The challenge of breaking the academia-business firewall in Czechia: comparing the role of differentiated knowledge bases in collaborative R&D projects

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1 ABSTRACT

Contemporary innovation processes increasingly involve a large number of networked actors, and cross-fertilization between knowledge institutions and firms has thus become a significant driver for innovation. Important insights into the differing nature of R&D collaboration in particular sectors have been provided by research inspired by the knowledge-base approach. This study aims to contribute to this body of literature by applying the concept of differentiated knowledge bases to the former state-socialism countries, where the innovation system operates through a 'firewall' between academia and industry. Data on collaborative R&D projects co-financed by public resources have allowed a detailed analysis of the nature of collaboration networks, revealing emerging patterns of academia-industry linkages and questioning the prepositions stemming from the knowledge-based approach. The study concludes that, in case of Czechia, factors other than geographical proximity seem to be more important in networks drawing predominantly upon either analytical or synthetic knowledge bases.

Keywords: knowledge bases; collaborative projects; network analysis; innovation system; the Czech Republic

2 INTRODUCTION

The current policy discourse clearly emphasizes the role of research and development (R&D) as one of the key drivers of innovation and 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 and Winther, 2011). Contemporary knowledge processes are increasingly involving a large number of networked actors possessing diverse knowledge capabilities, and cross-fertilization between research organisations and firms has become especially significant for innovation (Levén et al., 2014).

Innovation actors are embedded in particular locations and socio-economic contexts that are shaped by institutional conditions as well as by policy actors, as emphasized in the innovation system (IS) literature (e.g. Cooke et al., 2004; Lundvall, 2007). Moreover, this literature also fully acknowledges the role of past evolutionary trajectories and new path-creation on the basis of key characteristics of ISs such as the level of organizational thinness or specialisation (Boschma, 2013; Isaksen and Trippl, 2014). This evolutionary perspective is especially relevant in the specific context of the transition economies. In these Central and East European countries, the ISs have been developing under conditions of profound institutional and
societal changes and sudden exposure to global competition after the collapse of state socialism (Blažek et al., 2013). While several valuable studies provided insights into evolution of ISs in these countries (e.g. Žížalová, 2010; Blažek et al., 2011; Hofer et al., 2011; Lengyel and Leydesdorff, 2011; Radosevic and Yoruk, 2013), according to our knowledge, no systematic attempt to analyse the nature of science-industry interaction has yet been undertaken.

Therefore, this paper aims to fill the gap in the case of the Czech Republic (hereinafter Czechia). Conceptually, differentiated knowledge bases have been employed, as this approach underlines the view that all industries and not only high-tech ones can be innovative and, moreover, it provides the analytical tools for explaining inter-sectoral variations of innovation patterns (Trippl et al., 2015). Furthermore, this approach 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, this paper investigates joint R&D projects as one of the most important modes of science-industry relations. In addition to the spatial dimension of cooperation, the paper scrutinizes the underlying characteristics of knowledge involved, as they shape the pattern of collaborative linkages. Moreover, it discusses the institutional and policy-related factors influencing the pattern of science-industry collaboration in Czechia.

The paper is structured as follows. After a conceptual section, specific features of the Czech IS are briefly explained, and then more extensive methodological notes precede the comprehensive analysis of collaborative networks. Starting with a general geographical description, the spatial dimension of the R&D networks are subsequently analysed with respect to differentiated knowledge bases. Finally, the concluding section summarizes the main findings and outlines several policy recommendations.

3 CONCEPTUAL BACKGROUND

3.1 INNOVATION SYSTEM AND KNOWLEDGE SOURCING

The IS approach represents a useful conceptual environment for a discussion on science-industry relations as well as for considering the strategic role potentially played by policy (Cooke et al., 2004). A cornerstone of the IS 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, p. 883). In his pioneering definition, Freeman (1987) accentuated two important elements of an IS, when he described it as a network that initiates and diffuses new technologies. Lundvall further developed the IS approach by stressing the need to analyse the interaction between knowledge institutions and firms by underlining the role of interactive learning and effects derived from the institutional set-up.
(Lundvall, 1992). However, the sources of innovation extend far beyond scientific inputs, as expressed by different forms of knowledge and modes of innovation (e.g. Jensen et al., 2007).

Knowledge-sourcing has become crucial, but seems to be getting more and more complex. Undoubtedly, the level and quality of interaction within the IS are of critical importance for system efficiency (Fritsch and Slavtchev, 2011). Firms that want to keep pace with their competitors cannot rely exclusively on their internal knowledge, at least in the long run, but have to engage in various collaborative networks. In this respect, particular emphasis has been put on science-industry linkages (e.g. Mansfield, 1998; Tassey, 2005; Perkmann et al., 2013), considering, some consensus seems to exist on the positive impact of science-industry cooperation on innovation performance (Salter and 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 (Lam, 2011). The differences seem to stem from the attributes of the underlying knowledge, and to a lesser degree from individual characteristics of actors involved (Bekkers and Freitas, 2008) or industry origin (Salter and Martin, 2001).

Innovation is now widely seen as the result of interactive processes. Science-industry linkages constitute an outcome of a voluntary matching process, motivated by the considerations of complementarity and resources (Perkmann et al., 2011). Academia typically offers new technical and methodical knowledge needed in the early stages of the innovation process. However, the majority of innovation activities are located in the latter stages, i.e. in the adjustment of already existing products and processes (EC, 2001). Although we recognize that science-industry interaction in collaborative R&D projects is far from being an exclusive source of innovation (see Figure 1), we are convinced of its importance for disruptive innovation and as a vital process in a versatile IS.

Figure 1: Collaborative R&D projects as source for innovation

![Collaborative R&D projects as source for innovation](image)

Source: Authors’ conceptualisation.
3.2 DIFFERENTIATED KNOWLEDGE BASES IN INNOVATION NETWORKS

The ongoing interest in the nature of the innovation process and knowledge flows has resulted in the introduction of three knowledge bases (KBs). Following the initial distinction of Laestadius (1998), three types of KBs have been distinguished: analytical (science-based), synthetic (engineering-based) and symbolic (creativity-based) (Asheim, 2007; see Table 1). The innovation process differs substantially in different spheres (Asheim and Gertler, 2005). Therefore, the concept enhances the understanding of the way the companies innovate and especially how they source knowledge (Tödtling et al., 2013).

The analytical KB aims at understanding features of the world, thus innovation is primarily driven by scientific progress (Tödtling et al., 2013). Therefore, rational cognitive processes, theory-building, formal models and abstraction constitute the basis for knowledge creation (Asheim, 2007). Knowledge outputs are relatively easier to codify. Frequent and more formally organized science-industry interaction typically complements in-house R&D in companies. Due to its stronger reliance upon codified knowledge, it tends to be less distance-sensitive, which facilitates global knowledge networks, even though they are accompanied by more localised ones (Moodysson et al., 2008; Asheim et al., 2011a). The synthetic KB is associated with an integrative application and novel combination of existing knowledge in order to develop products with desired functions (Herstad et al., 2014). It is built predominantly on tacit, practical knowledge with a strong learning-by-doing and experimentation component. Therefore, collaboration in the synthetic KB is much more sensitive to distance (Moodysson et al., 2008). Synthetic knowledge is found predominantly in industrial settings (Asheim, 2007). The interaction with actors along the value chain remains more frequent than in R&D activities (Tripl et al., 2015). Nevertheless, science-industry links are still present in the form of projects of joint development and testing (Tödtling et al., 2013). Lastly, the symbolic KB draws on the creation of the cultural meaning of ideas, images and design by provoking reactions in the minds 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 the other two KBs, informal interaction with consumers plays a greater role (Manniche, 2012).

Importantly, the underlying idea behind the differentiated KBs 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). KBs should be understood as ideal types, thus, the degree to which a certain KB dominates relates to the characteristics of the industry, firm, or even specific activities performed, for example, during the different phases of product development (Moodysson et al., 2008). Martin and Moodysson (2011) found that elements of all KBs can be identified within a single firm.
**Table 1: Differentiated knowledge bases**

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

Source: Authors’ modification of Asheim et al. (2011a); Blažek and Uhlíř (2011).

4 **INSTITUTIONAL CONTEXT FOR R&D COLLABORATION IN CZECHIA**

As widely agreed by IS literature, firms and knowledge institutions do not act in a space-less world, but they are embedded in socio-economic contexts shaped by institutional conditions and policy actors (e.g. Strambach and Klement, 2012). Unsurprisingly, significant disparities persist between countries and regions regarding the broadly defined innovation potential (EC, 2014b). Acknowledging this is essential for understanding the specific context of the former state-socialism economies such as Czechia. The overall IS setting is a result of path-dependent development. Consequently, the organization of knowledge linkages cannot be understood outside the country-specific context (Žížalová, 2010; Hofer et al., 2011).

Over the last 25 years, the Czech IS has been developing under the conditions of fundamental institutional changes and sudden openness to global competition after the collapse of state socialism (Blažek et al., 2013). Nevertheless, the heritage of state socialism can be identified in a number of features. At the onset of transition, the IS was fragmented, weak and suffering from significant institutional as well as sectoral lock-ins. It consisted of two totally incoherent segments – academic institutes of basic research and weak companies with no long-term strategic vision. After EU accession in 2004, the economy embarked on a catching-up trajectory. Czechia was recently classified as a moderate innovator (EC, 2014a), and R&D expenditures and the number of tertiary students have been increasing steadily, but many innovation-output-related indicators document that the country is lagging behind the EU28 average (Srholec, 2014).

Limited financial flows between the private and public sectors indicate the persistence of significant barriers. Only 6.7% of the business expenditure on R&D was directed into the public sector. Moreover, two-thirds of this expenditure came from foreign firms (CZSO, 2014). These cross-sectoral funding flows do not represent collaborative activities as such, but do provide hints on the division of labour (Hofer et al., 2011). Low intensity of connections as demonstrated by the small amount of mutual financing can be attributed to legal
barriers, inexperience, conflicts of interest and expectations, and, importantly, by structural mismatch between knowledge supply and innovation demand (Žížalová, 2010). Moreover, the business community tends to be a priori suspicious of the competencies of public research representatives, and vice versa (Blažek et al., 2013). The mentality and values in these two segments differed fundamentally, giving rise to a sort of 'academic-business firewall'.

5 METHODOLOGY

5.1 METHODS

Studies have illustrated that innovation networks represent an important driver of knowledge diffusion (Ter Wal and Boschma, 2009). A number of authors have used networks as a broad interpretative factor, generally arriving at the conclusion that the denser the networks the better, with rare exceptions (e.g. Grabher, 1993). However, some empirical studies pointed to the fact that access to knowledge can be highly selective, even within small communities, which illustrates well the complexity of knowledge networks (Giuliani and Bell, 2005). Real networks are non-random in some revealing ways (Giuliani, 2007).

Giuliani (2011a) identified two basic methodological approaches to investigate innovation networks. First, a qualitative, process-oriented case-study approach inquiring into the motivation for and the nature of existing relations (e.g. Camagni, 1991); and second, a structuralist approach based on social network analysis (SNA) focusing primarily on the structure of networks and analysing the determinants of networks and of actors’ positions within networks (Zaheer and Bell, 2005; Giuliani and Arza, 2009; Giuliani, 2011b). SNA helps to describe the topography of knowledge networks by identifying central nodes and the spatial reach of linkages (see Carrington et al., 2005). In addition, one can investigate the variety of knowledge sources to which each node is linked, and seek the underlying factors for that behaviour (Tödtling et al., 2013; Giuliani and Pietrobelli, 2014). However, nearly all applications of SNA take a static perspective, depicting the network at a certain point in time (Ter Wal and Boschma, 2009). SNA is rapidly becoming adopted by economic geographers, which entails the potential risk of favouring the structure of a network while simultaneously neglecting processes, the content of linkages and the characteristics of actors (Steiner, 2011). Moreover, it frequently treats network interactions as a black box (Giuliani, 2011a, but for exceptions see Fleming and Frenken, 2007, or Steiner and Ploder, 2008).

Consequently, our research employed SNA to evaluate collaborative networks in the specific context of Czechia, with the primary focus on the spatial pattern and topography of science-industry linkages with respect to the prevailing KB. Given that the specific evolutionary trajectory of the Czech IS under state socialism led to a profound cleavage between academia and businesses, we wanted first of all to identify the
extent to which the state support programmes have been successful in stimulating mutual cooperation. The structural inconsistency between the knowledge supply of academia and the knowledge demand of private companies was expected to prevail, resulting in a deep persistence of fragmentation of national ISs. Consequently, only immature science-industry linkages were foreseen, with sharply uneven geography centred upon a limited number of key centres. Particularly weak linkages were expected at the regional level, indicating weakness in the emerging regional ISs. Our second research question focused on the identification of the dissimilarities in the pattern of linkages among actors with differing predominant KBs. In particular, we expected that the analytical knowledge network would feature more frequent connections, as innovation exploits mostly R&D inputs in that KB. Moreover, the linkages should span over longer distances compared to a synthetic KB. However, the differences described would be partly mitigated by companies’ limited absorption capacity to exploit the results of more fundamental research.

5.2 DATA

Our research was based upon the analysis of a unique database on collaborative R&D projects co-financed by public sources. Data was excerpted from the Czech R&D Information System (hereinafter the database).¹ The database combines samples of individual data, which are relatively complete (public support of R&D is subject to information liability) and up-to-date. It contains interconnected records on actors, programmes, projects and results of R&D activities retrospectively. Our analysis started with projects that had been initiated since 2004, to capture the evolution of collaboration patterns over the last 10 years. The pooled data from the database were linked with several other sources, in particular with the Business Register where all the entities are listed with unique identification numbers, and additional data included location at a detailed (municipal) level. Thus, our dataset consisted of 2,707 collaborative R&D projects jointly investigated by at least one knowledge institution (either university, or research institution) and at least one private company.

The project participants listed in the database were legal entities (institutions), in the case of universities further divided into faculties. This yielded more fine-grained results than at university level and ensured a more appropriate juxtaposition, especially when considering the differentiated KBs. Four main types of participants were distinguished according to their legal status – private firms, faculties of public universities, public research institutions, and finally a group of other actors that consisted particularly of non-profit and public service organisations. The group of other actors had a minor representation in our dataset and a mixed role, hence it was considered as auxiliary to the other three groups. Altogether, 1,962 unique entities participated in our sample of collaborative projects. Within the SNA, network nodes represented entities,

¹ http://www.isav.cz.
while edges between them illustrated relations. The weight of linkages was based on the co-presentation of partners in joint projects (frequency count).

In order to trace variation in the pattern of linkages in accordance with the prevailing KB, we extended our dataset with information about the specialisation of actors. This was performed on the basis of the R&D results listed in the database, which describe quite precisely the nature of each actor’s activities. Thus, each result listed was assigned to one of the 123 research branches within the database classification. The way the branches are defined allowed an evaluation of the inclination of a given branch towards each of the three KBs. To obtain more robust results than would be achieved by the contemplation of authors, the assessments of three independent experts were used. Consequently, each research branch was classified by two authors and three independent experts according to its share of a particular KB (see Figure 2 for inclination of selected research branches to a particular KB represented by the average of scores given by the authors and three experts). We believe that this scoring mechanism, which allows the expression of the different inclination of entities to all three KBs, is more adequate than using the NACE classification of economic activities, as the literature contains quite contradictory classifications of the exclusive assignment of NACE categories to one of the three KBs (e.g. Sedita et al., 2015; Skokan, 2012; EC, 2006).

**Figure 2: Relative inclination of research branches to a particular knowledge base**

Note: Every point on a ternary plot represents a different composition of the three KBs in a research branch. The percentage of a specific KB decreases linearly with increasing distance from the respective corner (red – analytical, green – synthetic, blue – symbolic). Yellow points in the middle represent branches without a decisive share of one KB. The deeper the colour, the more branches are attributed to the point (because of overlaps). Source: Own assignment based on the experts’ voting.
6 DISCUSSION OF THE RESULTS

6.1 THE NATURE OF COLLABORATIVE PROJECTS AND PARTICIPANTS

A notable increase in public support targeted at the resurgence of science-industry linkages has been recorded since 2004. From a variety of support measures, programmes with two different objectives can be distinguished. The first group focuses on rather short-term one-off innovation tasks, where the decision on whether to engage in collaborative activity with a knowledge institution is up to the firm. The second group is associated with long-term strategic cooperation in the form of R&D centres, where the involvement of participants across sectors constitutes a natural component. In general, total costs and the complexity of tasks are much higher in the latter case.

However, the number of collaborative R&D projects (2,707) represents only a minor subset of all R&D projects supported by public funds since 2004 (approximately 13%). Our dataset compounded very diverse cases. The average costs of a collaborative project approximated €0.9 million. We can see an apparent shift of the total budget being divided into fewer but more costly projects during the 10-year period under examination, especially in basic research. However, applied research dominated, being indicated in two-thirds of joint projects. Projects associated with traditional Czech manufacturing industries proved to be most frequent (see Marek, 2015). Altogether, of the 1,962 unique participants in our database of collaborative R&D projects, 82% of them were private firms.

Table 2: Descriptive statistics of R&D projects and participating entities

<table>
<thead>
<tr>
<th>R&amp;D projects</th>
<th>Number of projects</th>
<th>Total costs [€ million]</th>
</tr>
</thead>
<tbody>
<tr>
<td>All projects initiated 2004 and later</td>
<td>20,252</td>
<td>8,936</td>
</tr>
<tr>
<td>Projects investigated by two or more participants</td>
<td>7,101</td>
<td>4,457</td>
</tr>
<tr>
<td>Collaborative (science-industry) projects</td>
<td>2,707</td>
<td>2,337</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Participants</th>
<th>Number of entities</th>
<th>Number of participation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private firms</td>
<td>1,612</td>
<td>4,296</td>
</tr>
<tr>
<td>Faculties of public universities</td>
<td>167</td>
<td>2,769</td>
</tr>
<tr>
<td>Public research institution</td>
<td>58</td>
<td>1,051</td>
</tr>
<tr>
<td>Other entities (non-profit and public service organisations)</td>
<td>125</td>
<td>283</td>
</tr>
<tr>
<td>Total</td>
<td>1,962</td>
<td>8,399</td>
</tr>
</tbody>
</table>

Unsurprisingly, private firms were much more evenly distributed than knowledge institutions, which were located almost exclusively in regional capitals. Nevertheless, in general, the spatial distribution of collaborating entities broadly corresponded to the overall pattern of R&D intensity in Czechia (Figure 3). In line with previous findings by Hofer et al. (2011), a clear size-effect on innovation cooperation was identified in our data. Moreover, foreign-owned firms tended to cooperate with knowledge institutions slightly less than their Czech counterparts of the same size. Among the knowledge institutions, the faculties of technical
universities, particularly those with specialisations in mechanical, civil and electrical engineering, seemed to be a major attraction for industry (7 of the top 10 faculties are located in Prague or in Brno). The marginal role of regional universities in collaborative R&D projects can be attributed to the fact that regional universities have traditionally focused upon education rather than research (Žížalová, 2010). However, regional universities can boast a few pockets of research excellence, for instance in the strong expertise in chemical engineering within the University of Pardubice. In science-based fields (molecular biology, physics, organic chemistry), the research institutions located in Prague dominated the collaboration (Figure 4).

6.2 GEOGRAPHY OF COLLABORATIVE NETWORKS

In this section, the overall spatial pattern of science-industry linkages is analysed (Figure 4). The network consists of 1,962 nodes (entities) identified by their geographical location and 4,103 edges (linkages) with a weighting of up to 32. The geography of the collaborative network to a large degree reproduced existing R&D capacities. Whereas 31% of the participants were concentrated in Prague, these entities attracted 60% of all linkages in collaborative projects. Interestingly, every fifth collaborative project was performed exclusively by entities located inside the city boundaries. The South Moravian region was next in significance, with Brno concentrating major resources particularly in the university sector, offering strong potential for collaboration with private companies (Srholec and Žížalová, 2013). In line with the observation by Tödtling et al. (2009), connections to knowledge institutions in areas outside large cities were notably less common due to the major focus of local actors on incremental innovations built predominantly upon non-R&D inputs (see Figure 1). In these areas, R&D capacities remained at a relatively low level and the number of potential partners was limited. Along the southwest border of Czechia, there was a strikingly low level of concentration of collaborating entities, with the exceptions of the cities of Plzen and Ceske Budejovice (Figure 3). This can be explained by a major rupture in the local economy caused by strategic considerations during the Cold War, when this area was perceived as a zone of likely first military confrontation and, consequently, under state socialism, significant investments were kept outside of this zone (Srholec and Žížalová, 2013).

When considering the spatial pattern of collaboration in distinctive branches, metallurgy belonged to the most clustered industries. For instance, entities in the Moravian-Silesian region were characterised by a lower number but repeated connections and strong specialization in dominant fields, which is typical for old industrial regions (Tödtling et al., 2013). This is in line with Neffke et al. (2011), who pointed out that the more mature the industry is, the more likely it is to benefit from specialized localization economies.
The role of physical distance seemed to be of rather secondary significance, while the decisive factor seemed to be the quality and specialisation of knowledge supply. For example, units from the regions along the eastern border tended to cooperate more with partners located in other regions rather than in their own or the neighbouring region. Therefore, a majority of collaborative linkages cut across the existing regional borders, while only 35% of linkages had intra-regional character. Reflecting the previous finding of Žížalová (2010), it can be concluded that even though intra-regional linkages exist in Czechia, they cannot be regarded as a vital source of knowledge. Therefore, the individual characteristics of partners need to be
taken into account together with the character of the knowledge in question. This pattern of collaboration can be attributed to the persisting dominance of the national IS and the national character of innovation policy.

In contrast to Yokura et al. (2013), who argued that academia-academia relations have a much greater spatial reach than linkages between private firms, our data revealed that firm-firm relations extend over slightly longer distances (Table 3). Moreover, an anticipated relation was found between physical distance and the costs of an R&D project used as a proxy for its complexity. In particular, partners involved in more costly/complex tasks tend to be located closer to each other. This may be explained either by a higher need for the transfer of tacit knowledge, or simply by the fact that most of the key actors collocate in main metropolitan areas.

Table 3: Average physical distance between partners in collaborative R&D projects

<table>
<thead>
<tr>
<th>Collaborating entities</th>
<th>Connected entities</th>
<th>Number of linkages</th>
<th>Average distance [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge institutions only</td>
<td>153</td>
<td>661</td>
<td>90.3</td>
</tr>
<tr>
<td>Private firms only</td>
<td>742</td>
<td>946</td>
<td>94.8</td>
</tr>
<tr>
<td>Knowledge institution - private firm (undirected)</td>
<td>1 491</td>
<td>3 548</td>
<td>88.0</td>
</tr>
</tbody>
</table>

Source: Czech R&D Information System; own analysis.

From this point onwards, we use force-based layouts to describe the character of collaborative networks more comprehensively. This visualisation positions the nodes based on their forces of attraction and repulsion using various algorithms. Geographical distance is completely disregarded in this case. The results show a dense tangle of indiscernible lines. Hence, as the first step, only science-industry linkages\(^2\) were selected, as they represent a core focus of this research. In Figure 5, distinctive, extremely centralised communities of small firms\(^3\) linked to faculties of leading technical universities can be clearly identified, which act as central nodes in the Czech IS. However, this pattern together with project details also implies that the majority of Czech firms collaborate on short-term tasks with a narrow thematic focus and with smaller financial volumes. In general, only one-third of companies have more than one connection to knowledge institutions in terms of joint projects. When considering repeated interactions, which generally bring substantial benefits in collaboration culture, the IS becomes notably fragmented.

\(^2\) As opposed to firm-firm, or academia-academia interactions.

\(^3\) In terms of frequency of connection as well as total costs of collaborative tasks.
6.3 COLLABORATION PATTERN IN DIFFERENTIATED KNOWLEDGE BASES

The concept of differentiated KBs is built upon assumptions that are expected to have an apparent impact on the pattern of collaborative linkages. As mentioned in Section 2.2, analytical knowledge is less sensitive to distance as compared to synthetic knowledge. Moreover, firms that draw mainly on the analytical KB should engage more frequently in collaboration with academia. In reflection of the fact that the two studies mentioned below brought mixed conclusions, our analysis aimed at shedding more light on the effects of different characteristics of knowledge on the collaboration pattern. Whereas Žížalová (2010) concluded that the geography of collaboration differs only slightly between the industries relying predominantly on analytical and synthetic KBs, and that the individual attributes of actors remain more important, Blažek et al. (2011) confirmed the existence of significant variation in the geography of knowledge sources according to the type of knowledge involved.

To employ the KB perspective fully, our initial sample was limited to those units that had been assigned at least one result in the database.\textsuperscript{4} Thus, the sub-sample consisted of 1,016 nodes and 2,677 edges. Then,

\textsuperscript{4} We use assignment of results into research branches to describe precisely proportion of each KB for respective entity (see methodological section). For entities without result listed in the database, we are unable to perform assignment.
the nodes were divided according to the prevailing\(^5\) KB – either analytical or synthetic. The symbolic KB was not considered due to its marginal occurrence in the dataset. Remaining entities, which use knowledge of mixed character, were kept apart. Moreover, only a limited number of entities embodied science-industry linkages within the respective KB. Finally, the collaboration network of actors drawing mainly upon analytical knowledge contained 115 nodes and 178 edges, as compared to the second network representing the synthetic KB, which consisted of 229 nodes and 295 edges (see Table 4).

Interestingly, entities were significantly more likely to collaborate with partners within the same KB than to connect over the KB frontiers – the average degree\(^6\) reached 2.4 for inter-base network as compared to 5.0 for the analytical KB and 3.1 for the synthetic KB. Thus, entities with a prevailing analytical KB showed a higher average number of linkages than entities with predominantly synthetic knowledge, which is in line with the assumption of the theoretical concept. When considering linkages between all types of actors, the connections in the synthetic knowledge network clearly spanned over longer distances – on average 88 km compared to 64 km recorded for the analytical knowledge network. However, when only science-industry linkages were considered (i.e. excluding both academia-academia as well as firm-firm connections), the proportion was reversed. When connecting knowledge institutions and firms, the analytical knowledge seemed to overcome long distances (see Table 4). A possible explanation of the tricky relationship to distance may lie in the existence of certain pockets of the prevailing KB, though with different geographies in science and industry sub-systems.

### Table 4: Science-industry linkages according to prevailing knowledge base

<table>
<thead>
<tr>
<th>Prevailing KB</th>
<th>Number of entities</th>
<th>Entities with science-industry linkages within respective KB</th>
<th>Number of science-industry linkages</th>
<th>Average physical distance [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analytical</td>
<td>196</td>
<td>115</td>
<td>178</td>
<td>253.4</td>
</tr>
<tr>
<td>Synthetic</td>
<td>485</td>
<td>229</td>
<td>295</td>
<td>139.9</td>
</tr>
<tr>
<td>Symbolic</td>
<td>5</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Indecisive</td>
<td>330</td>
<td>196</td>
<td>251</td>
<td>111.4</td>
</tr>
<tr>
<td>Total</td>
<td>1 016</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors.

Moreover, the topography of science–industry collaborative networks (Figure 6) differed significantly according to the predominant KB. In particular, the synthetic knowledge network was typified by the concentration of firms around technical faculties (especially around leading technical faculties in Prague and Brno). By contrast, public research organizations played a much smaller role as knowledge providers to companies, even though three cases of clustering of firms around these organizations were identified. The analytical knowledge network exhibited markedly different features. Namely, the network depicted a much more even distribution of linkages as well as a more balanced positioning of individual units. Moreover, public research organisations had a much stronger role compared to the synthetic KB. However, neither the

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\(^5\) Following the methodology, the share of the prevailing KB has to be 60% or higher.

\(^6\) The degree of a node is the number of edges incident to this node and can be understood as proxy for network density.
analytical nor the synthetic network seems to have been more efficient in transporting knowledge, as the average path length\(^7\) remained virtually identical; in any case, each type conveys advantages and disadvantages, and there is no single optimal network structure (Giuliani and Pietrobelli, 2014).

Figure 6: Science-industry linkages in analytical (a) and synthetic (b) knowledge bases

7 The average number of steps along the shortest paths for all possible pairs of nodes and can be understood as a proxy for the ability of the network to transfer knowledge.

7 CONCLUSIONS

The systemic perspective accentuates interaction as a driver of technological change. Cross-fertilization between knowledge institutions and firms has become especially significant 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 past development (Žížalová, 2010). Despite a steady increase in the frequency of joint R&D in Czechia, collaborative projects remain only a minor proportion (13%) of the R&D initiatives co-financed by public resources. The prevailing character of projects confirms some of the earlier findings that a relatively small part of joint R&D activities in Czechia can be considered as having long-term strategic character (Marek, 2014). The majority of the effort focuses on short-term individual tasks and minor KB enrichment, which bring only fractional change in the collaboration culture. Individual data on R&D spending in combination with methods of explanatory statistics represent the main opportunity for future research to look for causal relationships 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 R&D capacities. One-third of the participants were concentrated in Prague, where major national institutions are seated. Private firms were more evenly distributed compared to knowledge institutions, which are located virtually only in regional capitals. At the individual level, the faculties of technical universities, particularly those with specialisations in mechanical, civil, and electrical engineering, seemed to be the main attraction for industry. The limited reflection of regional universities in data on collaboration can be attributed to their focus on educational functions (Žížalová, 2010), with only a few pockets of research excellence. Ongoing co-specialisation occurs more naturally in industries with significant research inputs. Government intervention in specific sectors makes considerable sense in cases of mismatch – one sub-system being strong, the other modest – and within a short-term scenario (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 a comparatively higher propensity for collaboration as explained by the gateway function of actors in the capital (Fritsch and Slavtchev, 2007). The role of physical distance seems to be rather secondary, with more emphasis being placed on the position of the city in the settlement hierarchy and, consequently, on the quality and specialisation of knowledge supply. The vast majority of linkages clearly cut across the existing regional borders, which can be attributed to the persisting national character of the IS in contrast to the very little attention paid to innovation by 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 result 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 a third of companies have more than one connection to a knowledge institution. When we considered repeating interactions, not only was the network thin, but also several micro-communities of 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 KBs, actors are distinctly more likely to collaborate with partners inside the respective KB than to connect over the KB frontiers. Moreover, the network of units with the prevailing analytical KB shows a relatively higher frequency of linkages in proportion to the number of entities. The characteristics of science-industry linkages in reference to the predominant KB result in a very distinct topography of collaborative networks. The synthetic knowledge network reflects a more centralised system of groups of firms that connect to faculties of leading technical universities. The analytical knowledge network shows an evidently more even distribution of linkages and positioning of individual units. On average, the firm-
academia connections extend over longer distances. Public research organisations have stronger representation in the analytical KB. In any case, neither the analytical nor the synthetic network seems to be more efficient than the other in transporting knowledge.

The collaboration patterns in Czechia seem to be a complex phenomenon influenced by the combination of a specific institutional context and actor-related factors. The individual characteristics of partners together with the 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 outside the path-dependent context. These structural features should not only play an important explanatory role, but they should also be taken into account when designing policy instruments (Žížalová, 2010). Hence, more qualitative insight is needed into the role of soft factors in the principal stages of science-industry interaction – drivers, channels, and the perceived benefits (De Fuentes and Dutrenit, 2012).

SNA has the potential to tackle some of the limitations with which the previous studies have been struggling. Nevertheless, we still relied on a narrow definition of science-industry linkages that included only collaborative R&D projects. It was assumed that service firms in particular depend less on scientific knowledge and more on human capital (Freel, 2006), and for this reason that service activities could be underrepresented in our sample. With regard to the KBs, we acknowledge that much higher continuity might follow in reality than from the theoretical concept (Blažek et al., 2011). While rich in qualitative details, SNA generally fails to assess whether a policy has had the desired effects. Although we are able to link collaborative projects with their results, the use of such an approach to evaluation entails principal limitations. First and foremost, any qualitative perspective beyond a simple count of the results is entirely absent. A comprehensive impact evaluation needs to be carried out with econometric analysis (Giuliani and Pietrobelli, 2014). As Giuliani and Arza (2009) pointed out, linkages are not beneficial per se in terms of generating knowledge.

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


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