M U L T I P L E   C R I T E R I A   D E C I S I O N   M A K I N G
Vol. 12 2017

Barbara Gładysz[*]
Dorota Kuchta[**]

MULTICRITERIA ANALYSIS OF THE SUCCESS OF RESEARCH PROJECTS

DOI: 10.22367/mcdm.2017.12.02

Abstract

The present paper considers the problem of the success of a research project evaluated by its outputs (which can be seen as the project's success measures) related to its inputs (constituting the project's success factors). Data Envelopment Analysis (DEA) models are used. The inputs and outputs are selected on the basis of a review of the literature. Two models are applied to a set of research projects implemented in Poland. Advantages and disadvantages of the approach are shown. In particular, the selection of inputs, outputs and their weights needs to be researched further. But the models used in the paper, in spite of their imperfection and lack of generality, considerably help to assess and compare the projects. Therefore, DEA is an important tool for the evaluation of R&D activities.

Keywords: research project, project success, Data Envelopment Analysis.

1 Introduction

Research projects consume a large amount of financial and human resources, provided by both state and business. At the same time, they often fail to bring the expected results. On the one hand, this is the nature of research projects: they explore previously unexplored domains and thus can lead to less significant results or even to no results, if their hypotheses turn out to be incorrect (Betta

[*] Wrocław University of Science and Technology, Faculty of Computer Science and Management, Wrocław, Poland, e-mail: barbara.gladysz@pwr.edu.pl.
[**] Wrocław University of Science and Technology, Faculty of Computer Science and Management, Wrocław, Poland, e-mail: dorota.kuchta@pwr.edu.pl.

et al., 2017; Kuchta et al., 2017; Gładysz and Kuchta, 2016). But it is still important to evaluate their outcomes or success as compared with the resources and effort invested, having in mind that the success of a research project should be sometimes measured in a different, less quantitative and more subjective way than that of, for example, a construction project (Chan et al., 2002). Without such evaluation the resources and efforts spent on R&D activities would be completely out of control.

A method which allows to compare inputs and outputs is the DEA method, which evaluates the efficiency of the so-called decision making units which may also be projects. The aim of the paper is to apply the DEA method to a set of research projects, using various sets of inputs and outputs, and to analyse the results critically, in order to assess the possibility of the applications of this method to the evaluation of research projects and to elaborate initial indicators as to the construction of a DEA model.

The set of research projects analysed here consists of research projects implemented in Poland in the last five years whose project managers filled out a questionnaire. We received 35 questionnaires completely filled out. The project managers were asked to select one of their research projects. Then they were asked about its features, the project team and resources invested and also about the project outcomes and their subjective evaluation.

We present the necessary theory of DEA and its state-of-the-art applications to research projects. Next, we describe the selected models and discuss the results. The paper concludes with remarks regarding the choice of inputs and outputs and their weights for DEA models applied to research project analysis.

2 Data Envelopment Analysis in research projects analysis

Data Envelopment Analysis (DEA) is a method which allows to determine, for a given set of objects (decision making units), those objects which are efficient. The efficiency assessment is conducted on the basis of the set of objects under consideration. The results are therefore not absolute, but relative efficiencies of the objects being examined. DEA is based on the productivity concept introduced by Debreu (1951) and Farrell (1957). The efficiency (which is in some cases a synonym for productivity) is measured as the relation of the effects (outputs) to the expenditures (inputs). The objects for which this relation is maximal (as compared to all the objects from the group under consideration) are assumed to be efficient. There are several DEA models (see Castelli et al., 2010). We adopt here the following one:

$$Max\ g_{i_0} = \frac{\sum_{r=1}^{R} \mu_{ri_0} y_{ri_0}}{\sum_{p=1}^{P} \gamma_{pi_0} x_{pi_0}} \tag{1}$$

with the constrains:

$$\frac{\sum_{r=1}^{R} \mu_{ri_0} y_{ri}}{\sum_{p=1}^{P} \gamma_{pi_0} x_{pi}} \le 1$$

$\mu_{ri_0} \ge 0,\ r = 1, \dots, R$
$\gamma_{pi_0} \ge 0\ p = 1, \dots, P$
where:
$i = 1,\dots, N$ – the index of an object,
$i_0 = 1, \dots, N$ – the index of the object being evaluated at the moment,
x_{ri} for $r = 1, \dots, R$, $i = 1,\dots, N$ – the input values for the i-th object,
y_{pi} for $p = 1, \dots, P$, $i = 1,\dots, N$ – the output values for the i-th object.

The maximal value of the objective function (1) is taken as the efficiency of the i_0-th object. As it can be concluded from this model, each object, when being evaluated, can choose for itself and for all the other objects the weights μ_{ri_0}, γ_{pi_0}, $r = 1, \dots, R$ which show it in the best light.

The DEA method has been applied in the literature to project analysis. In that case the objects are projects. Here we focus on those literature items which deal with research projects. Research projects are projects which deal with Research and Development, which, in turn, "comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society and the use of this stock of knowledge to devise new applications" (Frascati Manual, 2002). The following inputs for model (1) have been used in the literature for research projects (Eilat, Golany & Shtub, 2008; Revilla, Sarkis & Modrego, 2003; Yuan & Huang, 2002):

- project cost (budgeted and actual);
- full time equivalents of highly trained personnel (managers, engineers and scientists, PhD, master, bachelor degree holders) used for the realisation of the project;
- total revenues of the organisation;
- total R&D budget of the organisation, total number of its corporate employees;
- total number of the organisation's employees.

It has to be stressed that the last three inputs refer not to the project being evaluated, but to the whole organisation implementing the project.

As for the outputs, the following have been used for research projects (Eilat, Golany & Shtub, 2008; Revilla, Sarkis & Modrego, 2003; Yuan & Huang, 2002), many of them qualitative:

- discounted cash flow generated by the project;
- performance improvement achieved thanks to the project;
- customer satisfaction with the product of the project;
- congruence with the strategy of the organisation implementing the project;
- synergy with other projects realised by the organisation;
- project team satisfaction;
- the number of team members trained in project management thanks to the project realisation;
- probability of technological and commercial success of the project's product;
- the size of the technical gap filled by the project's product;
- the novelty of the technology used;
- the complexity of market activities needed to commercialize the project product;
- new employees gained thanks to the project;
- total income generated by the project;
- number of patents and copyrights gained thanks to the project;
- number of dissertations completed thanks to the project;
- number of reports issued thanks to the project;
- number of technology innovations designed thanks to the project;
- number of seminars organised thanks to the project;
- number of technology transfers resulting from the project.

Project outputs can serve as a measure of the project's success and project inputs as the factors of the project's success and failure. This is in line with the common belief (Betta et al., 2017) that the success or failure of research projects is not easily measurable and has to be based on several criteria. Apart from that, the notion of success or failure of a research project can be understood in different ways; success criteria may differ depending on the context. For example, if projects to be evaluated are implemented in an organisation whose main aim is to fulfil formal requirements of financing institutions, the measures of success would be, first of all, the relations between the planned and actual time and budget. However, if the organisation is a more open one, focusing on researching new, unexplored scientific questions and directions, the main measures of success would be the number of research questions answered (also negatively, with no tangible results) and of new research questions and partners identified.

DEA seems to be the right approach for assessing projects, including research projects. But we have to find out which inputs and outputs to choose in various situations. For our case study, we chose inputs and outputs using suggestions from the literature, but also trying to minimise the length and difficulty of the questionnaire which we distributed among research project managers in Poland. Our selection was meant to be a starting point for a discussion about the choice of inputs and outputs for DEA models applied to research projects. The model we used and the results are presented below.

3 Data Envelopment Analysis applied to a set of research projects

The DEA method was applied to 68 research projects implemented in Poland, in all disciplines. The data were gathered using on-line questionnaires. Although 68 questionnaires were filled out, only 35 were filled out completely; in 33 remaining cases several pieces of information, related mostly to the project's budget, were missing. The set of 35 completely filled out questionnaires constituted the basis for the study. Each questionnaire was filled out by a project manager of one research project, all of the respondents were university assistants or professors.

Both in the entire sample (68 projects) and in the subsample (complete questionnaires), all academic disciplines were represented, except for art (humanities 13%, social sciences 20%, pure sciences 17%, natural sciences 17%, technical sciences 12%, agricultural, forest and animal sciences 4%, medical sciences 17%).

Two DEA models were used. Out of all the potential inputs and outputs for research projects listed in the previous section, we selected those whose value could be inferred from the questionnaire, which had to be as short as possible. In both models the following inputs were used ($i = 1, 2, \ldots, 35$):

x_{1i} – the number of people in the project team,

x_{2i} – the actual duration of the project [months],

x_{3i} – the actual budget of the project [Polish currency PLN].

In the first model only quantitative outputs were selected:

y_{1i} – number of publications in journals indexed in the Master Journal List,

y_{2i} – number of publications in conference proceedings.

In the second model qualitative outputs were also taken into account; their values were assessed subjectively by the project manager:

y_{3i} – was the project successful?

y_{4i} – was the main project objective achieved?

y_{5i} – were the actual project results consistent with the initial assumptions?

y_{6i} – did the project implementation lead to unplanned results, important from the theoretical or practical point of view?

The values of the subjective outputs were evaluated on the Likert scale (1 – Strongly disagree, 2 – Disagree, 3 – Neither agree nor disagree, 4 – Agree, 5 – Strongly agree).

The descriptive statistics and histograms of inputs (x_{1i}, x_{2i}, x_{3i}) and outputs $(y_{1i}, \dots, y_{6i})$, i = 1, 2, …, 35, are presented in Table 1 and in Figures 1-3.

Table 1: Descriptive statistics for inputs and outputs

Descriptive Statistics	Input			Output					
				Quantitative		Qualitative			
	x_{1i} People	x_{2i} Duration	x_{3i} Budget	y_{1i} M.J.L.	y_{2i} Conf.	y_{3i} Success	y_{4i} Goal	y_{5i} Plan	y_{6i} Other results
Mean	5.9	36.3	395	4.9	4.9	4.4	4.6	4.3	4.3
St. Dev.	4.5	11.2	326	7.3	6.4	0.6	0.5	1.0	1.2
Min	1	12	39	0	0	3	3	1	1
Max	25	60	1500	40	35	5	5	5	5

The project teams consisted of 1-25 people, with mean cardinality about 6. The project's duration ranged from one to five years, with the average of about three years.

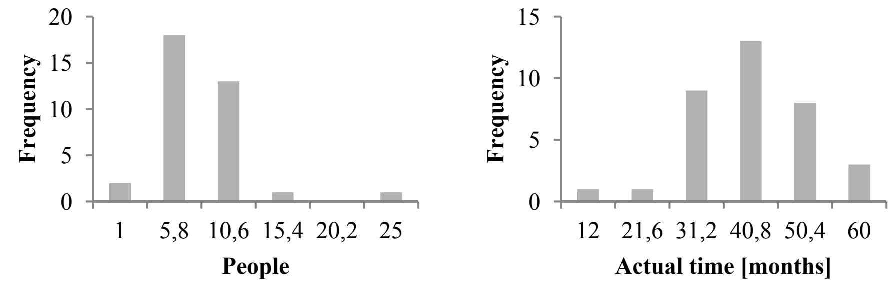

Figure 1. Histograms of inputs a): number of people in the project team and project duration (numbers represent interval endpoints)

The project budgets were between a few thousand and 1.5 million PLN, 400 thousand being the average.

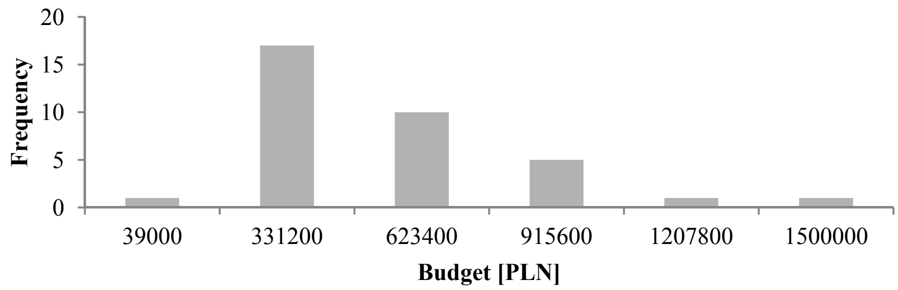

Figure 2. Histograms of inputs b): actual project budget (numbers represent interval endpoints)

The mean number of publications both in journals from the Master Journal List and in conference proceedings was about 5. However, the numbers of publications in journals from the Master Journal List were more diversified than those of publications in conference proceedings.

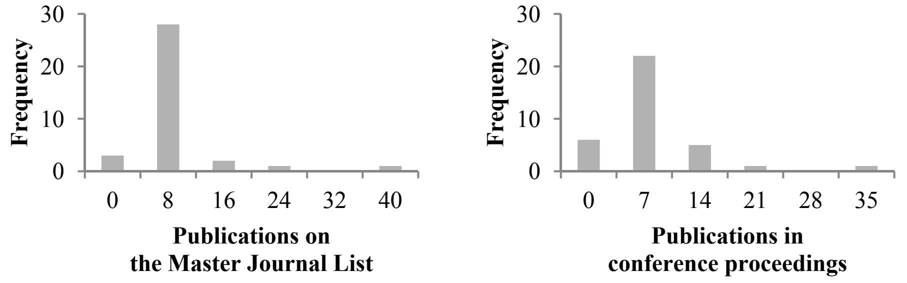

Figure 3. Histograms of quantitative outputs (numbers represent interval endpoints)

The mean qualitative assessment of four examined subjective measures of the research project's success is about 4.5. The assessments of the conformity of the project results with the initial plan and the attainment of unexpected but important results are more diversified than the other two assessments.

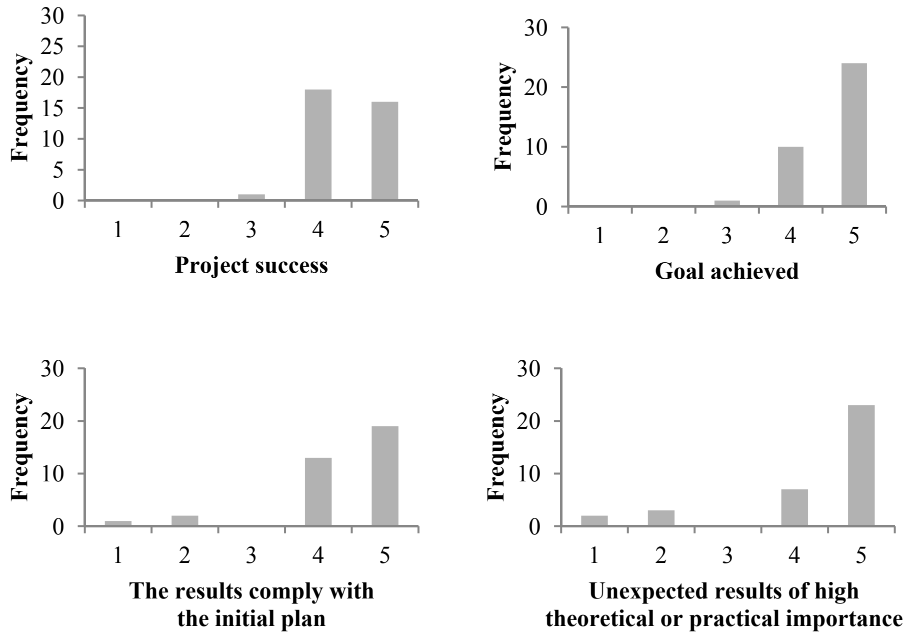

Figure 4. Histograms of qualitative outputs (numbers represent interval endpoints)

In the following section, the application of DEA to the set of projects described in this paper will be presented.

4 Results

Table 2 presents the results of the application of the DEA method using two versions of model (1): Model 1, with inputs (x_{1i}, x_{2i}, x_{3i}) and outputs (y_{1i}, y_{2i}), $i = 1, 2, \ldots, 35$, and Model 2, with the same inputs and with outputs $(y_{1i}, \ldots, y_{6i})$, $i = 1, 2, \ldots, 35$. In columns 11 and 12 the efficiencies calculated for the individual projects in both models are presented, in the last column the difference between the efficiency obtained in Model 2 and that calculated in Model 1 is shown.

Table 2: Inputs, outputs and project efficiencies

Project	**Inputs**			**Outputs**						**Efficiency**		**Difference**
No. (*i*)	x_{1i}	x_{2i}	x_{3i}	y_{1i}	y_{2i}	y_{3i}	y_{4i}	y_{5i}	y_{6i}	**Model 1**	**Model 2**	**M2-M1**
1	6	36	3000	0	2	5	5	5	4.3	0.10	0.65	0.55
2	2	24	100	5	0	5	5	5	1.2	1.00	1.00	0
3	3	30	108	0	7	3	4	4	1	0.92	1.00	0.08
4	3	27	50	5	3	5	5	4	5	1.00	1.00	0
5	5	13	39	0	2	4	5	4	5	0.73	1.00	0.27
6	7	36	205	5	0	4	3	2	5	0.47	0.61	0.14
7	3	24	99	3	2	4	5	5	1	0.51	1.00	0.49
8	10	36	400	9	7	5	5	5	5	0.56	0.69	0.13
9	2	26	68	1	4	4	5	4	4	0.04	1.00	0.96
10	4	48	750	7	4	5	5	5	5	0.84	0.75	-0.09
11	7	12	120	2	3	5	5	4	4	0.40	1.00	0.6
12	1	36	140	3	0	5	5	4	5	0.40	1.00	0.6
13	7	36	913	4	15	4	5	5	4	0.77	0.81	0.04
14	10	46	860	4	8	4	5	5	5	0.49	0.50	0.01
15	4	30	325	2	6	4	5	5	4	0.18	0.48	0.3
16	3	24	100	1	2	4	4	4	1	0.29	0.82	0.53
17	4	36	230	6	0	5	5	5	5	0.60	0.68	0.08
18	15	52	1500	40	0	4	4	4	2	1.00	1.00	0
19	3	48	336	1	0	4	4	4	5	0.10	0.50	0.4
20	7	36	335	3	3	5	5	5	2	0.21	0.51	0.3
21	1	26	60	1	3	4	4	2	4	0.71	1.00	0.29
22	5	36	516	3	11	4	4	5	5	0.50	0.60	0.1
23	25	57	440	2	1	5	5	4	5	0.10	0.25	0.15
24	4	24	100	2	1	5	5	5	4	0.33	0.88	0.55
25	10	36	460	3	5	5	5	5	5	0.17	0.41	0.24
26	5	48	600	3	12	4	4	4	5	0.55	0.53	-0.02
27	4	48	450	4	6	4	5	4	5	0.36	0.46	0.1
28	4	60	1000	2	10	4	4	1	5	0.57	0.15	-0.42
29	3	36	269	1	1	5	5	5	2	0.11	0.71	0.6
30	7	42	290	2	3	4	4	5	5	0.15	0.53	0.38
31	8	36	499	19	35	5	5	5	5	1.00	1.00	0
32	7	48	540	2	3	4	4	4	5	0.11	0.46	0.35
33	3	44	642	15	8	5	5	5	5	1.00	1.00	0
34	10	36	280	6	2	4	5	5	5	0.47	0.62	0.15
35	6	39	693	6	4	5	5	5	5	0.32	0.61	0.29

In the case of Model 1, in which only publications were counted as outputs, 13% of projects are effective to the degree 1. In the case of Model 2, where also qualitative (subjective) outputs were taken into account, 34% of projects were efficient to the degree 1. Here each project which was fully efficient in Model 1 was also fully efficient in Model 2. The distribution of project efficiencies are given in Table 3 and Figures 5 and 6.

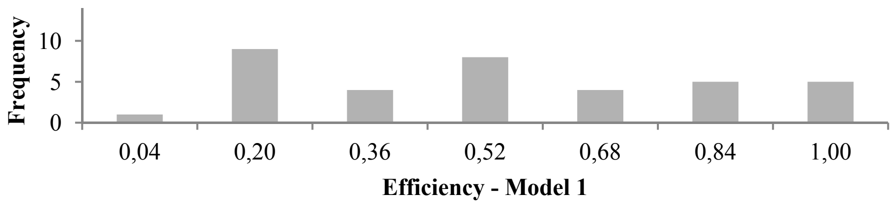

Figure 5. Histogram of project efficiencies for Model 1 (only quantitative outputs)

In the case of Model 1, although the best weights for each project can be chosen in (1), a large proportion of projects (about 54%) are clearly inefficient: their efficiency is under 0.5. The 13% of projects which turned out to be fully efficient are clearly better than most of the other projects. Only 20% of projects are characterised by an efficiency higher than 0.8.

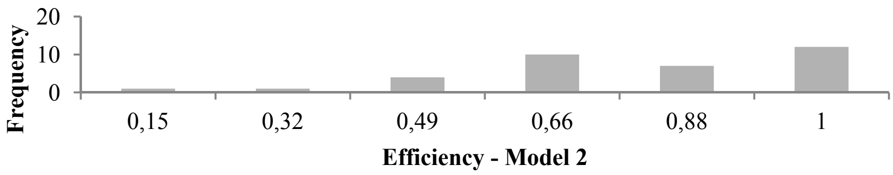

Figure 6. Histogram of project efficiencies for Model 2 (quantitative and qualitative outputs, numbers represent interval endpoints)

In the case of Model 2 the results are different. Over 40% of projects have proved to be efficient to the degree 0.8 or more and only less than 23% of projects are characterised by an efficiency smaller than 0.5. Of course, this is because adding more outputs often increases the project's efficiency with respect to Model 1. That is why in Model 2 the "picture" of the examined set of projects is much more favourable, which is visible also in Table 3.

Table 3: Efficiency of research projects

	Efficiency	
	Model 1	**Model 2**
Mean	0.48	0.72
St. Dev.	0.32	0.25
Min	0.04	0.15
Max	1	1

The results differ strongly between the two models. Thus, the question arises which model gives the "correct" information. As indicated in Introduction, in the literature on the applications of DEA to research projects, various inputs and outputs are considered, and therefore the issue is not clear. But the two models clearly point to a group of best projects (those which are fully efficient in Model 1) and to that of worst projects (those with an efficiency smaller than 0.4 in Model 2). These two groups can be analysed by the university management and treated as reference groups.

It is also interesting to look closer at projects whose efficiency varies considerably between the two models. For example, let us look closer at projects for which the absolute value of this difference is at least 0.6: projects 9, 11 and 12. All of them have a higher efficiency in Model 2.

- Project 9 had only one publication in a journal from the JCR basis, but all the qualitative assessments are equal to 4 or 5. The qualitative assessments were performed by the project manager, whose opinion may be subjective. But the project was not very expensive, had a small project team and was of medium duration. It is therefore possible that the importance assigned to the JCR basis unfairly underestimated the project and it is only thanks to the use of other outputs that the project was more fairly evaluated.
- Project 11 was assessed lower in Model 1 because it uses a comparatively large project team and budget. But again, the subjective assessment of the project manager considerably changed the assessment of the project.
- Project 12 was rather long and had no publications in conference proceedings, but the project manager assessed it highly. Hence the difference in the assessment of its efficiency in both models.

An interesting case is Project 28. It belongs to the small set of projects for which Model 2 found a lower efficiency than Model 1. This is because the project manager gave it a low mark in one of the subjective assessments, which was very rare in this set of projects. That is why its relative efficiency, when this low subjective assessment is taken into account (i.e. in Model 2), is rather low. This shows the dangers and problems related to subjective evaluations: the sensitivity of the results is very high in this aspect.

It is worth noting that four of the projects for which the assessment in Model 2 is much higher than in Model 1 belong to social sciences (projects 5, 9, 12 and 21). In these disciplines the importance attached to the publication quality is generally considered to be too high. Research in this field is often mainly of local interest and it is difficult to publish it in international journals. In this field, subjective assessments seem especially important. Moreover, most projects whose assessments in the two models do not differ very much, belong to pure, technical or medical sciences. Therefore it seems clear that project assessment should be conducted separately for various disciplines, as projects from different disciplines may be incomparable.

The final choice of outputs will depend on the definition of the success of a research project used by the organisations in question. If for the given organisation it is mainly the number of publications that counts (because of the national regulations in assessing research organisations), Model 1 or its modifications (for various groups of publications) will be used. If, on the other hand, the organisation has a less formal approach to the evaluation of research project success, trusts its project managers and wants to support also such projects to which not many publications can be linked directly, but which, in the opinion of the project managers, were efficient, it may want to adopt Model 2 or similar ones. This also depend on the field. Social sciences, for example, would require a more subjective model, while pure sciences, a more formal one.

It is worthwhile to emphasise the importance of subjective outputs. According to Chan and Chan (2004), project success (for projects generally) has to be evaluated using both objective and subjective criteria. As far as research projects are concerned, the research described in Betta et al. (2017) and based on about 70 interviews with research project managers in Poland and in France, clearly shows that research project managers criticise strongly such measures as the number and quality of publications and propose many other measures of research project success, most of them strongly subjective: new project ideas, new cooperation possibilities, providing an answer to an interesting research question etc. Most of the interviewed managers are convinced that any research project assessment ignoring subjective project outputs may distort project evaluation. It is thus important to include subjective outputs in DEA models for research projects.

In any case, using two models as different as Model 1 and Model 2 is also of some practical use, as small differences in the assessment point to those research projects whose assessment is more or less unequivocal. If we take the value 0.1 as the threshold for the absolute value of the difference from the last column of Table 2, we can see that the set of projects whose assessment was identical or almost identical in both models consists of projects 2, 4, 10, 13, 14, 17, 18, 22, 26, 27, 31, 33. For those projects, fairly conclusive statements can be made. We know to what extent they are efficient as compared with the other projects.

5 Conclusions

In our paper two DEA models have been applied to a set of research projects implemented in Poland. The models allowed to assess the projects using the relationships of project outputs (which can be regarded as measures of projects' success) and project inputs (which are measures of projects' relative efficiency). The method may help in the assessment of research projects.

However, the results have shown a high sensitivity of the results to the choice of inputs and outputs. We considered two models with the same set of inputs but different sets of outputs. The first set consisted of quantitative outputs only (the number of publications linked to the project, classified in various publication groups), the second set included the first one, but contained also qualitative, subjective outputs.

Our paper does not provide a final answer to the question which inputs and outputs have to be considered while assessing research projects. The problem is partially linked to the issue of defining the success of research projects, which is measured by means of its outputs. This is an open problem. One thing is clear: the understanding of a research project's success depends strongly on the stakeholder who decides about it (Davis, 2014); subjective outputs are at least as important as objective ones (Betta et al., 2017; Chan and Chan, 2004). Thus, the starting point in the selection of outputs should be an adequate definition of a project's success. Should it refer mainly to the number of publications resulting from the project and their quality or should it refer to the long-term potential future outputs of the project? In the latter approach, a project can be assessed as successful also when not many high-quality publications resulted from it, but it gave rise to new ideas or suggestions for further research. It is also clear that evaluation models should be built separately for various disciplines, since, for example, research in art or social sciences results in different outputs than that in pure or technical sciences.

As for inputs, they should reflect the most important expenditures (in a general sense of this notion) which the research organisation spends on research projects or its most scarce resources. They might be people (with various positions or degrees), time, money (quantitative inputs), but also expertise and experience in certain fields (qualitative inputs), laboratory space, work load etc. It may be that, for instance, the number of people in the project team should be modified to a weighted number of them, with the weight reflecting the irreplaceability and the experience of the individual team members. Also, the qualities of the project manager (also those expressed in qualitative terms) might constitute an input.

Another problem to be solved is related to the weights in model (1) which was the basis of our two models. In this model the weights can be freely changed to put the given project in the best light. This means that each project can "decide" which inputs and outputs are more important and the "decision" can be different for each project. But this approach may not be in line with the research institution's policy. If experienced researchers are scarce or if the publication on the Master Journal List counts for very much, it might be necessary to impose constraints on the corresponding weights. Such weights will not allow a project to overestimate its inputs and outputs which are only moderately important and underestimate the ones which are very important. This is line with the DEA approach, which allows for limits on weights (Podinovski, 2016).

In short, the DEA approach seems appropriate for the evaluation of research projects, but it needs more case studies in which project stakeholders and research institutions would participate. The aim of those case studies would be to determine inputs and outputs and the corresponding weights for model (1). There would possibly be various classes of situations (various strategies of the research institutions, various views of stakeholders) and for each different set of inputs, outputs and the corresponding weights would be generated. Once verified by numerous case studies, the DEA model for research projects might be a useful tool for assessing, comparing and then improving the efficiency of the research activities.

Acknowledgments

This work was partially supported by the National Science Centre in Poland "Czynniki sukcesu i porażki projektów badawczych. Studium przypadków Polski ("nowa" Unia) i Francji ("stara" Unia)", nb 2014/13/B/HS4/01660 and partially supported by the Polish Ministry of Science and Higher Education.

References

Betta J., Jastrzębska J., Frączkowski K., Gładysz B., Kuchta D., Prałat E., Ptaszyńska E., Rola P., Walecka-Jankowska K., Ropuszyńska-Surma E., Skomra A., Ryńca R., Klaus-Rosińska A., Mrzygłocka-Chojnacka J. (2017), *Success and Failure Factors of R&D Projects at Universities in Poland and France*, submitted to International Conference Business Risk in Changing Dynamics of Global Village April 26-27, 2017 at PWSZ in Nysa, Poland.

Castelli L., Pesenti R., Ukovich W. (2010), *A Classification of DEA Models when the Internal Structure of the Decision Making Units Is Considered*, Annals of Operations Research, 173, 207-235.

Chan A.P.C., Chan A.P.L. (2004), *Key Performance Indicators for Measuring Construction Success*, Benchmarking: An International Journal, 11(2), 203-221.

Chan A.P.C., Scott D. & Lam E.W.M. (2002), *Framework of Success Criteria for Design/Build Projects*, Journal of Management in Engineering, 18(3), 120-128.

Davis K. (2014), *Different Stakeholder Groups and Their Perceptions of Project Success*, International Journal of Project Management, 32(2), 189-201.

Debreu G. (1951), *The Coefficient of Recourse Utilisation*, Econometrica, 19(3), 273-292.

Eilat H., Golany B. & Shtub A. (2008), *Research Project Evaluation: An Integrated DEA and Balanced Scorecard Approach*, Omega, 36(5), 895-912.

Farrell M.J. (1957), *The Measurement of Productive Efficiency*, Journal of the Royal Statistical Society. Series A, 120(III), 253-281.

Frascati Manual (2002), *Proposed Standard Practice for Surveys on Research and Experimental Development*, 6th edition, www.oecd.org/sti/frascatimanual.

Gładysz B., Kuchta D. (2016), *Research Projects Success Factors*, Proceedings of EDULEARN16 Conference 4th-6th July 2016, Barcelona, Spain, 7591-7597.

Kuchta D., Gładysz B., Skowron D., Betta J. (2017), *Research Projects in Science Sector*, R&D Management, 47(1), 88-110.

Podinovski V.V. (2016), *Optimal Weights in DEA Models with Weight Restrictions*, European Journal of Operational Research, 254(3), 916-924.

Revilla E., Sarkis J. & Modrego A. (2003), *Evaluating Performance of Public-private Research Collaborations: A DEA Analysis*, Journal of the Operational Research Society, 54(2), 165-174.

Yuan B., Huang J.-N. (2002), *Applying Data Envelopment Analysis to Evaluate the Efficiency of R&D Projects − A Case Study of R&D in Energy Technology*, Technology Commercialization, 111-134.