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The challenge of breaking the academia-business firewall in a post-communist country: the case of collaborative RDI projects in the Czech Republic

David Marek
Charles University in Prague, Faculty of Science
Department of Social Geography and Regional Development
davidmarek@email.cz

Jiri Blazek
Charles University in Prague, Faculty of Science
Department of Social Geography and Regional Development
jiri.blazek@natur.cuni.cz

Abstract

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David Marek; Jiří Blažek

ABSTRACT

Contemporary innovation process is increasingly involving a large number of networked actors with complementary capabilities. Especially cross-fertilization between knowledge institutions and firms has become significant driver for innovation. Based on extensive data set, this paper aims at deeper understanding of knowledge linkages that have been created within joint RDI projects. Drawing network diagrams it combines individual characteristics of projects as well as actors involved to describe diverse pattern of knowledge linkages. In addition to the spatial dimension of networks, the paper observes underlying characteristics of knowledge involved as these shape the collaboration pattern. The paper concludes that in the case of the Czech Republic rather than physical distance, other forms of proximity seems to be more important. In particular, distinct patterns and varied intensity of collaboration were found between networks drawing predominantly upon either analytical or synthetic knowledge base.

Key words: knowledge linkages; collaborative projects; network analysis; innovation system; innovation policy; the Czech Republic

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1 INTRODUCTION

The current European and national policy agenda clearly emphasize the relevance of research and development (R&D) as a driver of economic growth (e.g. EC 2010). Innovation constitutes an effective response to global competition and societal challenges (Tödtling et al. 2013) in both high- and low-tech industries (Hansen, Winther 2011). Contemporary knowledge processes are increasingly involving a large number of networked actors with diverse capabilities. Especially cross-fertilization between research organisations and firms has become significant for innovation (Levén et al. 2014).

Innovation actors are embedded in particular locations and socio-economic contexts that are shaped also by policy actors and institutional conditions, as pointed out in the innovation systems literature (i.a. Cooke et al. 2004; Lundvall 2007). This is especially true in a specific context of transition economies. In new member states in Central and Eastern Europe, the national innovation policies are developing under the contradictory process of profound institutional changes and sudden exposure to global competition after the collapse of communism (Blažek et al. 2013). The routines of research organisation concerning knowledge exploitation are characterised by a strong inertia. Still, with exception of few valuable insights (Žížalová 2010; Blažek et al. 2011; Hofer et al. 2011), there has been surprisingly little research on science-industry interaction and, to our knowledge, no network analyses of engagement in collaborative projects in these countries.

Therefore, this contribution aims to fill this gap on the example of the Czech Republic. RDI initiatives sponsored by the Czech government increasingly involved a requirement for cooperation to facilitate the knowledge transfer, making it faster and more flowing (see Levén et al. 2014). Despite the general upsurge in supporting RDI in developed countries, we know little about the challenges associated with managing innovation networks (Manniche 2012). The joining mechanism seems far from being automatic, but it is rather contingent upon characteristics of participants (Zahra, George 2002). The need to go beyond simple dichotomy of codified vs. tacit knowledge has been widely acknowledged. Thus, the concept of differentiated knowledge bases is accommodated, as it provides a suitable framework for analysing varying role of R&D in particular spheres. Moreover, it constitutes an important element in constructing (regional) advantage (Asheim et al. 2011a; Tödtling et al. 2013).

Based on a unique database combining available data sources, the contribution investigates joint projects in research, development and innovation (RDI) as one of important modes of science-industry relations. In addition to the spatial dimension of cooperation, the paper scrutinizes underlying characteristics of knowledge involved as these shape the pattern of collaborative linkages. Moreover, it discusses the institutional and policy related factors influencing the pattern of science-industry collaboration in the Czech Republic. The paper consists of conceptual section, methodology, description of the innovation system in the Czech Republic and, finally, of analysis of knowledge linkages in collaborative RDI projects. This empirical section starts with the description of a composition and the geography of RDI networks. Then, the spatial dimension of the R&D networks is analysed with respect to differentiated knowledge bases. The paper concludes that in the case of the Czech Republic rather than physical distance, other forms of proximity seems to be more important. In particular, distinct patterns and varied intensity of collaboration were found between analytical and synthetic knowledge bases. Nevertheless, the collaboration pattern is a complex phenomenon influenced by the combination of a specific institutional context and specific actors-related factors. In virtue of the findings we derive possible implications for innovation policy.

2 CONCEPTUAL BACKGROUND

The innovation system (IS) approach represents useful conceptual environment for discussion on science-industry relations and a strategic role played by policy (Cooke et al. 2004). A cornerstone of the innovation system approach is that 'the rate of technological change is determined by the interaction', therefore, 'the system cannot be understood by focusing on the activities of any of its components in isolation' (Asheim et al. 2011c, 883). Thus, we apply innovation system perspective to analyse networks that are built between actors and used for knowledge sourcing.

In his pioneering definition Freeman (1987) accentuated two important elements of an innovation system (IS), when he described it as a network that initiate and diffuse new technologies. Lundvall further developed the concept to analyse the interaction between knowledge institutions and firms in the innovation process stressing need for interactive learning and effects derived from the institutional set-up (Lundvall 1992). The role of institutional setup often constitutes an explaining factor for system's behaviour (Tödtling, Trippl 2011) what, at the same time, cause certain fuzziness of the concept (Doloreux, Parto 2005). Earlier focus of the IS proponents on highly successful countries and regions have resulted in a criticism of description of full-blown systems at a point in time, without providing an analysis under what conditions the system evolved (Feldman 2001) and often limited appreciation of path dependencies (Uyarra 2010).

Building on the IS background we try to understand better the nature of science-industry interaction in the post-communist context. The level and quality of interaction in the IS seems to be of critical importance for system efficiency, as Fritsch and Slavtchev (2011) show in case of German regions. An IS is far from being self-sustaining in the long term, local activities have to be eke out with external inputs (Asheim 2007; Tödtling, Trippl 2011). In the long run, most firms cannot rely exclusively on internal knowledge. Strongly localised perspective built upon informal knowledge spillovers has drawn aside in favour of multilevel perspective (Tödtling et al. 2013). Knowledge sourcing has become even more complex.

2.1 KNOWLEDGE BASES AND INNOVATION NETWORKS

Innovation is seen as the result of interactive processes. The ongoing interest of spatial aspects of knowledge flows has brought together the distinction between differentiated knowledge bases (e.g. Asheim, Gertler 2005). "The concept of knowledge bases provides some further insights into the way in which companies innovate, and how they source knowledge" (Tödtling et al. 2013, 20). A key argument of the concept of differentiated knowledge bases is that the innovation process differs substantially in different spheres (Asheim, Gertler 2005). There is a large variety of inputs needed for knowledge creation, whereas distinct industries require specific types of knowledge. Detailing initial distinction of Laestadius (1998), three types of knowledge base were distinguished: analytical (science-based), synthetic (engineering-based) and symbolic (creativity-based) (Asheim 2007).

The analytical knowledge base corresponds with the rationale for analysis and understanding features of the world (Tödtling et al. 2013). Cognitive and rational processes, theory building, formal models and abstraction constitute the core in knowledge creation and lead to scientific discoveries (Asheim 2007). Knowledge outputs are relatively easier to be codified. Frequent and more formally organized science-industry relations typically complement in-house R&D in companies. Analytical knowledge tends to be less distance-sensitive, facilitating (not exclusively) global knowledge networks (Moodysson et al. 2008; Asheim et al. 2011a), for example in life sciences, biotechnology and nanotechnology (Tödtling et al. 2013).

The synthetic knowledge base is associated with integrative application and novel combination of existing knowledge, constructing something to attain functional goals (Tödtling et al. 2013). It is built predominantly on tacit, practical knowledge and learning by doing. It favours local collaboration (Moodysson et al. 2008). Usually it is found in industrial settings, and occurs in need to solve specific problems (Asheim 2007). The interaction with actors along the value chain remains more frequent than R&D activities. Nevertheless, science-industry links are still present in the form of joint development and testing. Innovations are user and market driven, as is the case for instance in automotive, advance manufacturing, electronics, software, or textiles (Tödtling et al. 2013).

Finally, the symbolic knowledge base draws on creation of cultural meaning of ideas, images and design by provoking reactions in the mind of consumers (Asheim et al. 2011a). It has most resonance in industries where the aesthetic attributes of products are high, i.e. culture, design, fashion, advertising and media. Compared to other two knowledge bases, informal interaction with consumers plays a bigger role (Manniche 2012). Importance of symbolic knowledge base has risen together with the shift from the use-value of products to the sign-value of brands (Asheim 2007).

Table 1: Differentiated knowledge bases

	Analytical (science based)	Synthetic (engineering based)	Symbolic (arts based)
Rationale, goals	Developing knowledge, applying scientific laws, know why	Combining existing knowledge in novel way, know how	Creating meaning, symbolic value and impression
Knowledge in use	Scientific knowledge, models, deduction	Problem solving, testing, induction	Understanding conventions, experimentations
Knowledge types	Predominantly codified, universal	Predominantly tacit, context specific	Rather tacit, handicraft, creativity, interpretation, context specific
Actors involved, attributes of collaboration	Intensive formal R&D collaboration between research units (in-house and academic)	Long-term, trust-based and strategic between actors along the value chain	Short-term, creative inputs from diverse sources
Importance of spatial proximity	Rather low	Rather high	Rather high

Source: Own modification of Asheim et al. (2011a); Blažek, Uhlíř (2011)

The underlying idea behind the differentiated knowledge base approach is not to explain the R&D intensity of firms but to characterize the nature of the knowledge inputs, rationale, or interplay between actors in innovation processes (Asheim et al. 2011c). The concept explains the broader organisational and geographical implications of different types of knowledge, including patterns of cooperation and importance of proximity (Asheim et al. 2011b). Knowledge bases should be understood as ideal types, thus, the degree to which certain knowledge bases dominate relates to the characteristics of industry, firm, even specific activities, for example, during the different phases of product development (Moodysson et al. 2008). Martin and Moodysson (2011) found that elements of all bases can be identified within a single firm.

Increasing complexity of economic activities entails a more profound division of labour between firms as well as localities. Dispersion and concentration seem to coexist (Vatne 2011). Research on the geography of innovation in the past twenty years was largely concerned with a basic question, whether knowledge does tend to flow more easily among spatially proximate actors (Breschi 2011). For instance, Laursen et al. (2011) found that physical closeness is an important determinant for science-industry interaction.

'The notion of proximity is a sort of umbrella concept consisting of different dimensions' (Harmaakorpi et al. 2011, 557). Boschma (2005) distinguished five dimensions of proximity (i.e. cognitive, organisational, social, institutional and geographical). Proximity helps to reduce the uncertainty of various economic activities. Being proximate enhance the probability of agents to interact in an effective manner. Mainstream economic development policy in Europe has relied on the logic of proximity and agglomerations when largely adopted a cluster approach (Harmaakorpi et al. 2011). Recent research has questioned learning as a process conditioned by territorial agglomeration as such (Moodysson 2008). Several scholars have argued that radical innovations are better reached through the search for informational diversity (Laursen, Salter 2004). Hence, recent discussions have rather followed the logic of cross-fertilization and use of proper mix of distance and proximity under the notion of related variety (Frenken et al. 2007) as a fuel in innovation process (Boschma, Frenken 2011; Iammarino 2011).

Studies have illustrated that innovation networks forms an important driver of knowledge diffusion. Networks are characterised by transactions among interrelated groups of actors that engage in reciprocal and mutually supportive actions (Powell 1990). A large group of studies have used networks as a broad interpretative factor, in general concluding with a causality the denser the networks the better, with rare exceptions adopting more explanatory perspective (e.g. Grabher 1993). A selective access to knowledge can be found even in small communities (Giuliani, Bell 2005). Recent contributions have followed an inductive approach and explored more rigorously the relationship between network structure and induced knowledge flows (Ter Wal, Boschma 2009) by using tools of social network analysis.

2.1.1 SCIENCE-INDUSTRY INTERACTION

Science–industry relations started to fill the innovation policy debate together with an increased emphasis on the IS approach (e.g. Mansfield 1998; Tassey 2005; Perkmann et al. 2013). Empirical investigations largely found a positive relationship between academic achievements and commercial success of related industries (Gulbrandsen et al. 2011), therefore, some consensus seems to exist on the positive impact of science-industry cooperation on innovation performance (Salter, Martin 2001, Cohen et al. 2002). There seems to be much less agreement on the relative importance of particular modes of interaction, conditional factors, and motives for science-industry relations. Several papers have engaged in the endeavour to measure relative importance of particular channels (Cohen et al. 2002; Bekkers, Freitas 2008) bringing ambiguous evidence. The differences seems to stem from the attributes of the underlying knowledge, and to a lesser degree from individual characteristics of actors involved (Bekkers, Freitas 2008), or disciplinary/industry origin (Salter, Martin 2001). Collaborative research seems to be important to engineering fields as well as science-intensive industries (Bekkers, Freitas 2008). Even in respective context of the Czech Republic joint R&D projects in national programmes were among the most accentuated channels for science-industry knowledge transfer (Hofer et al. 2011).

Recent policy initiatives encourage public research organisation to play an active role in economy. Despite this effort, science-industry linkages remain outcome of a voluntary matching process, motivated by the consideration of complementarity and resources (Perkmann et al. 2011). 'Hence, firms not only need to decide whether to involve universities in their R&D activities or not, but they also need to carefully decide the most suitable organizational form' (Cassiman et al. 2010, 883). Grimpe and Hussinger (2013) confirmed a complementary relationship between formal and informal modes of interaction in case of German manufacturing firms, as formal collaboration modes mostly coincide with informal links to academia. . Informal contacts represent common form of interaction in case of need of ad hoc advice and networking. Commercialisation and collaborative arrangements are driven by different dynamics, during the latter benefits are yet to be generated through cross-fertilisation and mutual learning (Perkmann et al. 2011). Research organisation typically offer new technical and methodical knowledge needed in the early stages of the innovation process. However, the majority of innovation activities are located in latter stages, i.e. in the adjustment of already existing products and processes to market needs (EC 2001).

3 INSTITUTIONAL AND POLICY CONTEXT

As pointed out by IS literature, firms and knowledge institutions do not act in a space-less world but they are embedded in a socio-economic contexts shaped by institutional conditions and policy actors. Both factors are seen essential in a specific context of transition economies such as the Czech Republic. The overall system setting is a result of path-dependent development. Therefore, unsurprisingly, significant disparities between countries and regions regarding the broadly defined innovation potential tend to persist (EC 2014b). Consequently, the organization of knowledge linkages cannot be understood out of country specific context (Žížalová 2010; Hofer et al. 2011).

Czech national IS is developing under the conditions of fundamental institutional changes and sudden openness to global competition after the collapse of communism (Blažek et al. 2013). Nevertheless, the heritage of a post-communist country can be traced in a number of characteristics of national and regional innovation systems. To start with, during the early transition period, the RDI system has been significantly downsized. After the EU accession in 2004, the system embarked on a catching up trajectory, however, the lag behind EU12 remains quite significant. According to the Innovation Union Scoreboard 2014, the Czech Republic is classified as a moderate innovator (EC 2014a). R&D expenditures and number of tertiary students have been increasing steadily, yet, many innovation-output related indicators document lagging behind the EU28 average (Srholec 2014). Gross expenditure on R&D as a percentage of gross domestic product reached 1.91% in 2013, which is slightly below the EU28 average (CZSO 2014). Although one can identify certain domains of top-level research, the overall performance remains rather poor by the EU standards. On the other hand, the country enjoy a relatively strong position in the medium-tech sectors such as automotive, electrical engineering and mechanical engineering (Blažek, Uhlíř 2007).

Limited financial flows between private and public sector indicate existence of significant barriers that exist between businesses and public R&D institutions. Only 6.7% of the business expenditure on R&D was directed into the public sector (higher education and research institutes). Moreover, two thirds of these expenditures were coming from foreign firms (CZSO 2014). These cross-sectoral funding flows do not represent collaborative activities as such, but provide hints on division of labour (Hofer et al. 2011). The less intensive connections demonstrated by low level of mutual financing can be attributed to legal difficulties, inexperience, conflict of interests and expectations, and structural mismatch between knowledge supply and demand (Žížalová 2010).

An important structural weakness of the Czech IS lies in a lack of science-industry cooperation and an absence of a coordinating mechanism in the grey zone between research policy and business development (Blažek, Uhlíř 2007). Moreover, the business community tends to be a priori suspicious of the competencies of public research representatives, and vice versa. Until nowadays, certain mistrust prevails in the perception of respective counterparts (Blažek et al, 2013). Nonetheless, 40% of firms believe that insufficient science-industry linkages are a barrier for the Czech IS (Hofer et al. 2011).

The Czech Republic drafted first fully-fledged national-level innovation strategy only in 2005, and placed public-private collaboration on the top of policy agenda (Blažek, Uhlíř 2007). However, the introduced performance-based funding model 'focuses exclusively on countable research outputs and fails to motivate researchers to cross the gap between academia and industry' (Blažek et al. 2013, 279). Currently, 14 self-governing regions (NUTS 3 level) vary greatly in respect not only to the quality, but even the very existence of regional innovation policy. However, as regards the overall geography of innovation, Žížalová (2010) has not found a decisive role of the regional level. Rather, the national boundaries delimit fundamentally the RDI interactions in the Czech Republic.

The capital city of Prague has a strong concentration of about half of the public research capacities. As it hosts particularly high-end research organizations, Prague functions as a scientific gateway for the Czech Republic (Žížalová 2010). This potential, however, is not reflected in the existing institutional and policy context, resulting in internal debt in technical infrastructure, which is partly attributable to limited eligibility to draw support from the EU Structural Funds (Marek et al. 2013). Nonetheless, the fundamental internal problem of the Prague rest in the lack of political will among city representatives in Prague to support R&D (Blažek et al. 2013). The two other major concentrations of innovation capacities are represented by the South Moravian Region, with its regional capital Brno (the second-largest city), and the Moravian-Silesian

Region, with its core in the Ostrava agglomeration. The former is regarded as a leader in innovation support as local innovation policy designers are effectively helping to utilize the innovation potential of the regional R&D actors from both public and private sphere. In contrast, the old industrial region of Moravia-Silesia used to focus primarily on attracting foreign investors and upon building of cluster initiatives. The main structural constraints included the overly specialized nature of the regional economy in declining industries. Nevertheless, especially ICT and automotive sectors are strongly developing in this region. Moreover, local technical university has gradually succeeded in establishing relatively strong organizational structures available for innovation activity (Blažek et al. 2013).

4 METHODOLOGY

4.1 METHODS

Giuliani (2011a) indicated two basic methodological approaches adopted to investigate innovation networks. A qualitative, process-oriented case-study approach inquire into the motivation for and nature of existing relations (e.g. Camagni (1991). A structuralist approach based on SNA focuses primarily on the structure of networks and analysing the determinants of networks and of actors' positions within networks (Zaheer, Bell 2005; Giuliani, Arza 2009; Giuliani 2011b). SNA helps to describe topography of knowledge networks, identifying central nodes and the spatial reach of linkages (for the methodological review see Carrington et al. (2005)). In addition, one can investigate the variety of knowledge sources to which each node is linked, and what are the underlying factors for that behaviour (Tödtling et al. 2013; Giuliani 2011b; Giuliani a Pietrobelli 2014). In spite of SNA attracts increasing attention in economic geography, nearly all contributions take a static perspective, depicting the network at a certain point in time (Ter Wal, Boschma 2009). SNA is rapidly becoming adopted by economic geographers, what entails the potential risk of favour structure of a network, while simultaneously neglecting process, content of ties and characteristics of actors (Steiner 2011). It frequently treats network interactions in networks as a black box (Giuliani 2011a), for exception see Fleming and Frenken (2007), or Steiner and Ploder (2008). Use of data set of collaborative R&D projects remains rare. To our knowledge this kind of relational data have been analysed by Yokura et al. (2013) only.

The way the linkages between actors are distributed has obvious consequences for the way knowledge is diffused. Giuliani (2011a) summarised the key findings of a body of SNA literature. Real networks are non-random in some revealing ways, leaving a number of actors (semi)isolated (Giuliani 2007; Boschma, Ter Wal 2007). Regardless of geographic proximity some actors may occupy more central place than others, thanks to their innovative performance (Giuliani, Arza 2009) or other firm-level characteristics (Steiner, Ploder 2008). A strong correlation exists among the absorptive capacity, external knowledge linkage and the centrality of actors(Giuliani, Bell 2005). The actual significance of proximity for the emergence of innovation networks has been the subject of many recent publications (e.g. Ter Wal 2009). Juxtaposition of various networks may reveal what structure is more likely to carry innovation-related knowledge. The spatial aspects of networks are of particular interest for understanding the role of geography in knowledge sourcing. Investigation of R&D networks revealed that the spatial reach depend on the technical field as well as on the actors involved. Academia–academia cooperation spans over much larger distances than the one including private firms (Yokura et al. 2013). Morrison (2008 in Ter Wal, Boschma 2009) showed that some large firms with strong extra-local linkages were acting as gatekeepers, passing the acquired knowledge on to local firms. With special focus on the role of prevailing knowledge base, Plum and Hassink (2013) analysed patterns of innovation in automotive industry using SNA. Incremental innovations were mainly based on the new combination of existing knowledge that is typical for a synthetic knowledge base. Knowledge relationships were organised at the national level, predominantly vertically along the value chain, as opposed to rather weak relations with universities.

We aim to further elaborate some of the previous findings in the specific context of post-communist country, especially those concerning spatial pattern of science-industry linkages and topography of networks with respect to prevailing knowledge base. We describe evolution of the collaborative networks, analyse what is the most common spatial level at which the networks originate and discuss whether the characteristics of knowledge affect subsequent pattern of science-industry linkages.

4.2 DATA

Large collections of data are necessary for applying SNA to an science-industry collaboration (Yokura et al. 2013). In our contribution, the networks are built upon joint participation in collaborative RDI projects, which involve at once at least one firm and at least one knowledge institution (either university or public research institution). Out of these entities, other types of actors may take part in a collaborative project (for instance non-profit organisations or public service organisations). Nevertheless, the major focus is directed to the science-industry interaction. Network nodes thus represent units and edges between them illustrate relations. When the co-presence of the same entities in collaborative projects has repeated character, the particular edge is of higher weight. The weight of linkages is based on frequency counts of co-presence of units in joint projects. In spite we consider financial data (total costs of individual projects and for individual units), it would be obviously misleading to translate the financial data into the weight of linkages. The costs may only stay associated with respective units. To visualise the collaborative networks we have chosen an open source platform Gephi[1] from many available software options.

We draw on extensive database of the RDI Information System of the Czech Republic (IS RDI)[2]. IS RDI combines ample of individual data, which are relatively complete (public support of RDI is subject to information liability) and relatively up-to-date (full data of the projects supported in 2013 and earlier). It contains interconnected record on actors, programmes, projects and results of RDI activities retrospectively. Therefore, we lean against a sufficient number of cases, even when divided into subgroups. To the point of our departure (end of October 2014) the IS RDI included record data on 41 thousand projects and more than 820 thousand results. We limit our initial population to projects that have been initiated since 2004 for the reasons that 2004 onward the responsible public bodies gradually launched several initiatives supporting science-industry cooperation. Moreover, we are interested primarily in development of the cooperative landscape in past 10 years. The data from IS RDI is coupled with several other sources, in particular with the Business Register where all the entities with unique identification number are listed, and additional geographical data (domicile location at the lowest level of public administration; that is a municipality or urban district; altogether almost 6400 units).

We work at the level of legal entities. Projects participants registered in the IS RDI are either organisation with legal identity or their department. Nevertheless, only universities are further divided (into faculties). Hereafter we use the notion units for all the entities listed in the IS RDI system. Unit-level analysis yields more fine-grained results than would organisation-level and ensure more appropriate juxtaposition, especially when considering varying size and the differentiated knowledge bases. We distinguish four main types of participants according to their legal status - private firms (PF), faculties of public universities (UN), public research institutions (RI), and finally a group of other actors (OT) that consist particularly of non-profit and public service organisations. The group of other actors has minor representation in our data set and a mixed role, hence it is considered auxiliary to other three groups.

In order to trace differences in pattern of linkages in different knowledge bases, we have extended our dataset with information about specialisation. Unfortunately, to our knowledge, there is no single right way to follow. The Czech equivalent of the Statistical classification of economic activities (CZ-NACE) is seen as a reasonable choice only for the group of private firms, because at the level of two-digit divisions virtually all the knowledge institutions fall into two categories - Education in case of universities and Scientific research and development in case of research institutions. An alternative way to describe knowledge specialisation of actors involved in collaborative RDI projects is to use the IS RDI classification. It consists of 123 research branches consolidated into 10 groups. Several branches (the main branch and two secondary) are assigned to every single project in the database. Hence, it allows us to filter out those projects that correspond to our criteria. However, it is tricky to translate the project focus into the characteristics of all investigators, especially in case of cross-disciplinary projects. Hence, we concentrate on the results of RDI activities, which represent information with relatively low granularity. Results describe quite precisely the nature of RDI that was done in respective projects. Consequently, for the participants that recorded results (1,016 participants) we used the results as a proxy for classifying participants into research branches.

[1] *http://gephi.github.io*
[2] *http://www.isvav.cz*

Depends on the structure of associated results/projects for each entity we have computed specialisation pattern based on the proportion of 123 branches. Moreover, using three independent researchers with distinct expertise and deep understanding of the nature of IS RDI classification as well as R&D landscape in the Czech Republic, we have rated each of the 123 research branches in terms of prevailing knowledge base to describe in a more compact way the prevailing character of knowledge each unit relies on. Final product of this assessment exercise is formed by percentage share of three different knowledge bases (analytic, synthetic, and symbolic) in a participant's specialisation pattern.

In the Czech Republic, the number of collaborative projects (2,707) represents only a minor subset of all the RDI activities supported by public funds since 2004 (approximately 13%). Collaborative projects involving both firms and public research organization represent 38 % of all the projects investigated by two or more participants, regardless of their type. In financial terms, the relative numbers remains virtually the same. Thus, the initial population consist of 2,707 collaborative projects engaging 1,962 unique participants. Only this sample is subsequently subjected to a detailed scrutiny of the pattern of science-industry relations, in our case over the last 10 years.

5 DISCUSSION OF THE RESULTS

5.1 THE NATURE OF COLLABORATIVE PROJECTS

Shortly after the fall of communism in 1989, the collaborative projects were rather rare. Nevertheless, a notable increase in public support targeted to this type of science-industry linkages has been recorded since 2004. In general, one can see a steady increase in number of collaborative projects supported, as well as increase of their total cost (including public funding). Thanks to this, business-academia engagement has become more frequent in comparison to projects with more than one participant investigated separately by public knowledge institutions (in sum 2,381), or by private firms only (426).

From a variety of support measures resulting in join RDI activities we may distinguish programmes with two different objectives. The first group, clearly dominating in number, focuses on rather short -term one-off tasks, where the decision is up to the firm, whether to engage in collaborative activity with knowledge institution. The public support is rather indirectly stimulating science-industry interaction. The second group is associated with long-term strategic cooperation in the form of RDI centres. The engagement of several participants across sectors constitutes a natural component of such a project. Generally, total costs and complexity of tasks are much higher in the latter case. Still, the set of collaborative projects is not biased by large one-shot infrastructural investments that have change the Czech RDI landscape significantly during the last EU programming period Marek et al. (2013).

Our set of collaborative projects compounds very diverse cases. The average costs of a collaborative project oscillate around € 0.9 million (running from single thousand euros to tens of millions. We can see an apparent shift of total budget being divided into less but more costly projects during the ten-year period under examination, especially in basic research. In virtue of cross-sectoral character, applied research strongly dominate being indicated in two-thirds of joint projects. The investigation period ranges for a vast majority of projects between three and four year, though it reaches even eight years in case of strategic research centres (for more see Marek 2015).

Industry related branches dominate the content of collaborative projects, prevail in 50% of projects, which represent 60% of total costs (unit price are relatively high), but at the same time they enjoy lowest relative level of public support from all the branch groups. In more detail classification, branches associated with traditional manufacturing industries are ranked among the most frequent (electronics and optoelectronics, metallurgy, engineering, transport systems), together with non-nuclear energetics and civil engineering. Less frequent but of higher overall costs are the collaborative projects in aerospace and nuclear energetics. As regards the prevailing knowledge base (according to our methodology, two-thirds share or higher), almost half of the collaborative projects rely dominantly on synthetic knowledge, as compared to 21% of project drawing primarily on analytical knowledge. The latter group involve in average slightly higher number of participant in a project. For the rest of the projects, the prevailing knowledge base is not decisive.

5.2 THE CHARACTERISTICS OF PARTICIPANTS

In sum 1,962 unique participants engage in our sample of collaborative projects, 82% of them being private firms, 9% university faculties (167 faculties of 21 universities), and 3% research institutions. Knowledge institutions take part in tens of projects on average, whilst firms usually participate in less than three projects. Significant differences remains in financial terms. Firms' engagement is associated with almost twice as high costs compare to knowledge institution. Similarly to average rate of co-financing from public budget, this reaches 54% in case of firms, but more than 90% for knowledge institution. In case of firms, every second RDI projects is done in cooperation with a knowledge institution. To the contrary, universities' and especially research institutions' industry engagement stays significantly less frequent.

The collaboration pattern of CZ-NACE two-digit divisions is consistent with the prime industries concerning total R&D spending in corporate sector (Technology Centre ASCR 2014). Tendency to collaborate is higher in Manufacturing, client relations seem most important in Information and communication, what is conform to findings of Hofer et al. (2011). With one major exception in the Manufacture of motor vehicles, which is considered to be the clearly leading industry in the Czech Republic, show only medium importance as regards science-industry collaboration in a form of joint projects. A possible explanation may lie in the strategy of companies in question. Each time a firm decides to externalize R&D activity, it has to consider several aspects. For strategically important projects, the company is more likely to resort to formal contracting, thus it is more able to respond to unanticipated circumstances (Cassiman et al. 2010). Unfortunately, individual data on R&D spending (except IS RDI) has to be anonymised by law, therefore, we are not able to trace if it is the case. For the same reason, methods of explanatory statistics cannot be used to find causal relations between the level of R&D spending and the propensity to engage in collaborative projects.

Geography of science-industry collaboration in joint projects to a large degree reproduces existing RDI capacities. One third of the participants concentrate in Prague, where major national institutions are seated. Next, there is the South Moravian region with Brno concentrating major resources particularly in the university sector, possibly sparking agglomeration effects (Srholec, Žížalová 2013). Ostrava agglomeration in the heart of the Moravian-Silesian Region is built on several large companies in the heavy industries and mining, together with strong science base in related fields. Low concentration of collaborating entities stretches along the southwest border, with exceptions of cities Plzen and Ceske Budejovice in spite of a large part of this area is attractive for business (see figure 1). A major rupture in the local economy caused by resettlement of German population after the WWII apparently persists. In case of Ceske Budejovice it may be explained partly by a mismatch between specialization of the local university and of businesses (Srholec, Žížalová 2013).

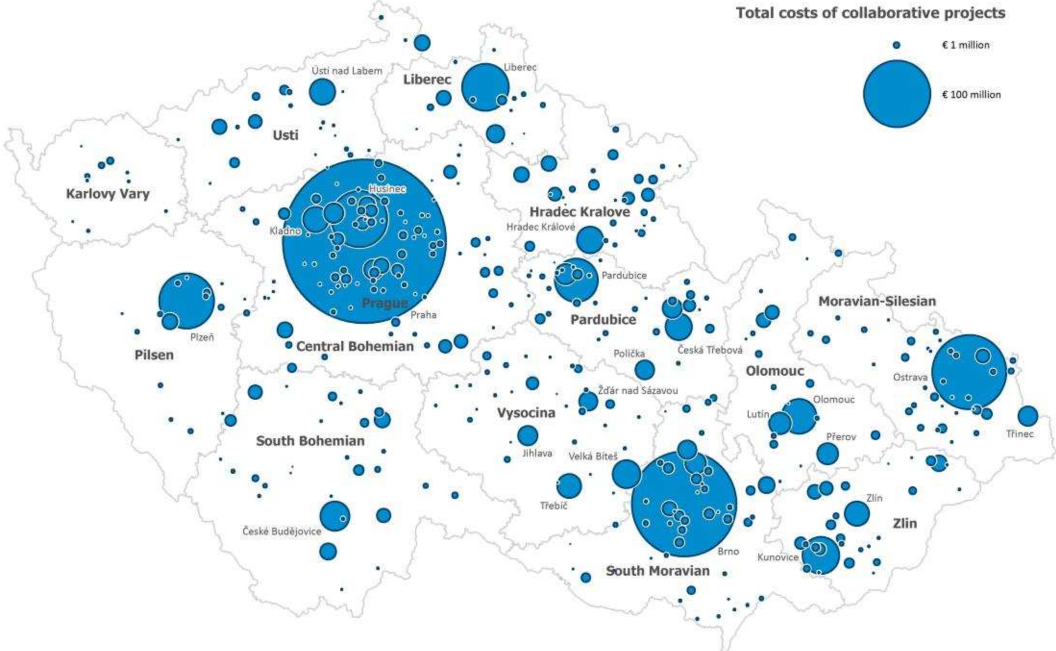
Private firms are more evenly distributed as compared to knowledge institution, which are located virtually only in regional capitals. It arises primarily from R&D in the public sector being much less dispersed than in the business sector (Srholec, Žížalová 2013). In three major metropolis (Prague, Brno, Ostrava), the costs of collaborative projects roughly match to the distribution of total R&D expenditure. At lower level of the settlement hierarchy, this relation becomes more affected by location of attractive technical universities in regional capitals (Plzen, Liberec) or important industrial firms in small towns (Kunovice, Velka Bites). In general, the overall locations of collaborating entities largely correspond to overall R&D intensity (figure 2).

At the individual level, the faculties of technical universities, particularly those with specialisation in mechanical, civil and electrical engineering, seem to attract principal attention of industry. Although this focus is common among technical universities, seven out of top ten faculties are located in Prague or in Brno. Limited reflection of regional universities in data on collaboration can be attributed to the specific institutional context where regional universities are largely focused towards educational function (Žížalová 2010) with a few pockets of excellent research, as for instance in regions with strong expertise in metallurgy (Ostrava) or in chemical engineering (Pardubice). In science based fields (molecular biology, physics, organic chemistry) the research institutions dominate the collaboration. High-end institutions of this kind are almost exclusively located in Prague. Therefore, the capital functions as a gateway for the Czech research for many of the disciplines, which relate strongly on global pools of knowledge (Žížalová 2010).

Specific situation take place in industry, as the structure of players underwent substantial changes. After 1989, the state owned institutes of applied research were privatized (Blažek, Uhlíř 2007). The same happened with enterprises that are now controlled by multinationals. Foreign-owned subsidiaries account for 50% of production (Hofer et al. 2011) and use 55% of expenditure in the business sector in the Czech Republic (ČSÚ 2014). Consequently, there are two distinct groups of private companies. The first consist of transformed institutes and several other firms that focus mainly on professional, scientific and technical activities. The second group is represented by traditional manufacturing producers, which engage in R&D to maintain their competitive advantage (see Marek (2015)).

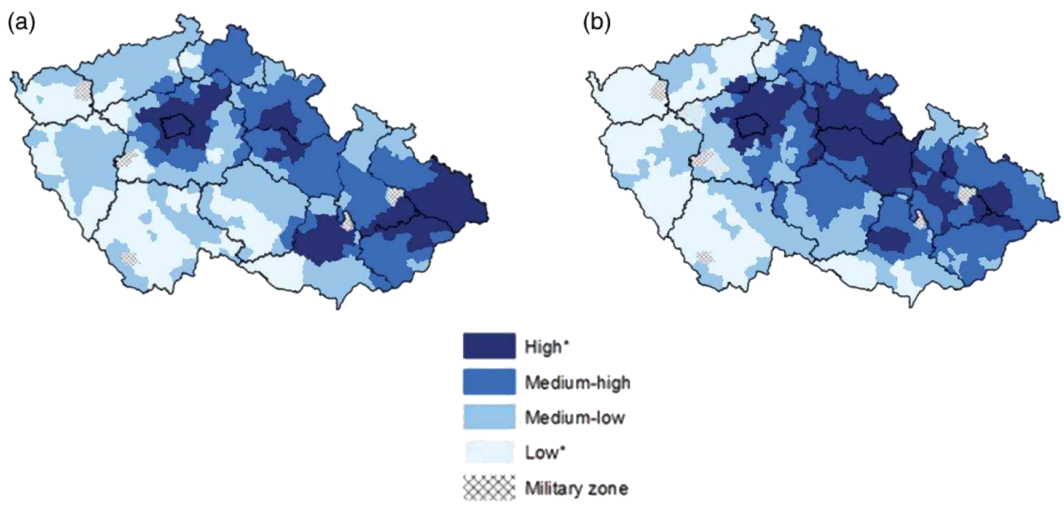
As pointed out by Hofer et al. (2011) on the basis of national innovation survey, there is clear size effect on innovation cooperation in general. Furthermore, foreign ownership has a slightly negative effect on domestic cooperation with knowledge institutions. We have applied binomial logistic regression to check how each of the available characteristics influences the propensity of entities to engage in collaborative projects. We have confirmed both the size effect favouring large units as well as lower propensity to collaborate of firms with foreign ownership. Apparently, these questions need to be further elaborated by using an extended data set.

Figure 1: Total costs of collaborative projects according to the residence of participants



Source: Based on Marek (2015)

Figure 2: Cluster map of business R&D employment over 2005-2009



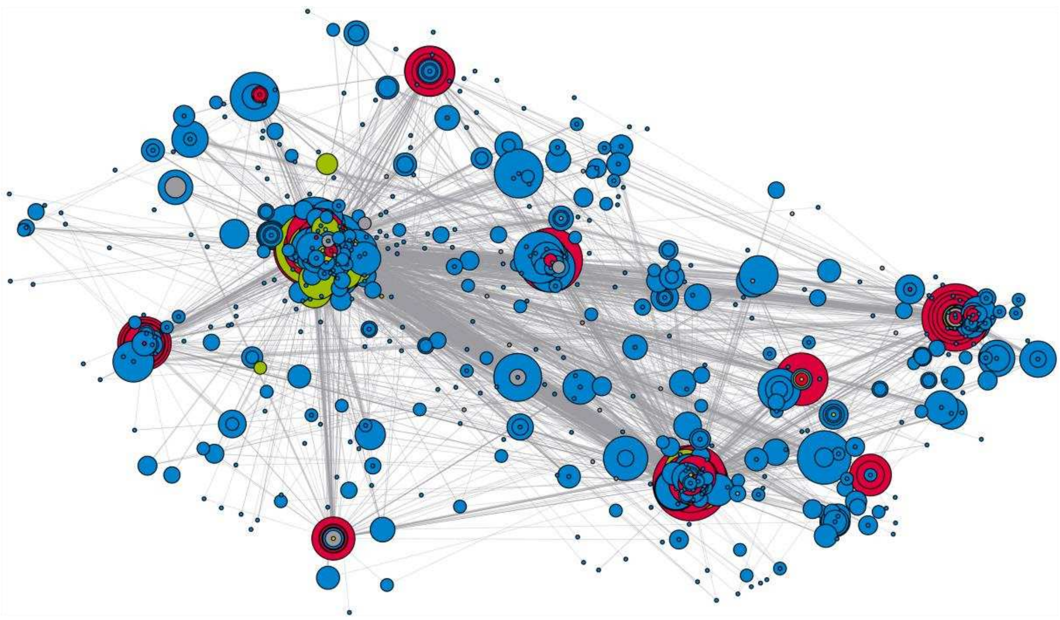
Note: a) Per km2; b) % of population
Source: Srholec, Žížalová (2013)

5.3 COLLABORATIVE NETWORKS

We proceed with description of spatial pattern of science-industry linkages in figure 2), where the location of nodes is tightly stuck to their geographical location. The network consists of 1,962 nodes and 4,103 edges of the weight reaching up to 32. Admittedly, the lucidity is reduced by a substantial overlap of circles, especially in Prague, where is located 31% of units. The propensity to collaboration of units from Prague is comparatively higher to other regions, probably because of higher average spending on R&D activities. It may be explained by the gateway function the capital (similarly e.g. Fritsch and Slavtchev (2007)). Prague accommodates organizations from the whole spectrum of expertise and therefore offers a unique opportunity to find potential partners (Žížalová 2010) as well as global suppliers (Blažek et al. 2011). Prague acts as the very central node as it attracts 60% of all linkages in collaborative projects, whereas 19% is limited inside the city boundaries. The role of physical distance seems to be rather secondary, with more emphasis being place on a position of the city in settlement hierarchy and on a consequent quality of knowledge supply. For instance units from the regions along east border of tend to cooperate with partners located in other that neighbouring regions.

A vast majority of collaborative linkages clearly cut across the existing regional borders, only 35% of linkages have intra-regional character (19% falling on Prague). It can be attributed to persisting national character of innovation policy in contrast to very little attention paid to innovation by the local political leaders (Blažek et al. 2013). In more peripheral areas connection to knowledge institutions are notably less frequent on behalf of customers and suppliers involved in incremental innovation (Tödtling et al. 2009). RDI capacities stay at the relatively low level and the number of potential partners is simply limited. We found contradictory evidence to Yokura et al. (2013), who argues that academia-academia relations have a much greater spatial reach than linkages between private firms. In our data set of collaborative project, firm-firm relations are spanning over slightly longer distances. Moreover, we found a relation between physical distance and the costs of RDI cooperation as a proxy for its complexity. Partners involved in more complex tasks tend to be closer to each other. This may be explained by higher need for transfer of tacit knowledge or simply by the fact that most of the large spenders collocate in main metropolitan areas.

Figure 3: Collaboration network: all linkages in geographical layout



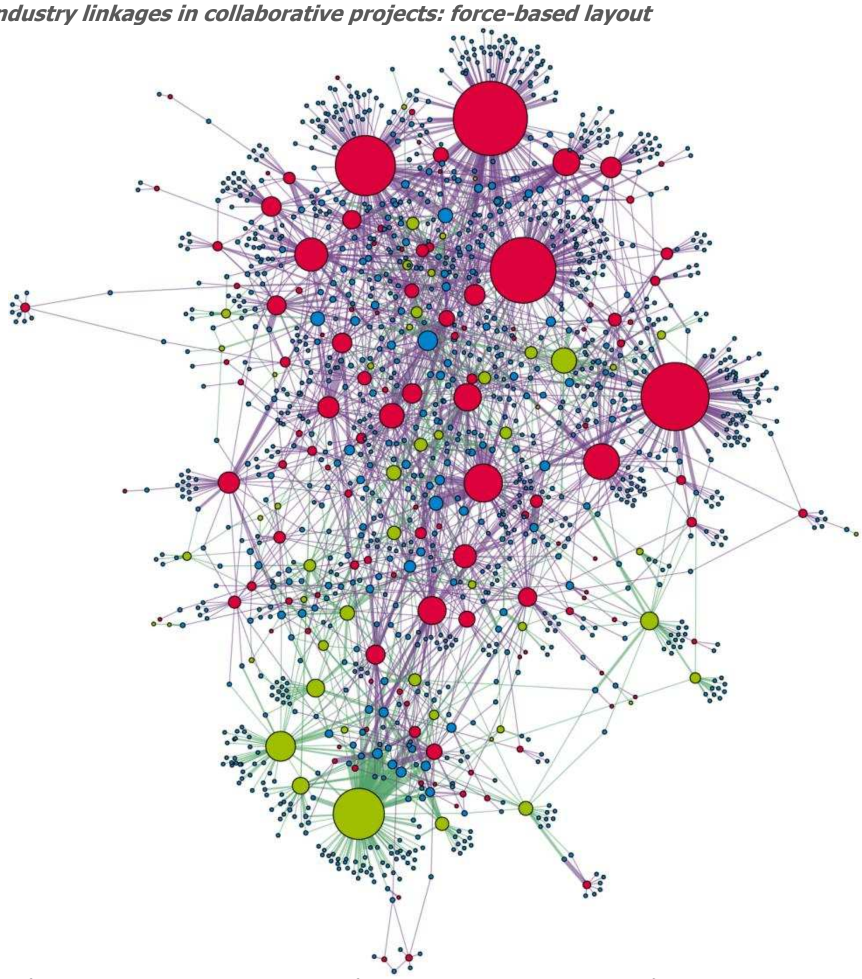
Note: ●Private firms, ●Faculties of public universities, ●Public research institutions, ●Other actors. The nodes are stuck to their geographical location. The circle size refers to the number of participation, with logarithmic transformation.
Source: Based on Marek (2015)

The role of geographical proximity for knowledge collaboration is far from being decisive. Similarly to previous finding of Žížalová (2010) we conclude in this respect that even though intra-regional linkages exist, they cannot be regarded as a vital source of knowledge, especially for more complex RDI tasks. Therefore, the individual characteristics of partners together with character of knowledge in question need to be taken into account. The collaboration patterns in the Czech Republic ’seem to vary in accordance with the business strategy, market characteristics, ownership or level of specialization’ (Žížalová 2010, 803).

From this point onwards we use force-based layouts to describe more comprehensively the character of collaborative networks. This way of visualising networks positions nodes based on attractive and repulsive forces using various algorithms (geographical distant does not matter in this case). The size of a node is attributed to its degree, i.e. number of direct connections. Application of this procedure leads to a dense tangle of indiscernible lines, which needs to be further divide into parts. Hence, we filter out only science-industry linkages (as opposed to firm-firm, or academia-academia interactions), as they are perceived essential for utilising results of public research in innovations (figure 4).

There are distinctive, extremely centralised communities of small firms (in terms of frequency of connection as well as total costs of collaborative tasks) linked to faculties of leading technical universities. This shows very central position of technical universities in the Czech IS and majority of firms to collaborate in form of rather short-term projects, with narrow thematic focus and lower overall costs. In general, only one third of companies have more than one connection to knowledge institution in terms of joint project. When we consider repeating interactions only, as they should bring substantial benefits in collaboration culture, the innovation system becomes relatively fragmented. Not only the network starts to be thin, but several micro-communities up to five units remain unconnected to the central network. Those micro-communities seem to be stemming from close regional or thematic collaboration.

Figure 4: Science-industry linkages in collaborative projects: force-based layout



Note: ● Private firms, ● Faculties of public universities, ● Public research institutions, ● Other actors. Force-based layout, the circle size refers to the number of direct connections (with logarithmic transformation).
Source: Authors

Differentiated knowledge base concept expects that analytical knowledge is less sensitive to distance as compared to synthetic knowledge. Firms that draw mainly on the analytical knowledge base should more frequently engage in collaboration with academia. Because of the mixed evidence of two previous studies, we try to shed more light on the effects of different characteristics of knowledge on the collaboration pattern. Whereas Žížalová (2010) conclude that the geography of collaboration differs only slightly between the industries relying dominantly on analytical and synthetic knowledge base and individual attributes of actor remain more important, Blažek et al. (2011) confirm the existence of significant variation in the geography of knowledge sources according to the type of knowledge involved.

In order to trace an effect of cognitive proximity we restrict our sample exclusively to private firms. Thus, the resulting network consists of 744 nodes and 793 edges of the weight reaching up to 7. Only 39% of linkages exist do not cut across sections of CZ-NACE classification, half of them connecting manufacturing firm that express relatively higher propensity to collaborate in contrast to other industries (particularly ICT). In a closer view at two-digit level, the share of intra-division linkages decreases to 19%. However, there are significant differences between industries. Whereas, in Scientific research and development 70 units show 44 linkages (of rather higher weight), in Computer programming the proportion changes into 40:9, likewise in Machinery or Metal products. On the contrary, in Chemicals the propensity to collaborate tends to be higher (34:18), similarly in Other transport equipment, where we can find particularly long-distance and repeating linkages.

When considering the spatial pattern of collaboration, Metallurgy belongs to most clustered industries. This is in line with Neffke et al. (2011), who pointed out that the more mature an industry is, the more likely it is to gain from specialized localization economies. The likelihood of lock-in tends to be markedly higher for mature industries. Units in the Moravian-Silesian Region are characterised by less but many times repeating connection and strong specialization in dominant fields, what is typical for old Industrial regions (Tödtling et al. 2013). Direct or mediated linkages between companies and faculties of local technical university dominate the network. Academia-academia connections, though not rare, have entirely extra-regional character. This contrasts with Yokura's et al. (2013) assumption that in the manufacturing field, there is little need for the knowledge of actors who are located in distant localities.

To employ fully knowledge base perspective we limit our initial sample solely to those units that have assigned at least one result in the IS RDI. Thus, the subsample consists of 1,016 nodes and 2,677 edges. Then, we divide it according to prevailing[3] knowledge base - either analytical, or synthetic. We desist from detaching symbolic knowledge base because of its minor occurrence. The network drawing mainly upon analytical knowledge contains 151 notes and 378 edges, as compared to second network of 316 nodes and 483 edges. Remaining actors, which use knowledge of mixed character, are keeping apart.

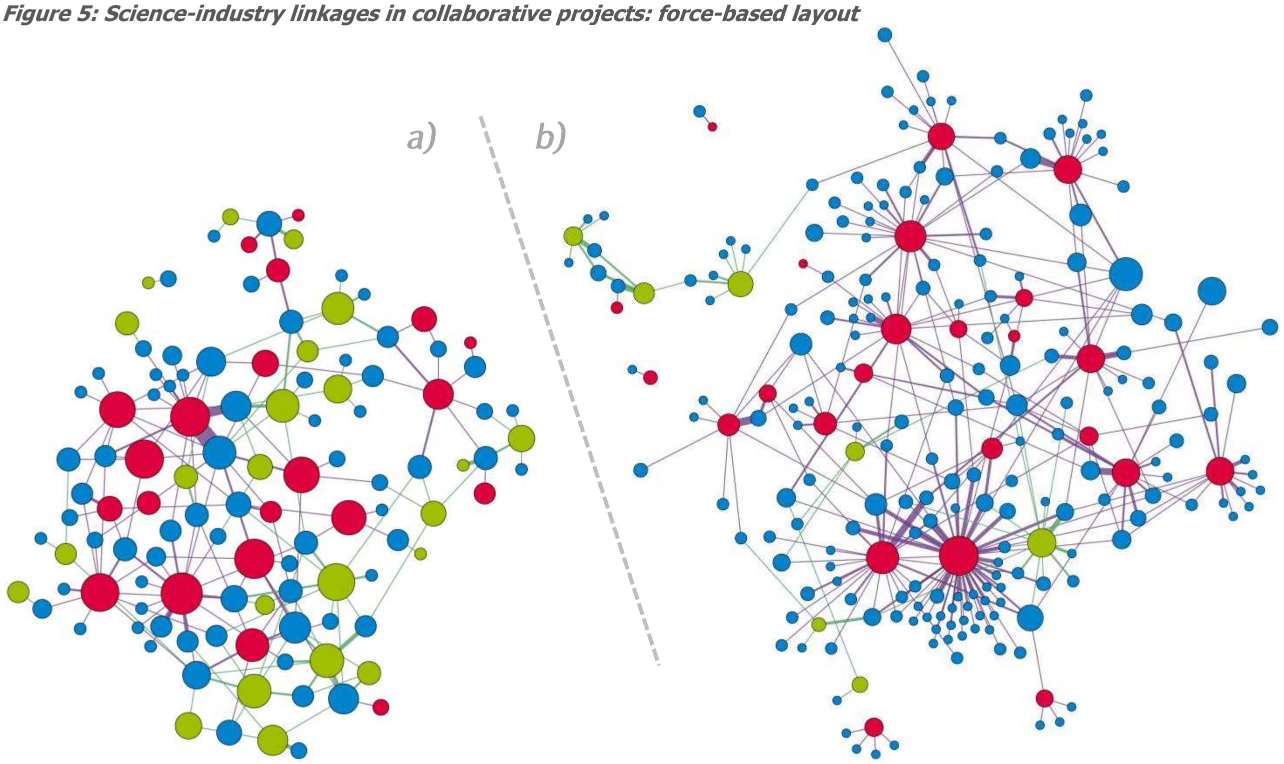
One among the key finding is that units are distinctively more likely to collaborate with partners inside respective knowledge base than connect over the knowledge base frontiers - the average degree reaches 2.4 for inter-base network as compared to 5.0 for analytical and 3.1 for synthetic knowledge base. The network of units with prevailing analytical knowledge base shows highest frequency of linkages in proportion to number of entities. When considering linkages between all forms of actors, the connections in the synthetic knowledge network are clearly spanning over longer distances - in average 88 km unlike 64 km of analytical knowledge network. However, the proportion becomes reversed in situation when we consider science-industry linkages only (not connections exclusively inside either science, or industry). When connecting knowledge institutions and firms, the analytical knowledge seems to overcome long distances. A possible explanation of the tricky relationship to distance may lie in existence of certain pockets of prevailing knowledge base, though with different geographies in science and industry subsystems.

Moreover, the characteristics of science-industry linkages in reference to predominant knowledge base results in very distinct topography of collaborative networks (figure 5). The synthetic knowledge network reflects more centralised system of groups of firms, which connect to faculties of leading technical universities (almost exclusively in Prague and Brno). Repeating collaboration seems to be a way how several firm-faculty pairs interact. The analytical knowledge network shows evidently more even distribution of linkages as well as positions of individual units. Public research organisations have stronger representation

[3] *Following the methodology described above, the share of the prevailing knowledge base has to be 60% of higher*

than in earlier case. Anyway nor analytical, nor synthetic network seems to be more efficient in transporting knowledge, as the average path length[4] remains virtually identical. Besides, there is no single optimal network structure (Giuliani, Pietrobelli 2014), each type conveys advantages and disadvantages.

Figure 5: Science-industry linkages in collaborative projects: force-based layout



Note: a) Analytical knowledge base (115 nodes, 178 edges); b) Synthetic knowledge base (229 nodes/295 edges)
●Private firms, ●Faculties of public universities, ●Public research institutions, ●Other actors. Force-based layout, the circle size refers to the number of direct connections (with logarithmic transformation).
Source: Authors

6 CONCLUSIONS

The systemic perspective accentuates interaction as a driver of technological change. Especially cross-fertilization between knowledge institutions and firms has become significant contexts for innovation (Levén et al. 2014). In transition economies science-industry cooperation seems to be far more limited, with the collaboration pattern strongly influenced by the past development (Žížalová 2010). In spite of a steady increase in frequency of joint RDI in the Czech Republic, the collaborative projects remain only minor part (13%) of all the RDI initiatives co-financed by public resources. The prevailing character of projects confirms some of the earlier findings that relatively small part of joint RDI activities in the Czech Republic can be considered as having long-term strategic character (Marek 2014). Majority of the effort focuses on short-term individual tasks and minor knowledge base enrichment, which bring only fractional change in the collaboration culture. Tendency to collaborate is higher in Manufacturing, client relations seem most important in ICT, what is conform to findings of Hofer et al. (2011). Individual data on R&D spending in combination with methods of explanatory statistics conceals huge mail chance for future research to seek for causal relations between the level of R&D spending and the propensity to engage in collaborative projects.

The geography of science-industry collaboration in joint projects to a large degree reproduces existing RDI capacities. One third of the participants concentrate in Prague, where major national institutions are seated. Private firms are more evenly distributed as compared to knowledge institution, which are located virtually only in regional capitals. It arises primarily from R&D in the public sector being much less dispersed than in the business sector (Srholec, Žížalová 2013). At the individual level, the faculties of technical universities, particularly those with specialisation in mechanical, civil, and electrical engineering, seem to attract principal attention of industry. Limited reflection of regional universities in data on collaboration can be attributed to

[4] The average number of steps along the shortest paths for all possible pairs of nodes

their focused towards educational function (Žížalová 2010) with only a few pockets of excellent research. Ongoing co-specialisation occurs more naturally in industries with a significant research inputs. Government intervention in specific sectors makes deep sense in case of the mismatch, one subsystem being strong, the other modest, and rather in a short-term horizon (EC 2013).

To sum up the key part of our analysis a concentric character of linkages is apparent with principal cores in Prague, Brno and Ostrava. Prague shows comparatively higher propensity to collaboration as explained by the gateway function of actors in the capital (Fritsch, Slavtchev 2007). The role of physical distance seems to be rather secondary, with more emphasis being place on a position of the city in settlement hierarchy and, consequently, on quality of knowledge supply. A vast majority of collaborative linkages clearly cut across the existing regional borders. It can be attributed to persisting national character of the IS in contrast to very little attention that have been paid to innovation by the local political leaders (Blažek et al. 2013). The results indicate a need for policy coordination across multiple administrative levels. A strict regional demarcation of innovation support measures may results in sub-optimal science-industry partnerships.

The pattern of science-industry collaboration shows distinctive, extremely centralised communities of small firms (in terms of frequency of connection as well as total costs of collaborative tasks) linked to faculties of leading technical universities. In general, only one third of companies have more than one connection to knowledge institution. When we consider repeating interactions, not only the network starts to be thin, but several micro-communities up to five units remain unconnected to the central network. Similarly to Žížalová (2010), we conclude that the inherited fragmentation still dominates the Czech IS.

Concerning the knowledge bases, actors are distinctively more likely to collaborate with partners inside respective knowledge base than connect over the knowledge base frontiers. Moreover, the network of units with prevailing analytical knowledge base shows relatively higher frequency of linkages in proportion to number of entities. Characteristics of science-industry linkages in reference to predominant knowledge base result in very distinct topography of collaborative networks. The synthetic knowledge network reflects more centralised system of groups of firms, which connect to faculties of leading technical universities. The analytical knowledge network shows evidently more even distribution of linkages as well as position of individual units. At average, the firm-academia connections are spanning over longer distances. Public research organisations have stronger representation in the analytical knowledge base. Anyway, nor analytical, nor synthetic network seems to be more efficient in transporting knowledge.

The collaboration patterns in the Czech Republic seem to be a complex phenomenon influenced by the combination of a specific institutional context and actors-related factors. The individual characteristics of partners together with character of knowledge in question need to be taken into account. Overall, the results of our analysis underline the fact that the organization of knowledge linkages cannot be understood out of path-dependent context. These structural features should not only play an important explanatory role, but they should be also taken into account when designing policy instruments (Žížalová 2010). Hence, more qualitative insight is needed into the role of soft factors in main stages on science-industry interaction - drivers, channels, and the perceived benefits (De Fuentes, Dutrenit 2012).

SNA has the potential to tackle some of the limitation the previous studies have been struggling with. Nevertheless, we still rely on a narrow definition of science-industry linkages that includes only collaborative RDI projects. It has been assumed that particularly service firms depend less on scientific knowledge and more on human capital (Freel 2006), for this the service activities can be underestimated in our sample. As regard the knowledge bases, we have to acknowledge much higher continuity in reality than might follow from the theoretical concept (Blažek et al. 2011). While rich in qualitative details, SNA generally fails to assess whether a policy had the desired effects. Although we are able to link collaborative projects with their results, the use of such an approach to evaluation interfere with principal limitations. Firstly and foremost, any qualitative perspective beyond simple count of results is entirely missing. A comprehensive impact evaluation needs to be eke out with econometric analysis (Giuliani, Pietrobelli 2014). As Giuliani and Arza (2009) pointed out, linkages are not beneficial per se in respect to generating knowledge.

Furthermore, the so called strategic coupling connects actors and forces internal to regions with (inter)national flows induced by global production networks (Yeung 2009). Due to the relational character of the economy, majority of firms are vertically connected with suppliers and customers along their value chains. The position of a firm in respective value chain brings along various constrains, hence the future research on it might provide a valuable path towards a more holistic understanding of knowledge sourcing.

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