The Role of Proximity in Technology Dynamics of High-Tech Industries: the Case of Biotechnology and Aviation Industries

Małgorzata Runiewicz-Wardyn
Faculty of Economics, Kozminski University, Poland
mruniewi@alk.edu.pl

Abstract

Confronted with new global competitive environment, rising R&D costs, growing integration of different technologies, shorter life cycles, and increased pace of innovation, high-tech companies increasingly collaborate with external partners. Innovation networks became unconditional driver of technological dynamics and growth of high-tech industries. The article aims to explore the role of proximity in innovation networks formation in the two high-tech industries – biotechnology and aviation. Both industries are characterized by different stages of technological maturity, different product life-cycles and development periods, yet both equally depend on highly specialized human capital and collaborative innovation. The article addresses the following research questions: What is the role of proximity – geographical, cognitive, institutional, organizational, social and cultural – in facilitating innovation networks formation in the above mentioned high-tech industries? What type of proximities and the related network externalities assist these industries along their life-cycles? What is the relationship between technology dynamics and innovation networks formation?

Keywords

Aviation – Biotechnology – Industry – Proximity – Technology dynamics

1 Introduction

The interest in “innovation networks” and their role in sharing knowledge and ideas, as well as stimulating inventions and innovations, have been
progressively discussed (Freeman 1991; Powell et al., 1996; Hagedoorn 2002; Boschma, 2005; Boschma and Frenken, 2009; Ahrweiler and Keane, 2013). Several authors emphasized that collaborative innovation networks have become the dominant and most promising way to produce high quality output in research, especially in the knowledge-intensive high-tech industries (see Bozeman and Lee, 2005; Orsi and Belussi, 2015; Pippel, 2012). Not surprisingly, the rapid increase in the number of studies on innovation networks has led to a great variety of theories, concepts and methodologies to approach innovations, e.g. Triple Helix (TH) and Quadruple Helix (QH) networks (Etzkowitz, 2018; Carayannis and Campbell, 2012), high-tech R&D alliances (Orsi and Belussi, 2015, Siegel et al. 2003), university-industry links (Smith and Ho, 2006; Thursby and Kemp, 2002; Ahrweiler et al., 2011), inter-firm networks (Schilling and Phelps, 2005; Porter et al., 2005) or social networks (Powell et al., 2005; Barabasi et al. 2002).

Innovation networks may take multiple forms, which includes formal networks, based on contractual relationships among organizations, and informal networks, such as employee mobility and social networks. For Rubens et al. (2014), innovation networks form, re-form and dissolve within the specific innovation ecosystems – diverse institutional, political, technological and socio-economic environments. In order to understand the innovation processes and technological dynamics, one needs insight into the dynamics of these innovation ecosystems. Universities play an especially important role in the innovation ecosystems and collaborative innovation networks. Both, in the TH and QH models, as well as in the recent concept of so called Entrepreneurial University, universities abandon the old “ivory tower” paradigm, where they isolated themselves from their external environments. On the contrary, they use a synergetic cooperation with industries and other innovation ecosystem stakeholders to enhance innovation, technology dynamics and society welfare. An indirect assumption of the Entrepreneurial University is its embeddedness of the networks of relations, both human and organizational, that enable and facilitate the communication and the co-development (Etzkowitz, 2013, 2017; Cai and Ahmad, 2021). Entrepreneurial University, as explained by Etzkowitz et al. (2017), builds its entrepreneurial culture on the “depth of interaction with surrounding society and business, and ability to create, interact and enhance the local, regional and national economic and societal vibrancy” (2017: 3). Rothaermel et al. (2007) identifies innovation networks as one of the critical factors influencing the Entrepreneurial University and its commercial activity.

According to Powell et al. (2005), innovation networks stem from a dense network of relationships between firms, universities, research centres, suppliers and customers. Other studies, including Siegel et al. (2003), Phan et al. (2005),
Audretsch and Feldman (2004), Boschma and Frenken (2009; 2011) and Iansiti and Lieven (2004), showed that both, formal and informal networks dynamics are positively related to the geographical proximity to the local universities. The positive role of geographical proximity was also confirmed in the findings of Bochniarz et al. (2016) and Broekel and Boschma (2016), in the aviation cluster ecosystems in Poland and Netherlands. Ponds et al. (2007) evidenced (using co-publications as indicator for research collaboration in Netherlands) that the role of geographical proximity was especially important for the university-industry innovation networks in the life-sciences. The studies by Turkina et al. (2016) showed that in Poland’s Aviation Valley inter-firm networking exhibited global buyer-supplier subcontractor linkages and local R&D, knowledge and specialized local suppliers linkages. The cases of the world leading biotechnology cluster ecosystems, like Cambridge (UK), San Francisco Bay Area (US) and the Medicon-Valley (Denmark-Sweden) seem to confirm it. These ecosystems have been able to attract global talent, high-value multinational companies, and generate the most of global technologies in their fields of specialization.

The studies by Feldman (1999), Majava et al. (2016) and Kenney and Mowery (2014) all attributed their success to the industry-university networks and a geographical proximity to the leading life-sciences universities. Walshok and Shragge (2014) emphasized the key role of entrepreneurial culture in the success of the Californian life-sciences ecosystems. Whereas, Cooke (2018) and Garnsey and Heffernan (2010) linked high innovation performance of the Cambridge life-sciences ecosystem to the positive role of geographical proximity to the University of Cambridge, spin-out and venture capital investments.

Similarly, the success of the Medicon Valley, is attributed to the talent pools from the local Lund and Copenhagen Universities (Coenen and Asheim, 2008; Carreira and Vence, 2011).

Other researchers claim that geographical proximity is neither a necessary nor a sufficient condition for the interactive learning and knowledge-spillovers (Boschma, 2005; Boschma and Frenken, 2009). Boschma (2005) claims innovation performance is simultaneously influenced by other than spatial dimensions of proximity, i.e. institutional, organizational, cognitive, social and cultural. The role of latter types of proximity is discussed in specific context of high-tech fields industries in the works of Broekel and Boschma (2016), Audretsch and Feldman (2004), Davids and Frenken (2018), Boschma and Frenken (2009; 2011), Iansiti and Lieven (2004), Bochniarz et al. (2016), Ahmad et al (2013), Kozierkiewicz (2020), Levy and Talbot (2015), and Pucci et al. (2020). More specifically, the role of institutional proximity was evidenced by Bochniarz et al. (2016) and Porter and Takeuchi (2013) in case of Polish and French Aerospace Clusters. Bochniarz et al. (2016) demonstrated that since its
beginning (in 2003) the Polish aviation cluster kept strong formal and informal ties with the Faculty of Rzeszow University of Technology. Whereas, Porter and Takeuchi (2013) stated that government agencies funded and coordinated the French Aerospace Cluster companies’ cooperation with the French Civil Aviation University (ENAC) and Higher Institute of Aeronautics and Space (ISAE). In case of organizational proximity, in the study of Dutch aviation industry, Broekel and Boschma (2016) concluded that cluster related organizations were highly connected, and influenced the structure of the technical knowledge networks. The results of Levy and Talbot (2015) on the French Aerospace Valley cluster confirmed that the weaker organisational proximity was strengthened by the geographical proximity of collective action and collaborative projects. In terms of cognitive proximity, Boschma and Broekel (2016) found out that Dutch aviation industry organizations tend to link more with technologically similar organizations. Whereas, Broekel and Hartog (2013) stated that the organizations may differ in this respect and that cognitive proximity had only relative importance in the tie formation in the Dutch aviation industry. In the life-sciences, Boschma and Frenken (2011) showed that the certain degree of related cognitive proximity is a pre-condition for knowledge spillovers and interactive learning. The significance of social proximity was observed in the study by Pucci et al. (2020) in the Tuscan Life Sciences cluster and Kozierkiewicz (2020) in the Polish biotechnology clusters. Pucci et al. (2020) showed that both, the number of personal relationships within the cluster as well as the family involvement, positively moderated the effect of local relationships on R&D effectiveness in the local biotechnology industry. In Poland, Kozierkiewicz (2020), showed that very low social capital and social proximity among academic scientists and biotech firms resulted in low intensity of industry-university innovation networks. In the aviation industry, Boschma and Broekel (2016) found that common friendships and shared past employment in the Dutch companies seem to help their employees to establish and maintain knowledge sharing links. In case of the Polish aviation cluster, Bochniarz (2016) indicated that cluster’s business leaders have identified social networks as one of the important channels in the promotion of their innovation activity. Finally, Ahmad et al. (2013) gave strong evidence to the role of cultural proximity in the case of Moroccan aeronautics cluster. The authors revealed that the main investors and trading partners were greatly enhanced by the French speaking workforce and their cultural proximity.

Inspired by the above studies, this article has set two objectives. Firstly, to enrich the studies of Feldman (1999), Majava et al. (2016), Kenney and Mowery (2014), Walshok and Shragge (2014), Cooke (2018), Garnsey and Heffernan (2010), Coenen and Asheim (2008) and Carreira and Vence (2011) with the new
insights on the role of proximity and its various dimensions in the innovation networks formation in Cambridge (UK), San Francisco Bay Area (US) and the Medicon-Valley ecosystems. More particularly, the article aims to answer three major questions: 1) What is the role of institutional, cognitive, organizational, social and cultural proximities in facilitating innovation networks and innovation process in these ecosystems? 2) How does various dimensions of proximity moderate the nature and dynamics of interactions among ecosystem actors in these ecosystems? 3) What is the role of geographic proximity in moderating the other dimensions of proximity in these ecosystems?

The second objective of this article is to discuss the role of proximity in a comparative context of the two high-tech industries ecosystems settings – biotechnology and aviation. Based on the critical analysis of the above mentioned literature the article aims to answer: 1) What are the patterns by which proximities promote networks formation across the two high-tech industries ecosystem settings? 2) What is the role of proximity and its various dimensions in the mature (US, Dutch or French) and young (Poland) industry ecosystems? 3) How does the role of proximity and its various dimensions change, as the technology moves along its innovation cycle, in case of both high-tech industries settings?

The article is divided into four sections. The introduction is followed by a presentation of the key subject literature review and the description of the life sciences and aviation industries, their technological life cycles and innovation partnerships. The next sections discuss conceptual and analytical framework of the study, the applied research methodology and research results. The article ends with the research conclusions and implications. The results of these insights enable the development of strategies and policy measures that further unlock the innovation potential in these sectors and their local ecosystems.

2 Literature Review and Analytical Framework for Empirical Study

2.1 Concept of Proximity and Proximity Paradox
Developing successful technological innovation requires more in-depth understanding of what facilitates the interaction of actors with diverse and complementary pieces of knowledge, skills, and experiences. The term proximity refers here to the degree to which “one actor relates to the another”. The following section discusses the above mentioned subject related literature in more details with special emphasis on the role of proximity in networks formation. The analysis starts from the first works on proximity dynamics originating from the French school and the works of Rallet (1993) and Rallet and Torre (1999).
In their research the authors conclude that other forms of proximity besides geographical may facilitate interactive learning and the formation of innovation networks. Similarly, Dutch regional economist Ron Boschma has claimed that geographical proximity is neither necessary nor sufficient for inter-firm learning and innovation (2005). In the network based system, innovation is the outcome of an interactive and transdisciplinary process involving at least three types of stakeholders – academia, industry and government – as active players involved in co-creation, experimentation and valorization of the new knowledge (converting knowledge into commercial, feasible products/processes, services and/or societal value) (Leloux et al., 2009; Drooge et al., 2011; Arits and Duijvesteijn, 2012). The three helices commit themselves to cooperation based on their own overlapping interest or “boundary objects” through common trust, needs and stakes. Consequently, their common boundaries have greater chance to stimulate innovation within the particular industries. In general, the notion “proximity” is related to the interaction of actors with common boundaries within the networks. In this sense, geographical proximity or the physical closeness of two or more actors, provides opportunities for frequent, interpersonal contacts, allowing the reduction of information asymmetries, whereas organizational and cultural proximities influence social interactions and social capital formation (Fitjar et al., 2016; Lorenzen, 2007). While a high degree of proximity might be considered a prerequisite to make agents connected, some authors claim that proximity between agents does not necessarily increase their innovative performance and may even harm it. Boschma (2005), Broekel and Meder (2008) and Boschma and Frenken, (2009) refers to this as the “proximity paradox”. They claim that higher level of innovative performance depends on the existence of the “optimal” level of proximity between agents. Another topic dealing with the formation and performance of innovation networks is the path dependency in the network evolution. Ter Wal (2009) claims that the networks of innovation become less geographically proximate over time during the course of an industry lifecycle. Whereas several other authors, including Boschma and Frenken (2009) and Gluckler (2007) argue that the different proximities induce path dependency in network evolution, and may cause retention or lock-in in the local network. Therefore, Boschma and Frenken (2009) and Ter Wal and Boschma (2008) emphasize the importance of applying the dynamic network approach in the studies of networks formation, accounting for the evolution of network structures and its relationship to the different types of proximity. The section below discusses the importance of various types of proximities for the interactions and exchange of knowledge within innovation networks.
2.2 *Types of Proximity and Innovation Networks Formation*

Proximity does not create innovation, but serves as an enabling factor for it to happen. As stated by Boschma (2005), there are several types of proximities facilitating interactions as well as an exchange of knowledge and information between innovation ecosystem stakeholders, such as a geographical, cognitive, organizational, institutional, social and cultural one.

Geographical proximity appears as a distinctive element that leads to a clustering effect, especially useful for the transfer of tacit knowledge (Audretsch and Feldman 2004; Koschatzky et al. 2009). It is defined as the physical distance between actors. Porter (1998) showed that industry clusters provided some benefits in terms of entrepreneurship and innovation potential. The increasing role of geographical proximity in shaping economic and social interactions has triggered the “new” economic geography literature, and in particularly, the concept of clusters in facilitating knowledge exchange and innovation activities. Koschatzky et al. (2009) pointed out that in case of advanced technology sectors both territorial and sectoral determinants influence the development of innovative activities.

Cognitive proximity and technological relatedness or “technological proximity”, are less investigated by the researchers. Some notable contribution comes from the works of Petruzzelli (2011), Nooteboom (2000), Nahapiet and Ghoshal (1998), Brockhoff and Teichert (1995). In their findings, cognitive proximity is manifested by the homogeneity of competencies, capabilities and skills as well as the homogeneity of knowledge bases (Nooteboom 2000: 3–11). The first level of homogeneity refers to cognitive similarity between individuals: communication codes, written specific technical language, common professional or scientific backgrounds. Whereas the second level of homogeneity refers to the cognitive similarity between independent organizations (in their knowledge bases, capabilities, competences, and experiences). Having an overlapping knowledge base and a shared technical vocabulary enhances the actors’ ability to communicate and exchange information (Nahapiet and Ghoshal 1998). In relation to partners’ technological relatedness, Petruzzelli (2011) suggests that in order to increase innovative performance, a certain threshold of similar technological competencies between partners is required. However, too much similarity may in turn have a detrimental effect on the actors’ innovative performance since the development of valuable innovations may require dissimilar but also complementary sources of knowledge.

Institutional proximity refers to the interaction among actors from various institutions within innovation networks. Much of the literature focuses on the three institutional, Triple Helix (TH) spheres – university, industry
and government. However, as Jensen and Tragardh (2004) put it, cooperation within the TH model is complex, dynamic and ambiguous, thus the institutional architecture of particular university-industry-government innovation network models may differ by sector, for example in the case of aerospace the government would occupy a larger role than in the life sciences. Moreover, as evidenced in the research studies by Su and Wu (2015) and Silveira Luz and Monteiro Salles-Filho (2011), institutions can be greater enablers of innovation networks in the case of science-based industries, such as biotechnology, then in the case of the science-applied industries, like aviation.

Organizational proximity is related to the organizational dimension of the proximity. It identifies two levels of analysis: the inter-organizational and the intra-organizational (Antonelli, 2000). The latter division results from the fact that knowledge spills over from one to another organization, but also among different units within the same organization. People are simultaneously proximate to everyone else in their organization, as they move about the organization. The latter facilitates interaction both intentional and accidental. The inter-organizational proximity can be further distinguished from the low (loosely coupled) networks and weak ties between autonomous organization, to the highly networked, such as ownership and wholly-owned subsidiaries. In terms of the intra-organizational level, strong ties among different units define high organizational proximity, whereas weak ties correspond to a low proximity.

Social proximity and its concept originates from the literature on embeddedness. It claims that economic behaviour is heavily embedded in social relations, in which behavioural factors such as trust, openness, professionalism, complementarity and transparency are of key importance. The trustful relations among actors, driven by friendships or common experiences, encourage further development of new networks and the exchange of tacit knowledge between related actors (Maskell and Mallberg, 1999; Ziemiański, 2018; Etzkowitz and Leydesdorff, 2000).

Finally, cultural proximity refers to unwritten social and cultural rules for how people should behave in various contexts. Research show that shared norms and beliefs in networks play an important role (Adler and Kwon 2000; Runiewicz-Wardyn, 2020b). Nahapiet and Ghoshal (1998) state that norms represent a degree of consensus in a social system and so called the “norms of cooperation”. These norms have influence on people’s attitudes and motivations towards interactions and information and knowledge exchange. Culture affects how people perceive and interpret their environment. The latter implies that individuals sharing a common language and culture are more likely to perceive the social interactions and exchanges in similar ways.
### Analytical Framework for Empirical Study

The literature review on the innovation networks, presented in the Introduction section, and the concept of proximity, discussed in the earlier section, show that both spatial and non-spatial dimensions of proximity are crucial for the concepts of Entrepreneurial University and “innovation ecosystem”. The following types of proximity – geographical, institutional, cognitive/technological, organizational, social and cultural – make important non-spatial characteristics of innovative ecosystems and influence the formation of innovation networks between their actors (Figure 1).

Furthermore, it is hardly possible for one of the dimensions to generate innovation process alone, nor the simultaneous presence of all six can guarantee successful innovation networks formation. The actors must have the active will to do so. Thus, the focus of the research in the innovation networks must be scaled to the individual level. After all, in innovation ecosystems the network of formal relationships among organizations merges with the personal networks that every individual has in the ecosystem. The boundaries of every innovation ecosystem depend on its participants, which identify with the same ecosystem community. The innovation ecosystem is composed of the multitude of actors. Each have different roles to play (Figure 1). Scientists (SCs) conduct knowledge intensive research (basic and applied) in technology research areas. Managers (MNs) have technical and practical knowledge on technology markets. Technology transfer officers (TTOs) manage, consult and

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**TABLE 1** Innovative ecosystem and innovation networks concepts, and related with them types of proximity

| Innovation ecosystem | Proximity | Innovation networks |
|----------------------|-----------|---------------------|
| Related actors:      | Geographical | Enables joint learning and knowledge spillover through repeated face-to-face communication with related stakeholders; within a cluster attracts other actors (i.e., private and public investors). |
| University: scientists (SC); scientist-entrepreneurs (SCE); Heads of Labs (HUL); Heads of R&D units (HHR&D); Technology Transfer officers (TTO); managers of science parks (SP). |
| Industry: Head of R&D units (HHR&D); managers (MG); start-ups (SUP). |
| Government: Trade and Industry Councils (TIC); State/Regional/Local authorities (SRA/LA). |
| Intermediary organizations: non-profit professional (NP) and broker organizations (BO). |
| Complementary competences and sources; Interaction in innovation process |
| Enables inter-intra-organizational collaboration and interaction; interactions between intentional and accidental. |
| Institutional | Enables interactive learning through trust-based relationships driven by friendships or common experiences; encourages further development of new networks and the exchange of tacit-knowledge between related actors. |
| Organizational | Fosters effective communication and exchange of information through common language; common professional or scientific backgrounds. |
| Technological and Cognitive | Enables interactive learning through trust-based relationships driven by friendships or common experiences; encourages further development of new networks and the exchange of tacit-knowledge between related actors. |
| Social | Influences people’s attitudes and motivations towards interaction; facilitates information and knowledge exchange. |
| Cultural | | |

**SOURCE:** Own elaboration based on the reviewed literature sources
commericalize the IP generated by the research centre. Intermediary organizations and brokers (NP and BPs) bridge cognitive and technological distances through better understanding and recombining cross-disciplinary ideas, problems and solutions. Notwithstanding, it is social proximity that builds the trustful relations between the above actors, and encourage knowledge spillovers, and the exchange of tacit-knowledge between actors. The latter one is essential in solving real problems related to the commercialisation, adoption and diffusion of new technologies. The geographical proximity alone is not sufficient to explain how innovations happen within ecosystems. Rather, it is an enabling factor for the social interactions to happen. The above presented relations derived from the literature on innovation ecosystems, Entrepreneurial University, innovation networks and proximity constitute the analytical basis for the further empirical analysis in the article.

3 Research Methodology

Since the purpose of the study is not to test theory but rather to develop new insights the study applies a phenomenon-oriented approach and a qualitative multiple case study method. Studying multiple cases allows to understand the differences and the similarities between the analysed cases, identify the major contrasts, and more importantly create the new insights grounded in several empirical evidence (Vannoni, 2015). However, as more case studies are considered the less observation time the author has for the single case study. Nevertheless, this method allows a better understanding of the complex nature of innovation relationships and networking processes within the high-tech industries and their innovation ecosystems. The case studies have been chosen in the light of their unique cluster ecosystems and cover both nascent as well as well-established leading ecosystems. The principal aim of such research methodology was to gain insights and understanding of the role of proximity and its various dimensions in the innovation networks formation. The author conducted a qualitative research survey in the three leading biotechnology university innovation ecosystems in Europe and the United States during 2018–2019. The author conducted 47 interviews (22 in the San Francisco Bay Area, 12 in the Medicon Valley (Copenhagen and Lund regions) and 13 in Cambridge (United Kingdom), with the total time of 30–40 minutes per interview, with the business, public and non-public organizations, as well as academia representatives. The questionnaire contained mixed (open and closed) questionsstructured in four parts: (1) the mission, structure and types of networks; (2) the methods of networking and intensity of interactions; (3)
the role of different types of proximities in networking; (4) the impact of social networks on R&D collaboration and innovative performance. The “interview” technique was applied in order to collect in-depth content on how proximity promotes R&D and innovation collaboration, as well as to determine the role of multiple types of proximities in the networks formation. In order to analyse the evidence gathered data, a multistep thematic content approach was applied. The researcher transcribed the interviews to gain preliminary results, and then looked for common and different patterns for all the analysed ecosystems. The names of the companies and employees were coded according to non-disclosure agreements between the researcher and the interviewees. The interviews conducted in the three ecosystems have been redacted in order to protect the privacy of the interviewees. For these reasons, all interviews have been assigned an identification code. In each transcript is reported the role of the interviewee at the time of the research. Company names have been eliminated to ensure non-disclosure of secreted information. The interviews identification code is composed by three elements: an acronym to identify the ecosystem of affiliation of the interviewee, e.g. CBSP (Copenhagen Bio Science Park), the category of the actor and the month and year of the interview. e.g. interview with the manager of science park (SP) from CBSP conducted on August 2018 would bear the code: CBSPSP0818. Once common themes began to emerge, the researcher cross-referenced them with the findings with the similar surveys conducted by other authors introduced in the literature review section.

Applying the phenomenon-oriented methodology in the context of high-tech industries requires more detailed presentation of the major technological characteristics and innovation patterns of these high-tech industries. This knowledge will also help to respond the study research questions.

4 Technological Dynamics and Partnerships in the Biotechnology vs Aviation Industry

4.1 Biotechnology vs Aviation Industry
The modern biotechnology is a relatively young branch of bioscience, developed by the biopharmaceutical industry in the late 2000s. According to the literature, biotechnology industry started to form its shape in the early 1980s, when it improved the regulatory and patenting and licensing systems and launched government-lead research initiatives, especially in the United States (Zhang and Patel, 2005). Based on applications, there are five main branches of biotechnology: (1) Animal biotechnology, (2) Medical biotechnology,
Industrial biotechnology, Environmental biotechnology and Plant biotechnology (www.biotechhealth.com). The innovation processes within the biotechnology industry is not just one life cycle curve, but a succession of curves from organic chemistry/pharmacology to biochemistry, molecular biology, etc. The waves of molecular biology overlap the waves of biochemistry and are about to leap upward. Scientists and researchers are currently attempting to exploit basic molecular research to identify new drugs, the production of which will be based on recent advances in genomics technology. However, since biotechnology companies often focus on just small number of compounds within a specific area, many companies lack both the resources and experience required to bring novel drugs and therapies to the market. Therefore, partnerships with other key stakeholders in the specific fields are very important, and can take several forms, the agreements covering joint research, development, production, marketing and promotion, second- sourcing arrangements and in-, out- and cross- licensing (Gulati and Singh, 1998: 782). Moreover, biotechnology companies often prefer a light internal infrastructure, creating the need for externalised clinical development with partners. One example can include partnerships with contract research organizations (CROs), that provide research services primarily to pharmaceutical, biopharmaceutical, and biotechnology companies. Services include bioanalytical studies, clinical-study and clinical-trial support for drugs and/or medical devices (e.g. Syneos Health or IQVIA enterprises). Moreover, in the biotechnology, as in the whole life sciences sector, the past decade has witnessed the emergence of numerous interdisciplinary areas – bioinformatics, nanobiology, synthetic biology, biomaterials, tissue engineering, computational biology, etc. These new research fields have one common scientific path of development resulting from convergence and collaboration between different disciplines. In fact, this major share of this convergence happened in the very innovative, entrepreneurial and rich in social capital environment of the US Silicon Valley and San Francisco Bay Area (Runiewicz-Wardyn, 2020a). This provided a unique opportunity for life sciences firms to merge with the IT sector. In the late 1980s, UC Berkeley’s post-doctoral fellow and research scientist, Stephen Fodor, came up with the idea that semiconductor manufacturing techniques could be used to build vast amounts of biological data on a glass chip, which would facilitate the analysis of complex genetic information (Zhang and Patel, 2005). Moreover, rapid advances in technological convergence and its applications in life sciences also induce changes in the market conditions, forcing the transformation of current business models, research networks models, and public innovation and R&D support policies. This trend, along with the increasing global biopharmaceutical competition, drives specialization and increases the role of business
alliances and partnerships in research and innovation. Close collaboration is also important in the development of genomics technologies that requires massive amounts of information to be collected and analysed. In turn, the characterization of genes requires a means to manage, store and process enormous databases of biological information (bioinformatics).

Aviation is a science-based and science applied industry. It is related to several different engineering fields – mechanical, aeronautical, materials, electrical and electronic. From its beginnings in the mid-1930s and increasingly after its dominant design appeared around the, aircraft was a complex product, composed of several major modules or sub-systems, including fuselages, wings, tails, engines, nacelles, avionics, landing gear, electrical system and interior finishing (Zhegu and Niosi 2008). Therefore, industry is often presented as a pyramid, with primary contractors at the top (conducting assembling and sales) to final clients. Thus, the aviation industry deals with all-things aircraft-related within the earth’s atmosphere. These dealings include the design, manufacture and operation of many types of aircraft within this airspace. There are a few different sectors of aviation – Aerial Firefighting, Agricultural Aviation, Business and Personal Travel, Law Enforcement, Medical Transport, Overnight Delivery, Search and Rescue, Sightseeing – with three being the main pillars that uphold the aviation industry as a whole: commercial, general, and military aviation. One typical feature of this industry is the high and rising development cost of aircrafts, and the high risk involved (Niosi, 2008; Mowery and Rosenberg, 1998). Also, development takes several years, and companies cannot forecast what the market conditions will be at the time of the launching of the product. This is particularly true because of the strong cyclical demand for aircraft (Niosi, 2008). Thus, it is not surprising the importance of private-public partnerships in this industry. Many national agencies are involved in the support for aeronautical R&D. For instance, the Commission for the Future of the United States Aerospace Industry points to thirty-four different agencies and departments in the US federal government that share some responsibility and support for R&D in the aircraft industry. They include the Departments of Defence (DOD), Energy (DoE), Transportation (DoT), Education (DoE), and Commerce (DoC). A similar pattern can be found in the European Union (European Commission, HORIZON 2020).

The modularization of the aviation and more particularly aircraft industry has allowed international outsourcing of entire subsystems. The outsourcing practice allowed to reduce development costs in the industry by means of cost and risk-sharing agreements with foreign partners (on average, an airplane becomes a profitable product after 500 copies are sold, Niosi 2008). In the late 1970s, American companies started outsourcing entire subsystems
to Japan, and in the late 1980s to China (Zhegu and Niosi 2008). These long distance partnerships allowed both to reduce production and R&D training costs, because foreign governments subsidized their local companies in order to increase their learning and inward technology transfer capabilities. The growth of the aerospace engineering services outsourcing (ESO) industry is also facilitated by intensifying partnerships between original equipment manufacturers (OEMs) and service providers for leveraging cost-effective access to domain-specific technical expertise. For example, in February 2019, Diehl Aviation signed a multi-year agreement with Altair Engineering, Inc., with the latter company becoming Diehl Aviation’s strategic computer-aided engineering supplier (Market Analysis Report, 2019). As in words of Frank Wengler, Aviation market segment leader: “(...) diverse expertise and innovative ideas are important elements bringing aviation projects to life, therefore (...) partnering with small and disadvantaged businesses firms opens opportunities to bring in a broader range of capabilities (Wengler, 2019). The smaller firms often hold specialty expertise and local knowledge, skill sets that allow the larger project team to be responsive to changing project needs and demands. The future air transport growth is another factor stimulating the close collaboration and technological convergence in the sector, in particularly with information and communication technology (ICT), display and electronics industries.

| TABLE 1 Selected patterns of technological innovation: comparison of biotechnology and aviation industries |
|---------------------------------------------------------------|
| **Biotechnology** | **Aviation industry** |
| Technological maturity | young & growing | mature |
| Technological cycles | short | long |
| Mode of research | multi- and interdisciplinary | multidisciplinary |
| Factor intensity | knowledge-intensive | capital-intensive |
| Source of R&D funding | private | public & private |

Source: own elaboration based on Runiewicz-Wardyn (2020a), Zhang (2005), Zhegu and Niosi (2008) and Wengler (2019)

In sum, the above discussion confirms that both sectors – biotechnology and aviation – have both similar as well as very distinct patterns of technological innovation process. The table 1 summarizes the selected patterns of technological innovation process in these two sectors. Hence, aviation industry,
compared to the biotechnology one, is more mature, characterised by longer technological cycles, multidisciplinary modes of research, has fewer people dedicated to R&D, higher capital intensity and a larger involvement of government funding in the purchase of specialized machinery and equipment.

4.2 Innovation Life Cycle and Innovation Partnerships in Biotechnology and Aviation Industries

As was mentioned in previous section biotechnology industry is about very unique and complex products which have not one life cycle, but rather three different life periods: (1) an early development period, (2) a highly competitive mid-life period and (3) a late post-patent period (Bernard, 2013). At the early phase of preclinical research, various actors and teams of stakeholders may conduct closed-shop or collaborative research. Generally, the R&D is conducted in the academia and organizations research labs. The R&D function in an innovation-driven biopharmaceutical company has two important and interdependent roles. Firstly, to invent, evaluate, and later develop the molecules that eventually lead to products on the market. Secondly, to provide scientific expertise capable of identifying and evaluating external opportunities. These can be specific molecules at various stages in the value chain or technologies and ideas that can be directly developed into new molecules or contribute to other projects (Lipton and Nordstedt, 2016).

Given its length and the risks involved, a single biotechnology company is unlikely to undertake the whole R&D process alone. Presently, the global biotech companies pressure to partner with other biopharma companies and universities to embargo some research, with or without strong or immediate discovery commitment. Academia, on the other hand, finds it convenient to have financial support from industry, especially in the early-stage discovery and professional expertise on the possibilities of transferring their innovation into industry. Moreover, different stages of product development motivate different types of partnership (Rothaermel and Deeds, 2004). They also vary in duration. In terms of the time, upstream activities (such as basic and applied research development, verification and validation, prototype development, etc.) may take years. Similarly, downstream processes such as manufacturing and entering the market require substantial time. Moreover, the form of the value chain in the biopharma field is affected by the available resources and funding (Powell et al., 1996). Upstream activities are dependent on local resources and funding, whereas downstream activities (such as marketing) rely on global resources and developed through partnerships (Hine and Kapeleris, 2006). Partnerships may also be classified according to the objective: exploration or exploitation.
Rothaermel and Deeds (2004) link such partnerships to the different stages of biotechnology product development process: discovery and commercialization. In either form of partnerships, on average, only one to two of every 10,000 substances synthesized in laboratories will successfully pass all stages of development required to become a marketable medicine. Moreover, by the time a medicinal product reaches the market, an average of 12–13 years will have elapsed since the first synthesis of the new active substance. This is why intensifying social ties with people on both sides, especially in the early stage of clinical trials greatly increases the success of the project and its money value. In the early development phase of the innovation life cycle, social networks allow researchers and entrepreneurs to engage in discussions, share information and connect with others in order to expand their professional network and raise funds. Similarly, the success of commercialization at the post-launch phase will, to a large extent, be determined by the social and interpersonal networks between different groups of stakeholders (Figure 2a).

Aviation industry sector (both the aeroplane and spacecraft industries) is the industry that has extremely long product-life-cycles and development periods (Figure 2b). It is characterised by its renowned heavy upfront investments and exceptionally long programme lives. Governments subsidize the industry through many different policies, i.e. tax credits for R&D, direct subsidies, export credits, R&D loans, sponsoring expensive equipment, training and educating highly skilled labour force.

Therefore, the industry tends to be very regulated and also requires huge stocks of the existing knowledge (even though a slow deregulation of the industry in last decades lowered the entry barriers into its market). The process of technological substitution and adoption of new products and processes is very long. In technical terms, the technology diffusion for the aircraft manufacturing industry has obtained a high rate of maturity as now anyone who can afford the products in that market is able to obtain them without encountering difficulties (Runiewicz-Wardyn, 2013). However because of big lack of expertise of suppliers and users of specific technological processes, the diffusion process may be an “incomplete success or at times a failure on the part of the user to completely absorb the technologies provided by the suppliers” (Rasheed and Manarvi, 2008). Because of the high investments into R&D and high costs related activities it seems the industry is fairly concentrated. Universities did not play as important a role in the innovation partnerships as they had done in biotechnology or nanotechnology. Instead, knowledge is accumulated in companies. Nevertheless engineering schools help in the development of mechanical, electrical and material components and provide with high-skilled labour. Moreover, as the study by Runiewicz-Wardyn (2013) showed that industrial
diversity and co-location externalities turns out to be a particularly important input for new knowledge creation in the aviation industry. Therefore, some smaller firms with no access to adequate human resources, organisational and R&D capacities may be disadvantaged. In addition, the industry dynamics converge with the expansion of other industries. Access to IT and computer technology is becoming increasingly important and in general has become a necessity for many parts of operations and marketing in aviation industry (Subramanian et al., 1994; Anbil et al., 1991). Additionally, the industry has been facing a gradual deregulation of competition and recently noted consolidation
in the form of mergers between companies or takeovers of failing carriers and a part of the birth-and-death process in the aviation industry. Therefore strong, coherent research networks and innovation partnerships may drive further aviation industry as it approaches its early maturity stage. Last but not least, the industry’s cyclical nature is determined by its complex and sensitive nature relative to the external factors such as the emergence of low-cost carriers, the safety, pandemics or potential terrorist attacks, and the increasing volatility in fuel prices. The implies that it is crucial for the airline and aviation-related companies to be able to adapt dynamically to changing market conditions on a constant basis.

5 Research Results

The findings of the conducted interviews shed a light on the role what various dimensions of proximity play within the analysed innovation ecosystems, and how they help foster innovation networks. The following section synthesizes the interview results for each of the dimensions of proximity. The selected exemplary quotes that summarize the role of the proximity for the innovation collaboration and networks formation for the interviewed stakeholders are provided in Annex 2.

5.1 Geographical Proximity

In all the three innovation ecosystems geographical proximity defined by the interviewees as close physical (walking) distance to both academic institutions and mature companies, was mentioned as a very important driver of potential innovation collaboration and knowledge spillovers via the job mobility or participation in different academic and scientific events. Moreover, the proximity to the lead users in their ecosystems – patients and personnel at the city hospitals – was another factor that allowed to meet the complex and diverse health care needs of the new biotechnology markets. Both, formal and informal physical interactions were equally important for all the ecosystem actors. In addition, the respondents from the Stanford and Cambridge University ecosystems (academic faculty, TTOs, business representatives) emphasized the importance of “social infrastructure – sport centers, clubs, bars and coffees” that created opportunities for informal interactions. Only in the opinion of the Medicon Valley cluster representatives, geographical proximity was somewhat less significant for the informal interactions.
5.2 **Institutional Proximity**  
The study revealed that over 2/3 of biotechnology ecosystem respondents in the selected case studies kept collaboration with the representatives of diverse TH stakeholders. They confirmed that being institutionally proximate facilitated the knowledge transfer and research collaboration with universities. Moreover, the US respondents emphasized that intermediaries played essential role in narrowing both social and institutional distances between the interviewed stakeholders. They also noticed that once the established formal relationships between TH organizations i.e. industry-university or university-hospital, merged with the informal social networks, the institutional proximity became less important.

5.3 **Organizational Proximity**  
The study findings reveal that the primary motives for the partners in the selected biotechnology ecosystems to start talking, about research or academic collaborations, were found in their cognitive and organizational proximities. For example, respondents from the Bay Area ecosystem mentioned social networking events in the field of life-sciences, organized by their own company or intermediaries, strengthened their intra- and inter-organizational networks. They also admitted that informal social networking events stimulated inter-organizational knowledge sharing and improved their competences, capabilities and resources. Furthermore, organizational proximity strengthened the social networks between the Bay Area universities and colleges representatives. Job mobility was mentioned as an important process of bridging and networking between the various organizations. In fact, the researchers in the Bay Area mentioned that staying with one organization for around 4–5 years was an optimal period for successful career and professional network development. This contrasted with the respondents from the Cambridge and Medicon Valley ecosystems, who demonstrated poor job mobility and preferred long-term or undefined work contracts.

5.4 **Cognitive Proximity**  
The study findings provided with the evidence that distance in terms of a knowledge base and created an obstacle for the knowledge and innovative networks formation between the analysed biotechnology ecosystems agents and other non-local biotechnology colleagues. In fact, limited competence and poor absorptive capacities of the non-local actors made the successful research interaction harder. For example, several respondents from Cambridge life-sciences ecosystem found technological and cognitive proximities (the second
level of homogeneity) to be a major challenge when expanding innovation-driven networks with partners from Poland or Hungary.

5.5 **Social Proximity**
In terms of social proximity, the respondents located in the San Francisco Bay Area (university affiliated agents) pointed out that social networking is especially important in the process of search of ideas (early preclinical stage) as well as upgrading of R&D ideas (early maturity stage). Yet, since the early or so-called “idea search” stage is very often filled with certain precautions, some respondents (start-up and business agents) demonstrated their preoccupation with a possible copying or imitating of their ideas and concepts. Yet, for another group researchers and faculty members from Cambridge life-sciences innovation ecosystem, increasing intensity of social networking events presented some challenges. In general, the faculty members emphasized the importance of social relations and networking skills, however, they also pointed out to the potential challenges of putting too big pressure on scientists to invest into social “bridging” and “bonding” efforts.

5.6 **Cultural Proximity**
The findings from the three case studies revealed that at least for half of the respondents shared cultural, religious and linguistic backgrounds were very appreciated, however did not precondition successful social ties and interactions. Almost everybody, in the analysed biotechnology ecosystems, mentioned openness in sharing ideas and meeting people as essential for strong and long-lasting social networks. Furthermore, the respondents mentioned that cultural proximity, resulting in the same cultural norms (Swedish-Danish or Polish), habits and values, enabled one to build trust and thus a willingness to exchange information. For example, respondents with Polish, Chinese or Hindi cultural roots were involved also in their national-based scientific community networks.

In sum, social interactions constituted one of the central aspects that explained the capacity of the three world leading life-sciences ecosystems to foster innovation networks. Such interactions were fostered and moderated by several dimensions of proximity. Geographical proximity was an important precondition for the social/personal interactions within the ecosystems. It also moderated the cognitive and technological distances. The gap created by cognitive and technological distances (between the industry and university actors) was bridged by the geographical proximity. The local latter was done via the intermediaries i.e. non-profit professional organizations in San Francisco Bay Area and the entrepreneurial-scientists in the Cambridge University. On
top of that, innovation networks were orchestrated and engineered by these intermediary actors. Social proximity was important in facilitating the interactions and mutual interactive learning. It reinforced the institutional proximity and moderated the cognitive distances occurred along the technology life-cycle. Consequently, strong and long-lasting social networks between the ecosystem actors were built on cognitive and technological proximities, whereas social proximity helped to coordinate and maintain the established innovation networks. Moreover, the weaker inter- and intra- organisational proximities were strengthened by the geographical and social proximities, via broker and intermediary organizations. Cultural proximity was appreciated by all the interviewed actors. Yet, in certain cases, trust was culturally and linguistically embedded.

6 Discussion

This study has put forward two main objectives. Firstly, to gain knowledge and insights on how various dimensions of proximity facilitates innovation networks in the selected life-sciences innovation ecosystems. Secondly, to cross-reference them with the findings with the similar studies conducted by other authors, including Bochniarz (2020; 2016) in the Seattle (US) life-sciences cluster, Broekel and Boschma (2016) in the Dutch aviation cluster, Pucci et al. (2020) in the Tuscan life-sciences cluster; Kozierkiewicz (2020) in Warsaw and Krakow life-sciences clusters, Porter and Takeuchi (2013) in the Toulouse region aerospace cluster, Levy and Talbot (2015) in the French Aerospace Valley and Ahmad et al. (2013) in the Moroccan aeronautics cluster. The discussion section contains the comparative analysis of the results and outcomes of the author’s study with the subject literature.

The evidence gathered through interviews as well as the study findings by Pucci et al. (2020) in the Tuscan life-sciences cluster and Kozierkiewicz (2020) in Warsaw and Krakow life-sciences ecosystems clusters confirm the importance of the close geographic and physical proximities of the biotechnological and life science companies and the research institutes. The complexity and interdisciplinary character of the knowledge base and the need for the coordination between the myriad of different partnerships, especially at the early stages of product development, i.e. preclinical and clinical phases. Frequent physical contacts allow researchers and entrepreneurs to engage in discussions and share information on their work. Geographical proximity was also a driver of innovation networks formation in case of the Dutch aviation industry evidenced by Broekel and Boschma (2016) and the Polish aviation industry
evidenced by Bochniarz et al. (2016). Both studies applied semi-structured interviews with the key stakeholders active in manufacturing and engineering services in the aviation sector in Poland (Podkarpacie Aviation Valley) and Netherlands. However, in case of the Dutch aviation industry spatial scale of the networks was rather small, whereas Poland’s Aviation Valley networks were characterised by both high local R&D and knowledge linkages, and increasing global inter-firm networks.

Both the empirical studies and subject literature review evidenced the important role of institutional proximity in maintaining innovation networks in the two high-tech industries settings. Yet, the institutional architecture in the aviation industry differs significantly from the biotechnology industry ecosystem. In case of aviation, successful research and innovation strategies cannot be effectively formulated and implemented without the direct or partial government support (Bochniarz et al, 2016). Whereas in case of the biotechnology, successful innovations depend on the basic and preclinical research, the bulk of which is done at the universities. Moreover, contrary to the biotechnology, the aviation industry, requires the R&D collaboration through the entire technology life-cycle period. Hence, government R&D funding plays a significant role in supporting and moderating university-industry partnerships in the aviation industry. In the biotechnology, individual scientists and non-private organizations act as main intermediaries in the university-industry networks (with the exception of the Polish biotechnology ecosystems, in which public institutions and public cluster initiatives play such intermediary role, see Kozierkiewicz, 2020). Moreover, in case of the aviation industry, government funded agencies and universities, played a major role in education, research, and employment of the local engineers (Bochniarz et al., 2016; Broekel and Boschma, 2016). This was only partially true for the biotechnology industry ecosystems, which attracted engineers both locally and globally.

Even though, interviewees didn’t discuss closely the implications of organizational proximity with regards to innovation networks, they did agree that interactive learning and knowledge flows are positively influenced by organizational proximity. Also, in the studies by Bochniarz et al. (2016) and Broekel and Boschma (2016), the influence of organizational proximity on innovation networks in the aviation industry has only been investigated very broadly. Broekel and Boschma (2016) concluded that with few exceptions cluster related private and non-profit organizations were highly connected, and many firms referred organizational proximity as important technological knowledge sources. Levy and Talbot (2015) explained that the weaker organisational proximity in the French Aerospace Valley cluster was strengthened by the geographical proximity.
In terms of cognitive dimension in the biotechnology innovation ecosystems, the interview findings confirmed the overall conclusions of the study results by Kozierkiewicz (2020), Pucci et al. (2020) as well as Boschma and Frenken (2011). The authors agreed that certain degree of related cognitive proximity has been a condition for knowledge to spillovers. Moreover, the biotechnology industry stakeholders must take simultaneous advantage from the heterogeneity of actors, and their diversified backgrounds, as well as from the common knowledge base facilitating the interactive learning between them. Whereas, in case of the aviation industry, Boschma and Broekel (2016) and Bochniarz et al. (2016) found out that organizations tend to link more with technologically similar organizations. In fact, the authors found that a positive and significant impact of cognitive proximity increased likelihood of being linked to another organization. In other words, in the aviation industry the likelihood of being connected increased monotonically with the increase of technological similarity. Levy and Talbot (2015) explained that the higher was the technological proximity between the participants the more easily they could develop spatially-dispersed innovation relationships. The authors concluded that sharing common knowledge bases (which have even been co-developed during possible past interactions) created mutual understanding between the cluster ecosystem actors. This way cognitive and technological proximities facilitated remote interactions and reduced constraint of geographical proximity.

The interviews results confirmed that social interactions play an important role with respect to facilitating innovation networks interactions and interactive learning. Nevertheless, the industry and university stakeholders from the two European life-sciences ecosystems – Cambridge and Medicon Valley – preferred to build their social relationships at the base of the cognitive and technological proximities rather than personal friendships. In Poland, Kozierkiewicz (2020) showed that, even though innovation ecosystem stakeholders appreciated the role of social networks, the influence of social proximity on the industry-university innovation networks formation was rather low. This was explained by the low level of trust and the low level of organizational, social and cultural proximities, between scientists and industry players. As evidenced by Kozierkiewicz (2020), the scientists in the Polish biotechnology clusters ecosystems feared that cooperating with the industry stakeholders would end in the loss of control over their innovations. This is contrary to the findings by Pucci et al. (2020) in the Tuscan Life Sciences cluster ecosystem, in which the effect of local relationships on R&D effectiveness in the local biotechnology industry was positively moderated by the number of local personal relationships.
The role of social proximity was equally important in the studies by Boschma and Broekel (2016) and Bochniarz et al. (2016) for the case of the aviation industry. Boschma and Broekel (2016) found that common friendships and shared past employment in the Dutch aviation companies seem to help the employees, working for different organizations, to establish and maintain knowledge sharing links. Bochniarz et al. (2016) delivered the evidence that geographical co-location facilitated cooperation and generated the establishment of numerous social organizations within the Polish aviation ecosystem. The authors also indicated that cluster’s business leaders had identified social networks as one of the important channels in the promotion of the innovation activity. They also have been actively investing in the social networks in order to induce higher work and R&D efficiency.

Even though, the study findings by Boschma and Broekel (2016) in the Dutch aviation cluster didn’t refer specifically to cultural proximity it confirmed the role of common values on the innovation collaboration within the aviation industry. The case study by Ahmad et al. (2013) gives even stronger evidence to the role of cultural proximity. In the case of Moroccan aeronautics cluster – Groupement des Industries Marocaines Aeronautiques et Spatiales (GIMAS) the author revealed that the main investors and trading partners were greatly enhanced by the French speaking workforce and their cultural proximity.

7 Conclusion

The study confirmed the relevance of all the types of proximities – geographical, cognitive, social, cultural, institutional and organizational ones – for the innovation networks formation and technological dynamics in both, biotechnology and aviation industries. More specifically, the research findings contributed with the three insights related to the study research questions and the fundamental relationships that determine the role of proximity in the biotechnology and aviation innovation ecosystems:

Insight 1. Cognitive and geographical proximities are most important in nurturing social proximity and innovation networks formation. Biotechnology firms and scientists are more dependent on the tacit knowledge and face-to-face communication. Hence, geographical proximity allows them to hold more informal interactions, also with other ecosystem players, having different backgrounds. Therefore, geographical proximity is also a precondition for the stronger social ties in the biotechnology industry. In the aviation industry, spatial proximity is an equally important driver of innovation networks.
However, for much younger aviation ecosystems, such as the case of Poland’s Aviation Valley, a physical proximity in the local inter-firm and university-industry networks, and the access to global buyer-supplier networks are both equally important.

Insight 2. Innovation networks can be strengthened and enriched by the intermediaries and social brokerage. Even though, the social proximity should not be considered a panacea for increasing the levels of innovative activity in the high-tech sectors, yet, there is a sufficient evidence that social proximity helps to transform the interactions of the ecosystem players into the successful innovation networks. Conversely, the absence of social and cultural (culture of openness) proximities can create a barrier to the innovation and entrepreneurial processes (i.e. the case of Polish biotechnology innovation ecosystems). Intermediaries can narrow social distances between ecosystem players and keep the already existing networks open. Moreover, the successful brokering the network can be played by both professional intermediary organizations as well as entrepreneurial-scientists. The presence of intermediary organizations or entrepreneurial scientists are especially important in overcoming or reducing potential cognitive biases between the ecosystem players.

Insight 3. The presence of cognitive, social and institutional proximities remains important throughout all the innovation life-cycle stages of the technology. The path-dependent, interdisciplinary and dynamic growth of biotechnology industry, driven by the networks of heterogenous actors, implies that the speed of knowledge and information exchange is essential. Therefore, the presence of cognitive, social and institutional proximities accelerates entrepreneurial and innovation processes in the biotechnology ecosystems. More importantly, it allows to avoid and reduce possible cognitive biases as the biotech product moves along its innovation life-cycle. Geographical and social proximities are especially important at the early (pre-clinical, clinical) and late (maturity) stages of the innovation life cycle. In the technologically mature, aviation industry, long innovation development and commercialization processes are supported and moderated by the government-industry partnerships. Therefore, both institutional, cognitive and social proximities, are important as the new innovation products and technologies move along their life cycles.

The evidence gathered in the study sheds new lights on the concept of “proximity” and its role as enabling factor of innovations. The findings are important to gain understanding on the phenomenon of proximity in the dynamics of networks formation and inspire to further studying the relationships between the various dimensions of proximity in specific high-tech sectors settings. More importantly, the study findings imply that even though the
high-tech innovation ecosystems may not be fully engineered, governmental institutions and policy makers can still help to create some enabling conditions for proximity to unfold.

8 Research Limitations and Policy Implications

The following study has several limitations resulting from the rather small and unequally distributed (across time and space) sample of the biotechnology and aviation industries ecosystem case studies. There are at least several directions of the future research that stem from this study: first, further surveys could help to develop a more in-depth and comprehensive view of the role of proximity and relational capital behind the origin, growth and evolution of the specific high-tech industries ecosystems. The findings has important policy implications on how national and local governments could promote initiatives that narrow distances in the two analysed high-tech industries. The policy implications can be summarized in three essential points: 1) public institutions should be more active in bridging social and cognitive distances as well as encouraging and reinforcing innovation collaboration at the local, regional and global levels; 2) public higher education programs (in fields of biotechnology and aviation) should also promote the soft skills development, such as “communication” and “collaboration”; 3) instead of engineering high-tech ecosystems from scratch policy makers should focus on the creation of the enabling factors that lead to innovation. More specifically, the study findings suggest that there are higher chances in finding a cognitive overlap within the more mature EU and US clusters than between the younger clusters in the newer EU states (Poland). Thus, public and other non-profit institutions should be more active in brokering, encouraging and reinforcing the cross-sectoral cooperation in these industries at the local, regional and global levels. In particularly, the research findings imply that in case of the aviation industry, brokerage and intermediary managers should focus more on narrowing organizational proximity, while in case of the biotechnology industry the greater emphasis should be on the technological and cognitive proximities. Furthermore, the shortening technological cycles and rise of technological convergence in the considered high-tech industries, along with the rapidly changing business environment (with start-ups and the predominance of big companies) raise the need to combine competencies with others. Therefore, both in the biotechnology and aviation sectors innovation “partnerships” are the new standard, in which soft skills, such as “communication” and “collaboration” become of key importance. The results suggest that more focused policy measures are needed
to optimise knowledge exchange and innovativeness within the two types of high-tech industries ecosystems. Moreover, any policies should consider a complex set of factors, such as human capital and the innovative profile of research institutions, technological dynamics and technological maturity of industries, long-term research and business strategies of various stakeholders, and last but not least institutional, cultural and social realities of each high-tech industry ecosystem environment. A policy based on the limitation or replication of the supposedly best practices of other European and US leading clusters should consider the local variation of social and cultural capital and go beyond one-size-fits-all solutions.

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Availability of Data and Materials

The complete interviews-based study in the following life sciences ecosystems – San Francisco Bay Area (US), Cambridge (UK) and Medicon Valley (Denmark-Sweden) can be found in: Runiewicz-Wardyn, M (ed) (2020a) “Social Capital In the University-Based Innovation Ecosystems In the Leading Life Sciences Clusters. Implications for Poland”. Poltext, Warsaw. The more detailed interviews material cannot be shared due to privacy protection.

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## ANNEX 1  The selected cases studies design

| Location                        | Sector          | Level of analysis | Stakeholders                                                                 | Source                                      |
|---------------------------------|-----------------|-------------------|------------------------------------------------------------------------------|---------------------------------------------|
| Medicon Valley (Sweden-Denmark) | life-sciences   | regional/trans-regional | Heads of R&D and Faculty Units, Technology Transfer officers, intermediary agencies. | Runiewicz-Wardyn (2020a)                   |
| Cambridge (UK)                  | life-sciences   | regional          | Heads of R&D, Faculty and University Hospitals, Technology Transfer officers, SMSS, big companies, intermediary agencies. | Runiewicz-Wardyn (2020a)                   |
| San Francisco Bay Area (US)     | life-sciences   | regional          | Heads of R&D and Faculty Units, Technology Transfer officers, SMSS, intermedi- ary agencies. | Runiewicz-Wardyn (2020a)                   |
| Seattle (US)                    | life-sciences   | regional          | Heads of R&D and Faculty Units, Technology Transfer officers, intermediary agencies. | Bochniarz (2020)                           |
| Krakow & Warsaw (Poland)        | life-sciences   | national/ regional | Heads of R&D and Faculty Units, Technology Transfer officers, big companies, SMSS. | Kozierkiewicz (2020)                       |
| Dutch aviation cluster          | aviation        | national          | SMSS and bigger companies 59 members of the Netherlands Aerospace Group (NAG) | Broekel and Boschma (2016)                 |
| Tuscan cluster (Italy)          | life-sciences   | regional          | 145 SMS companies                                                              | Pucci et al. (2020)                        |
| Moroccan aeronautics cluster    | aviation        | national          | 100 companies                                                                 | Ahmad et al. (2013)                        |
| Aerospace Valley (France)       | aviation        | national/trans-regional | 465 companies                                                                 | Levy and Talbot (2015)                     |

source: own elaboration based on the literature source in the table
### Exemplary quotes relative to types of proximities

| Cluster | Exemplary quotes |
|---------|------------------|
| **Medicon Valley** (Sweden-Denmark) | (in relation to organizational proximity) “formal meetings are excellent channels for knowledge, concepts and idea sharing; if someone has an idea to discuss, he or she shares without any particular secrecy” (COBISSP0818); “serving personal comfort the internet reduces cost and time when compared to the face-to-face meetings or discussion panels” (MVASPO818). “geographical and cultural proximities underline the importance of further social contacts with Scandinavian colleagues; (...) Scandinavians are closely related, and their populations feel close to one another” (ISRA0818). |
| **Cambridge** (United Kingdom) | (in relation to social networks and proximity) “before we do the R&D project, we explore it closer to build a trust and not damage our reputation (...); Why widen one’s circle of casual acquaintances when one has established a well-functioning network already” (CUUHR&D0818); (...) there is a potential problem of putting too big pressure on scientists to attend to social events, as well as bridging and bonding efforts” (CUSC0818); (...) trust, openness, professionalism and complementarity become key drivers behind the social relationships and knowledge flows within the Cambridge ecosystem” (TCUHR&D0818). “technological proximities are major challenge when expanding the innovation-driven social networks with the partners from Poland or Hungary” (CUSC0818). “being institutionally proximate facilitates knowledge transfer and research collaboration; (...) intermediaries and institutional proximities play an essential role in narrowing the social distance” (AZBHR&D0818). “social infrastructure – sport centers, clubs, bars and coffees – create opportunities for informal interactions; (CNNP0818); Shared culture of giving in that ecosystem, sooner or later will get something back” (TCUHR&D0818). |
SAN FRANCISCO BAY AREA (UNITED STATES) (on social proximity and virtual networks) “one must be concerned about the digital forms of social networking, which, leave traces (SUSC0719). (...) telephone and Skype, serve as a means of maintaining the established network relationships; physical contact face-to-face is important the first time, then it can be electronic (NMNN0719). (...) naturally emerging formal and non-formal problem groups via bottom-up initiatives (e.g. by faculty members) may use digital platforms focusing on sharing and disseminating information” (OCTTO0719).

(in relation to social networks of smaller companies) “Social networking means promotion of oneself and one’s skill set. Yet, the early stage of idea development must be filled with certain precautions of not saying too much and to be not scooped up your ideas (...)” (2DGSUP0719).

(in relation to social networks and organizational proximity) “social networks allow to gain feedback and recommendation; connections to the important people in the field (...) as well as stimulate organizational proximity and interorganizational knowledge sharing” (TFSMN0719).

SOURCE: RUNIEWICZ-WARDYN, 2020A

List of abbreviations: University (CU), Trinity College (TC), Cambridge School of Clinical Medicine (CSCM), Cambridge Enterprise Limited (CEL), Cambridge Networks (CN), AstraZeneca (AA), Stanford University (SU), NuMedii Unnatural Products, Inc. (NM), Thermo Fisher Scientific (TFS), 2D Genomics (2DG); University of Copenhagen (UC), Medicon Valley Alliance (MVA), Copenhagen Bio Science Park (COBIS), Biopeople (BIOP), Invest in Skane (IS); University scientists (SC); scientist-entrepreneurs (SCE); Heads of R&D units (UHR&D); Technology Transfer officers (TTO); managers of science parks (SP); Head of R&D units in companies (BHR&D); managers (MN); start-ups (SUP); Regional authorities (RA); non-profit professional organization (NP).