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Efficiency - Model for Scientific Research Evaluation

Panaite NICA[1]
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Abstract
This paper proposes an model for R&D evaluation which links the cost of research with its various outputs. This model is different than others because it offers the possibility to calculate the outputs value of scientific research and based on these results we can achieve a hierarchy of institutions providing scientific research. Value is calculated for each category of outputs and for the main areas of scientific research and the model can determine the efficiency with which financial resources were used.

Keywords: *research, model, evaluation, performances, efficiency*

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Introduction

The evaluation of performances in scientific research aims at appreciating, at a global level, the efficiency of national programmes in attaining the objectives established by national strategies (Wholey 1970). The viewpoint of (Nagpaul and Roy, 2003), the main institution interested in evaluating the activities of this field is the government, the manager of the state budget and the main financer.

National Academy of Science (1999) identifies five reasons which make evaluation an important instrument: internal management (the source of information necessary to adjust processes to the changes that occur in their development); stakeholders (investors, contributors to the state budget); (internal and international) governmental reports; understanding specific phenomena (overcoming socio-economic, technological and scientific problems); information and education (the increase of the public's interest which will further ensure the support for developing certain programmes).

The purpose of this article is to integrate performance and its costs in a model. The relation between inputs and outputs will establish the efficiency degree for every institution and will ensure an instrument for hierarchising these entities. The model proposed will be different from the other existing models as it starts from the effective cost of each scientific research result. For establishing this cost, two research categories were necessary: literature review to identify the cost of a relevant indicator and a qualitative research by using the Delphi model in order to establish the differences between research fields.

The need to integrate cost and performance in the efficient use of financial resources was developed in articles by Geisler 1995, Coccia 2007, Handoko 2005, Taskova, Stojona, Bohanec, Dzeroski 2007. For this purpose, the complexity of the model developed by all mentioned researchers and the difficulty to ensure a unique instrument, specific to an area that may integrate some of the most reputed world personalities.

Review of Previous Models

Geisler (2005) identifies four categories of models in R&D and management: 1) evaluation of the economic impact of scientific research, the relations between research inputs and the economic results obtained downstream by innovative companies (Tubbs 2008), (Fontagne

2008), Hall (2007) and R&D effectiveness index created by McGrath and Romeri (1994) as the relation between the revenues obtained from the new products multiplied by the net profit and R&D investments. The strong relation between the R&D effectiveness index and other factors that measure the performance of a business led to the idea that we can compare results, measure added value and evaluate innovative companies in this way. 2) performance evaluation according to individual or group productivity (Gold 1989), Loch and Tapper (2002) Shockly (2007) Auranen, Nieminen (2010); 3) performance evaluation by selecting outcome indicators such as the number of publications, quotations or patents. 4) subjective evaluation of results as peer-review.

A different category of models are the ones that integrate all these models as relations between input and output. The inputs comprise human or financial resources, whereas the outputs include quantitative measurable results (number of ISI articles, number of patents, number of articles published in international conference proceedings, number of books published by reputed publishers, etc.).

Geisler (1995) develops an integrated cost-performance model starting from: 1) a cost model in which every input in R&D is calculated as a direct investment index in R&D. This cost includes the following categories of expenses: personnel, equipment, materials, consumables, and indirect; 2) a performance model based on output indicators and their impact. The author divides outputs in four categories: immediate or direct/ proximate (publications or patents); intermediate (such as new products, materials or models which can change the company or economy), penultimate (products and services generated for economy); ultimate (results which bring plus value to the company). The model may be criticized because it does not explain the way in which it establishes the importance of each indicator used by the model, an important variable in calculating the cost-performance index.

Handoko (2005) proposes a model which consists in identifying a way to assess the scientific importance of each indicator used in evaluation. Establishing the indicator with the maximum scientific importance, as well as the decreasing rate of importance for the other indicators used, allows the achievement of a series of scientific relevance. Starting from this series of the importance of indicators, the value of scientific performance can be mathematically calculated. The

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model proposes certain costs for every indicator but does not explain the way in which they were obtained. The idea of establishing the importance of every indicator is an excellent one, considering that we encounter irrelevant indicators for the field, as well.

Coccia (2007) reduces the correlation between several explicit variables by using discriminating analysis for the purpose of achieving a scientometric means of trust to evaluate the performance of scientific research entities. The model structure is based on two components: a) the first evaluates the entities having activities of scientific research in the field of social sciences and the humanities; b) the second analyses the entities of scientific research in the field of engineering and natural sciences (basic research, life quality, environment, technologies, engineering and informational sciences). Based on an econometric function, the author makes a hierarchy of scientific research entities.

Taskova, Stojona, Bohanec, Dzeroski (2008) come up with a new approach of the idea of evaluation of scientific research activity by using a soft product to establish performance in this field. Thus, based on certain decisional rules related to the two attributes of quality and relevance, authors establish an importance scale for every indicator employed which is ranked from lower to higher. From the logical combination of the importance of the two attributes, the performance of the entity or of the respective researcher is automatically calculated and marks are awarded: unsatisfactory, satisfactory, good, very good and excellent.

Methodology

The methodology of the model involved two different stages characterized by the specific methods and instruments used. For the scientific research enterprised, "the approach from individual premises to general conclusions" (Zait, Spalanzani 2006) consists in the construction of a model which comprises the stages from hypothesis to generalization.

For attaining the objectives in the first stage, we used foresight methods. The foresight method most often used in the last 40 years is Delphi, and many national programmes that employ the method have taken it for the foresight exercise (Handbook of Knowledge Society Foresight, 2003). Delphi involves a survey in which the opinions of

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experts in a field to a specific matter are expressed. The survey is conducted to give an informational feedback and not just to provide material necessary to a quantitative data processing.

In this sense, a number of personalities involved in the activity of scientific research in fields such as engineering, medicine, physics, economics, psychology, agricultural sciences, as well as decision-makers of the National Authority for Scientific Research of Romania were established as a target group.

The Delphi methodology involves two stages: in the first one, the experts in the field were asked to express their opinion with respect to matter 1 and 2; in the second one, after the analysis of the answers given and the establishment of results, the same group of experts were asked the same questions with the results of the first stage (Table 1 and Table 2).

1. You are a financer interested in increasing the performance of scientific research. If we awarded coefficient 1 for the necessary funds to draft and publish an article in an acknowledged Romanian review (C category), please estimate the coefficients necessary to multiply costs for the following indicators (both supraunitary coefficients and subunitary ones may be employed) (Table 1).

Table 1 – Indicators for performance evaluation in scientific research

Indicator *A*	Cost multiplication coefficients *1*	Average coefficients obtained after the first stage evaluation *2*	Estimated coefficients for the second stage *3*
ISI article		45	
Article published in international conference proceedings		21	
Article published in national conference proceedings		2	
Article published in an acknowledged Romanian review (B category)		3	
Article published in an acknowledged Romanian review (C category)	**1**	**1**	**1**

Book (of approx. 200 pages)published abroad	79
Book (of approx. 200 pages) published in Romania	29
International patent (in EU, USA, Japan, Canada)	364
International patent (in other countries than EU, USA, Japan, Canada)	196
National patent (The Republic of Moldova included)	27
New registered OSIM product	20

1. Maintaining the perspective from question 1, we ask you to assess the cost multiplication coefficients on various fields in relation to the costs incurred by the field of social sciences and humanities in which a value equal to 1 was considered (Table 2).

Table 2 – Scientific fields

Scientific field	Cost multiplication coefficients	Average coefficients obtained from the first evaluation stage	Estimated coefficients for the second stage
A		*1*	*2*
Engineering		6,5	
Agricultural sciences		5,6	
Physics		5,1	
Mathematics and applied mathematics		2,3	
Chemistry		6,2	
Biology		6,1	
Social sciences and humanities	**1**	**1**	**1**
Psychology		1,9	
Medicine		6,3	

The indicator "Article published in an acknowledged review (C category)" is given value 1 because researchers gain easy access to this type of reviews, and in many cases the publication has recently come out and editors are adopting a growth strategy. The main purpose is to develop an article database to select research papers which will further be published. Establishing value 1 for the field of social sciences and the humanities is significantly different from the main choice, the main problem being related to the cost of research in the other fields (research equipment, necessary chemical substances, mechanic and electronic devices, kits, etc.)

By eliminating the maximum and minimum answers, as well as the opinions that did not respect the requirement of obtaining a variation coefficient, calculated as the report between standard deviation and the answers' average, under 1, the results of the survey were established: *average multiplication coefficients for every performance indicator* and *average multiplication coefficients for every field of scientific research* (Appendixes 1 and 2).

The result of the questionnaire facilitated the identification of cost differences between performance indicators and the importance of the fields of scientific research (Appendix 3).

The second stage required a cost for one of the indicators in the set and their importance coefficients. By studying the bibliography at our disposal, we identified the research paper entitled "*The value of European patents evidence from a survey of European inventors*" which estimates the costs for an EPO European patent which are shown in Figure 1. Harhoff, Scheper and Vopel (2003) conducted a study in 6 European countries (Great Britain, The Netherlands, Italy, France, Spain and Germany) by applying a questionnaire to 7624 inventors that possessed a EPO patent which contained a single multiple choice question:

Which is the minimum price and the satisfactory value that would determine an owner to sell the patent copyright to a third party?

a)€ 30 000;
b) € 30 000 - 100 000;
c)€ 100 000 – 300 000;
d) € 300 000 – 1 000 000;
e)€ 1 000 000 – 3 000 000;
f) € 3 000 000 – 10 000 000;
g) € 10 000 000 – 30 000 000;
h) € 30 000 000 – 100 000 000;
i) € 100 000 000 – 300 000 000;
j) over € 300 000 000;

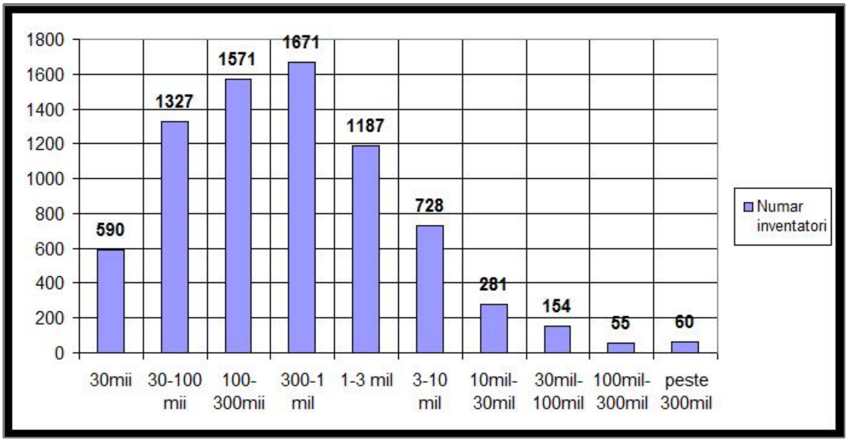

Figure 1 EPO patent price distribution

We notice that the sample is asymmetrically distributed to the right and the predominating values are lower than € 3 000 000, according to approximately 6346 subjects from all the respondents. Answer d), € 300 000 – 1 000 000 holds the highest frequency, therefore we are entitled to suppose that the average price for such a patent is € 650 000. The cost for such a patent may be set to € 400 000, considering that the set average price also includes the profit that a researcher wishes to obtain after using the patent.

Model Development

The model is based on the results obtained for each entity to the previous evaluations and the cost assessment of scientific performance indicators (x_1, x_2, ... , x_n). The performance of each entity will be calculated mathematically according to the importance of the scientific field by using a linear function such as the following:

$$F = c_{1D_1}(\varphi_1 x_1 c_{e1} + \varphi_2 x_2 c_{e2} + \ldots + \varphi_n x_n c_{en}) + c_{2D_2}(\varphi_1 x_1 c_{e1} + \varphi_2 x_2 c_{e2} + \ldots + \varphi_n x_n c_{en}) + \ldots +$$
$$+ c_{nD_n}(\varphi_1 x_1 c_{e1} + \varphi_2 x_2 c_{e2} + \ldots + \varphi_n x_n c_{en})$$

where:

c_{iD_i} = the importance coefficient of the scientific field D_i. The importance coefficient of the scientific fields is the result of the Delphi analysis (table 3) and refers to the importance of the costs incurred by a scientific field as compared to another. For instance, the expenses incurred by scientific research in a field such as physics in which the research infrastructure, the consumables, etc. are much higher than in economics.

Table 3 – Cost multiplication coefficients for all fields of scientific research

Scientific field	c_{iD_i}	Standard deviation	Variation coefficient
Science and technical field	5,9545	1,0103	0,1697
Agricultural sciences	5,0455	1,6849	0,3339
Physics	5,1818	1,1134	0,2149
Matemathics and applied mathematics	2,2727	0,6166	0,2713
Chemistry	6,2273	1,5720	0,2524
Biology	6,2273	2,0154	0,3236
Social sciences and the humanities	1,0000	0,0000	0,0000
Psychology	2,1364	0,8282	0,3877
Medicine	7,3636	1,8840	0,2559

$x_1, x_2, \ldots, x_n$ = indicators of scientific performance (ISI articles, international patents);

$\varphi_1, \varphi_2, \ldots, \varphi_n$ = quantity of every indicator $x_1, x_2, ..., x_n$ obtained (number of articles, number of patents);

$c_{e1}, c_{e2}, \ldots, c_{en}$ = calculated cost for indicators $x_1, x_2, ..., x_n$ (appendix 1). The calculus formula is the following:

$$C_i = \frac{C_i^{'} \times c_{mdj}}{c_{m\,dj}^{'}}$$

in which:

C_i = *i* indicator cost;

$C_i^{'}$ = *i* indicator average cost. We employed the term of average cost because we do not have international patents in all the scientific fields considered. For this reason, we will calculate an average value of multiplication coefficients corresponding to the fields in which the above mentioned indicator is relevant (table 4).

Table 4 – Average multiplication coefficient of the scientific field

Scientific field	**Average multiplication coefficient**
Science and technical field	5,95
Agricultural science	5,05
Physics	5,18
Chemistry	6,23
Biology	6,23
Medicine	7,36
Average	**6**

The average cost of each performance indicator used will be calculated using the following formula:

$$C_i^{'} = \frac{C^{'}_{PI} \times c_{mi}}{c_{mPI}}$$

In which:

$C_i^{'}$ = average cost of *i* indicator;

$C_{PI}^{'}$ = average cost of international patent;

c_{mPI} = multiplication coefficient of the international patent;

c_{mi} = multiplication coefficient of *i* indicator;

c_{mdj} = multiplication coefficient of *j* scientific field;

$c_{mdj}^{'}$ = average multiplication coefficient of the scientific fields which produced international patents;

If the entity of scientific research carries out activities in a single field, the importance coefficient value remains the same, and the function is reduced to:

$$F = c_{iD_i} (\varphi_1 x_1 c_{e1} + \varphi_2 x_2 c_{e2} + \ldots + \varphi_n x_n c_{en})$$

The financing amount of the research activity is established according to the values obtained for specific indicators. The differentiation of financial resources according to institutions is achieved according to: cost coefficients specific to every financial field, the impact of reviews that published the respective articles and the indicators calculated for every entity.

Calculating the Efficiency Indicator

Reporting the performance calculated by the function previously described at the financial resources used by every entity for the period analyzed, we can introduce an *efficiency indicator* for the research entities. This indicator will be calculated according to the following formula:

$$I_e = \frac{Achievements}{Financial\ resources\ used}$$

According to the values obtained for the *efficiency indicator* by the research institutes and the average result value for the category concerned, we will classify the Romanian entities of scientific research according to the methodology elaborated by Mihail Manoilescu (1986), as follows:

$I_{ei} > I_{em}$ - efficient research entities;
$I_{ei} = I_{em}$ – research entities whose efficiency equals the average;
$I_{ei} < I_{em}$ – research entities with an efficiency lower than average;
where:
I_{ei} = efficiency indicator of *i* entity;
I_{em} = efficiency indicator average;

Application of the Model

The validity of the model was tested on the results obtained by the National Institutes of Scientific Research and Romanian universities as these are the entities that periodically submit reports for this field. The data used were gathered for 2002, 2003, 2004, 2005, 2006, 2007 from the evaluation reports of the research institutions concerned. Before the analysis, we believe it is necessary to describe the systems in which these entities operate in Romania. According to the statistics of the National Institute of Statistics, the national system of research and development in Romania comprised a total of 130 such research units in the period analyzed, having the following structure:

- 44 national institutes of research and development, in approx. 15 technological fields coordinated by 8 ministries;
- 86 higher education units that carry out systematic and research activities;

From the total of the institutions presented, 33 research and development institutes from various technological fields (agriculture, biology, physics, chemistry, economics, engineering) and 28 universities (medicine, technical, …) were selected for analysis.

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The performance of the national institutes of scientific research measured with the help of the efficiency model by using the results obtained by these institutions to the output indicators shown in table 1 and the main input indicator: allocated financial resources.

According to figures 2 and 3, the scientific cost-efficiency analysis of the institutions subjected to the analysis, we could argue that the scientific research entities in Romania are divided in several categories:

- scientific research entities which use low financial resources and obtain high performances (INCDFM – National Research Institute for Materials Physics);
- scientific research entities that use high financial resources and obtain average performances;
- research entities that use high financial resources and obtain low performances;
- research entities that low financial resources and obtain low performances;

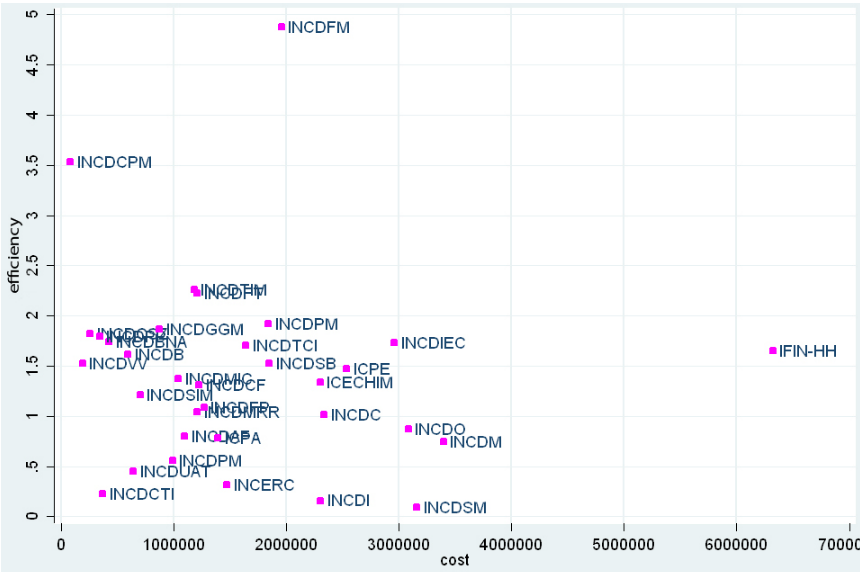

Figure 2. Scientific cost-efficiency analysis of the National Institutes of Research and Development in Romania

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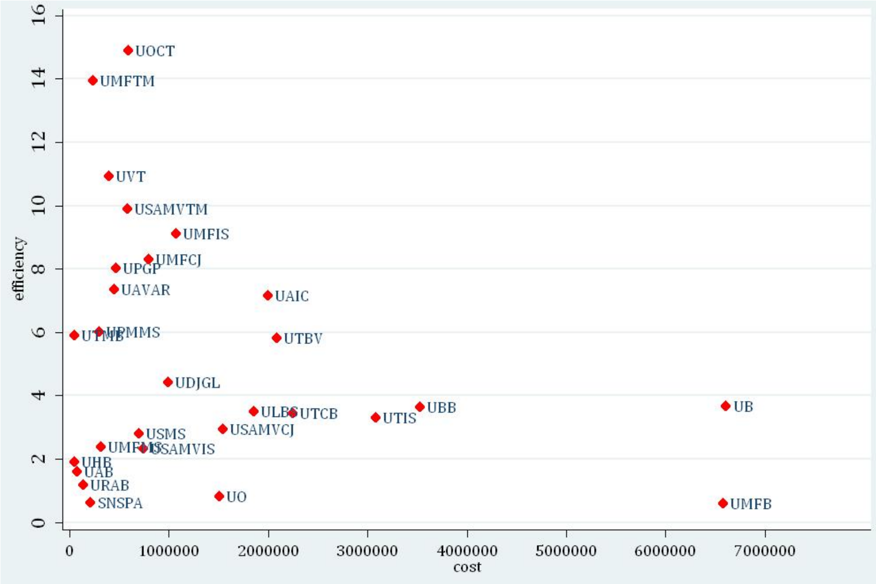

Figure 3 Scientific cost-efficiency analysis of Romanian Universities

The significant differences of the efficiency between the two categories of institutions occur due to the Romanian legislation which allows universities to receive funds allocated to scientific research by means of their basic financing, funds that have not been included in the calculation of the financial resources indicator. By including these amounts, the values of the efficiency indicator may be reduced.

Conclusions

The article aimed at creating an index to measure scientific research efficiency based on the costs calculated for every evaluation indicator. This index may be used both for establishing the efficiency of a researcher or organization involved in a field and a nation.

From a methodological viewpoint, the model evaluates performance by establishing a cost for every evaluation indicator (national and international publications, EPO, USPTO, and JPO patents). Turning all these results into a money value and establishing a relation with the main input indicator (allocated financial resources) will clearly highlight which scientific research institutions apply a performance management and which ones should change their strategy. Moreover, the model is a good instrument for allocating financial resources by the Ministry responsible for this field, further to a periodic evaluation process that decides where the funds go to.

The advantages of implementing such a model are the following: the possibility of accomplishing periodic reports on the system's performance and its institutions, ensuring transparency in the use of resources and evaluation, the quick dissemination of resources, the efficiency of the monitoring process, permanent access, automatic data processing, reduced costs for the activity of evaluation and connecting the system to international networks. The main disadvantages are: the problem of insecurity, the institutions' lack of interest to ensure transparency in evaluating scientific research activities, etc.

The methodology that allows the application of the model is a simple one, based on the main evaluation indicators and the allocated financial resources.

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Apendix 1 Multiplication coefficients for scientific research performance

Nr crt	Indicator name	Multiplication coefficients	Standard deviation	Variation coefficient
1	ISI article	41,6364	24,2047	0,5813
2	Article published in international conference proceedings	20,4545	11,9648	0,5849
3	Article published in national conference proceedings	5,5909	4,0944	0,7323
4	Article published in an acknowledged Romanian review (B category)	3,9091	2,4292	0,6214
5	Article published in an acknowledged Romanian review (C category)	**1,0000**	0,0000	0,0000
6	Book (of approx. 200 pages)published abroad	71,6364	39,2713	0,5482
7	Book (of approx. 200 pages) published in Romania	32,0909	15,8083	0,4926
8	International patent (in EU, USA, Japan, Canada)	385,0000	139,7319	0,3629
9	International patent (in other countries than EU, USA, Japan, Canada)	194,0909	137,7880	0,7099
9	National patent (The Republic of Moldova included)	31,3636	15,7323	0,5016
10	New registered OSIM product	20,4444	4,6455	0,2272

Apendix 2 Multiplication coefficients for all fields of scientific research

Nr. crt	Scientific field	Multiplication coefficients	Standard deviation	Variation coefficient
1	Science and technical field	5,9545	1,0103	0,1697
2	Agricultural sciences	5,0455	1,6849	0,3339
3	Physics	5,1818	1,1134	0,2149
4	Matemathics and applied mathematics	2,2727	0,6166	0,2713
5	Chemistry	6,2273	1,5720	0,2524
6	Biology	6,2273	2,0154	0,3236
7	Social sciences and the humanities	1,0000	0,0000	0,0000
8	Psychology	2,1364	0,8282	0,3877
9	Medicine	7,3636	1,8840	0,2559

Indicator	Average	Science and technical field	Agricultural sciences	Physics	Matemathics and applied mathematics	Chemistry	Biology	Social sciences and the humanities	Psychology	Medicine
Fields importance		5,95	5,05	5,18	2,27	6,23	6,23	1,00	2,14	7,36
ISI article	43258,6	42930,8	36376,5	37359,7	16385,8	44897,1	44897,1	7209,8	15402,7	53090,1
Article published in international conference proceedings	21251,5	21090,5	17870,6	18353,5	8049,8	22056,5	22056,5	3541,9	7566,8	26081,4
Article published in national conference proceedings	5808,7	5764,7	4884,6	5016,6	2200,3	6028,8	6028,8	968,1	2068,3	7128,9
Article published in an acknowledged Romanian review (B category)	4061,4	4030,6	3415,3	3507,6	1538,4	4215,2	4215,2	676,9	1446,1	4984,4
Article published in an acknowledged Romanian review (C category)	1039,0	1031,1	873,7	897,3	393,5	1078,3	1078,3	173,2	369,9	1275,1
Book (of approx. 200 pages)published abroad	74427,4	73863,5	62586,7	64278,2	28192,2	77246,6	77246,6	12404,6	26500,7	91342,7
Book (of approx. 200 pages) published in Romania	33341,2	33088,6	28036,9	28794,7	12629,2	34604,1	34604,1	5556,9	11871,5	40918,8
International patent (in EU, USA, Japan, Canada)	400000,0	396969,7	336363,6	345454,5	151515,2	415151,5	415151,5	66666,7	142424,2	490909,1

International patent (in other countries than EU, USA, Japan, Canada)	201652,9	200125,2	169571,8	174154,8	76383,7	209291,3	209291,3	33608,8	71800,7	247483,1
National patent (The Republic of Moldova included)	32585,6	32338,7	27401,5	28142,1	12343,0	33819,9	33819,9	5430,9	11602,4	39991,4
New registered OSIM product	21241,0	21080,1	17861,7	18344,5	8045,8	22045,6	22045,6	3540,2	7563,1	26068,5

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