .665g(S)m^{-2}a^{-1} optimal cooperation requires that also Soviet emissions will be abated. Down to the target level .532g(S)m^{-2}a^{-1} cooperation benefits will be realized in a form of lower abatement costs. At the target level .532g(S)m^{-2}a^{-1} the cooperative abatement costs are FIM 449.15 million lower annually than noncooperative abatement costs. The part of Soviet abatement costs is FIM 88.0 million annually. Thus although Finland should pay the Soviet costs, her net gain is FIM 361.15 annually i.e. cooperation decreases the Finnish abatement costs by 31%. Deposition levels below .532g(S)m^{-2}a^{-1} in Finland can be reached only in cooperation. The proportion of Soviet abatement costs is considerably higher in optimal cooperation

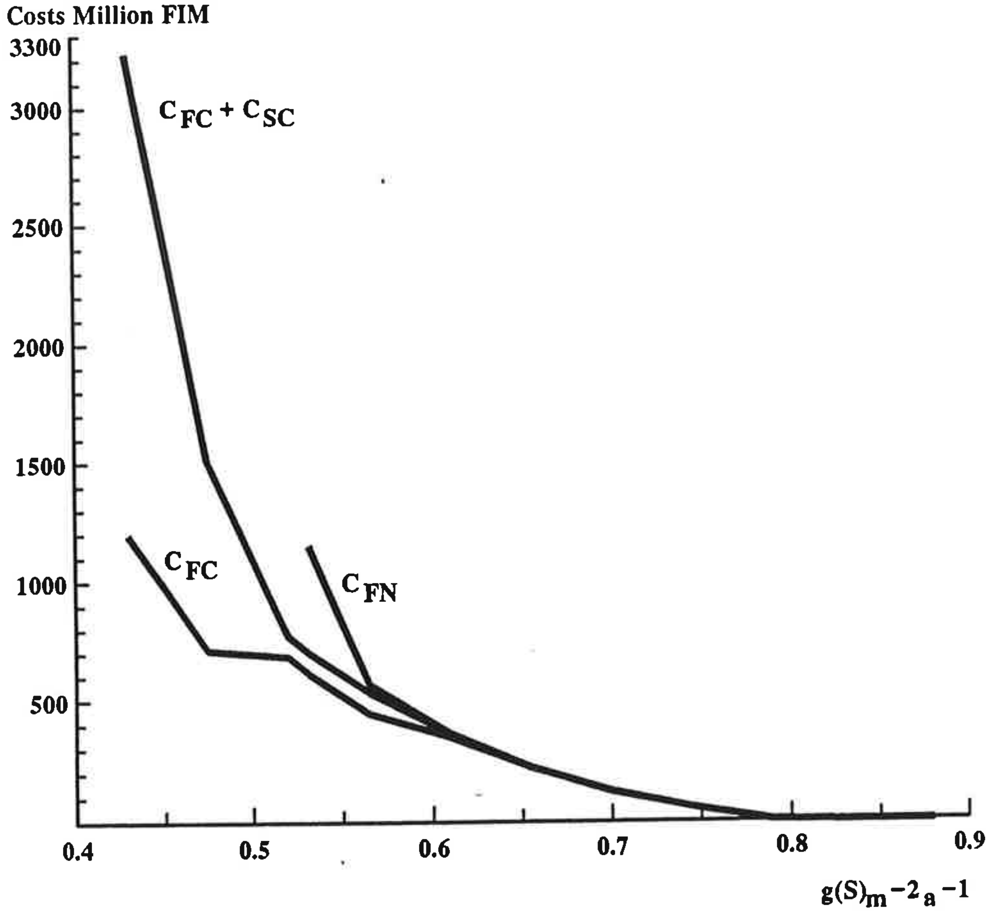

Fig. 3. Finnish cooperative and noncooperative and Soviet cooperative abatement costs as a functions of the Finnish deposition targets.

solutions. When the Finnish target is at the lowest attainable level, Soviet abatement costs are nearly 63% of the total minimum costs.

The optimal regional allocation of the Soviet abatement costs is an interesting question. The Finnish authorities are now devising a scheme to reduce emissions in Kola by about 90 per cent. It involves both technical and economic assistance from Finland. In this framework such a policy is not cost efficient. Above the Finnish target level

$.52g(S)m^{-2}a^{-1}$ Soviet emissions are optimal to abate only in Estonia. Below $.475g(S)m^{-2}a^{-1}$ but above $.43g(S)m^{-2}a^{-1}$ Soviet emissions should be abated in Estonia and in Leningrad area. Only at the lowest target level Soviet emissions should be abated in the Kola peninsula because of their contribution to the deposition in Southern Finland. The deposition target constraint of Northern Finland is not binding in any of these examples. However, there are at least two reasons why these results must be taken with caution. First, the whole Northern Finland is taken as one regional unit. The deposition is not uniformly distributed over this region, the deposition of the eastern part being at least twice as high as the deposition in the western part. Thus using smaller regions in Northern Finland may give different results. Second, the deposition target in Northern Finland should be lower than in Central and Southern Finland because of a more vulnerable environment.

7 CONCLUSIONS

We have analysed an acid rain game between Finland and the USSR. The sulphur deposition contributing to the environmental damages is an acute and severe environmental problem in each country. Despite strong local depositions the sulphur problem has strong transboundary components – an essential fraction of the emissions are transported distances exceeding local dimensions.

We analysed three different solutions to the sulphur emission game by assuming the approach that the target levels of the depositions are posed and are constraining. First, the cost efficient solution was analysed under the assumption that the countries agree to minimize the joint costs of reducing sulphur emissions such that the agreed targets for depositions will be reached. Second, the costs of the current agreement on 50 per cent reductions in sulphur emissions were determined. And third, the noncooperative game solution was analysed under different assumptions on the critical deposition levels. It was shown that the three solutions did not differ crucially from each other if the agreed target levels were applied even in the absence of cooperation in environmental policies, that is, under noncooperation. This means that once an agreement is reached, it is a safe agreement in the sense that no party has a strong incentive to cheat the partner, that is, to leave the agreement unobserved. The opposite side of this property is, however, that there does not exist a strong incentive for environmental cooperation either.

The conclusions change, however, if we observed that it is highly uncertain what kind of environmental policy will be followed in the USSR in the absence of environmental cooperation. There are reasons to expect that in the absence of communication on the environmental problems between Finland and the USSR there will be any advances in the protection of environment and the current situation will be the status quo. As was shown in section 5, in that case Finland cannot reach the target levels for deposition she has posed and the abatement investments will become expensive. In this situation the potential cooperation benefits are high. The problem is, however, that the Soviet Union will lose from cost efficient cooperation while Finland gains. This means that the implementation of cost efficient agreements may entail politically difficult financial transfers from Finland to the Soviet Union.

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