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A bibliometric approach to measuring societal impact of research in biomedicine based on the principle of productive interaction

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Abstract: This paper presents the evolvement of a hybrid framework for the analysis of societal impact of research, based on combining the theory of productive interactions with bibliometric data. This paper presents the next step in the development of the hybrid framework, after we have analyzed the social impact of scientific results as recognized in expert evaluation reports, in the second phase, presented in this paper, we have linked this data with bibliographic data obtained by harvesting the public bibliographic database Croatian scientific bibliography (CROSBI). This second phase of research presents the societally relevant output from public research institutions and faculties on public universities in Croatia in the field of biomedicine for the period from 2013 to 2017. The study has found evidence of measuring societal impact of scientific work using the theory of productive interactions on bibliometrics data in the biomedicine field, thereby contributing to the development of more robust understandings of measuring societal impact in science.
Key words: societal impact of scientific work, Croatian system of higher education and science, productive interaction

1. Introduction

Impact measurement is a highly demanding discipline in any field of human activity. Measuring the social impact of scientific work is additionally complex and challenging due to the fact that scientific output was produced primarily with scientific goals in mind. Common approaches, such as citation counts, are often criticized from the standpoint that traditional bibliometric indicators (Holmberg et al., 2015) do not measure impact of science on the wider community. Along with the change in funding allocation (Hicks, 2012) based on indicators, we have a strong public demand that the scientific activity should not be closed within the scientific community. One possible definition is that scientific work has a social impact when there is a reference to it outside the scientific community

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(Bornmann and Marx, 2014). Although intuitive, this definition does not suggest how to demonstrate and measure, rather than presume, social impact. Currently different approaches are being considered within various expert evaluation frameworks. This study will contribute to the exploration of the complex concept of social impact of scientific work and present possible approaches to measuring it by combining an analysis of narrative data gained in the evaluation process of HEI's in Croatia with the data obtainable by harvesting public bibliographic databases. This research is based on the framework of productive interactions, which defines productive interactions as exchanges between researchers and stakeholders in which knowledge is produced and value created that is both scientifically robust and socially relevant (Spaapen, and van Drooge, 2011).

In the first phase of the research we have tested the methodology on the expert reports produced in the process of the evaluation of public higher education institutions (HEIs) at universities and public research institutes in Croatia. For the purpose of quantitative assessment, we have developed a conceptual framework and analyzed the narrative texts of expert reports based on recognizing codified interactions, (Grubišić and Špiranec, 2019). In this study we will use the methodology based on the theory of productive interaction applied on the data harvested from CROSBI, a database that lists all outputs by individual researchers in Croatia. The listed scientific output will be classified based on the codification of the detailed attributes assigned to the publication in the CROSBI database. This is the second phase of our research of biomedical public research institutions and faculties on public universities in Croatia for period from 2013 to 2017.

2. Measuring societal impact of research in Croatia – the structural context of the study

Bibliometric measurement of the social impact of scientific work has not yet been conducted in the Republic of Croatia. Before we present our methodology let us describe the Croatian scientific system and then discuss how certain structural features impacted our study and the modelling choices for setting the scope of the analysis.

The system of science and higher education in the Republic of Croatia is defined by the umbrella Law on Scientific Activity and Higher Education (OG 123/03, 60/15). Scientific activity at the level of institutions is carried out by universities and their constituents, public scientific institutes, scientific institutes, the Croatian Academy of Sciences and Arts, as well as other legal entities and their organizational units listed in the Register of Scientific Organizations. All listed institutions are issued a scientific license. On the other hand, higher education is carried out by higher education institutions (HEI). The recognized HEIs are the universities, the constituent faculties and art academies which are independent legal persons within universities, polytechnics and colleges.

The evaluation procedures for the higher education and science systems do not officially measure social impact of scientific work. By analyzing the criteria and standards for evaluation, we have identified those standards that we can use as criteria for evaluating the social impact of scientific work. In accordance to the structure of the Croatian HEIs our analysis focuses only on the faculties within the public universities, because colleges and polytechnics in the Republic of Croatia are not obliged to carry out scientific activity according to the Law on Scientific Activity and Higher Education, i.e. they do not have to have a scientific license.

In the first phase of the research (focused on the public research institutions and faculties of public universities in Croatia in the biomedical field) we have shown that it is possible to measure the societal impact of research based on the analysis of the expert evaluation reports using the theory of productive interactions. Following (Spaapen and van Drooge, 2011) we assessed a sample of societal interactions submitted by an institution under evaluation as representative for their practice. Productive interaction can be categorized in three categories according to the taxonomy of (Spaapen and van Drooge, 2011):

- Direct interaction
- Indirect interaction
- Financial interaction

3. Methodological approach and research questions

In this paper we present a bibliometric approach to measuring societal impact of research of the same institutions and for the same period from 2013 to 2017. Our source of bibliometric data is Croatian scientific bibliography (CROSBI). Croatian scientific bibliography (CROSBI) [1] database lists a collection of all outputs by individual researchers. We will present in detail the categories that exist in the CROSBI database, with an emphasis on subcategories that we consider essential for measuring the societal impact of research using the theory of productive interactions. This approach leans on a previously recognized bibliometric method, which highlights the use of databases that include a broader output than just the scientific publications (Baker, K.E et al, 2011). Subcategories and types of publications that we consider essential for assessing the societal impact of research will be analyzed for institutions in the biomedical science field using the theory of productive interactions.

The scientific area of biomedicine is recognised as a good test case for studying societal impact because the connection between research and public health is indisputable. Therefore, we expect that within the purely scientific output we should find attributes that indicate societal interaction.

Using R software, we will analyze the type and proportions of different publications that are recognized as publications that show the societal impact of research relative to the total number of publications of the institutions analyzed.

Finally, we will compare the results obtained from the earlier analysis of the evaluation reports of expert committees in the process of re-accreditation of faculties and public scientific institutes in the field of biomedicine and the results obtained from the CROSBI database for the same institutions over the same time period. As the analysis of the final reports has shown, the type of financial interaction at institutions in the field of biomedicine is the least represented. This result is in line with the findings we have in the evaluation procedures in Croatia and with the allocations of the funding for scientific research, which are minimal in all scientific fields and in almost all institutions in the system of science and higher education. Due to all of the above, we expect that the results for financial interaction will be the least represented in the analysis of publications listed in the CROSBI database.

The research questions that guided our study are:

1. Can we find evidence for measuring the societal impact of research using the theory of productive interactions applied on bibliometrics data in the Croatian Scientific Bibliography?
2. Is there any difference between the results obtained from the analysis of the final reports of the expert panels and the analysis of publications in the CROSBI database for institutions in the biomedical field?
3. According to the analysis of publications in the CROSBI database, are there differences in recognizing the types of productive interaction for types of institutions (public scientific institutes vs. faculties at public universities)?

4. Croatian scientific bibliography CROSBI

The data source in our study is the Croatian scientific bibliography (CROSBI) database that lists a collection of all outputs by individual researchers. It is maintained and its accuracy monitored by the Center for Scientific Information of Ruđer Boskovic Institute. The CROSBI is a database that in one place brings together a comprehensive scientific publishing of all Croatian researchers, aiming at improving scientific communication and promotion of Croatian scientists and research conducted in the country and abroad. Today, CROSBI contains data on more than 520,000 publications by Croatian scientists, and from its very beginning was based on new and advanced concepts (functionality of open access repository so that along with the bibliographic record it is possible to archive full text).

In this way, the involvement of all areas of science, all institutions in the system of science and higher education, all types of publications and works resulting from research activities is ensured. Supervisors include librarians who possess competences for supervisory tasks over bibliographic data, and publication data is available in a timely fashion, even before publishing in formal publication. Furthermore, it is mandatory by bylaws of Croatian Science Foundations (CSF) for all researchers – participating in CSF funded projects – to maintain the records of all their research outputs accurate since these records can be used in

internal CSF evaluation procedures. An increasing number of institutions in the higher education science system in the Republic of Croatia have authorized administrators to enter and verify data in the CROSBI database.

The re-accreditation procedures of higher education institutions and scientific institutes conducted by the Agency for Science and Higher Education in the five-year cycle use bibliographic data for evaluation institutions and its staff. As this procedure is compulsory in the Republic of Croatia and includes a bibliography over a five-year period, the data in the database are nevertheless more credible than the usual accuracy of data similar to national databases entered by the scientists themselves.

The number of publications in CROSBI, when compared to the number of publications in commercial databases such as WoS, is significantly larger, i.e. it covers a wider range of publications for the same institutions in the same period. Let us point out that this additional publication data from CROSBI are the ones that tell us about the social impact of scientific work. CROSBI can provide quantitative information on the impact of scientific work on society using the framework of productive interaction since it lists research outputs like science popularization papers, expert reports, guidelines etc. From CROSBI database we obtain quantitative data and compare research areas solely against bibliographic indicators and based on a new indicator which includes measurement of all other types of publications. Papers contained in the CROSBI database will be divided into two basic categories; works that show scientific impact of scientific work and works that likely show societal impact of scientific work. The category of papers showing the societal impact of scientific work will be analysed according to a matrix for productive interaction. It is our assumption that additional publications, which are not indexed in commercial databases, represent a good starting point for classifying societal relevance of research results according to the conceptual framework of productive interaction.

5. Data in CROSBI database

To begin with, we present the number of publications in the CROSBI database for the period of our research. We provide views by the various categories and subcategories used in the said database according to its bibliometric subdivisions. We bring the elaborate view of the subcategories to those categories that are relevant to our research into measuring the social impact of scientific work. The database also has a separate category *Other publication* which it is not predefined at all. As stated earlier, the data is entered into the database by the scientists themselves and despite all the instructions and workshops, there are publications that do not have all the necessary attributes.

Year	Authored books	Edited books	Educational material	Book chapters	Journal articles	Conference proceedings papers	Conference abstracts	Theses	Other papers	Patents	Total
	Details	Details	Details	Details	Details	Details	Details	Details			
2017	490	418	178	1994	9243	4063	6960	6188	1331	13	30878
2016	511	371	240	2132	9420	4219	6571	6045	1358	7	30874
2015	550	364	232	2108	9358	4331	6796	7251	1348	14	32352
2014	519	394	450	2226	9883	4677	6779	6554	1342	19	32843
2013	562	384	280	2438	10277	4556	6529	7339	1656	20	34041
Total	2632	1931	1380	10898	48181	21846	33635	42381	9167	83	217187

Figure 1. Detailed view by period and type of publications 2013 – 2017

Picture 1 presents data for all scientific fields and for all scientists and institutions in the system of science and higher education in the Republic of Croatia. Bibliographic data are presented according to the categories listed in the CROSBI database [2].

Categories in CROSBI database are: authored books, edited books, educational material, book chapters, journal articles, conference proceeding papers, conference abstracts, theses, other papers and patents.
As expected, the most represented category is journal articles, then conference proceeding papers and conference abstracts. In this analysis, we will omit educational material and theses because we believe that these publications are primarily produced within the teaching process, which is not the primary interest of our analysis.

Category of journal papers have more subcategories. Those are: original scientific papers, review papers, short communication, preliminary notes, letters, professional papers, articles in press and other journal papers.

As expected most represented subcategories original scientific journal papers, then professional papers which we will use in this study of bibliometric measuring of social impact of scientific work.

Category of conference papers is divided in subcategories: scientific conference proceedings papers, professional conference proceedings papers and other conference proceedings papers.

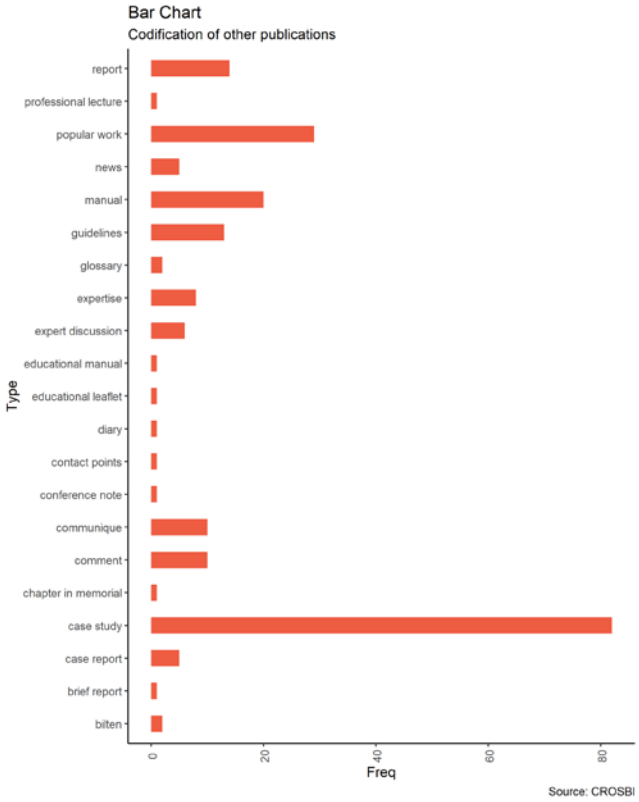
In this study of bibliometric measurement of the social impact of scientific work, special attention will be devoted to professional conference proceedings.

We did not include the other categories in the subcategories by groups, as they are less relevant at this stage of the research. For the sake of analysis, most attention was paid to the category *other papers*. According to a study conducted

on the reports of expert committees based on the evidence submitted by faculties on public universities and scientific institutes (Grubišić and Špiranec, 2019), most publications that discuss the social impact of scientific work on the institutions studied are in this category.

As the aforementioned category is the broadest and the least defined category for it on the pages of CROSBI database, there is no detailed representation by subcategories for the requested period as we have shown so far. We have analyzed this category independently by using R-software. Since the whole category is included in the database as an additional category, covering publications not recognized in the classical evaluation procedures in the Republic of Croatia, we believe that publications in this category speak beyond the scientific evaluation of scientific work. Thus, we assume that this category includes publications that are indicators for bibliometric measurement of the social impact of scientific work.

Here we show all types that fall into the Other papers' category:



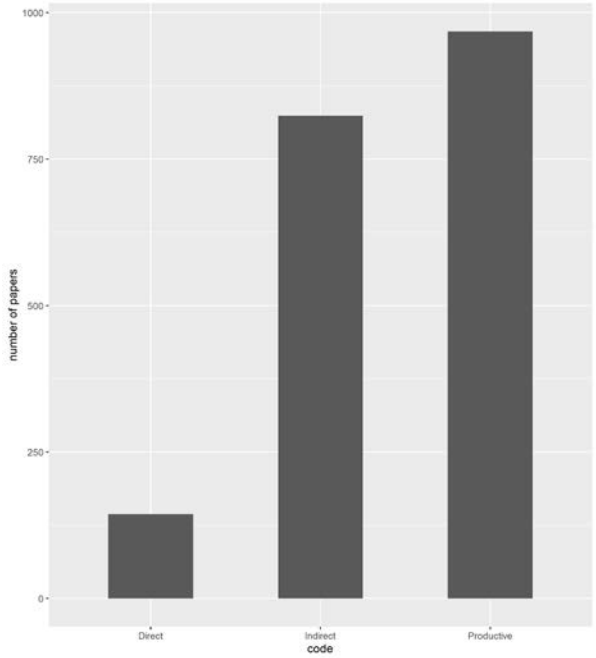
Graph 1. Number of publications in Other publications

Graph 1. presents the number of publications in the database category *Other publications* in the studied faculties and institutes in the biomedical areas in CROSBI database in period from 2013 to 2017. On the *x* axis we place the number of publications that we have included in this analysis. The axis y shows types of publications that we have included in this analysis. Our analysis has shown that, the most common type of publications are case studies, followed by popular work, reports, manuals and guidelines. The least represented types of publications are professional lecture, educational manual, diary, contact points, conference note and chapter in memorial with only one mention.

6. Results

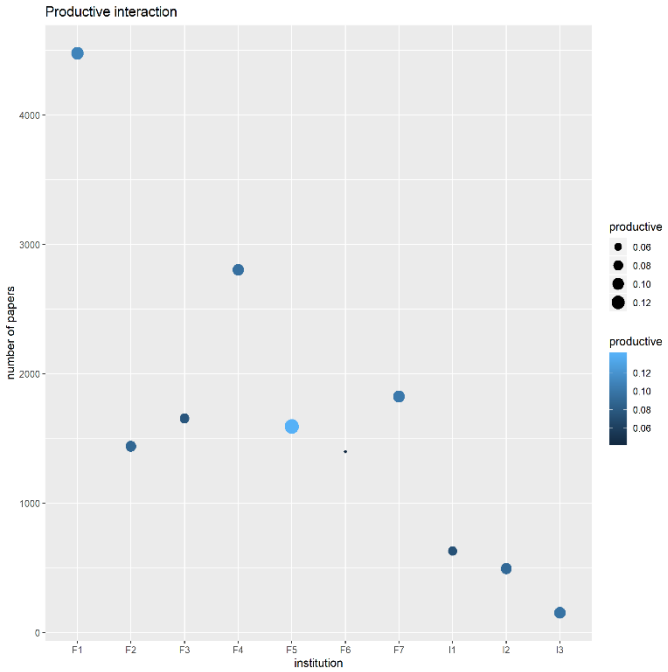
Let us now summarize the previously obtained findings based on the analysis of the final reports in the process of re-accreditation of higher education institutions and public research institutes. More codes for direct and indirect interaction were recognized in public institutes than on faculties for biomedicine (Grubišić and Špiranec, 2019). Both public institutes and faculties in biomedicine have recognized codes in financial interaction, especially in professional contracts.

We have combined these findings in the form of a high-level summary of codes with the attributes of CROSBI listed publications. The majority of codes for direct interaction are recognized in the field of biomedicine, while professional publications were recognized as important for indirect interaction in biomedicine.



Graph 2. Number of publications presenting productive interactions

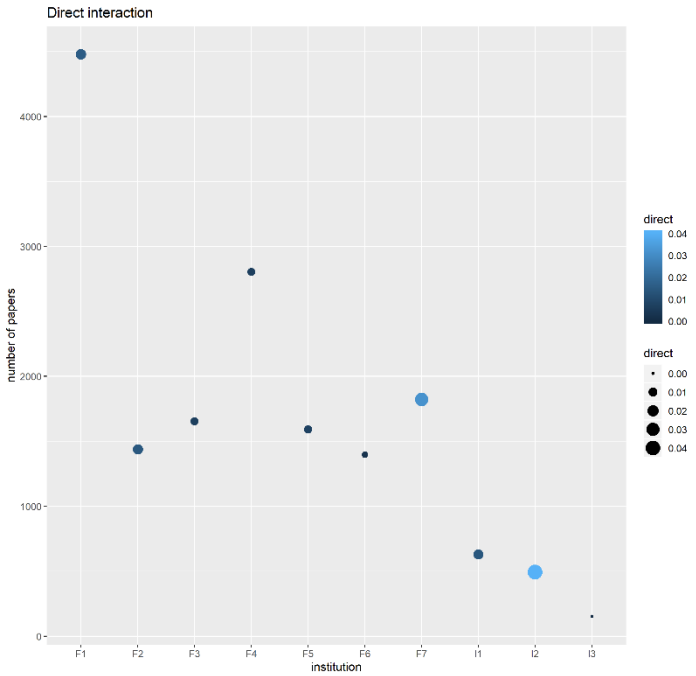
Graph 2. presents the number of publications that present productive interaction on the seven faculties and three institutes in the biomedical area in CROSBI database from 2013 to 2017. The share of publications that are recognized as direct interaction is significantly lower than the share of publications that are recognized as indirect interaction.



Graph 3. Share of publications showing productive interaction in the studied faculties and institutes in the biomedical area

Graph 3. presents the share of publications showing productive interaction in the studied faculties and institutes in the biomedical area in CROSBI database from 2013 to2017. Axis *x* displays the indices of analyzed institutions. The indices are integers ranging from 1 to 10. Range from 1 to 7 are faculties on public universities and the range from 8 to 10 are public research institutes. Axis *y* displays the absolute number of publications for each institution in CROSBI database for period from 2013 to 2017. The size of the circles tells us the proportion of publications that represent productive interaction in the total number of publications of the institution displayed. The greater the proportion of publications that present productive interaction, the brighter and larger the circle. The highest percentage of publications that we recognize as productive interaction has Faculty 5, followed by Faculty 1 and Institute 3. It is important to emphasize here that Institute 3 is the smallest by the number of publications

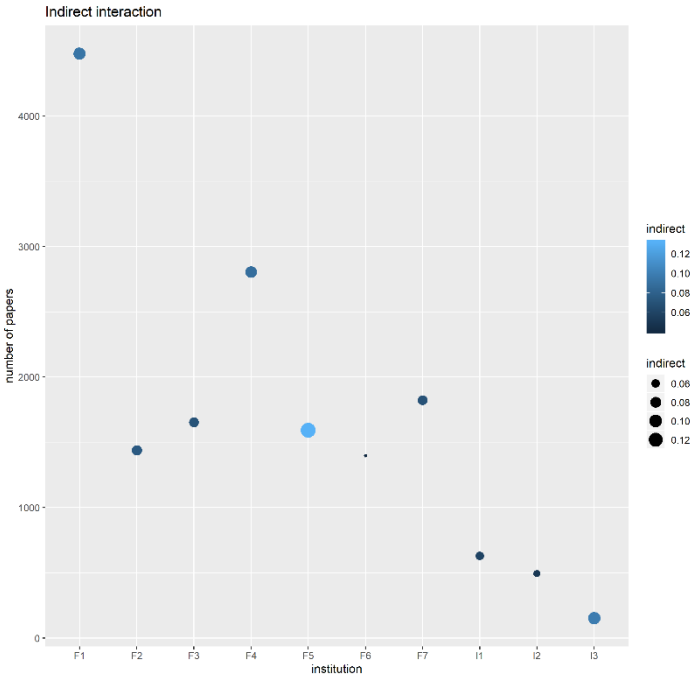
among all the analyzed institutions. Faculty 1 is the biggest by the number of publications among all the analyzed faculties. Faculty 6 has the absolute smallest percentage of publications that we recognize as productive interaction and is the smallest by the number of publications among the faculties. Faculty 6 is the smallest by the number of publications among all the analyzed faculties.



Graph 4. Share of publications showing direct interaction in the studied faculties and institutes in the biomedical area

Graph 4. presents the share of publications showing direct interaction in the studied faculties and institutes in the biomedical area in CROSBI database in period from 2013 to 2017. Axis *x* displays the indices of analyzed institutions. The indices are integers ranging from 1 to 10. Range from 1 to 7 are faculties on public universities and the range from 8 to 10 are public research institutes. On *y* axis we place the absolute number of publications for each institution as represented in the CROSBI database. The size of the circles tells us the proportion of publications that represent direct interaction in the total number of publications of the institution displayed. The greater the proportion of publications that present direct interaction, the brighter and larger the circle. The highest percentage of publications that we recognize as direct interaction has the Institute 2, followed by Faculty 7 and Faculty1. Institute 3 has the absolute smallest percentage of publications that we recognize as direct interaction.

Institute 3 is the smallest by the number of publications among all the analyzed institutions.



Graph 5. Share of publications showing indirect interaction in the studied faculties and institutes in the biomedical area

Graph 5. presents the share of publications showing indirect interaction in the faculties and institutes in our sample. Axis *x* displays the indices of analyzed institutions. The indices are integers ranging from 1 to 10. Range from 1 to 7 are faculties on public universities and the range from 8 to 10 are public research institutes. Axis *y* shows the absolute number of publications for each institution from our sample. The size of the circles tells us the proportion of publications that represent indirect interaction in the total number of publications of the institution displayed. The greater the proportion of publications that present indirect interaction, the brighter and larger the circle. The highest percentage of publications that we recognize as indirect interaction has the Faculty 5, followed by Faculty 1 and Institute 3. Institute 2 has the absolute smallest percentage of publications that we recognize as indirect interaction and is the smallest by the number of publications among the institutes. Institute 3 has the highest percentage of publications that we recognize as indirect interaction among institutes and is the smallest by the number of publications among the institutes.

7. Conclusions

This paper presents an evolvement of the hybrid framework for the analysis of societal impact of research. As there is a lot of uncertainty regarding evaluating such impacts, through our research we have tried to contribute to more nuanced understandings of societal impacts of research. We present an approach using bibliometric data derived from a non-commercial national database which includes broader scope of scientific outputs than just the scientific journal publications. This data was linked with results obtained from the first phase of research, consisting of analysis of narrative data gained in the evaluation process of HEI's in Croatia. We have based our research design on three research questions:

1. Can we find evidence for measuring the societal impact of science using the theory of productive interactions on bibliometrics data in the Croatian Scientific Bibliography?

Our research has shown that we can find evidence of measuring societal impact of science using the theory of productive interactions applied on bibliometrics data for seven faculties of public universities and three public scientific institutes in the field of biomedicine as entered in the Croatian Scientific Bibliography for period from 2013 to 2017.

2. Is there a difference between the results obtained from the analysis of the final reports of the expert committee and the analysis of publications in the CROSBI database for institutions in the biomedical area?

Findings based on the analysis of final reports in the process of re-accreditation of higher education institutions and scientific institutes from the biomedical area have shown that more codes are recognized for direct interaction. From analysis of publications in the CROSBI database, the share of publications that are recognized as direct interaction is significantly lower than the share of publications that are recognized as indirect interaction. This is the first difference between the results.

Findings based on the analysis of final reports in the process of re-accreditation of higher education institutions and scientific institutes from the biomedical area have shown that more codes for direct and indirect interaction is recognized for public research institutes. From analysis of publications in the CROSBI database, the highest percentage of publications that we recognize as direct interaction has the Institute 2, followed by Faculty 7 and Faculty1. But the other research institutes have significantly lower percentage of publications that we recognize as direct interaction. From analysis of publications in the CROSBI database, the highest percentage of publications that we recognize as indirect interaction has the Faculty 5, followed by Faculty 1 and Institute 3. This is the second difference in the results.

Some findings are confirmed like the majority of codes for direct interaction are recognized in the field of biomedicine are professional publications. This finding

obtained from the analysis of the final reports of the expert committee is confirmed on the data analysis made on CROSBI data.

We can conclude that the results obtained from the analysis of the final reports of the expert committee are not entirely conforming with the results obtained by the analysis of publications in the CROSBI database for institutions in the biomedical area.

3. According to the analysis of publications in the CROSBI database, are there differences in recognizing the types of productive interaction for types of institutions (public scientific institutes vs. faculties at public universities)?

Share of publications showing productive interaction in the analyzed faculties and institutes in the biomedical area is from 6% to 12%. Faculties at public universities have more publications that represent productive interaction than public research institutes in the area of biomedicine. In the Republic of Croatia, faculties are larger in number and number of employees and have more publications in the observed period. Faculties also have a much wider range of share of publications that we recognize as productive interaction. Three institutes have a more evenly distributed percentage of publications that represent productive interaction. Share of publications showing direct interaction in the studied faculties and institutes in the biomedical area is from 0 to 4%. Share of publications showing indirect interaction in the studied faculties and institutes in the biomedical area is from 6% to 12%. Faculties have a much wider range of share of publications that we recognize as indirect interaction. We can conclude that the three institutes have a more evenly distributed percentage of publications that represent indirect interaction. Direct interaction is significantly underrepresented compared to indirect and its percentages go 0 from 4%.

In conclusion, faculties of public universities in the area of biomedicine have a much wider range of share of publications that we recognize as productive interaction, especially publications that we recognize as indirect interaction. On the other hand, institutes have a more evenly distributed percentage of publications that represent productive interaction, especially indirect interaction.

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