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# THE ROLE AND SIGNIFICANCE OF SCIENTIFIC COLLABORATION FOR THE NEW EMERGING SCIENCES: THE CASE OF SLOVENIA

**Abstract**. *The article addresses some issues related to the definition and analysis of scientific collaboration. Starting with a general presentation of studies on Slovenian co-authorship networks of researchers in four different disciplines, the article seeks to ascertain if there are any differences between disciplines that are more committed to the "Mode 1" production of knowledge and disciplines more committed to the "Mode 2" production of knowledge. The research is based on a bibliometric analysis of co-authorship networks, a quantitative web survey among scientists and qualitative interviews among a small group of leading representatives of the scientific community and R&D policy institutions in Slovenia.*



**Keywords**: *scientific collaboration, co-authorship publications, Slovenian scientists, Mode 1 and Mode 2 production of scientific knowledge*

## Introduction

Collaboration is becoming one of the most significant features of scientific and technological activities in the 21st century. Of course, collaborative work is not novelty in the scientific environment. It has instead evolved gradually to become one of the most important forms of knowledge production since World War II. As argued by O'Brien (2012), the influence of structural changes in science and science policy has contributed significantly to the current omnipresence of scientific collaboration: scientific competition, scientific specialisation, changes in the funding of science etc. In the years before and after World War II, a lot of investments were made in large laboratories. As a consequence, scientists became ever more dependent on large and very sophisticated instruments, while the existence of large

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research centres became closely connected with expensive research equipment that requires and integrates different technical expertise from various scientific fields.

The growing trend of scientific collaboration since the 1980s is linked with stronger processes of internal (cognitive) convergence in science and technology. During many past decades, small-scale cognitive convergences were taking place in science. Today, large-scale convergences are radically changing the cognitive nature of science and technology. The recent development of emerging sciences and technologies is based on multi-, inter- and trans-disciplinarity. There are various reasons for these developments, with the most important being the growing recognition that modern scientific production is indeed strongly interconnected. It seems that since the mid-1990s the concept of "Mode 2" knowledge production, first presented in the book *The New Production of Knowledge* (Gibbons et al., 1994), has become the symbolic banner for these new processes of scientific convergence and collaboration. Rogers Hollingsworth says that today science and technology are in the development phase, which requires the building of common knowledge networks consisting of shared theoretical frameworks plus a common stock of models and mechanisms that integrates a broad range of domains normally occupied by different scientific disciplines (Hollingsworth, 2006).



The external (social) factors contributing to scientific collaboration are almost endless. Namely, scientific collaboration is an intrinsically social process and, as with any form of human interaction, there may be at least as many contributing factors as there are actors involved in scientific collaboration. In recent times, policy factors (at the regional, national and transnational levels) have become key factors in scientific collaborations. Namely, they are a basic instrument for channelling financial resources for R&D, for selecting a research topic in the context of evaluation processes, adjudicating scientific authority etc. For example, the European Commission, which requires that researchers seek collaborative partners before they apply for financial support, is one of the most important drivers of (international) scientific collaboration. More than EUR 50 billion was planned to be spent between 2007 and 2013 on EU Framework Programmes 7 (FP7) (Royal Society, 2011: 66). The new Framework Programme (Horizon 2020) should even more strongly encourage collaborative work particularly in the field of newly emerging technologies with the goal to "...extend Europe's capacity for advanced and paradigm-changing innovation" (Feltrin, 2013: 5).

From a methodological point of view, modern scientific and technological collaboration can be observed in different ways. Various quantitative and qualitative approaches have been developed over the last few decades to explain and understand recent trends in scientific collaboration, such as bibliometrics, interviews, observations, controlled experiments, surveys, simulations, self-reflection, social network analysis and several types of qualitative approaches (for more, see: Shrum and Mullins, 1988; Shrum et al., 2007). Nevertheless, research collaboration is often operationalised as publication co-authorship due to several advantages of bibliometric analysis[1]. Co-authored publications represent a measurable output of research collaboration since the publishing of research results has become a necessary part of the research process (Bukvova, 2010). Thus, publication co-authorship represents one of the most formal manifestations of scientific communication[2]. It also generates a network that can be visualised and further explored. This is a perfect way to gain an understanding of both the network features and individual features of a co-authorship network (Erfanmanesh et al., 2012). Namely, the analysis of co-authorship networks is a very good bibliometric instrument for studying not only the general structures of scientific collaborations, but the status of individual researchers as well (Carillo et al., 2012: 7–8).

In our contribution, we will also follow scientific collaboration in the form of co-authorship publications. This type of very formal and one of the most important forms of scientific cooperation has grown significantly around the world in the last few decades. In the theoretical subsection of the article, the basic concepts, dimensions, factors and consequences of stronger processes of collaboration in modern scientific and technological fields will be briefly described.



In the second, empirical subsection, the situation in Slovenia will be presented. First, an outline of the main trends of co-authorship networks in selected disciplines in Slovenia will be given. According to the selection of disciplines, our starting research question is: are there any differences between the 'old' and 'new' type of scientific disciplines or (more precisely) between disciplines which are more committed to the "Mode 1" production of knowledge and disciplines which are committed to the "Mode 2" production of knowledge or between 'lab' and 'office' disciplines concerning recent trends in scientific co-authorship? We are chiefly interested in trends in the field of biotechnology. Modern biotechnology can be defined as a newly emerging technoscience characterised by the shift to the "Mode 2"

*[1] First, one of the important benefits is that the data on co-authorship can be easily and accurately extracted from publication databases (Pike, 2010: 431). Second, co-authorship data are generally considered as one of the most "tangible and formal ways of analysing collaboration" and consequently also as "the most frequently used information" when exploring collaboration patterns among researchers (De Stefano et al., 2011: 1092). Third, co-authorship as part of scientific publication plays a crucial role in the development of science in general as well as in "the reward structure for academics in particular" (Acedo et al., 2006: 958).*

*[2] Although the analysis of co-authorship networks is very similar to the analysis of citation networks, the first networks indicate a much stronger connection between researchers than citations, which occur without personal acquaintance (Toral et al., 2011).*

production of scientific knowledge. In some sense, in the last two decades it has acted as a tipping point for radical changes across all new emerging technosciences. Of course, we are aware that the broad changes in the production of scientific knowledge (the shift from "Mode 1" to "Mode 2") are only the background or point of departure for looking more in-depth into different forms of research collaboration. Notwithstanding this, the shift from Mode 1 to Mode 2 is a useful heuristic tool for observing recent trends in co-authorship networks in Slovenian science.

After presenting the main co-authorship trends in the selected group of scientific fields in Slovenia, we shall try to identify the main driving forces of these trends. In the analysis, an (analytical) distinction between the structural and individual factors driving scientific collaboration will be used. Although structural factors (new forms of communications, new financial incentives etc.) can strongly foster scientific collaboration, there is no doubt that the individual motivations of scientists actively involved in research processes (individual factors in our analytical scheme) can play an even much more important role. To obtain basic knowledge on the background of scientific co-authorship trends, we employed two methodological approaches: a quantitative web survey among scientists as well as qualitative interviews among a small group of leading representatives of the scientific community and R&D policy institutions in Slovenia. Namely, our assumption is that modern scientific collaboration is a very complex social phenomenon that needs to be analysed and described through a combination of quantitative and quantitative methodological tools.



## Scientific collaborations processes in recent dynamic scientific technological progress

As mentioned in the introduction, scientific and technological collaboration can be studied in different ways. Co-authorship networks represent the focus of our interest. These networks are defined by the connections between scientists which are formed through joint publications. These networks thus display the social structure of academia, and also allow conclusions about the structure of scientific knowledge (Staudt et al., 2013: 1).

Apart from co-authorship networks as one of the most frequently used indicators of scientific collaboration, other bibliometric indicators are used.[3] Some critics of co-authorship bibliometric analysis are even stronger. They say that the biggest part of collaboration is not acknowledged as co-authorship; it is therefore not necessarily the case that co-authorship represents

[3] *Even sub-authorship, evident in the acknowledgment section of articles, can be represented as the manifestation of collaboration (Glanzel and Schubert, 2004: 258).*

the most efficient measure of collaboration. They emphasise that a considerable share of collaborations are left invisible in co-authorship. From this perspective, co-authorship merely represents a partial indicator of scientific collaboration (Katz and Martin in Glanzel and Schubert, 2004: 258; Laudel in Glanzel and Schubert, 2004: 258–59). In spite of this criticism, analysis of co-authorship networks is still accepted as the best bibliometric 'tool' for measuring different patterns of collaboration within different types (disciplines, specialities etc.) as well as sectors (industry, academy etc.) of science (Glanzel and Schubert, 2004; Newman, 2001).

Generally speaking, especially when viewed from the perspective of co-authorship networks, scientific collaborations can be classified in several ways (Ziman, 2000; Shrum and Mullins, 1988). They can take various forms ranging from micro to macro social levels. The large diversity of research on scientific collaborations usually contributes to a variety of terminology and methodological approaches. The categories and criteria employed in various classifications are neither universally defined nor mutually exclusive. For example, inter- and multi-disciplinary collaboration may be used interchangeably according to some views and defined as different concepts by others. An international scientific collaboration may also be an interdisciplinary collaboration, and it may be difficult to ascertain how each characteristic or combination of them contributed to the scientific process.



One of the most frequent distinctions is the difference between intramural and extramural collaboration (Glanzel and Schubert, 2004: 258):

1. Intramural collaboration relates to collaborative work within a department, research group or institute. The formal organisation of science at universities and in industrial laboratories usually follows the disciplinary boundaries; multidisciplinary collaboration therefore mostly requires the crossing of organisational boundaries. Cummings and Kiesler (2005) established that projects whose collaborating scientists are located in the same university are usually more successful than projects that bring collaborators from different universities together. Similarly, Glanzel and Schubert (2004) argue that multidisciplinary projects performed within a single university can be very successful in producing new ideas and knowledge.
2. Extramural collaboration relates to inter-institutional collaboration and international collaboration. Inter-institutional collaboration (Glanzel and Schubert, 2004; Toral et al., 2011) refers to collaboration among different research institutions as well as to collaboration among different sectors, for example among university, industry and government (intersectoral collaboration). International collaboration is largely acknowledged. The intensity of international collaboration is determined by geographical proximity and other factors, such as the size of a country, political and

economic reasons, mobility and migration on the individual level. International collaboration is an important element especially for small scientific communities such as the scientific community in Slovenia. Isolated and parochial scientific communities can no longer be a suitable environment for scientific excellence.

From the perspective of the recent tremendous scientific and technological progress, a very interesting question arises of whether the new modes of production of scientific knowledge across various scientific fields have any impact on the recent processes of scientific collaboration and interlinking (see Jansen et al., 2010). Andrea Bonaccorsi highlighted the role of the distinct cognitive characteristics of scientific fields in how scientific knowledge is produced in these fields (Bonaccorsi, 2007; Bonaccorsi, 2008). In doing so, he distinguishes between two broadly different types of science: the old and the new sciences. The old (established) scientific fields (chemistry, mathematics, physics) developed following the scientific revolution in the 17th century. The new scientific fields (computer and information sciences, biotechnology, etc.) have developed since World War II. Bonaccorsi argued that the crucial difference between the old and new sciences is seen in the mode and dynamics of knowledge production. "Mode 1" is characteristic of the old sciences. Here, the production of knowledge is typically thought to be disciplinary and primarily located in (academic) scientific institutions. "Mode 2" characterises the new sciences. Here, the production of knowledge is thought to take place in a trans-disciplinary and trans-sectorial manner. Mode 2 knowledge production emphasises changes that occur outside the scientific area in terms of the joint creation of the applicability context that is focused on problem-solving and is trans-disciplinary in nature. In this context, traditional quality criteria are replaced by pragmatic criteria of functionality that are defined by various stakeholders. In the empirical part of our discussion, we shall use the above mentioned concepts ('new science' versus 'old science', 'Mode 2 knowledge production' versus 'Mode 1 knowledge production', 'lab' versus 'office' sciences) when observing co-authorship networks in Slovenia.

While experts dealing with co-authorship networks agree quite strongly that there is a correlation between the forms and intensity of collaboration on one hand and the cognitive-institutional structure of scientific fields on the other, controversies still exist among them about the effects of various network structures on scientific productivity and its impact. These controversies form part of the broader theoretical disagreement in social network theory. Namely, in social network theory, following Coleman (1988), densely embedded closed social networks should have advantages over open social networks because they foster the development of mutual trust. Contrary to Coleman, Burt (1992) argued that brokerage opportunities arise in open social structures, i.e. "structural holes".

Concerning the issue of the optimal social network in science facilitating the scientific knowledge output and impact, a lot of additional explanations concerning the former general concepts of closed and open networks may be given. Many empirical analyses have found that open networks such as the scale-free model are more useful for publication productivity and impact in science. Mark S. Granovetter provided the idea of "the strength of the weak ties" (Granovetter, 1973: 1362) meaning that loose and not very intensive network relations allow access to various types of knowledge and information and thus encourage innovativeness. It is argued that innovations occur in networks with weak ties, i.e. actors who are positioned closer to "structural holes" have greater chances of being successful in science. The "strength of weak ties" argument has spawned numerous empirical tests and applications. In Slovenia, Ziherl et al. (2006) studied the impact of a research group's social capital on the scientific performance of the members of that group. They proceeded from the theoretical distinctions of social capital, such as weak versus strong ties, structural holes versus the cohesion and homogeneity of a collaboration network. The results of the study showed that the junior researchers who were involved in the research groups with bridging social capital (groups with a larger number of researchers from different institutions connected with each other by ties of moderate strength) showed a better performance than those researchers who were members with bonding social capital (smaller homogeneous groups with strong cooperation ties) or weak social capital (smaller groups with weak cooperation ties among researchers).



In relation to the question of scientific network structures and their impact on scientific productivity, some other (logistic) models have been developed. For example, James Moody elaborated three models for large-scale scientific networks which should theoretically correspond to expectations about scientific production: small-world network structure, power-law network structure, structurally cohesive network (Moody, 2004). If scientists in scientific fields (disciplines, specialities etc.) collaborate with each other, then we would expect to find distinct clusters in the knowledge production network that correspond to a small-world network structure. If a network is generated by preferential attachment, where young authors write with well-established 'stars', then we would expect to find a power-law network structure. If a network is based on cross-topic collaboration, then we would not expect any strong fissures in the network, but would find a structurally cohesive network. Many bibliometric studies conducted since Moody's elaboration of the three models confirm that the network configurations lead to the efficiency and dynamics of these networks.

The network structure is not the only factor that determines the effectiveness of scientific collaboration. The effectiveness of scientific collaboration also depends on how the work is organised in research teams. Hara et al. (2003) distinguish between complementary and integrative research teamwork. In the complementary type of collaboration, the success of a project depends on the knowledge and contribution of all participating scientists, where one part of the group does its part of the work, then the other part of the group continues with it (for example, theoreticians and empiricists). Nevertheless, this kind of collaboration can lead to conflicts over the responsibility and shares of contribution to a particular research subject. In the integrative type of collaboration, the success of a project depends on close collaboration through the entire research process. All participating partners are involved in all phases of problem-solving, improving ideas and analysis of the research problem, while with complete collaboration throughout the entire process they share responsibility for their work.

As indicated in the introduction, different factors affect the practice as well as dynamics of scientific collaboration. Numerous authors have proposed many factors to account for the dynamics of scientific collaborations. J. S. Katz and B. R. Martin (1997) produced a long list of various factors which crucially contribute to an increase in multiple-author papers: changing patterns of the level of funding, the desire of researchers to increase their scientific recognition, ever more complex and large-scale instrumentation, etc.



In broader terms, the factors that affect the practice and dynamics of scientific collaboration can be divided into two groups:

1. External factors are often related to the interest of policy decision-makers who strive for encouraging scientific collaboration. As a result, environmental changes occur in the scientific landscape. The most commonly mentioned external factors include academic culture, financing, size of the collaborative team, resources, institutional support and the existence of research centres (Bukvova, 2010). It appears that financial resources play a significant part in scientific collaboration; however, their effect has not been explored very well since data on research financing are not easily available (Jeong et al., 2011). Financial factors are also related to achieve competitiveness and economic growth (Toral et al., 2011). This is one reason that private and public funding agencies encourage interdisciplinary, international and inter-institutional collaboration (Sonnenwald, 2007). Namely, research collaboration is important for challenging the global changes confronting science. The growing number of research topics requires an interdisciplinary approach where different research departments and organisations from various

scientific fields have to collaborate (Toral et al., 2011). Social or institutional organisation is another external factor that is also strongly related to the rise of international collaboration, contractual scientific collaboration, establishment of interactions among scientists as well as of university offices that regulate the relations among them (Hackett, 2005).

2. Internal factors affect the motivation of individual scientists to collaborate with others. The most commonly mentioned internal factors include mutual agreement on the quality of work, considerations regarding merits and rewards when engaged in collaborative work, coordination, communication, facing the differences among collaborators, familiarity with other members of the group, the question of leadership and personal features (Bukvova, 2010). The key feature of successful collaboration on the personal level is compatibility. Personal compatibility is critical for the complementary type of collaboration, where everyone does their part of the work, for example the collaboration of theoretical and empirical researchers. Personal compatibility is critical also for the integrative type of collaboration, where all participants equally collaborate in the project, which requires compatibility in the approach to the scientific work (compatibility in work style, writing style, work priorities). There are also other forms of compatibility, for example in terms of geographical proximity, history, interests, values, similar career experiences etc. (Hara et al., 2003). Here, past experiences play an important role. Namely, from researchers' point of view there is a great chance that they will successfully collaborate with previous co-authors of their scientific articles since they have already 'paid' the starting costs of their collaborative work in terms of language, research approaches and methodologies (Toral et al., 2011). Jeong et al. (2011) emphasise three factors that motivate an individual researcher's collaboration and affect their success in co-authored publication activities: informal communication (researchers prefer to collaborate with partners with whom they develop close personal interactions), cultural proximity, as well as the academic excellence, position and status of scientists.



Finally, a few words should be said about the advantages and disadvantages of scientific collaboration in modern times. In a general sense, all actors (institutions, researchers, managers and policymakers) agree about the benefits of scientific collaboration: education institutions gain visibility when they collaborate with distinguished researchers; researchers gain an opportunity for collaboration with interesting people and teams that possess different skills; while policymakers are occupied with collaboration mostly in terms of achieving competitiveness, economic growth and sustainable development within the national research system (Toral et al., 2011). Overall, gaining and obtaining connections with the best scientists gives researchers and research institutions an opportunity to remain in the centre of global innovative networks (Toral et al., 2011). However, scientific collaboration also has some disadvantages that might influence decisions on collaborative work. The first relates to the problem of the invisibility of individual authors. Namely, the majority of collaborators are invisible to the larger scientific community; there are only written names and anonymous scientists (Toral et al., 2011). Second, a group or a project leader can lose contact with the research process. A group leader without direct contact with the research activities might encounter reduced creativity since most of his/her activities are focused on administrative work and obtaining financial resources (Toral et al., 2011). Third, the privatisation of research can have a negative effect on the research ethos; the creation of academic entrepreneurship can promote negative strategies, data confidentiality and additional limitations on the free flow of ideas and materials in research; collaboration with other competitive laboratories might also serve as espionage and lead to harmful practices in science (Toral et al., 2011). This is connected with the additional concern regarding epistemic and ethical responsibility in terms of taking responsibility for the work when many scientists collaborate (Laudel, 2002).



Studying changes in collaboration practices through co-authorship publications as well as individual and structural factors of collaboration, i.e. the forces that drive and enable collaboration, is heuristically a very productive way to understand the dynamics of the recent and future progress of science and technology in national and transnational contexts. In the next (empirical) section, we shall focus on the situation in Slovenia by presenting the main results of our longitudinal empirical analysis conducted in the past few years with an emphasis on the characteristics and dynamics of scientific collaboration.

## Some characteristics of scientific collaboration in Slovenia

### *The trends of co-authorship networks and their structures in a selected group of scientific disciplines*

We have studied co-authorship networks using longitudinal data on the Slovenian science system in order to explore their dynamics (Ferligoj and Kronegger, 2009; Mali et al., 2010; Kronegger et al., 2011; 2012). In earlier bibliometric approaches, several studies focused on collaboration activities in the social or natural sciences, but very few entailed a comparison among different disciplines (De Stefano et al., 2011).

In the Slovenian case, the dynamics of co-authorship networks were studied on the basis of bibliographic data[4] of scientists from four different disciplines (Kronegger et al., 2012). The selection of disciplines (sociology, mathematics, physics, biotechnology) in Slovenia was based on the following theoretical assumptions already explained in the first subsection: first, distinctions with regard to the cognitive-institutional features of scientific disciplines (i.e. the distinction between 'old' and 'new' scientific disciplines) and, second, the distinctions concerning the multi-, inter-, trans-disciplinary and trans-sectoral (applicative) mode of production of knowledge (i.e. the distinction between Mode 1 and Mode 2 scientific disciplines). The distinction between 'office' and 'lab' sciences has been added. Taking this general typology into account, we could (tentatively) describe (1) mathematics as an old and Mode 1 discipline where research processes (solving universal abstract problems) are performed in offices; (2) physics as an old and Mode 1 discipline where the research process is cognitively-institutionally organised in research groups and within laboratories; (3) sociology as an old Mode 1 discipline where research processes (oriented to local problems) are performed in offices; and (4) biotechnology as a new and Mode 2 discipline. Modern biotechnology can be defined as a discipline in which scientific processes are organised in laboratories. It is an example of newly emerging techno-sciences where its multidisciplinary nature along with its demands for various resources (funding, equipment, technological know-how and materials) requires scientific collaboration across various institutional settings (Oliver, 2004: 585).

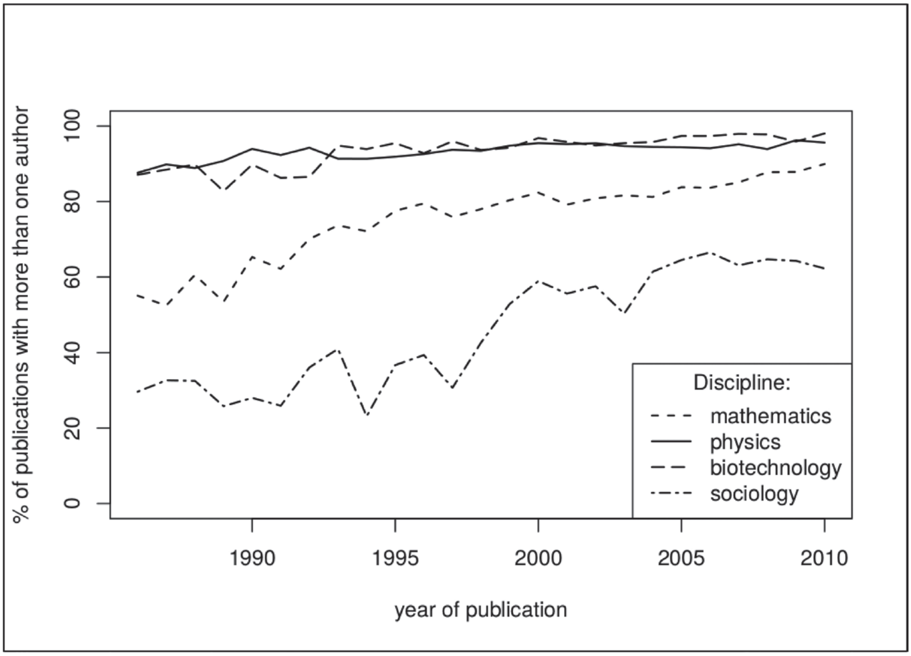


Our bibliometric analysis of co-authorship networks in the period from 1986 to 2010 revealed: (1) a high proportion of single-author publications within sociology and within mathematics and thus consequently lower but slightly increasing levels of co-authored publications; and (2) high and relatively steady levels of collaboration by physicists and biotechnologists within their discipline and/or with authors from abroad (Graph 1). The results of our analysis supported the finding of earlier bibliometric analysis in other countries (or parts of the world) that collaboration is particularly common in lab sciences involving the use of large and complex research instruments. Of course, one crucial reason for the high degree of scientific collaboration

[4] *Even when scientific collaboration is defined through co-authorship, there are different data sources for collecting bibliographic data such as interviews, questionnaires or international as well as local bibliographic databases (De Stefano et al., 2011: 1093). However, we believe that the national bibliographic database used in the co-authorship analysis of Slovenian researchers represents a unique opportunity to cover all types of publications as well as to include information on the education, positions and employment of researchers, research groups and institutions. International bibliographic databases might not cover all of this data, therefore local databases may be the best way to obtain data on high impact papers and more locally oriented research outputs published by all researchers involved in a particular scientific community in order to define their co-authorship relationships (De Stefano et al., 2011: 1093–96).*

in lab sciences is the need for a formal division of labour. It is interesting that biotechnologists in Slovenia are characterised by collaboration with researchers from other disciplines within the country, although with much more fluctuations than in other disciplines (Kronegger et al., 2012). This means that biotechnology as a newly emerging field of research is still in the pre-mature phase. It is in the process of defining the form of its collaborative activity.

*Graph 1: TRENDS OF CO-AUTHORED PUBLICATIONS IN THE FOUR DISCIPLINES 1986–2010*




Our analysis of co-authorship network structures in physics, mathematics, biotechnologists and sociologists also revealed interesting results (Kronegger et al., 2012). A power-law network structure based on the principle of preferential attachment was strongly confirmed in the co-authorship network of physicists. This indicates the stability of this network with a large number of significant scientists. The characteristics of the network of physicists indicate that those scientists who mostly collaborate with a large number of scientists inside their group have fewer possibilities to establish new connections with other physicists within the Slovenian scientific community. In contrast, physicists who collaborate intensively with foreign scientists more commonly also collaborate with other Slovenian physicists. The co-authorship network of mathematicians indicates different characteristics: those scientists who collaborate with scientists outside the Slovenian community and have published a larger number of articles in journals with an impact factor have greater opportunities to establish new connections within Slovenian communities. In the case of the co-authorship networks of sociologists, the extent of collaboration within the Slovenian scientific community has a positive effect on collaboration, while collaboration with foreign scientists brings negative effects for collaboration within the national research community. This means that the dynamics of biotechnologists' networks do not follow the principle of preferential attachment but some other principles such as the prevalence of work within the same research group.

### *The sources of research collaboration*

We conducted a web survey among researchers from the four scientific disciplines in order to understand which kinds of incentives, perceptions and personal strategies explain collaboration from the perspective of an individual scientist (Iglič et al., 2014). The results of the analysis show that the survey data complement the information obtained through co-authorships in an important way. If we ask researchers about the proportion of their active work time they spent collaborating with others during the last year, the differences between disciplines are much smaller when assessed through interviews than when obtained from bibliometric data. Thus, researchers from the social sciences do not necessarily collaborate less, but the attribution of authorship is different in the social and natural sciences. Collaborators from the social sciences are less likely to find their way onto the list of authors; instead, they are mentioned on the title page. As expected, biotechnologists spent the biggest share of their working time collaborating with others. As a newly emerging discipline focused on the applicability context, biotechnology requires trans- and inter-disciplinary cooperation which takes place in extensive collaboration networks.

Although they do not differ considerably in the extent of their collaboration, disciplines vary according to who the collaborators are. Here the distinction between basic versus applied disciplines is especially useful. Physicists and mathematicians from basic sciences have much wider and far-reaching collaboration networks than sociologists or biotechnologists. Since their research is less embedded in the needs and specifics of the local contexts, their collaboration networks contain more international partners. On the other hand, the extensive collaboration networks of biotechnologists seem to be more limited and focused on local partners.

Disciplines also differ in the overall style of collaboration, ranging from very informal to formal. The formality of collaboration in terms of the centralisation of coordination, strict division of labour and attribution of authorship according to individual contributions are all indicators of highly formalised collaboration. Collaboration style is related to the second dimension of disciplines' classification, i.e. to the dichotomy of experimental versus theoretical disciplines. Physicists and especially biotechnologists from two experimental disciplines have a much more formalised collaboration style than either sociologists or mathematicians.

The extent of collaboration can be explained at the individual level by different sets of factors: structural opportunities, cognitive characteristics of the scientific field, the social organisation of work, perceived benefits of collaboration, previous experience with collaboration, and different strategies individuals employ when searching for partners. Scientists will be more likely to collaborate when there are more opportunities to obtain research money, when they easily overcome status differences between senior and junior colleagues, have a high level of agreement about what constitutes good quality research and perceive each other as competitors. They also spend more time collaborating when they have a positive experience of previous collaboration, see a lot of benefits in collaboration such as good research results and faster individual promotion, and pay attention to professional complementarity when choosing research partners.



### *The structural factors contributing to scientific collaboration*

Following the argument that scientific collaboration cannot be fully understood simply by measuring co-authorship and through quantitative surveys about individual scientific motives – it is a sociological phenomenon that also needs to be studied and described through qualitative investigation (Melin, 1999: 164) – qualitative interviews with policymakers and representative members of the scientific community from three of the scientific disciplines under study were conducted in December 2012 and January 2013.[5] Key questions focused on the respondents' views on the differences in the dynamics of scientific collaboration in the four disciplines as well as their opinions on systemic mechanisms aimed at promoting collaboration and productivity among researchers. Our main interest was to acquire a deeper understanding of the broader (sociological) factors that promote or inhibit scientific cooperation.

*[5] Altogether, six interviewees participated in interviews. A semi-structured questionnaire format was used to guide the interviews and ensure consistent coverage across the participants. Following the standard recommendations for the analysis of qualitative data (Mesec, 1998), the interviews were recorded and transcribed to allow the key issues to be more easily identified. In the next phase of the analysis, the written material was summarised and labelled by the most illustrative statements. Out of three invited policy actors and four scientists (a mathematician, biotechnologist, sociologist, and physicist), only one (the physicist) did not respond to our invitation to collaborate in our research.*

The interviewed scientists agree that the success of and opportunities for scientific collaboration depend largely on past experiences. They allow researchers to become familiar and compatible with each other's work methods as well as with other aspects of collaboration. Sometimes collaborative partners share a common interest, although where there is no 'true chemistry' among them, common work as well as communication become impossible. In this respect, personal acquaintance represents the basis for future collaboration. According to the interviewed scientists, financial support also plays a crucial role in scientific collaboration. The lack of it reduces the positive effects of those policy measures that encourage scientific collaboration. In terms of establishing new and maintaining already existing network connections, the problem for young researchers is that they should take over, continue and upgrade their existing connections. However, due to saving measures, young researchers often do not have the sufficient conditions or opportunities to work in academia and research institutes.

An interviewed sociologist problematized the Slovenian science evaluation system that favours the positivistic type of sociology that is closer to the natural sciences. In his opinion, this is especially problematic for those disciplines that are conceptually oriented. As a result, many social scientists are to a certain extent forced to publish scientific articles that involve empirical data. One interviewee also complained about the proportional scoring of co-authored scientific publications especially in biotechnology, which usually produces articles with several co-authors. In addition, one of the interviewees complained that science-industry collaborations are still poorly evaluated while scientific publications with high impact factors and a high citation index matter the most.



When asked what should be done regarding the future promotion of scientific collaboration, the interviewed scientists refer to establishing additional policy measures, first in terms of encouraging more research collaboration among different fields, starting with younger generations perhaps already within interdisciplinary study programmes involving different faculties and, second, in terms of changes to the evaluation system that should assign a greater value to relevant publication references and ignore involvement in past research projects.

The responses of the interviewed policymakers were similar to those of the interviewed representatives of the scientific community. They attributed the differences in the dynamics and structure of co-authorship networks to the different nature of the work in various disciplines. They assessed that the increase in co-authorships in Slovenia is comparable with trends in the rest of the world, particularly due to the overall rise of international collaboration. However, when comparing Slovenia with the broader international framework within which these structural changes are occurring, they acknowledged that in the Slovenian scientific community researchers who co-author their publications with foreign scientists are at the top of Slovenian science according to all key quality indicators (citation index, publications with an impact factor).

Besides the science evaluation system that according to the policymakers sufficiently encourages international collaboration, official contractual agreements on scientific collaboration between two countries prepared by Slovenian Research Agency are particularly important. The impact of a normative instrument, such as the national research and development programme, was also emphasised by one interviewed policymaker. When questioned about the future challenges of scientific collaboration, one of the policymakers argued that scientific collaboration in Slovenia should be upgraded by connecting universities with research institutes. The flow of researchers between these two types of institutions is mainly individually and not systemically motivated. In these terms, additional policy measures should involve more systematic mechanisms for collaboration between universities and research institutes.

With respect to collaboration between university and industry, one interviewed policymaker suggested the system of scientific priorities (instead of the system of scientific excellence) that already exists in certain other EU countries.[6] Another suggestion offered by one interviewee was that changes should be made at the level of programme group evaluation where the importance of the economic and social relevance of their research work as well as scientific excellence should be emphasised more intensively. If we look at the views of scientists as well as policymakers in Slovenia overall, there is no doubt that both groups are aware of the importance of broader structural factors for encouraging the various forms (international, inter-sectoral, inter-disciplinary etc.) of collaboration.



## Conclusion

The paper addresses some issues related to the definition and analysis of scientific collaboration. Scientific collaboration is a complex phenomenon that has contributed significantly to the production of new scientific knowledge as well as to the sharing of special competencies (De Stefano et al., 2011). Various studies examining the extent, intensity and different forms of scientific collaboration have emphasised the importance of the disciplinary context when establishing collaboration and co-authorship networks.

[6] *This statement relates to the way science is funded. The system of scientific priorities means that science policy encourages research and development in predefined scientific fields and/or research areas (usually with respect to broader social or economic needs), while the system of scientific excellence emphasises particularly excellent achievements in science (publications in prominent journals etc.).*

One of the most useful and efficient approaches to measuring the degree and structure of scientific collaboration is co-authorship analysis, although it does not provide a complete picture of this phenomenon. However, it is often recommended because bibliometric studies offer a very reliable approach to the observation of collaborative activities and the presentation of important aspects of research collaboration (Jeong et al., 2011). In studying scientific collaboration in Slovenia, a bibliometric analysis of co-authorship relationships was used to examine the structure of scientific collaboration and knowledge production in four different disciplines. In addition, a survey analysis on the motives of scientific collaboration among researchers was conducted so as to evaluate the importance of different factors that have an effect on scientific collaboration. For an even more detailed analysis of collaboration practices, a qualitative investigation among key representatives and policymakers was conducted to gain an insight into their views on significance of scientific collaboration. While the policy mechanisms that aim to encourage collaborative work among researchers are an important factor for establishing research networks, the interviewed scientists believe that long-term and successful collaborations derive from researchers' efforts and their individual engagements, but only where suitable conditions have been created by policy mechanisms (such as those that encourage international mobility, interdisciplinary as well as interinstitutional/intersectorial collaboration). Research activities, especially in new fields of science, are becoming ever more interdisciplinary in nature and are being conducted more in both domestic and international networks in order to create new knowledge (Oliver, 2004: 583). Along these lines, we found that the structure and dynamics of co-authorship networks, following the bibliometric analysis of scientific publications, provides a unique opportunity to explore and illustrate how science is developing within a particular research group, field of knowledge, or individual country, particularly when we want to examine the development of newly emerging techno-sciences.



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