Regional and Local Studies
special issue 2010
ISSN 1509-4995

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Spatial Aspects of Collaborative Networks in Science – Lessons from Poland[1]

The notion of a network is one of the key terms used to describe the contemporary world. The role of cooperation networks is also stressed in the context of innovation and its spatial aspects. In this particular case, most attention is given to metropolises as major networks of flows not only of people, capital or goods but also of information and knowledge. The paper discusses selected spatial aspects of collaborative networks in Polish science. The discussion of examples is preceded by a theoretical introduction intended to outline various aspects of innovation networks at national and regional levels, with particular emphasis placed on the role of metropolises in collaborative networks.

Introduction

We live in a 'world of connections' (*The Economist* 2010) where the notions of a network and networking have become veritable buzzwords. On the one hand, this is undoubtedly part of a certain trend manifested both in science and the media. On the other hand, however, we must acknowledge the existence of such network-based phenomena as the Internet or social networks, whether virtual (e.g. Facebook) or physical. Some thinkers believe networks to be so omnipresent that they are used to explain how the contemporary world works. This gave rise to the notion of *Network Society*, popularised by Manuel Castells in his major trilogy: 'Dominant functions and processes in the Information Age are increasingly organized around networks. Networks constitute the new social morphology of our societies, and the diffusion of networking logic substantially modifies the operation and outcomes in processes of production, experience, power, and culture (Castells 1996, p. 500).

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[1] The paper embraces fragments of the authors' earlier publications: Olechnicka A., Płoszaj A. (2010). 'Sieci współpracy receptą na innowacyjność regionu?' in: Gorzelak G., Tucholska A. (eds.) *Europejskie wyzwania dla Polski i jej regionów*, Warsaw: Ministerstwo Rozwoju Regionalnego, EUROREG. Olechnicka A., Płoszaj A. (2009); 'Metropolie a innowacyjność', in: Jałowiecki B., *Czy metropolia jest jeszcze miastem*, Warsaw: Scholar; Olechnicka A. Płoszaj A. (2008). *Polska nauka w sieci. Przestrzeń nauki i innowacyjności. Raport z badań*, Warsaw; Olechnicka A. Płoszaj A. (2009). 'Zasoby i przepływy kapitału intelektualnego. Analiza bibliometryczna aktywności publikacyjnej polskich ośrodków naukowych', in: Okoń-Horodyńska E., Wisła R. (eds.), *Kapitał intelektualny i jego ochrona*, Warsaw: Instytut Wiedzy i Innowacji.

In this paper, we discuss selected spatial examples of network connections associated with collaboration in science. The discussion of examples is preceded by a theoretical introduction in which we analyse the practicality of network analyses in innovation research at national and regional levels. The role of the spatial dimension of network analyses relating to science and innovation is tackled in a separate chapter which focuses on the importance of metropolises in knowledge flow networks. Examples of cooperation regarding publications indexed in the Web of Science database and the research projects of the Sixth EU Framework Programme, discussed in other chapters of the paper, are products of the authors' empirical work. In addition to the spatial model of collaboration, its impact on the volume and quality of the scientific product has been discussed. The examples provided fittingly illustrate the role of network research in the studies of innovation and outline the potential for further analyses.

Collaborative networks

The questioning of the linear model of innovation gave rise to discussions concerning the issues of innovation and flow of knowledge in the context of networks, cooperation and linkages in various institutional and spatial configurations (cf. e.g.: Olechnicka 2004). The multitude of theoretical works and empirical studies found in scientific literature proves that the role of such phenomena is growing (cf. e.g. Pittaway, Robertson, Munir, Denyer, Neely 2004). The key concepts which tackle the issues of cooperation networks and innovation vary considerably insofar as network analyses are used. For instance, network analysis is used as the main tool in the concept of strong weak ties. For enterprises, the differences in the practice and role of weak and strong ties are the most important. Strong ties encourage the transmission of complex and uncodified knowledge (tacit knowledge), while weak ties are vehicles for conveying less complex or more codified knowledge (Fleming, King, Juda 2007). Another important regularity is that strong ties foster incremental innovations and weak ties further radical innovations; weak ties give access to sources of knowledge which were not known before, just as it was in the case of the first studies by Granovetter on seeking information about vacancies (Peng, Ju, Peng, Wang 2008). It is weak ties that lead to generating truly novel solutions, whilst strong ties only facilitate small modifications and improvements. Therefore, only weak ties can significantly influence innovation measured by patent applications, because patents largely denote novel ideas and solutions (Hauser, Tappeiner, Walde 2007).

Similarly, a number of empirical studies embedded in the Small Worlds Theory utilise network analysis to seek to find out how the network structure influences the innovativeness of its participants (individuals or businesses). The pioneers of this research, Manfred Kochen and Ithiel de Sola Pool, point out that such networks foster the diffusion of innovations, which has implications for the technological change (Pool, Kochen 1978). This corroborates another,

frequently quoted study on the dissemination of knowledge (and thereby its use) about innovative medicines among physicians (Coleman, Katz, Menzel 1957). Structures with the attributes of 'small worlds' encourage innovation as, on the one hand, groups of interconnected nodes (small distance between individuals or units) increase mutual trust and close cooperation, which makes the network more capable of transmitting knowledge. And, on the other hand, distant ties (sporadic links between well-connected groups) ensure access to varied types of information, different in content from information that is accessible for closely collaborating entities. This is corroborated both by studies on creative individuals (Uzzi, Spiro 2005), and innovative enterprises (Schilling, Phelps 2007).

Furthermore, in the open innovation model, extensive collaboration with other entities, transposed into solutions and arrangements which are difficult (and frequently costly) to obtain otherwise, also plays a pivotal role. Unlike companies embracing the closed innovation model, businesses which have adopted the open innovation model focus on making use of opportunities available outside the company, and seek ways to identify such opportunities and commercialise them. Neither do they avoid opposite situations, when ideas generated in the company are implemented elsewhere. On the contrary, they are active in grasping such opportunities, e.g. by establishing spin-off companies, undertaking joint ventures with other enterprises or selling licences (Chesbrough 2003b).

Conversely, the theory of clusters suggests two reasons for which businesses operating in a cluster should be more innovative than those outside it: firstly, they benefit from the agglomeration effect, and, secondly, they gain from the network effects, which should be understood as benefits from collaboration (Porter 1990). Some research reveals that it is network collaborative linkages that are so crucial for the innovativeness of clusters. For instance, A. Saxenian concluded, from his comparison of the history of Silicon Valley and Route 128, that network-based collaboration, and not the agglomeration effect, is the decisive factor in determining the competitive edge of clusters. He proved that the future of both clusters depended on two the different strategies which were adopted in the wake of the crisis in the electronics and computer industries. Companies located in Silicon Valley (such as Hewlett-Packard or Sun Microsystems) turned to outsourcing and cooperation, adopted vertically disintegrated structures and formed many alliances in the sphere of R&D. At the end of the day, the autarkic, vertically integrated (from R&D to sales) large corporations of Route 128 permanently lost their position to competitors from Silicon Valley (Saxenian 1994). Network analysis is basically absent from the theory of clusters or is merely viewed as an analytical 'bolt on' element. For instance, Krätke offered an analysis of the Potsdam/Babelsberg media cluster using this method (Krätke 2005), which involved questionnaires and interviews in a group of cluster participants to define the strength and directions of linkages between them. It can be said therefore that the questions asked tend to focus on transaction and communication ties between partners within and without the cluster.

Other theoretical approaches, similarly to the theory of clusters, have a fallacious look at networkedness as co-occurrence in a specific location (spatial proximity, cf. e.g. Boschma 2005), and not as network-based cooperation, that is, cooperation between individuals or organisations having a predominantly horizontal, non-hierarchic nature. This can, for example, be observed in the Triple Helix concept whereby whatever happens within each of the helixes (academia, business and administration) and the relationships between them translates into the functioning of the region's socio-economic system. What we witness here is the interpenetration of institutions from these three spheres which start to take up roles initially ascribed to another sphere. For instance, universities are more enterprising and become places where businesses are started up and/or which take the role of local governments as animators of the region's activity. On the other hand, businesses, by sharing knowledge, training staff or participating in research projects, develop their academic functions. As a result, intermediary organisations emerge, which are located in a functional space between the three spheres: academia, business, and administration. These include: spin-off companies, incubators and technological parks, offices for research commercialisation and protection of patent rights, academic networks, or local production alliances (Leydesdorff, Etzkowitz 1998). Similarly, the concepts of national and regional innovation systems emphasise predominantly that national economies vary in terms of their structure of production systems and institutional underpinnings, whilst the essence of an innovation system is believed to lie in the unique form of the network of collaborating institutions whether they are from public or private sector (cf. Okoń-Horodyńska 1998). In other words, what matters is both the activity of individual institutions from a given territory (businesses, universities, research institutes, business environment institutions), as well as mutual interactions between them (Smith 1996, after OECD 1999, p. 24).

It should be added that these individual concepts and theories overlap and have various elements in common. As a result, their specific extent can hardly be delineated or distinguished. For example, the concept of the national innovation system and the Triple Helix model pertain to interactions between the worlds of business, science and administrations. Likewise, the theory of clusters emphasises that cooperation between enterprises should involve participation of higher education institutions, science and local authorities. We should also note that in referring to innovation, social networks or organisation networks, we usually have in mind collaboration between individual components making up a given system. For instance, in a network analysed at the level of a regional innovation system, we deal with collaboration at a rather abstract level (e.g. cooperation between the world of science and enterprises), whereas the theory of weak ties investigates relationships between individuals. Moreover, networks linking individuals quite obviously overlap with networks bringing together organisations, thereby influencing one another (cf. e.g. Kilduff, Tsai 2003; Płoszaj 2010).

Metropolises as hubs in the global network of flows

Innovative activity, which lies at the very core of the development of the contemporary global economy, is significantly characterised by spatial concentration. This trend has visibly increased over the years. Another easily observable phenomenon is that the more knowledge-intensive the activity, the stronger its concentration (Asheim, Gertler, 2006, p. 291). Such areas of particularly intensive innovative activity include restructured industrial districts, university regions, technopolises, and above all metropolitan areas (Longhi, Keeble, 2000). For example, concentration of research and innovative activity, and thereby of economic growth in robust metropolitan centres, can be observed at the European level (cf. e.g.: European Commission 2007; Płoszaj, Wojnar 2009). Although we can hardly say that available data enable a comprehensive analysis of innovation indicators for individual cities, the disparities in the innovation level Europe-wide at the NUTS2 level indicate that regions where European metropolises are located report the highest levels of innovation (Fig. 1).

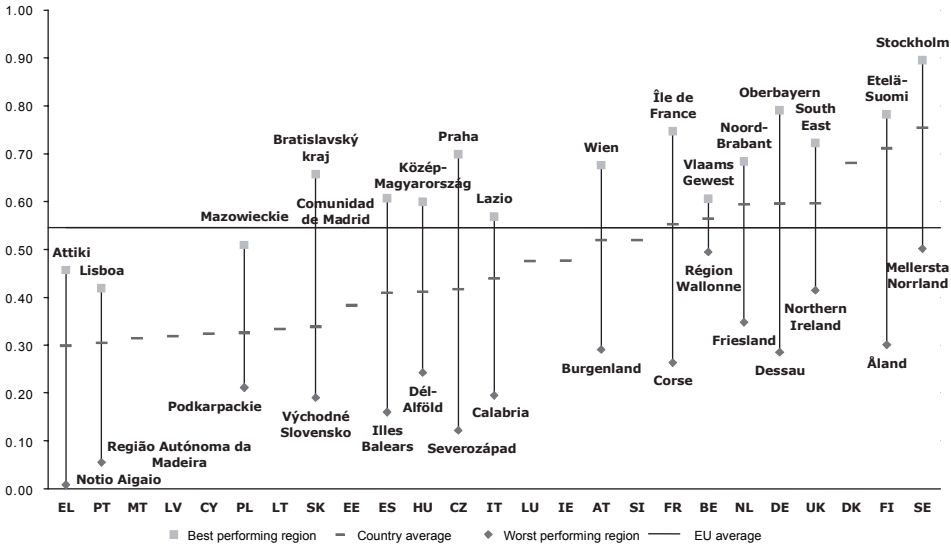

Figure 1. Differences in the level of innovation in Europe.

Source: European Regional Innovation Scoreboard 2006, p. 8.

The discussion on the innovativeness of metropolises has its origin in a wider debate concerning the innovativeness of urban centres (Florida 2004; Lobo, Strumsky 2008). Cities which offer easy access to a multitude of varied business entities, universities, research centres and decision-makers have always provided 'an ideal environment for innovation' (Athey et al. 2008). The researchers emphasised that urban innovation systems are largely determined by factors which could be categorised in two groups: the first includes factors relating to the city

as an urban hub, which comprises the size of the market and resources, whereas the second incorporates those connected with local links, i.e. institutions and networks of ties. At the same time, every city is characterised by a dissimilar set of factors underpinning its operation and role (Athey et al., 2008).

Innovation is also listed as one of the key features of metropolitanism in the literature on metropolises. In addition to a large population, high-quality services, institutions and facilities, and unique character of the place, attributes typically associated with metropolises include the multi-faceted potential for innovation in the technological, economic, social, political and cultural sphere (Bassand, 1997, p. 45, [cited in:] Jałowiecki, 2000, p. 21). Contemporarily, metropolises function, not as command posts in the global economy or key locations for finance corporations, but also as places where innovations are generated and as markets for innovative products (Sassen, 1991, pp. 3–4). Alongside the functions of centres of business activity, spatial centres for business and transport hubs, metropolises are also ascribed the functions of science and knowledge centres (Kuć-Czajkowska, 2009, p. 89).

It is frequently underlined in the metropolitan discourse that metropolises differ from what used to be known as a city in that they have a particularly high level of human capital, intensive research activity as well as accumulation of innovative companies and public institutions, etc. These factors foster the rise of groups of inventors and network-based links within the metropolis (Graf, Henning 2006). Nevertheless, the role of these two phenomena for the effectiveness of generating innovations is still debated (Lobo, Strumsky 2008). Due to the exceptional natures of metropolises, the mutual relationships between metropolises matter for them much more than their linkages with other parts of the world. Naturally, it would be too far-fetched to say that metropolises do not have any connections with non-metropolitan areas at all. It should be stressed however that such linkages apply to innovation only fractionally and are a game in which usually the city (and rural areas) loses to the metropolis (e.g. in the form of brain drain). The flows between metropolises are strong because the regions surrounding them and/or urban centres of lesser significance are unable to provide the metropolises with the resources they need (Gorzelak, Smętkowski 2005 and 2008). Besides, such flows are results of the organisational, relational and professional proximity of the metropolis, which is of much greater importance than geographical proximity for the generation, identification and flow of tacit knowledge (Asheim, Gertler 2006, p. 309). This is also often accompanied by an adjustment of supply and demand in various markets (consumer goods, labour market).

However, it would be untrue to say that only metropolises can be innovative. Some researchers claim that the size of a city (its population) is not the factor that determines its level of innovation. For example, Mattiessen, Schwarz, find evidence to suggest that significant knowledge production represented by publications indexed in the Web of Science is not always associated with cities with a large population potential, *vide* such cities as Cambridge, Stockholm or

Uppsala (Mattiessen and in. 2002). In a similar vein, Athey, Nathan, Webber and Mahroum argue that many cities with the highest shares of companies and patents with a substantial load of innovation in the United Kingdom are centres small in size but with well-developed internal and external ties (Athey et al. 2008). It should be noted that, on the one hand, it is emphasised in the definitions of the metropolis that the size of an agglomeration is not the decisive factor, and on the other hand many small innovative cities benefit from their location within the sphere of metropolitan influence and from good ties with the metropolis, cf. the example of Reading in England (Athey et al. 2008).

A review of the research relating to the differences between the metropolis and the city in terms of broadly understood innovation shows that the size of a given city or the volume of its innovative 'production' does not explain the existing differences. Arguably, the strength of connections with other cities (Table 1) is a good indicator of metropolisation. We can say therefore that the difference between a metropolis and a city is the concurrence of two features: a metropolis is both bigger and has stronger links with other centres, particularly other metropolises.

Table 1. Typology of urban centres

		Size – number of the population	
		small	large
Networking – ties with other metropolises	high	academic city or a specialised research centre	metropolis
	low	city	large city (agglomeration)

Source: prepared by the authors.

Data and methodology

The examples quoted in this paper come from empirical research conducted by the authors in the autumn of 2008 and cover two aspects of scientific activity: publications and participation in international research projects. We will discuss in more detail the sources of data and the methodology used to introduce the extensive empirical material underpinning further analyses.

Papers

Studying the development of science using quantitative text analysis has a long tradition, and has developed rather sophisticated methods and tools (cf. e.g. Nowak, 2008; Price, 1967). Research in this area is conducted on a broad scale in Poland and in various centres abroad, but it nevertheless very rarely focuses on regions or individual academic centres. Electronic databases indexing bibliographical references of publications and science citations indexes are the basic resources used for this type of analyses. Among many such databases,

the Web of Science (WoS) is the most extensive; it is also most frequently used for bibliometric analysis. The Scopus database, newer than WoS, also offers an extensive potential for analysis.

This paper uses the data from the Web of Science. We identified all papers entered in 2001–2006 into the database which quoted Poland in the bibliographic reference as the place of work of at least one author (the so-called affiliation)[2]. The data obtained in this way were processed and then subject to complex verification, which produced a database containing 72,817 papers, encompassing in all 201,928 affiliations.

Research projects

Framework Programmes (FPs) are European Union's instruments designed for financing scientific research in Europe. This mechanism is intended to ensure a lasting and coherent impact on research initiatives owing to concentration on high-quality scientific research which has a permanent and creative role, builds the foundations of science and technology and aims at maximum 'added value'. The Framework Programmes fulfils this task by supporting and encouraging transnational cooperation, integration of research and research providers, and focusing on selected research priorities. During the four years of the Programme's implementation (2003–2006), public and non-public research establishments, enterprises, research institutions, industrial associations, public administration, researchers and students were eligible for co-funding.

This paper is based on two sources concerning Poland's participation in the Sixth FP: statistics of the National Contact Point of the Sixth FP (Supel, 2007) and information available from the databases of the Community Research and Development Information Service CORDIS (www.cordis.europa.eu), where all projects implemented under the EU Framework Programmes are registered. For analysis, we selected only those projects which involved at least one Polish institution, which produced in all 1,341 projects with the overall participation of 22,368 Polish and foreign partners. After the necessary corrections or adjustments made with the use of the project websites, we identified 1,826 Polish partners, of whom 189 acted in the capacity of project leaders.

Collaboration in the field of scientific publications

Scientific publications can be divided into four categories. The first includes independent publications, that is, articles affiliated with institutions located in one subregion, and therefore written without any collaboration reaching beyond the subregion (called a 'research centre' for ease of reference). This is the most

[2] The survey was conducted in August 2008 using all the three sections of the database, viz.: Science Citation Index Expanded (SCI Ex), Social Science Citation Index (SSCI), and Arts and Humanities Citation Index (AHCI).

numerous category, as over a half of the papers written in 2001–2006 are independent articles, prepared by institutions from only one Polish subregion. The second category, which accounts for around 7% publications, are articles written within the frame of domestic cooperation, which means that their authors came from institutions located in at least two different subregions. The third category brings together publications produced, in effect, from foreign cooperation – that is, at least one of the authors worked in a Polish, and at least one, in a foreign institution. This set encompasses over 35% of the publications. Lastly, the fourth, and least numerous category (4%), comprises publications written in Polish, with foreign collaboration, that is papers whose authors originated from Polish institutions located in at least two different subregions, and at least one of the authors came from a foreign institution.

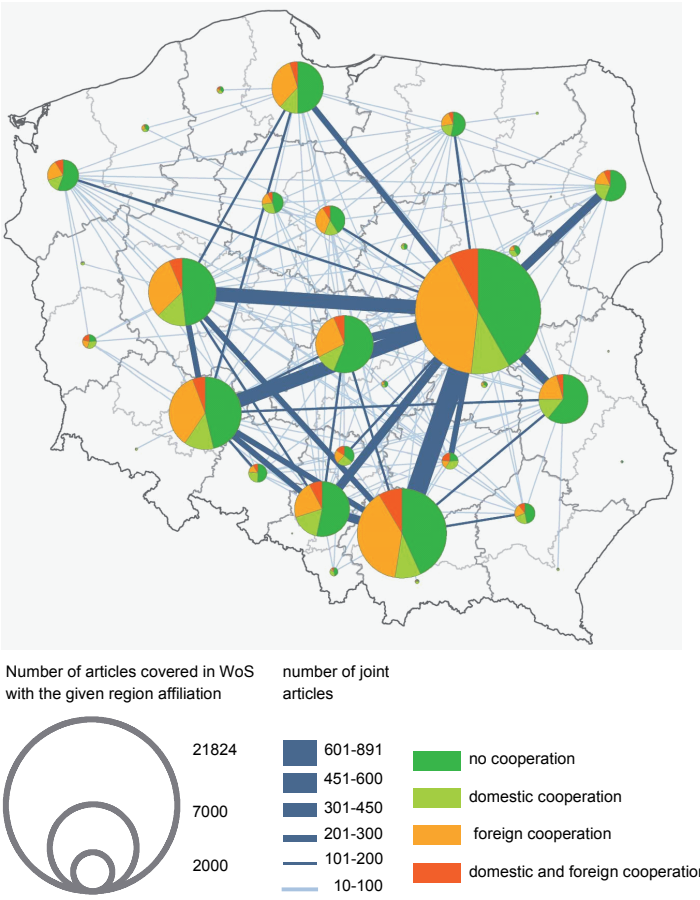

Figure 2. Collaboration of subregions related to publications in 2001–2006

Source: prepared by the authors based on the Web of Science.

These four categories of publications take different proportions in each of the subregions (cf. Fig. 2). For instance, some research centres generate a distinctly higher share of publications produced solely by institutions located in their area, which is the case e.g. of the Lublin, Łódź or Szczecin subregions. On the other hand, there are centres which collaborate in the sphere of publications with foreign research institutions more frequently than with other types of institutions. This is mainly true for subregions with a significant number of publications or established research traditions, such as Kraków or Warsaw.

The map above also shows the intensity of cooperation between individual subregions. The graphic manifestation of collaboration is the width of the line connecting different locations, representing the number of joint publications (publications whose authors are affiliated with institutions in both subregions). The first and foremost conclusion from the analysis of spatial linkages between Polish subregions is that Warsaw emerges as the main hub of collaboration in the sphere of publications. For the majority of subregions, it is the primary partner in this regard. Also, institutions located in the Kraków-Tarnów, Central-Silesian, Wrocław and Poznań subregions have strong collaborative links. This general picture is even more complex when we analyse the collaboration networks of individual centres, particularly the smaller ones, which, in a sense, disappear when we take the whole of the country as the level for analysis.

Table 1. Correlation of the number of publications in subregions and the share of individual categories of collaboration in the sphere of publications (Pearson's correlation)

	Number of papers
Independent (%)	0.132
Domestic cooperation (%)	–0.681 (**)
Foreign cooperation (%)	0.745 (**)
Domestic and foreign cooperation (%)	–0.251

** The correlation is significant at the level of 0.01 (bilateral).

Source: prepared by the authors based on the Web of Science and GUS.

The intensity of both foreign cooperation and domestic cooperation is quite distinctly correlated with the number of papers affiliated in the subregions (cf. Table 1). Interestingly (and surprisingly), however, the directions of these interrelationships are dissimilar. Whilst the intensity of foreign cooperation (a large share of publications being effects of foreign cooperation) is positively correlated with the aggregate number of publications, the share of domestic cooperation reveals the opposing tendency (cf. Figs. 3 and 4). It is clearly visible therefore, that the role of cooperation is not unequivocally positive in the case of collaboration in the field of publications. This does not mean however that cooperation between domestic centres does not yield the desired results; domestic cooperation matters significantly for weaker centres, which lack the sufficient potential to step up domestic cooperation. On the other hand, foreign cooperation is of

great importance for the strongest research centres, which need broad international contacts to maintain a sufficiently high scholarly and research level.

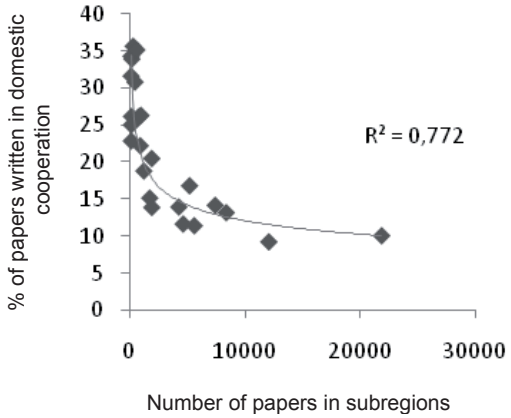

Figure 3. Volume of articles and domestic cooperation (2001–2006)

Source: prepared by the authors based on the Web of Science and GUS.

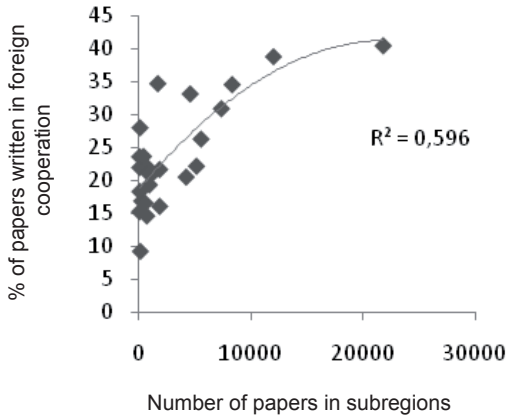

Figure 4. Volume of articles and foreign cooperation (2001–2006)

Source: prepared by the authors based on the Web of Science and GUS.

Collaboration and the quality of publications

Cooperation has a favourable effect not only on the quantity but also the quality of publications. The question, however, arises as to how to assess the substantive value of several dozen thousand works from various scientific disciplines. It goes without saying that doing this in a direct manner is not technically feasible. Instead, data on the number of citations of individual publications can be used. This is based on the assumption that a text which has more citations is more significant than one which is cited less. More frequent citations can be

proof of a greater substantive value of a given publication. This, however, does not have to be a rule, since a text may be frequently cited as a negative example (e.g. to prove its fallaciousness). In addition to that, citations used as a measure of scientific quality are fraught with many other limitations which should also be taken into account (cf. Nowak 2008). For this reason, the quality of publications measured using the citation index is rather difficult to interpret as it can, potentially, prove the scientific quality of a publication or simply be a token of its recognisability in the world (which in itself can be a valuable piece of information).

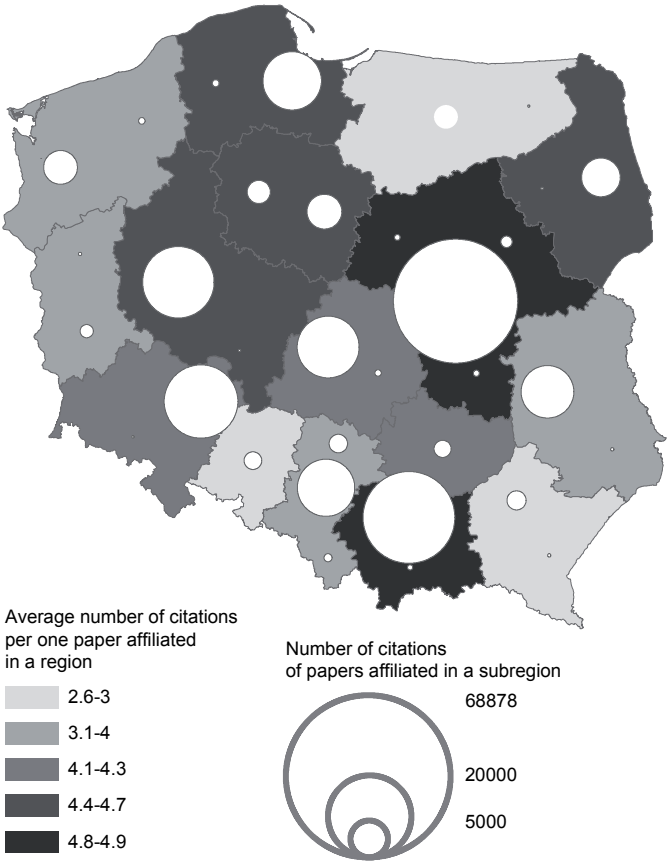

Figure 5. Spatial differentiation of the number of citations of articles from the period 2001–2006

Source: prepared by the authors based on the Web of Science.

The quality of publications is a variable which is rather difficult to measure. One of the indicators which could be used to 'capture' it is the number of citations and the citation index for a given paper, i.e. the average number of

citations per publication originated in a given location. Due to the fact that citations, to some extent, reflect the number of publications, the subregions with a large number of publications are also those with the highest number of citations. However, quotations are more distinctly than publications concentrated in the strongest regions: 92% of all citations originate from 10 subregions with the highest number of citations. The differentiating measure for the subregions, and thereby regions, (voivodships) is the citation index, the values of which are the highest for Małopolskie and Mazowieckie, and the lowest for Podkarpackie, Opolskie and Warmińsko-Mazurskie regions (cf. Fig. 5).

Interestingly, the number of citations does not always translate into the rate of citations. For instance, when we compare the voivodships of Podlaskie and Lubelskie, we notice that despite the higher number of quotations recorded for Lubelskie, the citation index is higher in Podlaskie. At least to some degree, this is certainly a reflection of the differing fields of specialisation of the regions' research centres. Owing to the fact that individual scientific disciplines have their inimitable patterns of citation behaviours, the citation index cannot be directly used to compare the quality of individual research centres. To make such a comparison legitimate, we would need to compare the rates of citation for individual disciplines, preferably as narrow as possible because individual specialisations in e.g. medicine, can significantly vary in the average number of citations per publication, e.g. oncology – 20.2; orthopaedics – 4.4 (Wróblewski 2001).

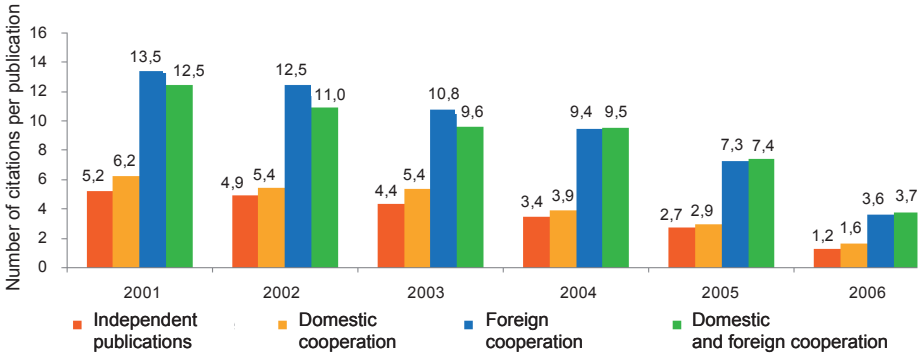

Figure 6. Correlation between citations and the nature of collaboration in 2001–2006

Source: prepared by the authors based on the Web of Science.

Figure 6 shows the average number of citations for papers published in the years following their publication up to September 2008. The first conclusion which can be drawn from these data is rather obvious: the number of citations increases with time.

The second conclusion pertains to the role of collaboration in the field of publications. The analysis indicates that the number of quotations of a given

paper depends on how it was categorised earlier. Publications which are results of domestic cooperation render only slightly better results than those which were developed in one research centre only. Quite strikingly, articles written as part of foreign cooperation have a decidedly higher number of citations than those written independently and in domestic collaboration (up to 3 times more in 2006). This clearly means that papers written together with foreign partners have a higher recognition level in the scientific world; possibly, they also represent higher quality, although, as said before, the rates of citation should be interpreted with a great deal of caution.

Collaboration in the sphere of research programmes

Projects implemented by Polish institutions as part of the Sixth FP can be categorised, similarly to publications, with regard to the type of collaboration, or lack thereof, into independent projects (i.e. carried out by an institution or institutions from one subregion), projects implemented in collaboration with at least one domestic partner from another subregion, projects implemented together with a partner from another country and those which involve participation of institutions from at least two Polish subregions and one or more foreign institutions.

The decisive majority of the Sixth FP projects were delivered in collaboration with foreign entities (81%) and in mixed collaboration involving domestic and foreign entities (14%), which reflects the overall idea of EU Framework Programmes. Independent projects made up only 5% of all projects under analysis (in the sphere of human resources and mobility), and domestic projects involving collaboration between subregions were of minor significance (1%).

The network of subregional cooperation relating to projects carried out as part of the Sixth FP largely reflects the pattern of collaboration for publications indexed in the Web of Science database (see above). The strongest collaborative links measured by the highest number of joint projects exist between the subregions of Warsaw, Poznań and Kraków-Tarnów, in addition to Warsaw and Łódź. As we can see, the Warsaw subregion represents the strongest link in the network of ties in this field since, for most of the remaining regions, projects carried out in collaboration with institutions from the Warsaw subregion represent the crucial share of their cooperation. Among the regions with the highest shares in the Sixth FP, the Warsaw subregion is the key partner for the Kraków-Tarnów subregion (31% projects), Poznań, Wrocław and Gdańsk (27% in each case), Łódzkie (40%), and Lubelskie (35%) (cf. Fig. 7). Still, some exceptions to this general trend can be observed. For example, the Central Silesian subregion has a relatively better developed project collaboration with the Kraków subregion (27%) than with Warsaw (25%), and the Szczecin subregion has stronger ties with Wrocław and Poznań (17% projects in each case).

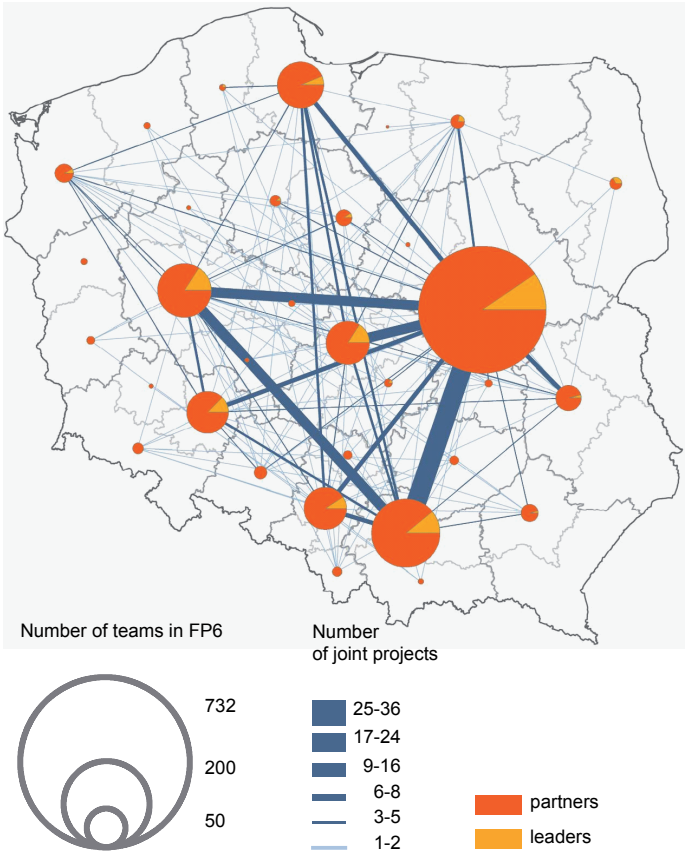

Figure 7. Domestic cooperation as part of the Sixth Framework Programme projects

Source: prepared by the authors based on the CORDIS data.

Domestic cooperation in the Sixth FP projects also corroborates the observation following from the analysis of activity in the sphere of publications, namely that weaker research centres in many cases cooperate with the nearest stronger region, which is proved by the directions of cooperation of several subregions with a scant number of projects, e.g.: the Elbląg subregion cooperates with the Olsztyn subregion, the Legnica subregion – with the Central Silesian; the Słupsk subregion – with Gdańsk, and the Świętokrzyske and Nowy Sącz subregion – mostly with the Kraków subregion (cf. Fig. 7). Furthermore, analyses of cooperation networks in the Sixth FP projects confirm the natural tendency whereby the spatial differentiation of collaboration (measured by the number of cooperating subregions) depends on the number of implemented projects. Quite naturally, this correlation is stronger in the case of regions involved in external cooperation on a smaller scale.

Conclusions

The concepts linking innovation with collaborative networks as well as examples of empirical research related to collaboration in science, discussed in this paper, well illustrate the extent of this phenomenon and how dynamically this new 'research front' is developing. Duncan Watts' observation about the emerging 'new science of networks' (Watts 2004) is corroborated by research on innovation. The directions of policy intervention at supranational, national and regional levels confirm that the network paradigm is well grounded in theory and practice. The majority of specialists who deal with regional development issues have no doubts that, in order to be successful in the knowledge-based economy, a region should develop an internal structure of linkages and cooperation networks in order to make use of its indigenous resources, alongside a network of external linkages to be able to 'absorb' knowledge from the outside (Brandt, Hahn, Kiese 2009).

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