Improving Quality of Surface Waters with Coalition Projects and Environmental Subsidy Negotiation

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Abstract

We can observe new reasons for improving water protection policies: climate change calls for higher security for drinking water sources, increasing demand for improving water quality for swimming purposes in recreational areas, higher pressure on responsibility for water quality crossing national borders. Our paper presents an application of combinatorial auction theory to the problem of cleaning waters in streams where individual polluters can create various coalitions when submitting proposals for financial support to individual or common projects. The practical case has shown significant savings of social costs if the coalition solutions are realized. There is an information asymmetry between the polluters when elaborating common application for an investment subsidy for their projects. A series of economic laboratory experiments was carried out to pretest subjects' potential behaviour here. The results showed that 75% of the groups found the (theoretical) first best solution. Subsidies required tended to be relatively low, making the competition for subsidies very stiff.

Introduction

Managing water pollution is one of the key problems of environmental policies. We can observe several stages in developed countries. After a period of terrible deterioration of the watercourses in the 1960s-80s, there was a period of significant improvement in the 1980s-90s (depending on the country and region) caused by dealing mostly with larger pollution sources. Currently we can observe new challenges and reasons for improving water protection policies:

climate change, with its difficult-to-predict impacts on water regimes, calls for higher security for drinking water sources, an increasing demand for improving water quality for swimming purposes in recreational areas, and higher pressure on responsibility for water quality crossing national borders.

Planning and management of surface water protection programs and projects is a typical area of environmental protection where governments intervene. Various public funding programs for (especially public) capital investment projects in water protection are some of the typical forms of intervention (political instruments). Achieving at least

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close-to-cost-effective allocations of these sources is a standard (both theoretical and practical) requirement.

Until recently, building individual wastewater treatment plants (WWTP) at each city and town over 2000 inhabitants (according to [1]) has been the most frequent technological solution to the policy requirements. Dealing with relatively steep individual and aggregated wastewater treatment abatement curves and their potential shifts due to environmentally oriented technological progress were typical problems when struggling for high environmental efficiency of wastewater treatment.

The new policy strategies and goals assume solving river basin pollution problems at small pollution sources as well, and focusing on critical parts of large river basins. Due to the fact that these polluters are located near each other in many cases, a relatively new phenomenon enters the scene – various common projects to reduce water pollution are possible. For a similar idea see the U.S. Department of Agriculture's Mississippi River Basin Healthy Watersheds Initiative," where rather than working with dispersed individual polluters, a portion of conservation program funds is used to work with many cooperating polluters – farmers located in select, high-priority watersheds [2]. We would like our paper also to contribute to promoting "river basin management at the lowest appropriate level" [3].

This brings new challenges to the theory and practice of the social science side of the problem. Combinatorial auctions seem to be one of the most relevant methodological solutions that can be developed and applied. They help search for optimal (cost-efficient) solutions and calculate parameters of background models that can be used in economic laboratory experiments pre-testing subjects' behavior, especially in situations where there an information asymmetry between the regulator (authority, government) and polluters, and among the polluters. (For a review of experiments related to environmental markets see [4].)

The methodology that introduces the combinatorial auctions theory for solving the problem is described in the first part. For the theory of combinatorial auctions see [5, 6]. For an example of experimental testing the models of combinatorial auctions see [7].

An illustrative application is the case of a small river basin with four municipalities polluting Powder Brook, which is presented in the second part. In spite of some necessary simplifications, the authors have striven for maximum approximation to the real situation in one of the tributaries of the Elbe river basin near the Czech-Polish border. Similarly as in [8] and [9], it is a case where the (state) authority offers financial support to wastewater cleaning projects. In the present study, however, polluters apply for such support in multiple (1-4) member coalitions. A series of economic laboratory experiments was carried out to pre-test whether the subjects could find the optimal solution, i.e., find the optimal coalition, and what would be their total surplus and how the surplus would be divided among the parties under informational asymmetry. The institutional setting of the experiments in based on Czech legislation and the experiments allow us to eval-uate the proposed institutional changes with relatively low costs and in a short time [10]. These experiments are described in the third part of the paper.

Background Methodology

Step-by-Step Process Description

The whole procedure of initiating or updating river basin plans consists (when simplified) of six steps (Fig. 1). The provisions of [11-13] and their respective executive decrees [14, 15] create the policy background for this process in the Czech Republic. For more details about this methodology, see its pilot application in Section 3 of this paper (especially Tables 1-8) and [16].

When a decision is made about initiation of the plan acquisition or updating, the planner shall make or arrange to make an analysis of problems in water management in the area and then announce – e.g., as part of publishing a "Preliminary overview of major problems in water management" – the fact that sewage and wastewater treatment will be solved with respect to the facts identified in the area (step 2.1). In the next step (2.2), a draft list of individual and coalition designs for wastewater treatment projects is elaborated
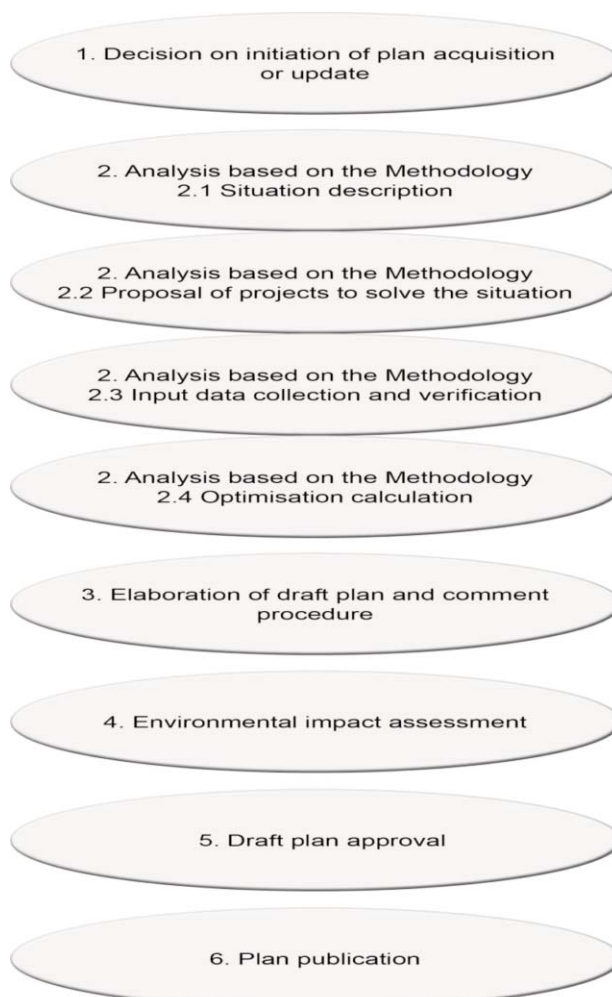

Fig. 1. Planner's work procedure using the methodology.

Table 1. List of projects proposed for assessment pursuant to the methodology.

Project No.	Project title	WWTP location
Individual projects		
1.	A	by municipality A
2.	B	by municipality B
3.	C	by municipality C
4.	D	by municipality D
Coalition projects		
1.	AB	by municipality B
2.	ABC	by municipality C
3.	BC	by municipality C
4.	CD	outside either municipality
5.	BD	at confluence of Powder Brook and Unnamed
6.	BCD	at confluence of Powder Brook and Unnamed
7.	ABCD	

Table 2. Data on proposed projects – calculated wastewater production.

Project No.	Project title	Number of EI	WW production (m^3/day)	WW production (m^3/year)
Individual projects				
1.	A	100	15	5,475
2.	B	250	37.5	13,687.5
3.	C	500	75	27,375
4.	D	750	112.5	41,062.5
Coalition projects				
1.	AB	350	52.5	19,162.5
2.	ABC	850	127.5	46,537.5
3.	BC	750	112.5	41,062.5
4.	CD	1250	187.5	68,437.5
5.	BD	1000	150	54,750
6.	BCD	1500	225	82,125
7.	ABCD	1600	240	87,600

(Table 1). The list includes all projects that evidently (based on an "expert's first sight") cannot be excluded for technical, economic, environmental, morphological, political (people in municipality *X* may disagree with building a joint WWTP with municipality *Y*, even though it is an efficient option economically and otherwise), or institutional reasons (e.g., requirements for use of public subsidies rule out the project). There is a fact that may lead to an increase in the number of coalitions/projects. It is situation that a WWTP for an individual polluter or for a group of polluters may theoretically be located on one (usually near the last polluter downstream) or at multiple (alternative) sites.

Input data collection and verification is the next step (2.3). The analysis author shall produce the following information:

(i) Calculated wastewater production before and after WWTP implementation using indicators required by the legislation plus other indicators if important for the given case

(ii) Information on receiving watercourses into which the treated wastewater from the sites will be discharged is collected

(iii) The assessment of compliance with requirements on water discharge into surface waters (according to requirements specified by the Water Act and its executive decrees)

(iv) The most important for the issue discussed in our paper (search for cost-effective ways of the solution) is a cost estimate for all the individual and coalition designs (Table 8).

The cost estimate (an interval estimate is also possible) shall be made by the expert(s) based on the real expected costs of the respective technologies, typically consisting of the WWTP investment costs, sewage investment costs, pumping station investment costs, and investment costs of other facilities that are acquired under the project (settlement pools, etc.).

An optimization calculation is carried out (see the following section *Model for Optimizing Abatement Costs* for details on the calculation methodology related to step 2.4 in Fig. 1) and its results enter the draft plan (step 3), which undergoes an internal and external comment procedure. The conclusions from the comment procedures have to be fully resolved – the comments are either accepted or their rejection is duly substantiated. One of the possible comments may be a requirement to include in the analysis additional, typically coalition projects or projects with different WWTP locations. It may also become evident that the first/previous round included a design/project that would have been unfeasible and is pointless to include in the optimization calculation. In such a case steps 2.2-2.4 are repeated and a new optimization calculation is made and the draft plan is modified according to its result.

The modified draft plan concept is then commented upon and assessed pursuant to Act No. 100/2001 Coll. on Environmental Impact Assessment [17] (step 4). The comments and position statements obtained within the environmental impact assessment are integrated into the draft plan. The final draft wording is prepared, including alternative options and required annexes. The draft is submitted to the superordinate authority for approval. If the plan is approved (step 5), it is subsequently published (step 6) on the specified website and becomes binding for the area in question.

Model for Optimizing Pollution Abatement Costs

An optimization calculation is made for the approved possible individual and coalition designs (projects). Its purpose is to find a combination of projects, individual and coalition ones, that will achieve the set watercourse pollution reduction targets at the lowest costs.

The solution to this problem is based on the reverse combinatorial auction exercise. The reverse combinatorial auction problem is characterized by a single buyer (the environmental public authority in our case) and a larger number of sellers (municipalities-polluters in our case). The advantage of this model is that the number of polluters and their projects can be very large, which makes finding the optimal solution with an intuitive way quite difficult.

The buyer tries to buy at least the required set of items from the sellers at minimum costs. Let us assume that m potential sellers $S_1, S_2, ..., S_m$ are offering set R with r items, $j = 1, 2, ..., r$, to the one buyer B (Fig. 2).

The bid b_h made by the seller S_h, $h = 1, 2, ..., m$, is defined as:

$$b_h = \{C, c_h(C)\} \tag{1}$$

...where $C \subseteq R$ is a combination of items, and $c_h(C)$ is the offered price by seller S_h for the combination of items C.

The objective is to minimize the buyer's cost given the bids made by sellers. Constraints establish that the procurement provides at least a set of all items.

Bivalent variables are introduced for model formulation:

$y_h(C)$ is a bivalent variable specifying whether the combination C is bought from the seller S_h ($y_h(C) = 1$).

The reverse combinatorial auction can be formulated as follows:

$$\sum_{h=1}^{m} \sum_{C \subseteq R} c_h(C)\, y_h(C) \rightarrow \min \tag{2}$$

subject to

$$\sum_{h=1}^{m} \sum_{C \subseteq R} y_h(C) \geq 1, \quad \forall j \in R, \tag{3}$$

$$y_h(C) \in \{0, 1\}, \ \forall \ C \subseteq R, \ \forall h, \ h = 1, 2, ..., m. \tag{4}$$

The criterion function expresses the objective, i.e., minimization of the buyer's (authority's) costs. The restriction ensures the purchase of the required set of items.
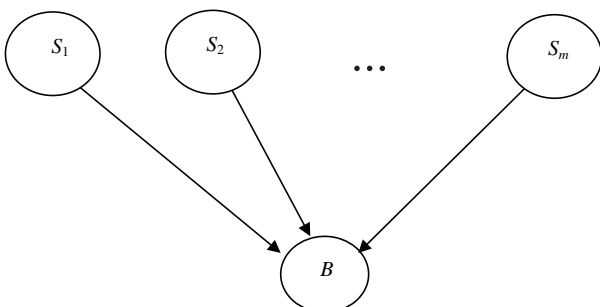

Fig. 2. Reverse auctions.

There is a question if or to which extent the optimum result can be achieved by means of a real auction in the case of information asymmetry between the subjects. We pre-tested behaviour in this situation by economic laboratory experiment (see the *Laboratory Pre-Tests of Subject Behavior* section).

Nevertheless, the optimum result can be calculated knowing the cost information determined by an educated estimate. The CRAB (CombinatoRial Auction Body Software System) can be used for more complex situation (i.e., larger number of designs being offered, particularly coalitions). It enables generating, solving and testing of combinatorial auction problems [18]. The system solves the problems using the Balas method or a primarily dual algorithm. Any solver for bivalent programming tasks can also be applied to solve the cheapest combination of preselected possible designs (projects).

The optimum combination of projects calculated is presented as a draft plan for the comment procedure (step 2.4 in Fig. 1).

Powder Brook Case Study

Based on legislative requirements of the Czech Republic, i.e., with respect to obligations specified by Section 22a of Water Act No. 254/2001 [12], the owner of the Catchment Plan has to make an update that will lead to an improvement in the Powder Brook catchment in order to ensure achievement of targets defined for surface waters pursuant to item (a) of said section. These targets should be achieved using the most cost-effective measures. The planner has decided to use the certified methodology briefly described in this paper for elaborating on the analytical documents.

Situation Description

The Powder Brook catchment (Fig. 3) contains municipalities A, B, and C. Municipality D lies in a sub-catchment of the Powder Brook (Unnamed). The two catchments are separated by the Titmouse Hills ridge, which is a nature
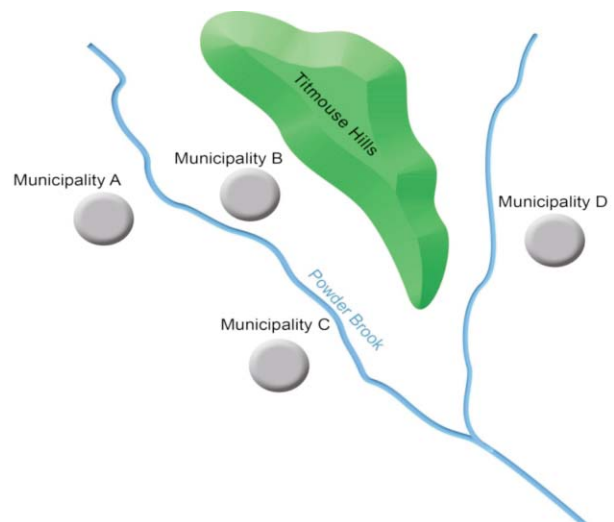

Fig. 3. Layout of the Powder Brook catchment.

reserve. At present, wastewater is discharged directly into the watercourses of the Powder Brook and its Unnamed tributary. With the exception of municipalities C and D there are only minor pollution producers in the basin. In spite of this, it is necessary to design a way to significantly reduce the amounts of pollutants discharged in the area, because fish populations in the Powder Brook have died out in the past and the brook runs into a reservoir from which water is taken for drinking purposes.

The planner made an analysis of the water management problems in the area and then, along with the publication of the "Preliminary overview of major water management problems," it announced that sewage and wastewater treatment would be provided with respect to the facts identified in the Powder Brook basin.

Data Collection

As concerns cooperation of the municipalities, four individual and 11 coalition solutions can be theoretically assumed in this case The experts developing the analysis proposed a list of individual and coalition project designs for wastewater treatment that cannot be excluded beforehand for technical, economic, environmental, morphological, political, or other reasons (Table 1). To keep the case simple, only the most realistic location of the WWTP was considered for each project.

The analysis author collected data for each individual and coalition design pursuant to the list in Table 1 and entered them in the respective tables. The calculated wastewater production from the municipalities was entered in Table 2.

The collected data on the wastewater production in each locality (municipality) were used for calculating the data on pollution production monitored pursuant to Government Regulation No. 61/2003 Coll. [19], and ČSN 75 6401 [20], which specifies the daily production of BOD_5 at 0.06 kg/EI, P_{total} at 0.0025 kg/EI, N_{total} at 0.015 kg/EI, and $N-NH_4^+$ at 0.011 kg/EI (Table 3).

There is rich literature dealing with pollutants in rivers and lakes. The analyses of concrete situations at concrete sites always have to deal with the specific pollutants. While the basic indicators are usually the same or similar in different conditions, the experts deal with different pollutants. Every analysis should fit with the legislative requirements on the water quality, which is in new EU countries mostly harmonized with EU legislation. Readers of *Polish Journal of Environmental Studies* could meet several approaches of involving pollutants for analysis. For example, when determining the quality category of stream waters included in the small retention program in three areas of Malopolska in view of their use for public supplies of water intended for consumption, Kanownik et al. [21] investigated 20 physico-chemical and two microbiological indicators. Indicators of COD_{Mn}, BOD_5, NH_3-N, TP, TN, F, surfactants (AS – alkyl-sulphate, LAS – linear alkylbenzene sulfonate), SO_4^{2-}, and Cl were included in a study by Hezhong et al. [22]. Descriptive statistics of physico-chemical data of water temperature, dissolved oxygen, hardness, total nitrogen, total phosphorus, N:P, and chlorophyll-*a* are provided for 13 Polish ponds in

Table 3. Data on proposed projects – calculated wastewater pollutant production.

Project No.	Project title	BOD_5	P_{total}	N_{total}	Suspended solids
		(kg/year)			
Individual projects					
1.	A	2,190	91.25	547.5	2007.5
2.	B	5,475	228.125	1368.75	5018.75
3.	C	10,950	456.25	2737.5	10037.5
4.	D	16,425	684.375	4106.25	15,056.25
Coalition projects					
1.	AB	7,665	319.375	1916.25	7026.25
2.	ABC	18,615	775.625	4653.75	17,063.75
3.	BC	16,425	684.375	4106.25	15,056.25
4.	CD	27,375	1,140.625	6843.75	25,093.75
5.	BD	21,900	912.5	5475.0	20,075.0
6.	BCD	32,850	1,368.75	8212.5	30,112.5
7.	ABCD	35,040	1460	8760.0	32,120.0

[23]. A total of 25 VOCs (volatile organic compounds) and 38 SVOCs (semivolatile organic compounds) were selected from the "black list" of priority organic water pollutants jointly developed by China's Ministry of Environmental Protection in a study by Han et al. [24].

Table 4 shows the calculated pollution production after implementation of the individual (alternative) WWTP. The assumed treatment efficiency was set at 90% in all cases.

Table 4. Data on proposed projects – assumed wastewater pollutants production from WWTP after their implementation.

Project No.	Project title	BOD_5	P_{total}	N_{total}	Suspended solids
		(kg/year)			
Individual projects					
1.	A	219	9.125	54.75	200.75
2.	B	547.5	22.8125	136.875	501.875
3.	C	1,095	45.625	273.75	1,003.75
4.	D	1,642.5	68.4375	410.625	1,505.625
Coalition projects					
1.	AB	766.5	31.9375	191.625	702.625
2.	ABC	1,861.5	77.5625	465.375	1,706.375
3.	BC	1,642.5	68.4375	410.625	1,505.625
4.	CD	2,737.5	114.0625	684.375	2,509.375
5.	BD	2,190	91.25	547.5	2,007.5
6.	BCD	3,285	136.875	821.25	3,011.25
7.	ABCD	3,504	146	876	3,212

Table 5. Characteristics of watercourses to receive treated wastewater.

Assumed WWTP location	Receiving watercourse	Basic hydraulic characteristics of watercourse	Basic water quality characteristics of watercourse	Remark
A	Powder Brook	Q_{min}, max. M, ...	BOD_5, COD_{Cr}, Suspended solids, $N-NH_4$, P_{total}...	salmon stream
B	Powder Brook	Q_{min}, max. M, ...	BOD_5, COD_{Cr}, Suspended solids, $N-NH_4$, P_{total}...	
C	Powder Brook	Q_{min}, max. M, ...	BOD_5, COD_{Cr}, Suspended solids, $N-NH_4$, P_{total}...	
D	Unnamed	Q_{min}, max. M, ...	BOD_5, COD_{Cr}, Suspended solids, $N-NH_4$, P_{total}...	
Outside municipalities	Confluence of Powder Brook and Unnamed	Q_{min}, max. M, ...	BOD_5, COD_{Cr}, Suspended solids, $N-NH_4$, P_{total}...	salmon stream, coalitions BCD, and ABCD

Table 6. Permissible minimum efficiency of treatment of wastewater discharged (minimum decrement percentage) in percentages, pursuant to Annex 1 to to Government Order No. 61/2003 Coll [19].

WWTP category (EI)	COD_{Cr}	BOD_5	$N-NH_4^+$	N_{total}	P_{total}
< 500	70	80	-	-	-
500-2000	70	80	50	-	-
2001-10,000	75	85	60	-	70
10,001-100,000	75	85	-	70	80
> 100,000	75	85	-	70	80

For discharges of treated wastewater into the receiving watercourse, the experts collected data on the watercourses into which the treated wastewater will be discharged in each location (Table 5).

The assessment of compliance with requirements for water discharge into surface waters again worked with requirements set by the Waters Act and its executive decrees (Tables 6 and 7).

Table 8 shows estimates of the respective one-off costs of the measurements included in analysis, with respect to specific conditions.

Direct investors' costs were introduced into the analysis. More social costs could be introduced in more detailed analyses.

Computing Optimal Solution

The mathematical model of the exercise for analysis is as follows:

$$N=6500y_A+16250y_B+29000y_C+32750y_D+$$
$$27750\,y_{AB}+41750y_{BC}+59000y_{BD}+65000y_{CD}+50000y_{ABC}+$$
$$69000\,y_{BCD}+73000y_{ABCD}\rightarrow min$$

$$y_A + y_{AB} + y_{ABC} + y_{ABCD} \geq 1$$
$$y_B + y_{AB} + y_{BC} + y_{BD} + y_{ABC} + y_{BCD} + y_{ABCD} \geq 1$$
$$y_C + y_{BC} + y_{CD} + y_{ABC} + y_{BCD} + y_{ABCD} \geq 1$$
$$y_D + y_{BD} + y_{CD} + y_{BCD} + y_{ABCD} \geq 1$$
$$y_h(S)\in \{0,1\}, \ \forall S \subseteq \{A, B, C, D\}, \ \forall h, h = 1, 2, \ldots, 11$$

The optimum solution to this exercise is:

$$y_A= 0, y_B = 0, y_C = 0, y_D = 0, y_{AB} = 0, y_{BC} = 0, y_{BD} = 0,$$
$$y_{CD} = 0, y_{ABC} = 0, y_{BCD} = 0, y_{ABCD} = 1$$

This means that one coalition project, ABCD, should be proposed for implementation. The total costs are N = 73,000.

Table 7. Emission standards (mg/l) pursuant to Annex 1 to Government Order No. 61/2003 Coll [19].

WWTP category (EI)	COD_{Cr}		BOD_5		$N-NH_4^+$		N_{total}		P_{total}	
	Average	Max.	Average	Max.	Average	Max.	Average	Max.	Average	Max.
< 500	150	220	40	80	-	-	-	-	-	-
500-2000	125	180	30	60	20	40	-	-	-	-
2001-10,000	120	170	25	50	15	30	-	-	3	8
10,001-100,000	90	130	20	40	-	-	15	30	2	6
> 100,000	75	125	15	30	-	-	10	20	1	3

Table 8. Estimated (one-off) cost of projects (in thousand of CZK).

Project No.	Project title	WWTP	Sewage	Other facilities	Total costs	Remarks
Individual projects						
1.	A	4,000	2,500	None	6,500	
2.	B	10,000	6,250	None	16,250	
3.	C	14,000	12,500	2,500	29,000	Pumping station for a hamlet
4.	D	18,000	14,750	None	32,750	
Coalition projects						
1.	AB	14,000	8,750	5,000	27,750	Extra piping
2.	BC	18,000	18,750	5,000	41,750	Pumping station
3.	CD	22,000	28,000	15,000	65,000	Bridge over a brook, pumping station
4.	ABC	23,000	23,000	4,000	50,000	Pumping station
5.	BD	20,000	39,000	-	59,000	
6.	BCD	26,000	28,000	15,000	69,000	Bridge over a brook
7.	ABCD	28,000	30,000	15,000	73,000	

The costs of individual projects, which is a common practice, would be CZK 84.5 million. This solution therefore constitutes a savings of CZK 11.5 million compared to the implementation of individual projects only.

Laboratory Pre-Tests of Subject Behavior

A laboratory experiment was conducted in order to simulate the process of forming coalitions among municipalities when applying for subsidies for their pollution abatement projects. To approach reality as much as possible, real data were utilized in a process resembling an application for EU or Czech State Environmental Protection Fund subsidies. This is in line with the conclusions of Tisdell [25], who suggests that using real geophysical data can lead to different results than utilizing stylized ones. It is different from our first attempts to pre-test similar hypotheses on subjects' behaviour, where ideal data were used [26].

The model presented in the previous section was used to calculate the optimal solution. Furthermore, rewards for the laboratory experiment participants (subjects) were designed in a way to copy the incentive structure faced by real representatives.

Experimental Design

Each subject represented one of four differently sized municipalities in the Powder Brook basin. This region was identical in all cases so the participants were divided into groups of four, and each foursome faced the same situation. The representatives were asked to address the pollution of the brook by constructing a WWTP. They could choose from individual or coalition projects, which could include two, three or four municipalities.

Each representative received only information about their own costs and funds and was not allowed to show it to others. It was thus concealed from participants which solution would be Pareto-optimal and motivated them to obtain information about the costs and funds of others through negotiations. At the same time, it was in their interest to pretend they had fewer funds at their disposal than was true because then they could free-ride in a coalition without others knowing.

The optimal solution was a coalition of all four parties, as shown in the previous section. The differences, however, were not so striking as to be noticed if players bid significantly less than they could (for information, the costs of the optimal solution ABCD were 86% of those of its opposite A+B+C+D).

Nevertheless, the players did not play only against the other three in their group. In order to be implemented, each project required a subsidy, as the maximum investment of each participant was set at 30% of their individual project costs, i.e. a willingness to contribute from their own municipality budget was introduced to the experiment. They were told that there were sufficient assets to subsidize only about 50% of the projects in the respective fund and that the ones requesting lowest subsidies relative to size would be selected.

The subjects were promised a basic show-up financial reward regardless of the result of their negotiation. They were, however, offered a bonus if their project obtained a subsidy (and could therefore be implemented) and a further bonus if they spent less than their maximum while still receiving the subsidy. This design was supposed to create a dilemma between deceiving project partners by bidding less and at the same time behaving responsibly not to jeopardize the success of the whole coalition.

The experiment was pilot tested on 3 groups of University of Economics, Prague master students of

Table 9. Experiment results.

Experiment group No.	Coalition structure (project group)	Total		Investment			
		Costs	Subsidy	A	B	C	D
1	(AB), C, D	89,500	64,525	1,650	4,800	8,700	9,825
2	(ABCD)	73,000	49,560	1,900	4,140	7,800	9,600
3	(ABCD)	73,000	49,405	195	4,875	8,700	9,825
4	(ABCD)	73,000	49,726.5	1,657.5	4,831	6,960	9,825
5	(ABCD)	73,000	47,650	1,950	4,875	8,700	9,825
6	(ABCD)	73,000	53,650	1,850	2,000	5,700	9,800
7	(ABC), D	82,750	60,350	1,600	4,300	7,000	9,500
8	(ABCD)	73,000	48,000	1,700	4,800	8,700	9,800

Environmental and Resource Economics and Policy courses. The feedback was incorporated into the final materials for the experiments.

Experiment Results

The experiments were conducted with eight student groups of four members each playing the roles of representatives of the municipalities located in the Powder Brook basin. The experiments took place in November 2013 with students of University of Economics Prague (16 students of the Decision Theory course, eight students of the Environmental Policy course and 8 students of the Public Administration of Environmental Protection course).

The optimal solution with respect to the total costs (coalition structure (ABCD), total costs 73,000) was compared with experimental results (Table 9).

Participants in the experiments created the optimal coalition structure (ABCD) in six cases out of the eight groups. In one case (group 1 in Table 9), a two-member coalition (AB) plus two individual submissions were formed, and in one case (group 7), a three-member coalition (ABC) plus one individual submission were formed. These coalitions, however, require higher costs than the optimal four-member coalition. Higher costs lead to higher subsidies required. Limited resources for provision of subsidies leads to a reduction in requirements for these subsidies. It is therefore interesting to analyze the results with respect to the magnitude of the subsidy required.

As mentioned in the experimental design, only 50% of the project groups (regions in reality) were supported as an expression of the scarcity of financial sources. So, participants in the individual groups competed among themselves and experimental groups competed with each other to obtain support and make it as high as possible. In our case, only 4 out of the 8 experimental groups (groups 2, 3, 5, 8) received subsidies. All these groups concluded their negotiations with the optimal coalition structure. The highest support received was 49,560 for group 2.

Negotiations among the group members regarding the value of their investments, which would complement support to total costs, were also important. The investment structures for groups 2, 5, and 8 were substantially similar. The investment by member A was very low in group 3 in comparison with the other groups. This raises a presumption that the participants agreed in favour of A, to maximize the benefit of the remuneration policy and subsequently split the win.

Conclusions

While tackling problems connected to environmental protection where for minimizing the social costs it is efficient to create coalitions and apply for subsidies for joint projects, the theory of combinatorial auctions can provide a good theoretical background. At the same time, the theory itself can be enriched through examining such cases.

In the paper one can find the case of the high-priority basin of the Powder Brook, where the priority is to improve water quality for drinking purposes and for biodiversity protection. There are several polluters in the basin, who in the case they cooperate, i.e., realize common projects on cleaning the water, can save social costs, and share the extra cake created.

The presented model can serve for computing optimal solutions in situations where we trust expert estimates of abatement costs. It could be a situation of the costs of municipal WWTPs. In the case of asymmetric information, i.e., where subjects do not share information on their costs with other polluters and/or the authority, the model can still be useful:

(i) For computing the structure of the coalition projects submitted to minimize spending from the fund

(ii) For computing the theoretically optimal solution for testing various hypotheses on subjects' behaviour under various institutional settings and behavioural rules in laboratory experiments

This study takes advantage of the latter option and designs an experiment that copies the incentive structure of

the actual municipalities. Such a setting should be able to indicate whether it is possible to achieve an optimal solution in the real world. The results seem to be very optimistic in this respect. Participants tended to realize the savings offered by coalition projects; out of the eight groups, there were six coalitions of four (which was the optimal solution), one coalition of three, one coalition of two, and only three individual projects. Furthermore, the subsidies required tended to be relatively low, making the competition for subsidies very stiff; the fourth-best offer (the last one to obtain the subsidy) requested 104% of the minimum subsidy (i.e., a case where every representative bids their entire funds).

The experiment was proposed to match the situation of real municipality representatives as closely as possible. However, this means that it cannot be easily described using game theory terminology. For a more game theory-focused approach, see [27]. It may be an interesting challenge for future research to replicate the experiment with slightly alternated parameters or stricter limitations on the means of negotiations.

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