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REVERSE COMBINATORIAL AUCTIONS IN MUNICIPALITY WASTEWATER MANAGEMENT: ECONOMIC LABORATORY EXPERIMENTS WITH 13 SUBJECTS

A reverse combinatorial auction was applied to find an optimal solution for reduction of the water pollution problem under information asymmetry. A case study of 13 polluters in a selected microregion watershed was developed to conduct laboratory experiments to test stakeholders' behavior and study the process of negotiation between them. The results suggest that the tested method of reverse combinatorial auction might have a potential to produce solutions close to the optimal one.

Keywords: *water pollution; wastewater management; economic laboratory experiment; combinatorial auctions.*

JEL: Q5; C92; D82.

Алесь Ліса, Петр Шауер, Петр Фіала

ЗВОРОТНІЙ КОМБІНАТОРНИЙ АУКЦІОН У МУНІЦИПАЛЬНОМУ УПРАВЛІННІ СТІЧНИМИ ВОДАМИ: ЕКОНОМІЧНИЙ ЛАБОРАТОРНИЙ ЕКСПЕРИМЕНТ НА 13 СУБ'ЄКТАХ

У статті продемонстровано застосування зворотнього комбінаторного аукціону для пошуку оптимального способу зниження забруднення води в умовах інформаційної асиметрії. Експеримент проведено на 13 суб'єктах в абстрактному мікрорегіоні в басейні ріки для перевірки поведінки учасників переговорів. Результати експерименту доводять, що зворотній комбінаторний аукціон можна використовувати як спосіб знаходження оптимального рішення соціально-економічних проблем на окремій території.

Ключові слова: *забруднення води; управління стічними водами; економічний лабораторний експеримент; комбінаторний аукціон.*

Табл. 5. Літ. 15.

Алесь Лиса, Петр Шауэр, Петр Фиала

ОБРАТНЫЙ КОМБИНАТОРНЫЙ АУКЦИОН В МУНИЦИПАЛЬНОМ УПРАВЛЕНИИ СТОЧНЫМИ ВОДАМИ: ЭКОНОМИЧЕСКИЙ ЛАБОРАТОРНЫЙ ЭКСПЕРИМЕНТ НА 13 СУБЪЕКТАХ

В статье показано применение обратного комбинаторного аукциона для поиска оптимального способа снижения загрязнения воды в условиях информационной асимметрии. Эксперимент проведён на 13 субъектах в абстрактном микрорегионе в бассейне реки для проверки поведения участников переговоров. Результаты эксперимента доказывают, что обратный комбинаторный аукцион может быть использован как способ нахождения оптимального решения социально-экономических проблем на отдельной территории.

Ключевые слова: *загрязнение воды; управление сточными водами; экономический лабораторный эксперимент; комбинаторный аукцион.*

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Introduction. The most critical problems of surface waters pollution have been to a large extent solved in the most of developed countries during the previous decades. In the member countries of the European Union this positive effect can be attributed, next to other factors, to the Water Framework Directive implementation (Directive 2000/60/EC, 2000).

Because of a specific economic and societal structure of developed countries, a focus was initially put particularly on larger polluters dispersed across river basins, where the highest potential for a significant water quality improvement was expected. Typically, the process of water pollution reduction progressed from upstream, and/or large water pollution sources producing significant water pollution, to more downstream, medium/small, and creating less polluting ones.

In the course of time this approach resulted in a significant enhancement of surface water quality. Issues supposed to be formerly as less important ones, like water pollution in smaller areas of specific societal and natural value or with high developmental potential have appeared to be a next step to focus on within ongoing water quality improvement effort.

Problem statement and research objective. Various strategies to improve quality of environmental components have been discussed, tested, and refined by scientists and professionals in the last decades. These strategies include a broad scope of authoritative measures, market instruments, and voluntary approaches, as well as a vast array of their various combinations (Brink, 2002; Farmer, 2012).

In high-priority watersheds, which are usually not large by area, local polluters can often cooperate while preparing and implementing common "coalition projects" to improve water quality. Solving water pollution issues in the areas of drinking water reservoirs, lakes used for recreation purposes, and watersheds with special biodiversity protection requirements represents a situation in which this strategy can be studied.

Some authors (Kluvankova-Oravska and Chobotova, 2010; Weibust and Meadowcroft, 2014) argue that this strategy is to be applied – in particular when financial support is asked from the EU institutions – together with relevant models of negotiation within new multilevel environmental governance models to support the process of potential solution effective implementation.

The studied problem has two significant dimensions. First, based on information about the costs generated by experts to reach in a particular region – through negotiation and implementation of coalition projects – reach a cost-effective solution in terms of minimal social costs invested. Because a vast array of possible alternative solutions (combinations) usually exists, to compute an optimal solution is not a trivial process, and should be supported with an appropriate theoretical model and software. Such model is briefly introduced in the next section on methodology.

The second dimension of the problem lays in the fact, that some financial support from public funds is often necessary to implement a selected solution. Under such conditions a strong information asymmetry between a subject applying for support and an authority exists. To limit potential inefficiencies resulting from this asymmetry requires discovering (apart from other factors) institutional settings supporting relevant decision-making processes which would bring solutions close as much as possible to the optimal one (Sauer et al., 2003).

Methodology and laboratory experiment design. Economic laboratory experiments represent an important methodological approach to find these settings and to test their effectiveness. Vast literature on economic laboratory experiments, for instance, Guala (2005), Kagel and Roth (1995) among many others, deals with this approach both generally and in specific areas. Murphy et al. (2000) apply economic laboratory experiments to water management. In the next sections of this paper, a case of 13 municipalities which are to find a coalition solution for pollution reduction problem in a region, and the related laboratory experiment are described and discussed.

A model of reverse combinatorial auction has been applied in our laboratory experiment as a method to find an optimal solution for water pollution reduction problem. More details on combinatorial auctions could be found in: Cramton et al. (2006), de Vries and Vohra (2003), Pekec and Rothkopf (2003). An application of this model on environmental issues has been published first in Fiala and Sauer (2011). Readers of Actual Problems of Economics can find more details about the model of reverse combinatorial auctions, including math formulas, in (Sauer et al., 2014).

In the presented case an authority is defined as an (individual) buyer, and municipalities located in a watershed as sellers, offering individual and/or coalition projects to treat the polluted waters. To keep our model simple – with understanding that this exclusion does not make any difference in terms of the model nature – neither factors like operating cost or technological development, nor other potential parties (sellers) like agricultural firms or supranational bodies, were included.

The experiment has been built on a real situation within an area with a drinking water reservoir located in Central Bohemia. There are 13 municipalities contributing to water pollution of the water reservoir. They are located by 3 small rivers flowing into the reservoir. These three rivers have multiple small tributaries. All 13 municipalities must clean their waste waters to achieve the standards defined by legislation of Czech Republic (Government Regulation 20/2010). Every municipality can either choose to construct individually its own wastewater treatment plant, or to build a common plant together with several other municipalities.

For the presented experiment, 13 individual projects were worked out (A, B, C, D, E, F, G, H, I, J, K, L, M), and 49 realistic (in terms of costs, feasibility etc.) coalition projects (15 two-part coalitions, 15 three-part coalitions, 14 four-part coalitions, 1 six-part coalition, 2 seven-part coalitions, 1 eight-part coalition, and 1 nine-part coalition) were identified by the experts in the field. Thus, in total 62 potential projects were suggested.

Costs of respective individual solutions and the selected promising coalition solutions were estimated by the leading experts on the matter (see Appendix 1 as an example of relevant projects' costs related to municipality A). All data handing out during the experiment include 13 pages.

Following materials (in Czech language) were distributed to the subjects playing the role of polluters – municipalities representatives:

- The situation (case) description (including the list of municipalities with the potential to create coalitions and the map of the region).
- Confidential data for the experiment(s).
- Application form to request financial support from the authority.

A subject playing the role of authority had in his/her disposal the same materials as the subjects playing the role of polluters-municipalities, and the detailed description of the experimental process.

The subject playing the role of the authority distributed relevant materials, including instructions and procedure description. Subjects playing polluters have been informed that there is to be only one round of application submission, that financial resources for financial support are limited and thus only 50% of applications can be supported, and that the subjects playing the role of polluters-municipalities are to be financially rewarded after the experiment based on final results. Before the experiment started the subject playing the role of authority asked the participants if they understood all instructions and answered potential questions (in principle by repeating or reformulating the instructions, using different words/synonyms).

The participants received financial compensation for taking part in the experiment. Following scheme was used: all participants were paid show-up fee in the amount of 70 CZK (an amount approximately equal to income after taxation for 1 hour work on a short-time working contract). If they received support from public financial resources (50% of the groups with the lowest requirements on support from public funds), they received a reward calculated by the following formula: 100 CZK + premium 1 CZK for every 1% of the costs saved from the maximum, which the municipality is willing to pay for the project (Mmax).

Experiment results. In total, 78 bachelor students from the University of Economics, Prague, enrolled in Political Science, Diplomacy, International Business, Travel Business, and Multimedia in Economic Practice major study programs, took part in the experiment. Particular rounds of the experiment were run in the summer semester 2013/2014.

Participants, divided into groups composed of 13 members, were playing the roles of municipalities' representatives negotiating among themselves with an effort to successfully apply for public support for the construction of wastewater treatment plant. The experiment results are shown in Table 1.

Table 1. **Experiment results,** *produced by the authors*

Round No.	Coalition structure in the application	Total costs, ths CZK	Total requested support, ths CZK	Deviation from the optimal costs, %	Supported projects ("*")
1	J; C + D + F; H + C + M; A + B + E + G + I + L	180000	144000	+ 17	
2	E; G; I; A + B + J + L; H + K + M; C + D + F	175940	133985	+ 14	
3	B; E; G; I; J; H + K + M; C + D + F; A + L	166600	126470	+ 8	*
4	A; B; C; D; E; F; H; K; L; M; I + J + G	162000	118400	+ 5	*
5	J; C + D + F; H + K + M; A + B + E + G + I + L	180000	154070	+ 17	
6	A; B; E; G; H; I; J; K; L; M; C + D + F	157700	121000	+ 2.5	*
	Optimal coalition structure A; D; E; F; H; J; K; M; C + G; B + I + L	153800	x	x	x
	Solution with individual projects only	176100			

While the total costs of an optimal, cost-effective coalition solution are 153,800,000 CZK, the total costs of a solution based only on individual projects are 176,100,000 CZK. The difference of 22,300,000 CZK represents potential savings. In our experiment the method of reverse combinatorial auction resulted in 4 of 6 cases to better solution of water pollution reduction problem than a solution based on individual projects. In those cases when respective final solutions were more costly than the solution based only on individual projects, the average extra costs (3,900,000 CZK) were significantly lower than the average savings per project (10,540,000 CZK) calculated for all the solutions better than the solution with individual projects only, or average savings per project (14,000,000 CZK) calculated for the supported projects only.

Survey among the experiment participants. A questionnaire containing 7 questions was distributed to each student after the experiment to discover possible influence of various aspects of experimental settings and environment on the experiment results. Questions and distribution of answers can be seen in Tables 2–4.

Table 2. **Questionnaire & answers distribution,** *produced by the authors*

Question	Yes/No
Q1. Do you think that all members of your group understood experimental task?	11/2; 12/1; 12/1; 5/4 (4); 9/4; 9/4
Q2. Did you have sufficient time to negotiate?	6/7; 12/1; 12/1; 9/1 (3); 10/3; 10/3
Q5a. Did you share data about projects costs with other participants?	11/2; 8/5; 6/7; 6/3 (4); 10/3; 5/8
Q5b. Did you share data about maximal investment?	7/6; 5/8; 1/12; 0/10 (3); 2/11; 1/12
Q6a. Did you perceive other participants in your group rather as opponents?	5/7 (1); 6/6 (1); 4/7 (2); 0/8 (3); 3/8 (2); 6/5 (2)
Q6b. Did you perceive other participants in your group rather as partners?	9/4; 10/2 (1); 10/0 (3); 10/0 (1); 12/1; 8/0 (5)

Note: Figures in () stands for not filled/unclear answer(s).

Table 3. **Questionnaire & answers distribution,** *produced by the authors*

Question	Very/Partially/Little/Not
Q4. Did financial reward make you think through your negotiation strategy more thoroughly?	0/3/3/7; 1/7/0/5; 0/5/6/2; 1/3/4/2 (1); 0/7/5/1; 0/7/3/3
Q7. How much you were during negotiation aware of the fact that you are playing against other groups participating at the experiment?	3/8/2/0; 4/5/4/0; 6/4/3/0; 0/7/2/2; 3/7/3/0; 4/6/3/0

Note: Figures in () stands for not filled/unclear answer(s).

Table 4. **Questionnaire & answers distribution,** *produced by the authors*

Question	Great/Well/Medium/Not well/Poor/Other
Q3. How was your work with other participants?	3/5/1/0/1/2 (1); 4/6/1/1/0/0 (1); 1/6/4/0/0 (2); 0/5/0/0/1 (5); 1/5/2/2/1 (2); 3/4/0/1/1 (4)

Note: Figures in () stands for not filled/unclear answer(s).

Even though the total amount of experiments and participants was rather low to get statistically significant data on experiment settings, process, and content, the conclusions derived from the survey can help run next experiments. With these limits in mind, the data can be summarized as follows:

1. Aspects related to the contents and the process:

a) better understanding of the matter in hand (task, process, context) by involved parties brought better results, and thus can be expected to be an important prerequisite of successful application of a reverse combinatorial auction method;

b) parties which did not share data on maximal investment were more successful;

c) parties which were less willing to share data on projects costs were more successful;

d) more successful parties perceived other parties as partners rather than opponents.

2. Aspects relating to formal settings:

a) other studied factors did not have any significant influence. This might result from very small size of the sample, as well as from the same arrangements during all rounds (in terms of time set aside to negotiate, homogenous structure of participants etc.);

b) financial reward did not play in this experiment an important role neither in terms of experiment process, nor results; an immediate and higher payment might help to make this motivational aspect impact more on participants' conduct;

Conclusions and directions for further investigation. Testing hypotheses via economic laboratory experiments is exacting. Successful and credible testing requires, besides other factors, careful and consistent preparatory work, thought through experimental plan, clear and well-defined goals, relevant experiment settings, resources (time, space, financial funds) to run a necessary number of experiments with well-motivated participants, and researchers with the experience in this field.

Our laboratory experiment with 13 participants, who can work out common (coalition) projects, and negotiate on financial support for these projects from public sources, brought – regardless of unavoidable situational simplifications – interesting and rather promising results. While the best solution at the experiment departed only 2.5% from the optimal theoretical one, the worst ones were rather close to the solution based on the implementation of individual projects (without any negotiation among parties-polluters) only. Also, two thirds of solutions were better than the later one.

Basing on the results of this experiment, as well as on the results of the previous ones run with a smaller number of participating parties, we believe that the hypotheses on "institutional settings" can be tested and verified in a laboratory. However, it will be necessary to change partially the appearance, and incorporate additional parameters (like operating costs) into the experiment, to get the results reflecting reality even more, and thus bringing more detailed understanding and more reliable and realistic suggestions. Also, new parties-polluters – farmers who run business in the affected area, or non-governmental organizations with influence on decision-making, to name some, might be introduced.

Expected technological development can also change the perspective in which a selected solution suggested to be implemented is seen. For instance, larger coalitions can have better preconditions for future modernization (assuming the current structural/building parts will be preserved).

Undoubtedly, the best test of the studied approach would happen when it would be implemented in a selected watershed, and thus the results of a conducted laboratory experiment would be tested in real environment. The authors of this paper are currently looking for an opportunity to let the studied hypothesis undergo a real-life test. Based on the results of such testing, both understanding of relevant laboratory experiment settings, and of the problem of a reduction of the water pollution problem under information asymmetry during negotiations, would be enhanced. The authors' hope is that it might represent a useful and interesting contribution to social-costs savings, local policy development, quality of life, and sustainable development, among others.

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Appendix 1. **Confidential data for polluter/municipality [A],** *authors' data*

Members of meaningful coalitions	Project costs
[A]	8000
[A] + [B]	48000
[A] + [C]	36700
[A] + [I]	20000
[A] + [J]	15500
[A] + [L]	19000
[A] + [B] + [I]	56000
[A] + [B] + [J]	58000
[A] + [B] + [L]	60000
[A] + [B] + [E] + [I]	67500
[A] + [B] + [I] + [J]	65400
[A] + [B] + [J] + [L]	66740
[A] + [E] + [G] + [I]	39400
[A] + [E] + [I] + [L]	40900
[A] + [G] + [I] + [J]	36800
[A] + [B] + [E] + [G] + [I] + [L]	83000
[A] + [B] + [E] + [G] + [H] + [I] + [L]	138000
[A] + [E] + [G] + [H] + [I] + [J] + [L]	105000
[A] + [C] + [D] + [G] + [H] + [I] + [J] + [L]	125000
[A] + [B] + [C] + [D] + [E] + [G] + [H] + [I] + [L]	164000

M_{max} = 2400 (i.e. you are willing to spent/invest from your municipality budget maximally 30% of the costs of your individual project).

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