SOCIAL CAPITAL IN THE UNIVERSITY-BASED INNOVATION ECOSYSTEMS IN THE LEADING LIFE SCIENCES CLUSTERS

Implications for Poland

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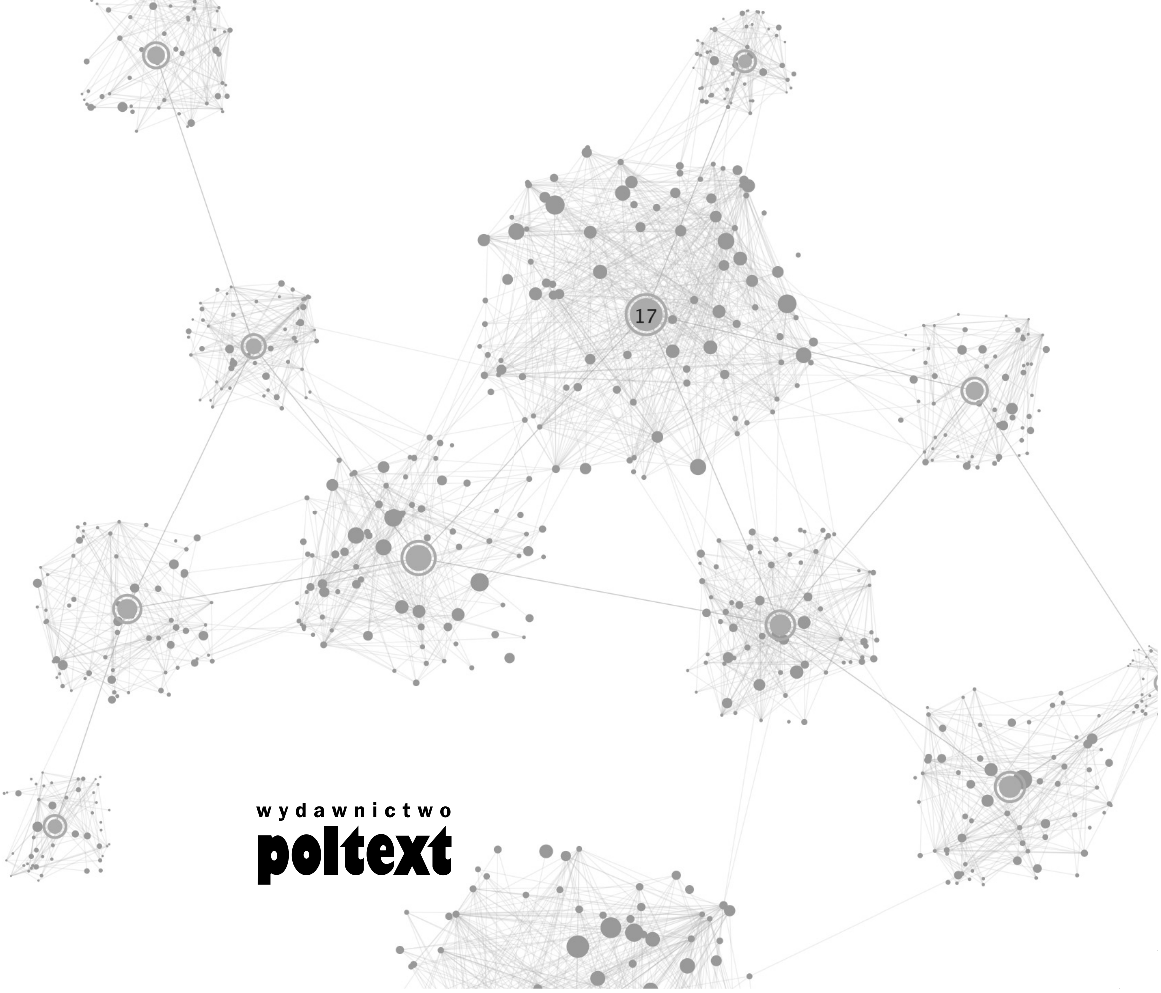
Małgorzata Runiewicz-Wardyn



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Preface

Over the last decade, research in the field of technology and innovation has subsequently progressed toward the development of the notion of an 'ecosystem'. Such an approach became particularly useful in understanding the dynamics related to the complex process of invention and its translation into an innovation which spreads further on into society and into what was highlighted in the latest Europe 2020 Growth Strategy and Cohesion Policy 2014–2020 as smart growth. The concept of an ecosystem lies within the idea that innovation and technological advances do not stem from the inventive efforts of one person, but rather collective research efforts and social interactions. In fact, smart growth starts from the bottom-up entrepreneurial discovery process about a region's assets, its challenges, competitive advantages and the potential for excellence (European Commission 2012). In this approach of the priority setting of the region's specialization, local dynamic externalities, social networks, and university-industry collaborations play a crucial role. The role of social collaboration networks seems to be even more important in the case of such dynamic industries as biotechnology where research is more complex and interdisciplinary.

The present monograph contributes to the emerging debate on the topic of innovation ecosystems by delivering new insights into and knowledge of the role of social capital, social networks and collaborative social environments in the successful life sciences innovation ecosystems. The authors applied a qualitative interview and direct observation methods which allowed to better understand the complex nature of the life sciences university ecosystem and more importantly, the process of social networking within it. The research study covered several well-established life sciences university-based ecosystems in the European Union and the United States. For the purpose of comparison, the study also considers Poland's emerging life sciences sector. It is expected that the research findings, along with the recombination of the relevant subject literature and other collected empirical evidence, will make it possible to contribute to the development of strategies and policy measures to further unlock the innovation potential of the emerging life sciences sector in Poland.

Introduction

The Triple Helix (TH) (university-industry-government interlinkages) approach to ‘innovation systems’ has been widely accepted, especially in the public sector. However, there has recently been an attempt to enrich this approach with a new concept of the Quadruple Helix (QH), which is grounded on the idea that innovation is the outcome of an interactive and trans-disciplinary process involving “all stakeholders as active players in jointly creating and experimenting in the new ways of doing things and creating new services and products” (European Commission 2015). Notably, the QH approach builds on the emerging concept of an ‘innovation ecosystem’ and widens the TH concept with one more helix – society and societal perspective (McAdam and Debackere 2018; Carayannis and Campbell 2012). Consequently, in the QH interactions, knowledge transfer among innovation actors is additionally strengthened by social, trust-based relations among the actors or so-called “social proximity”. The concept of an ‘innovation ecosystem’ refers to a network of interconnected organizations, connected to a focal firm or a platform that incorporates both production and uses side participants and creates and appropriates new value through innovation (Autio and Thomas 2014).

The life sciences industry, including biotechnology, is advancing at an unprecedented rate. As for 2018, the global life sciences sector accounted for approximately $1.6 trillion and was expected to reach over $2 trillion in gross value by 2023 (www.bisnow.com). Most of biotechnology research and industry innovation activities were concentrated in just few locations in the world. For example, San Francisco Bay Area is the largest recipient of the venture capital investments, along with the Boston-Cambridge area, and employs the highest share of biotechnology work force in the US (U.S. Life Sciences Clusters, 2019). In Europe, Cambridge (United Kingdom) life sciences is home to around 25% of Europe’s biotechnology companies and employs 57,000 people. It also accounts for 20% of the world’s Nobel Prize winners in medicine and chemistry (Cambridge Cluster 2019).

This high level of geographic concentration persists despite the subsequent rise in funding programs in the European Union to spur the development of the life sciences industry (Innovation Union Scoreboard 2018). In the last decade, another cluster in the north end of the United States – Seattle (Washington state) showed its incredible dynamics by becoming one of the fastest-growing life sciences market in the United States, with the rate of 16% growth on average in 2014–2017 (CBRE Research 2019). In Europe, a cluster on a cross-border region between Denmark and Sweden – the Medicon Valley – revealed its incredible scientific potential, which is reflected in the sharp increase of the volume of scientific publications in the life sciences – 23% between 2013–2016, and, to a lesser extent, in patent applications – 15% and 6% increase in Denmark and Sweden, respectively) (State of Medicon Valley 2018).

The success of these life sciences clusters poses questions as to which factors drove their success? There is a substantial amount of the high-tech-cluster-related literature considering the following success factors of the life sciences clusters: strong science and industry base, strong networks between industry and science, that facilitate the growth of both academic and industrial spin-offs, finance availability for new biotech companies (including venture capital and government funds), as well as traditions of local entrepreneurship (Maskell and Malmberg 2002; Su and Hung 2009). Relatively fewer sources mention the role of networks between faculty, investors, students, intermediary agents, and local authorities in sharing knowledge, information and thus stimulating inventions and innovations (Broekel and Boschma 2016; Ponds, Oort, and Frenken 2009; Audretsch and Feldman 2004; Audretsch and Stephan 1996; Adams 2002; Anselin et al. 1997; Golejewska 2018). The following study focuses on a relatively less discussed factor – social capital and social networks or larger social structures as a key determinant of the success of the life sciences ecosystem.

The core mission of the following study is to enable the reader to better understand the mechanisms and the significance of the networks and social capital in the selected sample of life sciences university-based ecosystems, as well as draw implications for the new emerging life sciences ecosystems in Poland. Thus, the study analyses the Triple (Quadruple) Helix networks within the life sciences ecosystems from a bottom-up perspective, by studying peoples` behaviour at the grassroots level. The study focuses on three major research problems: 1) the mission, structure and types of social networks; 2) the methods and the intensity of social networking/interactions as well as different dimensions of social capital; 3) the impact of social networks on R&D collaboration, innovative performance and future development plans.

In terms of methodology, most social science researchers acknowledge that the "social capital" and "social networks" are complex issues and therefore, they would benefit most from the integration of qualitative and quantitative approaches. In practice, however, effective quantitative research requires a larger sample size, which was not possible in the case of the following research study, due to the limited time and resources. Therefore, applying qualitative case-study research and direct observations were the best suited method to explore all sides of the social capital within the selected sample of life sciences clusters. The qualitative sample includes five case studies – life sciences ecosystems in San Francisco Bay Area (United States), Cambridge (United Kingdom), Copenhagen-Lund (Denmark/Sweden), Seattle (Washington State, United States) and Poland. The personal 'interview' technique was applied in order to collect in-depth content from the above ecosystems. The concept of a 'university-based ecosystem' was defined as a complex set of relationships among actors from universities and research institutes, enterprises, and other institutions, that lead to an inter-exchange of technology and information, and stimulate innovations. The broad goal of the interviews was to gain knowledge of and insights into how social interaction/networking fosters research collaboration and innovations. The questionnaire contained mixed questions (open and closed ones) and was composed of four parts: (1) the mission, structure and types of social networks; (2) the methods of networking and the intensity of interactions; (3) the role of different types of proximities in social networking; (4) the impact of social networks on R&D collaboration and innovative performance. The authors conducted interviews with the heads and deans of departments, the technology transfer offices (TTO), related educational institutions and companies in the following life sciences cluster ecosystems in the United Kingdom, the European Union and the United States. The list of all interviewed organizations is enclosed at the end of the paper. In order to analyze the evidence gathered, a multistep thematic content approach was applied. The researchers transcribed the interviews to gain preliminary results, then looked for common and different patterns for all the analyzed ecosystems.

The present monograph is divided into seven chapters. The introduction is followed by a presentation of the theoretical and conceptual framework of social networks, social capital formation and university-based innovation ecosystems. The second chapter discusses major trends, developments and the role of technological convergence in the life sciences sector. The next four chapters discuss the life sciences clusters in Cambridge, Medicon Valley, the Bay Area and the metropolitan region of Seattle. The last chapter presents the life sciences cluster in Poland: its structure, important drivers and challenges. The monograph ends with important conclusions and implications for further studies and public policies.

PART I

CONCEPTIONS OF SOCIAL CAPITAL AND ITS ROLE IN LIFE SCIENCES INNOVATION ECOSYSTEMS

Chapter 1

Social Capital Formation and Its Role in the Cluster's Innovation Ecosystem

Małgorzata Runiewicz-Wardyn

1. Introduction

Firstly, the present chapter discusses the concept of social capital and its role in research collaboration, innovation networks in the high-tech clusters and innovation ecosystem contexts. Secondly, it point out the role of physical, cognitive, organizational, social and cultural distances in the stimulating knowledge and information exchange, with particular focus on social trust as an important element for the Triple (Quadruple) Helix networks. The present chapter aims to explore and profile the nature and dynamics of the Triple (Quadruple) Helix (government, university, industry, civil society) model as an enabler of social networks within the university-driven innovation ecosystems. Finally, the chapter discusses the role of different types and strength of social ties in the innovation ecosystems, as well as the role of intermediaries in the exchange of knowledge and information in the view of the subject-related literature.

2. Defining Social Capital

There is also an ongoing process of the institutionalization of the category of social capital as an important factor influencing the social, economic and technological development of regions. Various authors provide similar and slightly distinctive definitions of social capital. Social capital is related to broadly understood formal and informal relations between at least two people. Positive social capital creates relationships based on trust, cooperation, openness, etc., negative capital refers to the social relations that are characterized by the suspicion, hypocrisy and secretiveness (Walukiewicz 2007). In his comprehensive study, Nan Lin (2001) defines capital, as "an investment of resources with expected returns in the marketplace" (Lin 2001: 3). Furthermore, he identifies social capital with such "products" as trust, shared values, and norms. A similar link to the private benefit resulting from social capital was mentioned by Pierre Bourdieu (1986), defining social capital as a private investment in social networks that brings the owner expected benefits, such as wealth, and "symbolic capital" (social position). James Coleman (1988), in turn, regarded social capital as an individual good that could be, however, traded through social networks for the advancement of broader human capital. Finally, the last two decades witnessed many new studies extending social capital from the individual or private good to more of a collective or even public good. This group of researchers include Fukuyama (2001), Putnam (2000), Rosenfeld (2007), Lin (2001), Landabaso et al. 2007, Woolcock and Narayan (2000) and others. According to Francis Fukuyama (2002), social capital is a set of informal norms and rules as well as ethical values shared by individuals and social groups that enable them to cooperate effectively. For Robert Putnam, social capital does not belong to anybody, but is a public good representing a set of social norms and civic attitudes supporting common actions and trust for both interpersonal and in public institutions (Bochniarz and Faoro 2016). Social capital is defined by experts from the European Commission (2005) in a similar manner – "Social capital refers to those stocks of social trust, norms and networks that people can draw upon to solve common problems". In turn, the World Bank defines it as a set of "institutions, relationships, attitudes and values that govern interactions among people and contribute to economic and social development" (Grootaert and van Bestelaer 2002). The institutional and relational context is also present in Roberto Camagni's definition of social capital, which is "the set of norms and values which govern interactions between people, the institutions where they are incorporated, the relationship networks set up among various social actors and the overall cohesion of society (…). [It] is the 'glue' that holds societies together" (Camagni and Capello 2012). The role of networks in the society was further extended in the comprehensive study by Franz Huber who proposes an interesting definition of social capital as "… resources embedded in social networks which can be potentially accessed or are actually used by individuals for action…" (Huber 2008: 19). Furthermore, he distinguishes "internal social capital" – resources mobilized through relationships between members of the collectivity – from "external social capital" – resources mobilized through relationships between members of the collectivity and actors outside of the collectivity. As an example of this dual character of social capital, Huber uses economic clusters, where the distinction depends on access to knowledge within the cluster and access to other clusters and outside individuals (Bochniarz and Faoro 2016). Philip Cooke adds the notions of reciprocity, trust and defines social capital "as the application or exercise of social norms of reciprocity, trust and exchange for political or economic purposes" (Cooke 2007: 102). He argues that knowledge-based industries are more engaged than others in building and performing social capital. Similarly, for Carlos Roman, social capital refers to a system of social relationships based on trust and working according to well-known rules (Landabaso et al., 2007). In turn, Stuart Rosenfeld interlinks the notion of social capital in clusters that gives opportunities to "know-who" to the notion of "know-how". He also classifies social capital from the point of view of openness as positive and negative one (Rosenfeld 2007). Positive social capital creates economic advantages that are major forces for clustering. Negative social capital can develop when there are efforts to limit membership in clusters and cultivate insularity or "lock-in". Finally, Cook and Rice (2006) in their chapter on the "social exchange theory" attempt to link social networks with social status, influence, solidarity, trust, affect and emotion. The authors emphasize the huge role of these connections and the macro-structures they create in the society.

To sum up, there is no common conceptual framework to the social capital concept. However, based on the above-quoted literature and for the purpose of the following study, social capital is defined as a type of capital that results from investments in building relations, institutions and networks that produce collaborative attitudes, shared norms and values as well as mutual understanding and trust.

2.1. Social Network Without or With "Closure"

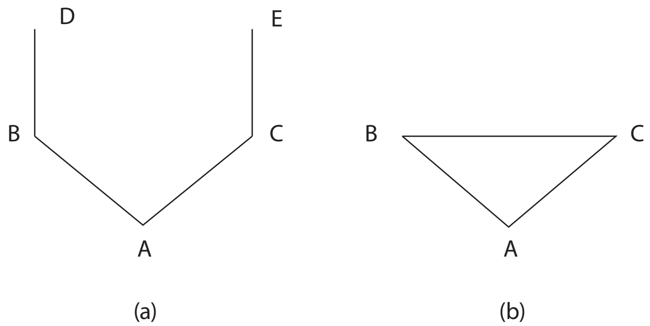
The attempts to conceptualize social capital have resulted in the identification of many different types and characteristics of social capital in the literature. The most common ones refer to the distinction of bonding and bridging, as well as structural and cognitive social capital (Halpern 2004). Bonding social capital is between individuals within a group or community (horizontal ties), whereas bridging is between individuals and organizations in different communities (vertical ties) (Dolfsma and Dannreuther 2003; Narayan 2002). Bonding social capital is related to thick trust, while bridging social capital is closely related to thin trust (Anheier and Kendall 2002).

Most of the literature refers to the Granovetter's (1992) introduced division between between the 'structural' and 'relational' social capital. The first one conforms to the view that social capital constitutes aspects of social structure, and therefore relates to the properties of the social system and the form of social organization. It is the network relationships, but not the quality of these relationships, since the quality of relationships is the relational dimension. Structural social capital facilitates access to the exchange and transfer of knowledge and makes it easier for people to engage in mutually beneficial collective action by lowering transaction costs and improving social learning (Uphoff and Wijayaratna 2000;

Ansari, Munir, and Gregg 2012; Andrews 2010). Relational social capital refers to the nature, characteristics and quality of the relationships within networks, such as trust, obligations, respect and even friendship (Lefebvre et al. 2016; Gooderham 2007; Cabrera and Cabrera 2005).

Furthermore, extending the major themes initiated by the studies of Coleman (1988, 1990) and Burt (2000) on social capital, it is important to distinguish the networks 'with closure' or 'without closure'. The argument for social capital with closure is that it creates strong interconnected elements, and the environment in which everyone is connected (dense network) is the source of social capital (bonding social capital). Coleman (1990) claims that social relations can save time by accessing direct information from different actors. Moreover, according to Coleman, network closure "facilitates sanctions that make it less risky for people in the network to trust" (Burt 2000). Thus, he argues that networks with a closed structure are better at facilitating social capital, as demonstrated in Figure 1.1(a), than social networks characterized by an open structure, which is illustrated by Figure 1.1(b).

Figure 1.1. Social network without and with "closure"



Source: Coleman (1988).

Burt (1992), who introduced the concept of structural hole in networks, argues, on the contrary, that low density and connectivity are the most beneficial features of a social network. He claims that social capital is created by a network in which people can broker connections ("bridging capital") (2000). Structural holes mean that an individual has persons in his or her network that do not know each other, and this is defined as "a relationship of non-redundancy between two contacts", which is illustrated by the hole between contacts in a network that do not have any relationship with each other. This way, that person is more likely to have access to so-called non-redundant information, i.e. information that is fresher and more unique. In turn, Coleman concludes that the quality of information may in fact deteriorate as it moves through different chains of intermediaries. Notwithstanding, Burt (2000) resolves this disagreement in such a way that dense or hierarchical networks lower the risk associated with transaction and trust, whereas the hole argument describes how structural holes are opportunities to add value with brokerage across the holes.

Moreover, Granovetter (1973) distinguishes between strong and weak ties and states that the strength of a social tie is defined by a combination of the time invested, the emotional intensity, the intimacy or mutual confiding between the actors. In other words, ties with a higher degree of emotional involvement are more important in the discovery of a business opportunity, and weak ties become more important when exploiting these opportunities. The described relationship would look as follows: if A has ties with B and A has ties with C, then the amount of time that C spends with B depends (at least in part) on the amount of time that A spends with B and C, respectively. If C and B have no relationship, common strong ties to A will probably bring them into interaction and generate one. Granovetter (1973) refers to that as "the strength of weak ties". The propensity of two nodes that are indirectly connected to form a link is also referred to as the "triadic closure" in the literature (Carayol et al. 2014). The "triadic closure" networks (collaboration with a partner of a partner) are particularly advantageous for international collaborations, in which reliability of different partners may be difficult to assess.

In the context of cluster ecosystem interlinkages, strong ties describe strong relationships, based on trust and are characterized by frequent interaction (both formal and informal one) which lead to a greater exchange of knowledge (Burt 2009; Rowley et al. 2000). At the same time, weak ties could potentially add heterogeneity to the knowledge base of cluster actors.

Table 1.1 presents the classification of the characteristics of bonding and bridging social capital based on the above-presented literature.

Table 1.1. Bonding vs. bridging social capital

Bonding social capital	Bridging social capital
Within	Between
Closed	Open
Inward looking	Outward looking
Horizontal	Vertical
Strong ties	Weak ties
Thick trust	Thin trust
Network closure	Structural holes

Source: Ramos-Pinto (2012).

Notwithstanding, the classification made above may lead to an overly simplified and even contradictory image of the social capital networks. In practice, social relationships are far more complicated and usually accompanied by multiple overlapping relationships that individuals have with each other. Thus, a typical relationship would have some characteristics of bonding and some characteristics of bridging social networks. Last but not least, bonding and bridging are not completely mutually exclusive and the final structure of the network configuration depends on the type of knowledge interlinkages present in a particular cluster, its technological dynamics, as well as the importance of other dimensions of social capital, i.e. physical, cognitive, organizational, cultural and communication ones.

3. Social Capital and Knowledge Sharing

There is no direct link between social capital and innovations. The impact of social capital is associated with the benefits of social networks as mediators in the university and industry collaboration process and their role in the softer forms of innovation, e.g. non-technological innovations, such as new methods concerning organization, research or marketing. In order to understand that better, one should refer to the evolutionary roots of technological change and innovation policies. In fact, until 1960s, the industrial innovation model followed the “technology push” concept, which means that it was basically perceived as a linear progression from a basic scientific discovery to the marketplace. From the mid-1960s to the early 1970s, a second-generation innovation model emerged based on the “market pull” concept of the innovation process. According to this model, the market was the source of new ideas, whereas the R&D was a reactive process to the market need. However, neither of these models considered real feedback and loops that occur between the different “stages” of the innovation process. In the case of innovation, one deals with creative activity which, as in science and art, is characterized by low susceptibility to all kinds of model generalizations. Thus, in order to understand innovations, one should learn what mechanisms give rise to innovative impulses and knowledge and information sharing associated with innovation processes. What stimulates inventiveness, innovations and their successful application? How does collaborative behavior strengthen innovation impulses? Providing unambiguous answers to these questions seems to be a big challenge.

A successful innovation involves more than a great idea. Therefore, social capital is a key component of broadly understood socio-economic development in the knowledge-based economy (Walukiewicz 2012). Even if it is ground-breaking, one needs to promote the idea so that others adopt it or buy it. Collaborating with others expands one’s social circle of connections to make things happen. Furthermore, increasing technological convergence incorporates diversity into the group and allows individuals to do a combination of individual and group work. As Robert Weisberg (2006) puts it, an innovative solution is often a combination of ideas, from conception to delivery. He studied famous creators and suggested that creative production results from "chains" of connected ideas that flesh out the original thinking. Collaboration with others can speed up the chains of connected ideas that result in something innovative. Speed is the last great competitive advantage, so if one wants to deliver something fresh, speed is crucial to delivering an innovation before others do. Having open-minded people around can quickly validate whether the idea will have merit and help build upon that idea. Alternatively, they can help one save time by burning through bad ideas (Karpa 2019). There are many studies focusing on the knowledge sharing process and its impact on innovation capability and innovation performance of firms (Kamas and Bulutlar 2010; (Emelo 2012; Suppiah and Sandhu 2011; Fong et al. 2011; Tohidinia and Mosakhani 2010; Kamasak and Bulutlar 2010; Lin 2007). It is something more than data or information and could be associated with justified specific and true belief, and classified into two types – explicit and tacit. The first type can be documented, codified, and expressed in formal language for easy access. The second type, in turn, is "uncodified" and thus incorporated into personal thought. Both complement each other and therefore are indispensable to create new knowledge and innovation. Thus, organizations encourage people to share their own individual knowledge, in order to achieve the greater benefit of knowledge embedded in workers' heads (Suppiah and Sandhu 2011). In this context, knowledge sharing can be defined as a process by which people exchange their tacit and explicit knowledge to create new knowledge together (Hooff et al. 2012). In a similar manner, Lin (2007) defines knowledge sharing as a process of social interaction by which people can exchange mutual tacit and explicit knowledge, experiences and skills within the organization. Thus, knowledge sharing involves mutual social behavior of individuals sharing their knowledge for the common good. Based on the above definitions, knowledge sharing involves two interlinked processes of collecting and donating knowledge (Lin 2007).

Although knowledge sharing is advantageous for both individuals and organizations, it is not an easy process, which does not occur spontaneously (Cao and Xiang 2012; Burke 2011; Tohidinia and Mosakhani 2010). Many people may feel the risk of losing their knowledge and thus have well-justified reasons to reject sharing their own knowledge (Husted et al. 2012; Aljanabi and Kmar 2012). Therefore, organizations come to different solutions to how to acquiring, developing, and strategically leveraging knowledge (Zboralski 2009; Drucker 1993; Kogut and Zander 1992; Leonard-Barton 1995; Nonaka and Takeuchi 1995). In this context, the concept of 'communities of practice' has gained considerable attention. The term 'communities of practice' refers to "a group of people in an organization who interact with each other across organizational units or organizational boundaries due to a common interest or field of application in order to learn and support one another, create, spread, retain, and use knowledge relevant to the organization" (Zboralski 2009). The development and growth of any company or research facility lies within the people and their mutual interrelationships. Therefore, members of the communities of practice should be nurtured in every possible way. Overall, knowledge sharing is a deliberate effort occurring with the existence of sufficient trust and willingness of individuals to participate in social interaction in order share their experience, skills and knowledge with others. Hence, in order to innovate in an efficient and timely manner, organizations – private and public ones – need to create a proper environment, where individuals could share knowledge and collaborate.

4. The Role of Social Capital in Clusters and Innovation Ecosystems

Last decades showed that both collective and private approaches to social capital have been very useful in explaining successful dynamic externalities and competitive advantage of many regions. Many international organizations, such as the European Commission, IMF, World Bank and OECD, put intense efforts to support local and regional social capital initiatives (European Commission 2005; Grootaert and van Bestelaer 2002; OECD 2001). Perhaps the first notion of the role that social capital plays with regions was already mentioned by the author of agglomeration externalities literature – Alfred Marshall (1920) – in his core argument that there are forces outside the organizations, but within a region that contributes to firms' competitive advantage. More recent concepts of clusters and innovation ecosystems extend this argument (Weresa et al. 2017; Kowalski 2016). For example, Michael Porter (2008) refers to the 'functional clusters' as spatial networks of like and functionally-linked industries, which enjoy basic positive externalities from geographic proximity (co-location) and frequent interactions. The progress of integration within these clusters moves up to the level of 'working clusters', where firms and other organizations, including academic, governmental and other institutions maximize benefits from the synergetic effects coming from integration, cooperation, and competition within the clusters. In fact, as Kowalski and Marcinkowski (2014) put it " the ability to quickly innovate maybe facilitated by opening up to other entities participating in the cluster ecosystem". Furthermore, Bochniarz and Faoro (2016) refer to the effective cluster, which is characterized by the rich social capital that enables all participants to efficiently cooperate with one another, which leads to the increased generation of positive externalities coming from co-location and building collaborative synergy within the cluster, as well as openness for cooperation with other clusters, which leads to knowledge spillovers among them and increasing innovations. Furthermore, the economic value of social capital depends on the time invested in developing relations and networks, institutions and shared values, attitudes and trust within a certain group of people. This investment begins at the micro level, for example a family/friends and continues through firms, clusters and regions, to the macro level of a nation or even global community (Bochniarz et al. 2008).

A more recent concept of 'innovation ecosystem'[1] develops from cluster perspectives, acknowledges that people, with their ability to create, integrate, and provide a supportive environment are at the heart of successful innovations. An innovation ecosystem refers to a loosely interconnected network of organizations that co-evolve capabilities around a shared set of technologies, knowledge, or skills, and work cooperatively and competitively to create new products and services (Moore 1993). Furthermore, processing and creation are aided by close proximity to the leading technological firms and research institutions, e.g. university labs. Granstrand and Holgersson (2019) propose the construct of innovation ecosystems and define it as "the evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors." Thus, the ecosystem approach requires an in-depth understanding of the objectives and the incentives that each actor has. The ecosystem approach views the perspective of all types of heterogeneous actors and intends to provide an unbiased perception and understanding of their interests. It investigates the specific incentives and behavior of the different types of actors and organizations in order to find out how they can collaborate successfully in innovation ecosystems.

Phillips (2006) argues that social capital is essential for a region to advance the knowledge environment enhancing high-tech economic development. Hence, the region must build trusting alliances and partnerships and promote networking as one of the key factors supporting successful clusters. According to Sztompka (2016), a cooperation, trust, and a fair exchange make up the so called "moral space" which is at the core of every community. In this sense, effective clusters and innovation ecosystem approach the same issue – the connections between the entrepreneurship process, localized economic and social contexts and knowledge spillovers (the importance of entrepreneurs drawing on knowledge outside of the firm to increase their competitiveness). As stated by Bochniarz and Faoro (2016), the 'effective cluster' is characterized by "rich social capital that enables all participants to efficiently cooperate with one another, which leads to the increased generation of positive externalities coming from co-location and building collaborative synergy within the cluster, as well as openness for cooperation with other clusters, which leads to knowledge spillovers among them and increasing innova-

[1] Here, the term 'ecosystem' alludes to the biological sense of the ecosystem. One could find several different types of ecosystems in the subject literature: the business ecosystem, innovation ecosystem, technology ecosystem, entrepreneurial ecosystem, etc.

tions”. This loosely-coupled structure helps to create a culture of innovation within the cluster ecosystem, allowing innovative ideas to not only be formed, but also to thrive and grow. In the effective cluster, groups involved in innovative projects will reach out to each other directly to solve problems rather than require a central office to mediate all communications. In the same spirit, the concept of ‘innovation ecosystems’ refers to dynamic communities who share complementary technologies and skills. Just like in the cluster theory, the innovation ecosystems take major research traditions in entrepreneurship, economic geography, and regional science, clusters and regional innovation systems.

The heterogeneity of participants in the innovation ecosystem models is of particular importance and difficulty when considering ecosystem boundaries. In the context of ecosystems, Mitleton-Kelly (2003: 30) makes a difference between endogenous (individuals and groups within the organization) and exogenous (organizations within the ecosystem) learning and transfer of information and knowledge. Furthermore, she states that “each organization is a fully participating agent which both influences and is influenced by the social ecosystem made up of all related businesses, consumers, and suppliers, as well as economic, cultural, and legal institutions.” Formal relationships among organizations and their actors merge with the personal network(s) in their particular social context in the innovation ecosystem.

The relation between innovation and social capital was also empirically examined by Hauser et al. (2007). The study covered a sample of European regions and applied the knowledge production function which also included a variable of the factorial value of social capital in order to explain the innovative output of regions. Their empirical results suggest that social capital does have a considerable impact on the production of knowledge. Furthermore, different dimensions of social capital have different effects on the innovation rate, i.e. the positive relationship between the weak ties in social interaction and innovation. Similar effects were also obtained by the researchers examining the importance of regional social capital for firms’ innovative capabilities. Their findings explain the importance of social capital in moderating the effectiveness of externally acquired R&D for innovations (Laursen et al. 2007). The study focuses on the structural dimension of social capital and combines the data on social capital at the level of 21 regions with data on innovative activities from a sample of 2,464 manufacturing firms in Italy. The authors argue that, after controlling the firms’ characteristics and regional ones, co-location in regions characterized by high levels of social interaction leads to a higher propensity to innovate as well as a higher influence of externally acquired R&D on innovation.

Finally, Ostergaard (2009) analyzed knowledge flows through social networks in a communication cluster in North Jutland, Denmark. The author aimed to answer to what extent social networks contribute to channeling knowledge flows between firms and the local university among engineers and computer scientists. Ostergaard's study proves that there are differences between extent and frequencies for the two types of informal contacts (between the firms and between the firms and the university). Mainly, both in case of the university-industry and industry-university informal contacts are less frequent (for example, a lower share of the engineers acquire knowledge from informal university contacts). These findings contradict the belief that knowledge sharing between firms is more likely to endanger their competitiveness, compared to university-industry knowledge sharing.

Contrary to the cluster theory in the innovation ecosystem theory, physical proximity is not the main condition for social proximity. For example, Feldman (1999) in her studies demonstrates that the decisions "by pioneering faculty members to start a company lead other faculty members to found companies as well", suggesting that physical proximity might not be enough to create the 'contagion effect' for the local university-based ecosystem players and the occasions for learning and knowledge exchange seem to be facilitated by a high level of the embeddedness of their social relations with other actors. The trustful relations among actors, driven by friendships or common experiences, encourage the further development of new networks and exchange of tacit knowledge between related actors (Maskell and Mallberg 1999; Ziemiański 2018). It is, in fact, defined in terms of "socially embedded relations between agents at the micro-level" (Boschma 2005). Therefore, common friendships and experiences among actors guarantee trust-based relations among the actors. These trust-based relationships also help building an open attitude of "communicative rationality" (Lundvall 1993), rather than market-oriented narrow communication between the members of the community. Contrary, Boschma (2005) evidenced that social networks are location-specific, suggesting that knowledge spillovers are geographically localized as well.

In sum, even though the two concepts – the cluster and innovation ecosystem – overlap in many areas, there is still much confusion and little understanding of what role is played by the physical, social and other types of proximities in the formation of the effective clusters and their innovation ecosystems. The next chapter attempts to contribute further to this discussion.

4.1. The Physical, Cognitive, Institutional, Organizational and Socio-cultural Dimensions of Social Capital

The research study by Boschma (2005) provides further observations and identifies several types of drivers or proximities facilitating personal interactions and the exchange of knowledge and information, such as physical, cognitive and technological, social, cultural and organizational one. In reference to the first one, knowledge spreads more rapidly in agglomerated urban areas and in close *physical proximity* to major universities. The role of university collaboration networks in geographically mediated knowledge spillovers has been emphasized and evidenced by a number of studies conducted by Baptista (2001), Adams (2002), Trajtenberg et al. (1997), and Ponds, Oort, and Frenken (2009). Interactive, huge, and diverse social capital makes large agglomeration regions with proximity to academic institutions ideal locations for the social networking events and knowledge exchange.

Yet, Feldman (1999) demonstrates in her studies that, for instance, the decisions of "academics to start a business were socially conditioned", suggesting that physical proximity might not be enough to create the 'contagion effect' for the local university-based ecosystem players and the occasions for learning and knowledge exchange seem to be facilitated by a high level of the embeddedness of their social relations with other actors. This is contrary to Boschma (2005), who has proven that social networks are location specific, suggesting that knowledge spillovers are geographically localized as well. Furthermore, the seminal study by Powell et al. (1996) on social network structure and innovation in the life sciences sector found that the nature of previous ties was an indicator of positional strength in these networks. In sum, it means that the role of physical and social proximities are self-reinforcing in stimulating knowledge exchange.

A relatively small number of researchers have investigated the role of *cognitive skills* and technological relatedness in the knowledge spillovers. Some titles include the works of Petruzzelli (2011), Nooteboom (2000), Nahapiet and Ghoshal (1998), Brockhoff and Teichert (1995). The cognitive dimension of social capital contains two main factors – shared codes and languages, and shared narratives. The empirical findings indicated that the respondents utilized network ties to old classmates to discuss and develop their business ideas, which can be related to shared codes and languages (Nahapiet and Ghoshal 1998). The creation of social capital may be influenced positively if people perceive and interpret the environment similarly and if they have some overlap in knowledge, they might be more able to combine their knowledge. The existence of shared language and codes leads to the creation of social capital. As Adler and Kwon (2000) put it, "social capital is unlikely to arise among people who do not understand each other" (p. 99). In fact, 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 the cognitive similarity between individuals: communication codes, written specific technical language, common professional or scientific backgrounds. In turn, the second level of homogeneity refers to the cognitive similarity between independent organizations (in their knowledge bases, capabilities, competences, experiences). Having an overlapping knowledge base and a shared technical vocabulary enhances the actors' ability to communicate and exchange information (Nahapiet and Ghoshal 1998). A similar conclusion in relation to partners' cognitive proximity or greater technological relatedness was made by Petruzzelli (2011). The author 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.

The *institutional proximity* refers to the interaction among actors from various institutions within the Triple Helix spheres. Much of the Triple (Quadruple) Helix literature focuses on the institutional spheres of university, industry and government in a holistic way, without going into detail about the specific actors within each sphere, their institutional identities, objectives and social interaction dynamics. As Jensen and Tragardh (2004) put it, cooperation within the Triple (Quadruple) Helix model is complex, dynamic and ambiguous, thus the institutional architecture of a particular Triple (Quadruple) Helix relationships model may differ by sector, e.g. in the case of aerospace, the government would occupy a larger role than in the life sciences. Furthermore, geographical proximity can facilitate collaboration between the institutions, however, social interactions and trust can make these interactions smoother and more successful.

Furthermore, several authors provide evidence that *organizational proximity* leads to knowledge sharing and stronger social ties on interorganizational and the intra-organizational levels (Boschma 2005; Antonelli 2000; Monge et al. 1985). The latter division results from the fact that knowledge and information spills over from one organization to another, 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 one. The interorganizational proximity can be further distinguished from the low (loosely coupled) social networks and weak ties between autonomous organizations, to the highly networked ties, 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 low proximity. Through interorganizational and the intra-organizational cooperation organizations attempt to increase their revenue, mitigate competition and gain access to crucial know-how, skills, complementary resources and capabilities (Ingram and Yue 2008; Kilduff, Tsai, and Hanke 2006; Powell, Koput, and Smith-Doerr 1996). Several researchers have tried to explain empirically the formation of interorganizational networks focusing on different levels of analysis. The study by Di Vincenzo et al. (2014) considered the structural dimension of social capital within a regional community of hospital organizations in Italy. The researchers conducted the original fieldwork and collected data on patient transfer relations. Their findings show that bigger hospitals have higher propensity to form more ties between them, and that belonging to the same Local

Health Authority (i.e. administrative unit) has a positive impact on collaboration. Their results overlap with the results of other studies, including those by Feldman (2000), Filippi and Torre (2003), particularly in the sense that same-size hospitals shared a common understanding of the working practices and similar routines. Furthermore, as organizations interact, they tend to become more similar in their structure, strategies, and behavioral approach, and therefore, they may find it easier to coordinate their activities (Powell et al. 2005).

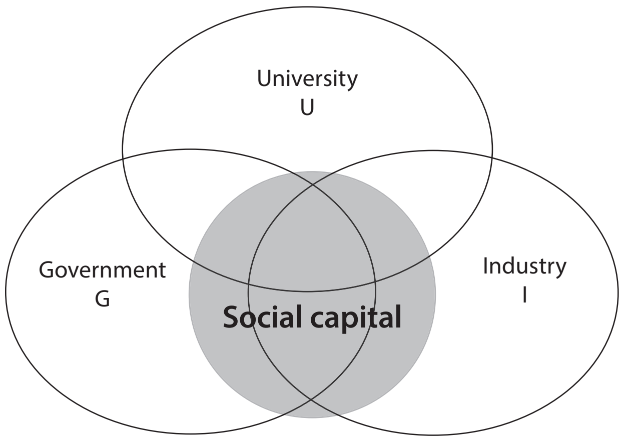
Last but not least, research shows that shared norms and beliefs in networks and social relations play an important role in the creation of social capital (Adler and Kwon 2000). The norms refer to the unwritten *social and cultural rules* for how people should behave in various social relations and contexts. Nahapiet and Ghoshal (1998) state that social norms represent a degree of consensus in a social system and that 'norms of cooperation' may influence the creation of social capital. These norms have an influence on people's attitudes and motivations toward social interactions and social exchange, which, on the other hand, affects the social capital embedded in a network. 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. For example, a culture of shared trust and similar habits can make knowledge transfer easier and people more willing to exchange information. In the same manner, Powell et al. (1996) found that the nature of previous ties was an indicator of positional strength in the networks in the life sciences sector. Notwithstanding, studies by Gordon and McCann (2000), point to out the risk of "too much social proximity", which means that people only relate to those to whom they are socially proximate. Furthermore, the study by Nahapiet and Ghoshal (1998) has shown that trust between the actors in a relationship has a positive influence on their willingness to interact with each other and thus facilitate social capital formation. Moreover, Adler and Kwon (2000) argue that trust should be viewed as both a source and an effect of social capital, since trust and social capital are interrelated. This means that some initial trust is needed in a relation in order to create social capital, which in turn will enhance the level of trust in the relationship. In addition, Nahapiet and Ghoshal (1998) suggest that trust may provide a person with access to people and higher expectations for the outcome of a relation. Obligations and expectations influence social capital through the access to people within a network (Nahapiet and Ghoshal 1998). An example could be that person A has a "credit slip" for person B and the return of a favor could be that person B introduces person A to person C. Obligations and expectations might also influence people's motivation to interact (Nahapiet and Ghoshal 1998), and an example of this situation could be that person A is grateful for a favor received by person B and wants to show some appreciation by returning the favor. As stated by Stanford sociologist, Karen Cook (2005), "Trust leads us to take risks of cooperating with others and therefore to enter into many social relations, some of which may provide social capital."

All of the relational factors discussed so far are interrelated and will influence each other. Trust and norms in a network influence the obligations and expectations that people have on each other, and the other way round, fulfilled obligations and met expectations affect the trust in the relationship. Time is an additional factor that is of importance in the creation of social capital. Stability and continuity in the social structure are important in order to develop trust between network actors (Nahapiet and Ghoshal 1998). This indicates that relational and cognitive factors of social capital, such as trust, norms, and shared narratives, are more likely to develop over time and, hence, that the amount of social capital also increases over time.

5. The Role of Social Networks in Triple (Quadruple) Helix Interlinkages and Innovation Networks

The theoretical concept behind the social networks within the innovation ecosystems originates from the theory of the Triple Helix (TH) – university-industry-government interlinkages and the more recent theory of Quadruple Helix (QH) university-industry-government-society interlinkages. Both the Triple Helix (TH) concept and the (QH) approach are grounded on the idea that innovation is the outcome of an interactive process involving different spheres of actors, each contributing in accordance with its 'institutional' function in society.

Figure 1.2. The role of social capital in Triple Helix networks



Source: own elaboration.

Contribution to innovation is envisaged in terms of knowledge sharing and the transfer of know-how, with the helices models assigning and formalizing a precise role to each sphere in supporting economic growth through innovation (European Commission 2016). Three, important elements are common for both analytical models of TH and QH: 1) the institutional element, covering actors from university, industry and government sectors; 2) the relational element, involving the relationships between all the mentioned actors, which include collaboration, moderation, leadership, substitution and networking; and 3) the functional element, described as processes taking place in what Etzkowitz (2008) calls "Knowledge, Innovation and Consensus Spaces". All the three elements – the institutional, the relational, and the functional one – involve an interactive learning process in which innovation is seen as socially and territorially embedded. Social capital provides important "positive associative effects for networks of heterogeneous agents in the triple helix geared to interactive innovation" and on the process of collective learning and innovation in the Triple Helix (Cooke 2003; Asheim and Coenen 2005). Furthermore, Adler and Kwon (2002) mention that social capital facilitates access to relevant knowledge and information sharing. Yet, social capital may involve risks and disadvantages resulting from too strong solidarity with in-group members, which may lead to the institutional and cognitive lock-in (Woolcock and Narayan 1998). As stated by Powell and Smith-Doerr (1994: 393), "The ties that bind may also turn into ties that blind." Thus, one of the questions arising is whether and how social-capital-based learning can be actively mobilized in a Triple Helix system (see *Triple Helix Networks and the Role of Intermediaries*).

The Evolutionary Development of Innovation System

Over the last two decades, a significant body of Triple (Quadruple) Helix theoretical and empirical research has been developed along with two main complementary perspectives: a (neo)institutional and a (neo)evolutionary one. The first one examines various Triple (Quadruple) Helix configurations and inducing mechanisms in national and regional contexts (e.g. Etzkowitz, Mello, and Almeida 2005; Saad and Zawdie 2011; González-López et al. 2014). The second one looks at university, industry and government as co-evolving subsets of social systems that interact through market selections, innovative dynamics, network controls, and communicate through specific codes (Etzkowitz and Leydesdorff 1995). In addition, a number and scope of other spheres, such as civil society and social interactions, became increasingly important in the innovation generation and diffusion processes. As a result, the relationships within the Triple (Quadruple) Helix model became complex and dynamic.

The beginning of the modeling efforts of this complex relationships between knowledge creation and its role in technological change in modern societies could be found in the book *The New Production of Knowledge – The Dynamics of Science and Research in Contemporary Societies* (Gibbons et al. 1994). The authors formalized two ways of knowledge production – Mode 1 and Mode 2. The first one refers to a knowledge production system led by universities as basic performers of basic research and suppliers of educational content structured in 'disciplinary logic', yet not focused on knowledge application (Gibbons et al. 1994). The second one refers to a knowledge production system led by universities based on the principles that science is applied and technology is transferred. As the authors put it, "there is sufficient empirical evidence to indicate that a distinct set of cognitive and social practice is beginning to emerge and these practices are different from those that govern Mode 1" (Gibbons et al. 1994). Over a decade afterward, Carayannis and Campbell (2006) introduced a third model – 'Mode 3', which is more complex as it has a higher number of interconnections and actors involved. Mode 3 entails the learning processes and dynamics of Mode 2, while integrating them with a bottom-up approach including civil society. The Mode 3 is a "(…) multi-layered, multi-modal, multi-nodal, and multi-lateral system, encompassing mutually complementary and reinforcing innovation networks and knowledge clusters consisting of human and intellectual capital, shaped by social capital and underpinned by financial capital" (Carayannis and Campbell 2009; 2006). Based on the definition of Quadruple Helix (Mode 3) provided by Carayannis and Campbell, Mercan and Göktaş (2011) formulated a definition of a modern innovation ecosystem: "an innovation ecosystem consists of economic agents and economic relations as well as the non-economic parts such as technology, institutions, sociological interactions, and the culture."

Unfortunately, there are still few studies that applied the social network concept in an empirical manner with regard to examining the social context of the research links between universities and industry sectors in a local innovation ecosystem (Vonortas 2009; Tortoriello 2015; Kim et al. 2018). The policies from such studies may help strengthen the links between universities and local communities, and boost innovativeness and the quality of life in regions. In fact, universities and their social environments are the key players in the technological, social and economic development of their communities. They serve as intermediaries between scientific knowledge and markets, and in such a way, they promote the diffusion of innovations and foster competitiveness (see the works of Huggins et al. 2019; Johnston and Huggins 2017; Kim 2013; Hughes and Kitson 2012; Garnsey and Heffernan 2010; Chapple et al. 2005; Feldman, 1999; Kenney 2000). What is more, universities, unlike industries, are characterized by open knowledge creation and dissemination environments, whereas companies limit access to their produced knowledge. As a result, universities and their ecosystems are considered to be natural environments for local knowledge spillovers.

Triple Helix Networks and Technology Dynamics

The interaction between individuals or various institutional entities (groups, organizations) plays a critical role in articulating and amplifying knowledge (Nonaka

1995). Yet, as Jensen and Tragardh (2004) put it, the institutional and social interactions architecture of particular Triple (Quadruple) Helix relationships model may differ by sector and its technological maturity, e.g. in the case of aerospace, successful research and innovation strategies cannot be effectively formulated and implemented without the government support, whereas in the life sciences, successful innovation depends on the basic and preclinical research in the life sciences, the bulk of which is done at the universities. Thus, it is possible to assume that certain types of dynamic externalities and social interactions assist the industry along its life cycle – from a young to a more mature stage.

It could be explained further based on a stylized description of the typical life cycle model, which follows the logistic S curve, starting with the introduction of new products, followed by a period of strong expansion of production, which then levels off and eventually leads to a decline. A new industry or industries at the introductory stage of their development benefit mostly from diverse knowledge infrastructure and inter-industry knowledge spillovers. Innovation intensity is high, as there are many unexplored technological opportunities (Neffke et al. 2009). At the growth stage of industry development, production becomes more standardized, which opens up possibilities for firms to exploit their divisions of labor and economies of scale. At the stage of maturity, firms typically face vigorous price competition. Profit margins are reduced and technological opportunities are exhausted. In terms of innovation, longer jumps in technology are less likely and so are radical innovations, as the industry has already invested heavily in technology and skill development. The R&D efforts require very specialized, fresh knowledge and skills. Such expertise is best acquired through processes of local tailor education, training systems and access to the university R&D labs and research output. The content of the social ties (both formal and informal ones) between the above actors is different, depending on the types of information and knowledge exchanged between them. In this context of social networking and co-location, next to the leading universities create positive externalities and are especially important for the industries that are undergoing rapid technological change or are in the growing stage of their economic life cycle.

In sum, the evolutionary (Triple) Quadruple Helix literature goes beyond the institutional interlinkages of university, industry, government and society, by going deeper into the specific actors within each sphere, their identities, objectives and social interaction dynamics. Therefore, the evolutionary approach of the Triple (Quadruple) Helix interlinkages addresses better the needs of the following study as well as the reality of the biopharmaceutical sector.

Triple Helix Networks and University-Based Innovation Ecosystem

The evolutionary approach to the Triple Helix interlinkages also revolves around the role of university in the community, and the broader economic development of regions. Etzkowitz (2000) refers to a new type of university – 'entrepreneurial university' – which takes an active role in the creation and practical application of knowledge, becoming a key contributor to innovation, as well as to the welfare of a country (Etzkowitz 2013). This approach gave a greater impulse to recent policies and incentive schemes designed to encourage interactions among universities, government and industry and support the so-called 'third mission' of universities in addition to teaching and research (Molas-Gallart et al. 2002; Rasmussen et al. 2006), via their active involvement in a variety of knowledge exchange activities with societal and economic/industrial partners (Huyghe and Knockaert 2015; Guerrero and Urbano 2012). Nevertheless, some earlier studies i.e. by Lee (1996), Florida and Cohen (1999), Cohen and Noll (1994), Blumenthal et al. (1996), Brooks and Randazzese (1999) and others point to a possible detrimental impact of combining academic research and business-related activities and a lack of synergies between both activity realms (Lee 1996). The conflicting nature of normative principles that guide academia and business sectors were at the base of these conflicts and concerns. This idea of conflicting nature has been also at the roots of the so-called 'corporate manipulation thesis' that warns against corporations seeking control over university research and use manipulation in order to make it useful to their own agendas (Mazza et al. 2008; Noble 1977). Florida and Cohen (1999) point to the risk of applied research being executed at the cost of basic research endeavors. The survey conducted by Florida and Cohen (1999) at the US university–industry research centers, suggested that research centers that valued the mission of improving industrial products and processes devoted relatively less R&D efforts to basic research in comparison to the research centers that did not value the industry-oriented mission. Blumenthal et al. (1996) conducted a survey in the life sciences faculties and companies that supported them. Their findings proved the existence of some secrecy problem, which resulted in faculty practices in delaying publications and restricting information sharing to gain enough time for the sponsoring company to file a patent application. Similarly, Cohen and Noll (1994) and Blumenthal et al. (1996) pointed to the existence of practices of secrecy that disrupted the free dissemination of scientific knowledge. Brooks and Randazzese (1999) evidenced such secrecy practices, yet also pointed to the fact that the best research universities seemed to make only modest concessions to the practical needs of the industry. On the other hand, in the more recent studies by Van Looy (2004), no empirical evidence was found that supported a correlation between an increase in the applied research and poorer outcomes in basic research. In the lack of sufficient evidence to the potential conflicting interests between academic research and business-related activities, the debate remains still very much open. Regardless of its final outcome, today, university needs to adapt its mission to have a relevant role in fulfilling societal and economic needs. Mainly, the university needs to add an entrepreneurial spirit to sustain its initial mission of a knowledge generator (Siegel et al. 2003; Etzkowitz 2013; Grigg 1994). Following the thought of Rosemberg and

Nelson (1994), the industry and academia need to understand and leverage their competitive advantages in order to attain greater effectiveness of their mutual efforts and enhance innovation. Both must join their strengths – the university's research capabilities and the continuous input from fresh minds (Etzkowitz and Leydesdorff 2000), and the industry's production and commercialization skills (Rosemberg and Nelson 1994). The latter, on the other hand, requires strong and tight networks between the actors belonging to these two helices. The attempts to introduce the 'entrepreneurial university' into the context of the regional innovation ecosystem resulted in the origin of such terms as the university-based technology ecosystem (Graham 2013) or the university-based innovation ecosystem (UIE), applied in the following study. Both concepts link to the university's role in generating scientific knowledge and exploiting it to innovate. The notion ecosystem provides a metaphor to describe a range of interactions and interlinkages between university, industry and other organizations. The UIE applies the same logic as the 'innovation ecosystem', which postulates that "value is co-created in a non-linear way by a multitude of independent actors", located in geographical proximity to one another, who identify with the same ecosystem community (Iansiti and Lieven 2004; Thomas and Autio 2012). Furthermore, the networks of formal relationships among these actors in the ecosystem merge with the personal networks. The typical ecosystem includes actors from university and research centers, technology transfer offices (TTO), incubators, science parks, scientist entrepreneurs, start-ups, industry and consultancy firms, investors and venture capitalists, governmental institutions and intermediaries acting as network catalysts. The significance of intermediaries and "network brokers" for understanding and recombining cross-disciplinary related challenges and solutions to generate innovation potential deserve special attention and are discussed below.

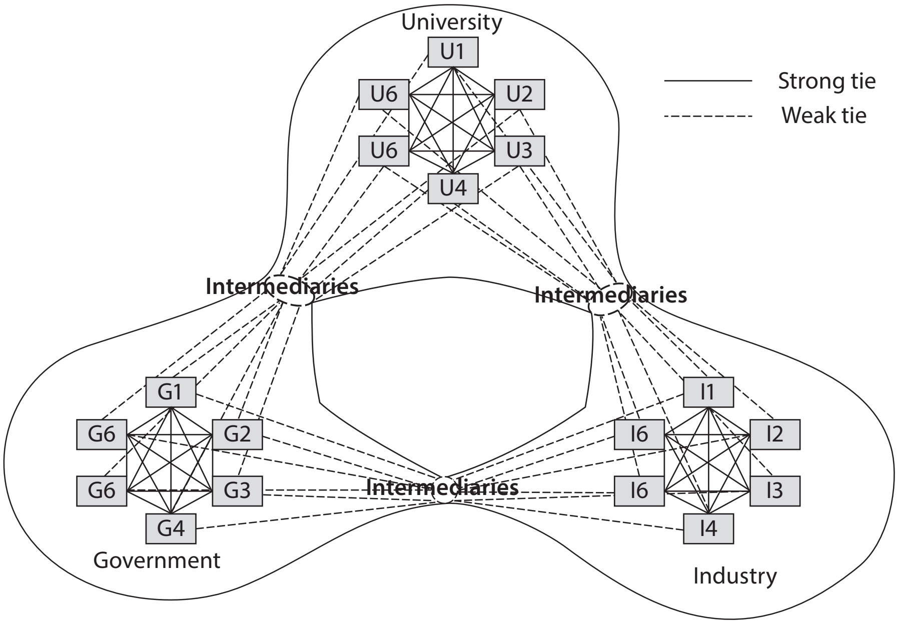
Triple Helix Innovation Networks and the Role of Intermediaries

Even though the concept of 'innovation networks' has gained popularity in the recent decade and much research has been dedicated to the relation between networks and innovation outcome, the problem with its definition still remains unsolved. Some authors attempt to establish a level of formality among ties in the innovation network and classify them (Gulati et al. 2000; Moller et al. 2002), others claim that networks are "boundaryless" (Ford et al. 2002; Iacobucci 1996; Hakansson and Ford 2002). For example, Moller and Rajala (2007) define innovation networks as "relatively loose science and technology-based research networks involving universities, research institutions, and research organizations of major corporations," while Iacobucci (1996) gives a very broad definition of networks which are "a set of actors and the relational ties between them." What is more important is the role that networks play in the efficiency of the Triple Helix interlinkages. Moenzart et al. (2000) emphasize that the process of information sharing within a network depends on the communication efficiency between the actors in the network. Furthermore, Powell 1990; Seppanen et al. 2007; Rowley et al. 2000; Cravens et al. 1994 emphasize the importance of trust in the network's success. Their research shows that networks with a higher level of trust require less coordination and lower governance costs. Such networks constitute an important source of new information and knowledge and play a supporting role in the innovation process. Networking between the Triple Helix actors enhances learning and development processes though creativity and innovativeness. Networks enable the exchange and convergence of diverse knowledge streams, which is necessary for the synthesis of ideas to culminate in innovation (Balthasar et al. 2000; Madill et al. 2004; Knorringa and van Staveren 2006; Capaldo 2007; Menzel and Fornahl 2007). Moreover, by integrating competencies of heterogeneous actors that constitute network dynamics, new processes of knowledge conversion emerge within the Triple Helix system. As explained in the earlier sections, 'external structural holes' arise due to differences in culture, resources, competencies and knowledge profiles between players in different institutional spheres or knowledge networks (Burt 2000). These differences may enhance cognitive distances and keep firms far apart. Yet, network players may use these as potential sources of new and non-redundant knowledge. For this to happen, intermediaries serve as bridge-builders (Burt 2000) and transform external structural holes into 'weak ties' that provide the basis for macro-knowledge circulation (Etzkowitz and Dzisah 2008) and create the opportunity for innovation through the combination of heterogeneous knowledge categories (Nonaka and Takeuchi 1995; Pyka 2002; Knorringa and van Staveren 2006).

Internal structural holes among firms with knowledge proximity arise from the lack of trust. The presence of internal structural holes means that firms or research institutions would be unwilling to share knowledge with one another. Such attitudes lead to a sub-optimal level of knowledge circulation among firms within the knowledge networks and hence to sub-optimal levels of network capital and technological capability development (Johnson 2009). Intermediaries and 'network brokers' can close these internal structural holes and transform them into strong ties that provide the basis for micro-knowledge circulation (Etzkowitz and Dzisah 2008; Ahuja 2000). Knorringa and van Staveren (2006) refer to this closure process as 'bonding social capital'.

As can be seen in Figure 1.3, a triple helix collaborative network contains both strong and weak ties. Strong ties of social networks within institutional spheres facilitate communication and collective actions as well as the complementarity of heterogeneous actors with different knowledge profiles. The latter provides the condition for new knowledge creation and innovation collaboration. On the contrary, interconnections within Triple Helix institutional spheres may be dysfunctional where 'structural holes' remain unclosed and unbridged. In this case, intermediaries are necessary to transform them into triple helix networks (Nakwa et

Figure 1.3. Role of intermediaries in the Triple Helix networks



Source: Nakwa and Zawdie (2012).

al. 2012). The intermediaries play sponsoring roles by providing guidelines and funds to promote network development, as well as brokering roles, linking actors and building collaboration mechanisms. They provide funding to create collective actions for building trust and thus closing internal structural holes. They also promote investments in the latest state of art technology and human resource development, therefore, they improve the absorptive capacities of network players, which reduces cognitive distances between actors in different institutional spheres, and thus bridge external structural holes. Last but not least, the intermediaries act as boundary spanners, providing operational services and facilitating knowledge circulation. As such, they (1) facilitate the exchange of tacit knowledge between actors within the institutional spheres through socialization; (2) convert tacit knowledge shared by actors within institutional spheres into explicit knowledge through externalization; (3) help upgrade technological capability of network players across knowledge boundaries and stimulate combination of the diverse knowledge strands of heterogeneous actors; (4) help commercialize newly combined knowledge or innovation, thus creating economic value through 'internalisation' (Nonaka and Takeuchi 1995; Nakwa and Zawdie 2012). In sum, the intermediaries play an important role in the evolution of triple helix networks into triple helix system by stimulating the network dynamics through the ongoing transformation of knowledge *into* a source of innovation. This transformation involves knowledge exploration across 'weak ties' and knowledge exploitation within 'strong ties' (Harryson et al. 2008; Capaldo 2007) within the triple helix network (see Figure 1.3). The intermediaries can stimulate knowledge exploration across networks through "socialisation and externalisation", thereby transforming compartmentalized networks with structural holes into 'loosely connected networks' (Nakwa and Zawdie 2012; Gilsing 2005), whereas the process of knowledge exploitation involves learning through the combination of diverse categories of knowledge, and the subsequent internalization and commercialization of this knowledge by individual firms. The latter provides the basis for the next round of knowledge exploration and knowledge exploitation (Nonaka and Takeuchi 1995).

6. Conclusions

In the past two decades, social capital has emerged as one of the most widely discussed concepts in social sciences. There are many research studies providing evidence that social capital and its various forms play a significant role in the process of knowledge sharing and innovation capability building in the cluster ecosystems. Yet, this process does not always occur spontaneously. Different types of proximities – geographical, social, cognitive, technological, institutional and cultural ones – precondition the stronger social ties and collaborative research behavior. The overview of the above literature reveals several controversies around the role of the different types and strength of social ties in the social capital formation around the cluster ecosystems. One of them relates to the ongoing discussion whether the open or closed social networks promote social capital of high-tech clusters. Another controversy is related to the argument about the role of strong or weak ties in facilitating knowledge exchange and social capital formation. Finally, the last controversy is related to the role of brokerage and bridges in *networks* and *social capital formation*.

Chapter 2

Innovation Networks and the Evolution of the Life Sciences Industry

Małgorzata Runiewicz-Wardyn

1. Introduction

The life sciences sector is one of the fastest-growing high-tech sectors worldwide. The sector encompasses companies in the fields of biotechnology, pharmaceuticals, biomedical technologies, life systems technologies, nutraceuticals, cosmeceuticals, food processing, environmental and biomedical devices. Modern biotechnology is fast emerging technological area, addressing basic human needs and social problems. It has the advantage of very high productivity compared to other sectors, and generates a wide range of products, including drugs, medical technology, diagnostics and digital tools, as well as products for consumer health. The following chapter aims to overview the evolutionary development of life sciences and the role of technological convergence and the importance of the social context in the collaboration within the life sciences industry clusters. Furthermore, the innovation life cycle of the biopharmaceutical products, the role of university-industry partnerships and the role of social networks in preclinical research and the process of innovation diffusion are elaborated.

2. Technological Trends and Technological Convergence within the Life Sciences Sector

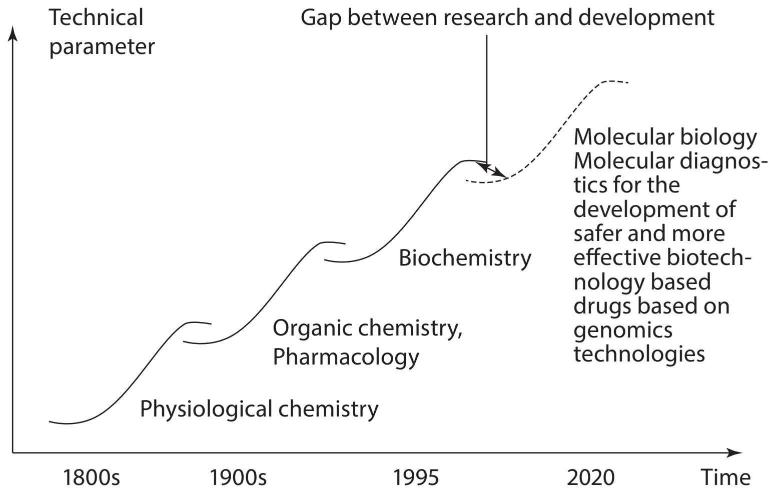
The life sciences industry represents technological evolution in the biopharmaceutical industry as a whole. The opportunities in the biotechnology industry largely mirror those in the pharmaceutical industry. The key difference between the two is that biotechnology firms are much more focused on research activities because they are still developing their initial products.

The beginning of life sciences sector and its precursor the pharmaceutical industry development (the word *pharmakon* means "drug" in Greek) dates back to the ancient Chinese Dynasty of Shen Nung era and can be traced though the ancient Hindu, Egyptian and Mediterranean civilizations (*A History of Pharmacy*, 2018). In the 15th and 16th centuries, most of the pharmaceutical practices concentrated mainly in Basel and London, which are still home for the largest pharmaceutical companies. The beginning of the modern pharmaceutical industry dates back to the 19th century, with the discovery of a manufactured medicinal compound, which replaced herbal medicines, linked to the German chemist Felix Hoffmann (1868–1946) who discovered acetylsalicylic acid, known today as "aspirin". Further on, the development of pharmaceutical industry can be analyzed as an evolutionary process from the very primitive methods of drugs production organized in an informal way (up to 1950), through new product development (1950–70) in the way of formalized in-house research, to the (post-1970) drug development, using genetic engineering in the discovery and production of new drugs. The latter was the beginning of biotechnology when Stanley Cohen and Herbert Boyer (Stanford University and the University of California, San Francisco) proved that one gene can be moved from one species to another. The pharmaceutical companies experienced a period of consolidation, yet largely ignored biotechnology and only started to interact in the late 90s (*The Life-Science Industry: An Introduction*, Open University 2011).

Thus, the modern life sciences industry, including biotechnology, is a relatively young branch of bioscience, developed by the biopharmaceutical industry in the late 2000s. According to the literature, the 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. The innovation process within the life sciences shows that there is not just one S curve, but a succession of S curves from organic chemistry/pharmacology to biochemistry and molecular biology (Figure 2.1).

It can be seen that the waves of molecular biology overlap the waves of biochemistry and are about to leap upward. Based on the theory of the innovation life cycle, the process of technological change in the life sciences industry represents technological evolution in the biopharmaceutical industry as a whole. 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. Scientific breakthroughs, such as genetic engineering, the ability to create monoclonal antibodies, and the mapping of the human genome, have opened up new areas of research, and the pace of discovery in basic biomedical science has accelerated dramatically over the past few decades.

Figure 2.1. Technological change and technological convergence in the life sciences industry

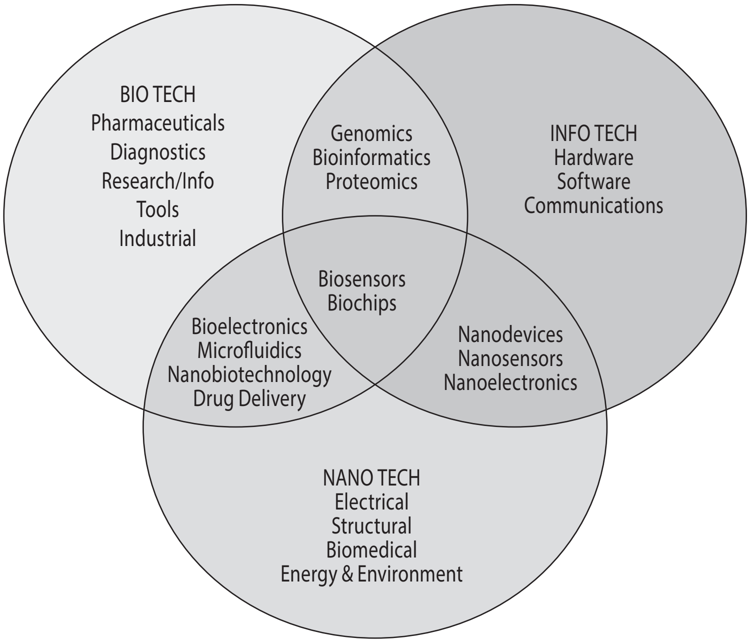


Source: own elaboration based on Utterback and Abernathy (1975), Fisher and Pry (1971) and Barrell A. (2005).

It is rather obvious that interdisciplinary research enriches knowledge, enhances new research – through the dissemination of different ideas, designs, models, inventions – and leads to new discoveries. In the life sciences, 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. As shown in Figure 2.1, the present and future development of life sciences is based on a confluence of different technologies, including communications (telemedicine), information technology, genomics, biochemistry, and others. For example, the convergence of chemistry, biology and semiconductor technologies, enabled researchers to develop biochips which, when used for the blood test, could detect the elevated risk of Alzheimer's disease. New types of plastics from the chemical industry may support the use of synthetic materials in resurfacing bone joints, and cartilage repair (Runiewicz-Wardyn 2019). The concept of 'technological convergence' in the life sciences technology cluster is demonstrated in Figure 2.2.

Converging technologies transform many clinical areas by creating solutions that are less invasive, more patient-specific, convenient, more affordable and usually less painful.

Figure 2.2. Technological convergence and multidisciplinary approach in the life sciences



Source: Barrell (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. As Evald et al. (2006) emphasize, the importance of strong social ties may bridge the existing gaps between biological and chemical sciences, which will further accelerate the dynamics in the life sciences.

Furthermore, close collaboration is also important in the development of genomics technologies that requires massive amounts of information to be collected and analyzed. In turn, the characterization of genes requires a means to manage, store and process enormous databases of biological information (bioinformatics).

In sum, the latest trends in the life sciences, along with the dynamic growth of the biopharmaceutical industry, require a convergent and a multi-disciplinary approach (applying a mix of knowledge from the biological sciences, chemical engineering, bioprocess engineering, information technology, biorobotics) to produce new technological discoveries. The technological convergence, on the other hand, signifies the importance of close social collaboration among the Triple (Quadruple) Helix actors (pharmaceutical firms, intermediary institutions, hospitals, various university departments, etc.) within the university-based innovation ecosystems.

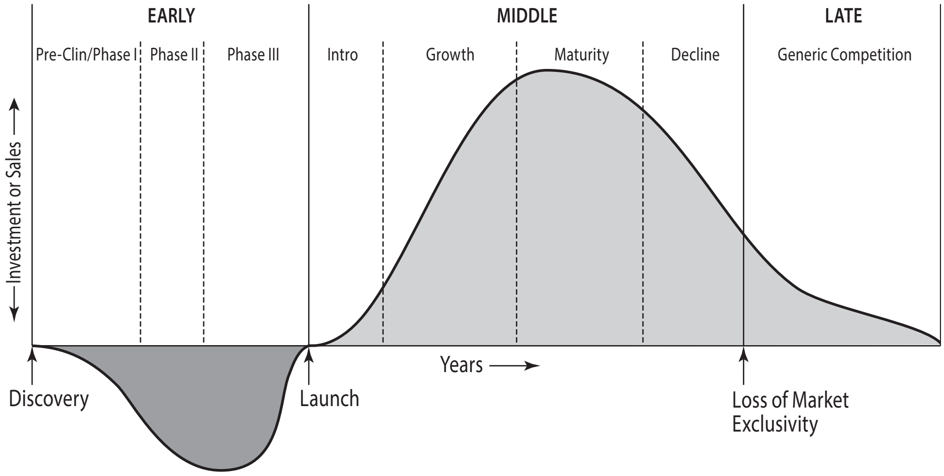
3. Innovation Life Cycle and University-Industry Partnerships in Biopharmaceutical Industries

Unlike other high-tech industries, biopharmaceuticals are unique products which have not one life cycle, but rather three different life periods: (I) an extensive early development period, (II) a highly competitive mid-life period and (III) a significant 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 research and development 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). Presently, the global biopharma industry pressures to increase the productivity and competitive force of companies to partner with universities to embargo some academic research without a strong, 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. Some universities have commercialization facilities, whereby the employees are focused on engaging with industry in order to create working relationships to develop the commercialization of university innovations. If partnering with industry is the eventual goal, intensifying one's social ties with people on both sides, especially in the early stage of clinical trials – phase I or II (Figure 2.3) will greatly increase the success of the research project and its money value. One should mention that costs associated with developing a new medicine have increased substantially in the last decade.

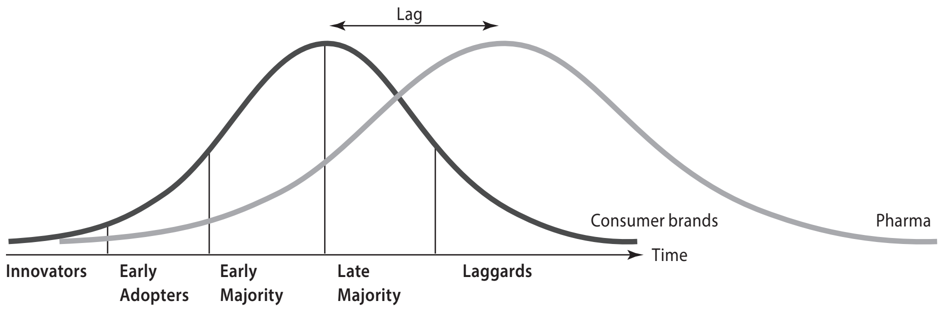
The possibility of partnering with industry for drug development increases if protection of the intellectual property (IP) by patents, trade secrets, and such is in place (Lipton and Nordstedt 2016). Indeed, the developmental premarketing phase is closely regulated and usually lasts a decade or longer.

Figure 2.3. Product innovation life cycle in the biopharmaceutical sector

a) Innovation life cycle of biopharmaceutical product: from the early development to the post--patent period



b) The lag in the diffusion of biopharmaceutical innovative products vs. consumer products



Source: Bernard (2013).

The cost of researching and developing a new chemical or biological entity was estimated at €1,926 million[1] ($2,558 million in 2013 dollars) in 2016 (DiMasi et al, Journal of Health Economics, January 2016). 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.

As a result, 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. During this period of scaling up toward commercialization, drugs are influenced

[1] While in 1975, development costs amounted only to €149 million (in 2000 prices), in 2000, development costs had already increased to €868 million (ECORYS 2009), whereas in 2013, they already reached $ 1.3 billion (2013 Deloitte report).

by an extremely diverse group of customers and stakeholders, each of whom can dramatically alter the conditions of access, utilization, pricing, and sales. The success of commercialization was, to a large extent, determined by the social and interpersonal networks between these different groups of stakeholders.

In the early development phase of the innovation life cycle of a biopharmaceutical product, 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. They also build trust, which might be very important when deciding whether to exploit research as a business idea. The biopharmaceutical product life cycle within the so-called second phase (II) mid-life phase in the innovation life cycle begins with regulatory approval and ends with the expiration of the patent. The whole life cycle concept could be explained, using a product's innovation diffusion model by Everett Rogers (1960). In his cycle theory, Rogers distinguishes five stages in which the product may find itself with five different user groups that accept the product or idea. These determine the success of the product. At the beginning of the introductory stage, only a small group of 'innovators' are interested in the product, once 'early adopters' come on board, the adoption accelerates and the product reaches early and late majority groups, and finally laggards. The whole process can take anything from weeks to years. The formation of the social network leads gradually to a collective evaluation of the innovation. In fact, by tracking social networks and behaviors over time, it is possible to determine how learning and adoption of a new idea spreads through these networks. Valente and Davis (1999) used this approach to study health behaviors, such as alcohol and tobacco use, contraceptive adoption, reproductive health, physician prescribing behavior and others. Their study of social network thresholds and collective behavior concludes that an individual engages in a behavior based on a number or proportion of people in the social system or community who have already engaged in the behavior. In their earlier study, Coleman, Katz, and Menzel (1966) highlighted the role of social networks in the technology diffusion process and identified the role of interpersonal networks in the diffusion of the antibiotic Tetracyline among doctors in Illinois. This is in line with the study by Granovetter (1978), who developed a model in which he explained the emergence of collective behavior – adoption of technology – through the threshold model in which people consider the decisions of others in their network when deciding whether to adopt a new technology. In his previous study, Katz, along with Lazarsfeld, (1955) found that 'opinion leaders' can serve as the bridges between media and the public. The authors found that majority of people are informed by opinion leaders rather than through-direct media sources. Thus, an actor's position as an opinion leader in the network influences the likelihood of the successful diffusion and adoption of new products. Rogers (2003) defines opinion leadership as "the degree to which an individual is able to influence other individuals' attitudes or overt behavior informally in a desired way with relative frequency." Opinion leaders refer to individuals or organizations that are usually experts within an industry and whose views are widely known and trusted. Some may make successful careers out of influencing their audience, commenting industry trends, and affecting the consumer behavior in a given community, whether that is a physical or an online community. Social media have further expanded the influence of opinion leaders. Nowadays, many biopharmaceutical companies became active users of the social media. The American company Lilly (https://www.lilly.com) uses the social media in clinical trial design and recruitment. Through the social media efforts on Twitter, @LillyTrials engages a growing audience of patients, researchers, innovators, and healthcare providers. Bayer (https://www.bayer.com) was the first big biopharmaceutical company to start using the Pinterest site. Several other pharmaceutical companies, including GSK, Roche Merck, and Johnson & Johnson, followed its steps. Boehringer Ingelheim (https://www.boehringer-ingelheim.com) launched its first social game on Facebook, called Syrum, designed to demonstrate the complex processes around medicine research and development through gaming mechanics. In development for more than two years, Syrum has already generated a high level of interest, both within the pharmaceutical industry and among gamers. More than 1,000 people have already signed up to play in advance of the launch via the website www.syrum-game.com. Many other healthcare professionals went into public social media channels such as Twitter and open forums to discuss clinical and practice matters. This trend was unimaginable a decade ago as stated by Daniel Ghinn, the CEO at Creation Healthcare (www.creationhealth.com). Yet, the above-mentioned examples are rather exceptions than the rule. Many biopharmaceutical companies are still lagging behind mainstream consumer companies in the diffusion process of their innovation (Bernard 2013). When it comes to social media and emerging channels, one can observe a delayed diffusion curve for pharmaceutical companies (Figure 3(b)). The latter means that while the majority of mainstream consumer brands may be facing their maturity (the late adopters) stage, biopharmaceutical products might only be at the early adopters stage. The delay causing the difference between the curves may be the subject of a specific product or field and could be somewhere between 1–2 years.

4. The Socio-cultural Context of the Preclinical University-Industry Collaboration

In order to access new talent and technologies, significant investment is being made by life sciences companies in building relationships with research labs and academia. Companies offer doctoral and post-doctoral research funds at leading universities worldwide in order to take steps in the active recruitment of core scientific, bioinformatics, and analytical talents. This diversity, interdisciplinarity and connectivity make some high-technology clusters natural environments for the life sciences development. These clusters have created social and institutional mechanisms allowing new ideas to move from one domain to another. Furthermore, the research done by Steinfield and Scupola (2008) concludes that ICT use appears to strengthen the life sciences cluster in Denmark and Sweden (Medicon Valley), and that firms located within the cluster appear to gain some unique advantages from their ICT usage that are not necessarily available to firms outside the cluster. Moreover, the authors concluded that small firms would not gain as much from the use of the ICT infrastructure if not located in a cluster with a strong reputation. Their study emphasized the key role of clusters in creating innovation-friendly ecosystems in the life sciences sector. The "innovation ecosystem" is defined here as "dynamic, purposive community with strong relationships based on collaboration, trust and co-creation of value and sharing complementary technologies or competencies" (Durst and Poutanen 2013). Yet, strong trust-based relationships are not easily built in the case of such different stakeholders as industry and academia. In fact, researchers from the industry and researchers from the academia work in a different culture and cognitive norms. One example may include the fact that the academic reward for scientific discovery consisting of quality publications or grant/research council funding is highly rank-conscious and individualized. In contrast, pharma industry researchers are salaried as contributors to a team effort aimed at helping invent marketable drugs. Thus, academic science researchers do not routinely operate with levels of collaborative interaction and cross-disciplinary teamwork environment, which is essential to drug discovery and the challenges of applying basic research to address therapeutic/medical needs (Janero 2015). The academic scientists are not equally trained in such matters as decision theory, collaborator relations, or risk and project management. Thus, preclinical university-industry discovery alliances can have discord over the fundamental laboratory findings, i.e. the overvaluation of procuring knowledge by university scientists and undervaluation of new knowledge by industry professionals whose expertise and vision are down the critical path toward market. Such organizational, social and cultural distinctions pose a challenge to discovery research collaborations between university and industry sectors. Establishing common ground for the university-industry discovery collaboration depends critically on the individuals involved, who can break institutional barriers and inculcate focus, cooperation, inclusion, and trust among its participants.

5. Conclusions

In sum, the shortening technological cycles and rise of technological convergence in the life sciences 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, biopharmaceutical partnerships are the new standard, where soft skills, such as "communication" and "collaboration", became important for the successful development of life sciences innovation ecosystems. Yet, different cultural and cognitive norms between academia and industry, and heavy regulation makes two-way social engagement more complex. Thus, the life sciences industry faces its set of challenges related to the diffusion of its innovations. Even though social capital should not be considered a panacea for increasing the levels of innovative activity in the life sciences, yet, there is there is sufficient evidence that the positive influence of social networks reveals a strong contextual and environmental influence on this activity.

Chapter 3

Investment Capital and Public Support in Building Life Sciences Innovation Ecosystems in the European Union and the United States

Małgorzata Runiewicz-Wardyn

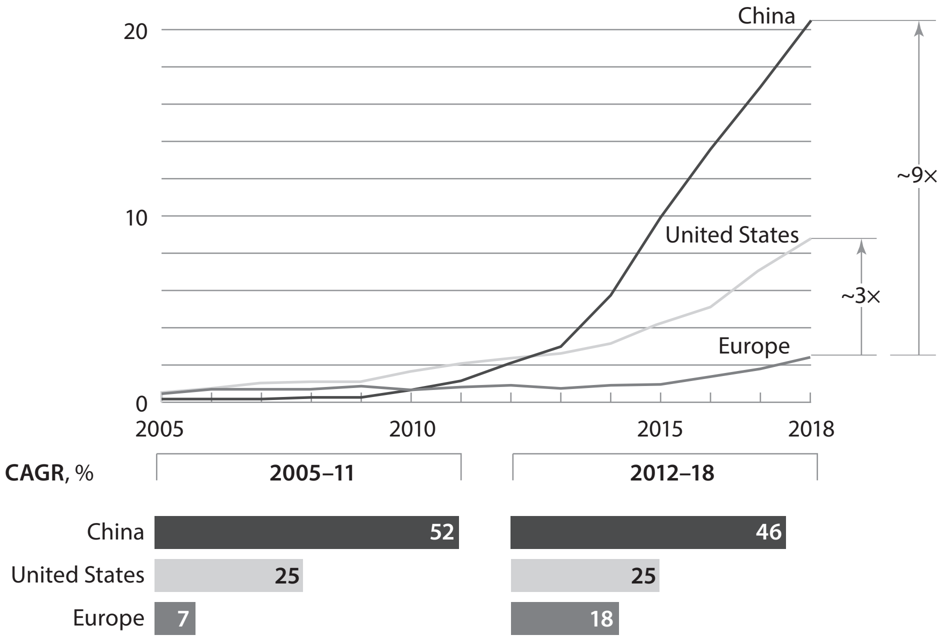
1. Introduction

The life sciences and its related industries – biotechnology, medical technologies and healthcare services – is a vital economic sector with innovation at their very core of evolutionary development. Yet, innovation in the life sciences is a lengthy and complex process, requiring adequate funding and access to the best human capital. The following chapter presents the overall socio-economic and institutional environment affecting the innovation potential, research collaboration and social capital formation in the life sciences industry in the European Union and the United States. The chapter starts with discussing the patent dynamics and venture capital flows in both unions, then focuses on the role of the two unions and their regions in the supply of talents. The last section of the chapter explains the EU and US public support for the research collaboration and networks in the life sciences.

2. Major Patent Trends in a Comparative Analysis of the European Union and the United States

Europe has a strong basis for researching and developing scientific and clinical innovations in its research institutions, medical centers, and hospitals. According to the CEOWORLD magazine rankings (2018) and the QS World University Rankings by Subject 2019 for Life Sciences and Medicine, the region is home to 16 of the world's top 50 universities for life sciences and publishers. The number of articles in top ten journals matches the US one, and is three times higher than in China. However, Europe's strength as a global engine for scientific research and publication does not translate into patents for new medicines. As for 2018, the United States originates about three times as many patent registrations for new medicines as Europe does and China originates about nine times as many patent registrations (Figure 3.1). While the explosion of domestic patent applications in life sciences in China is impressive, this growth does not necessarily correspond with dramatic advances in innovation. Critics point out that Chinese requirements on biological data are different to international approaches and the vast majority of patent applications in life sciences in China are not rigorously examined as the higher-grade invention patents (www.chinapower.csis.org/patents).

Figure 3.1. Patent registrations for new medicines by region*, in thousands, 2005–2018



Source: https://www.mckinsey.com/industries/pharmaceuticals-and-medical-products

* number of patents registered, only the 1st registration region is counted; Europe's statistics exclude Russia.

Further observations of the global innovation trends reveal that European companies were responsible for originating only 13% of the new drugs produced by biotechnology companies and approved by the U.S. Food & Drug Administration in 2017–2018, while the US biotechnology was responsible for 78% (McKinsey report 2019). In fact, in the case of both early innovation (measured by publications and patents) and late innovation (based on approval and innovative candidates), Europe's performance is much lower than that of the United States.

All in all, Europe is lagging behind in taking advantage of its scientific base and patenting commercially relevant innovations. From a geographical standpoint, half of the European activity related to the life sciences and biotechnology is based in three countries – France, Germany, and the United Kingdom. Smaller countries, such as Belgium, the Netherlands, and Switzerland, are gaining in relevance. In the same manner, the United States' life sciences innovation map is characterized by the increasingly unequal distribution of patent registrations, with several states, such as California, Pennsylvania, Massachusetts, Illinois, New York, and New Jersey, being leaders in bioscience-related patent distributions. California is, by far, the leading state in patent awards (accounting for nearly one in three patents during the 4-year period) (U.S. Patent & Trademark Office 2019). Other states, such as Iowa, Indiana, Missouri, North Carolina, Washington, and Wisconsin, demonstrate more focused niche strengths in one or two predominant technology areas.

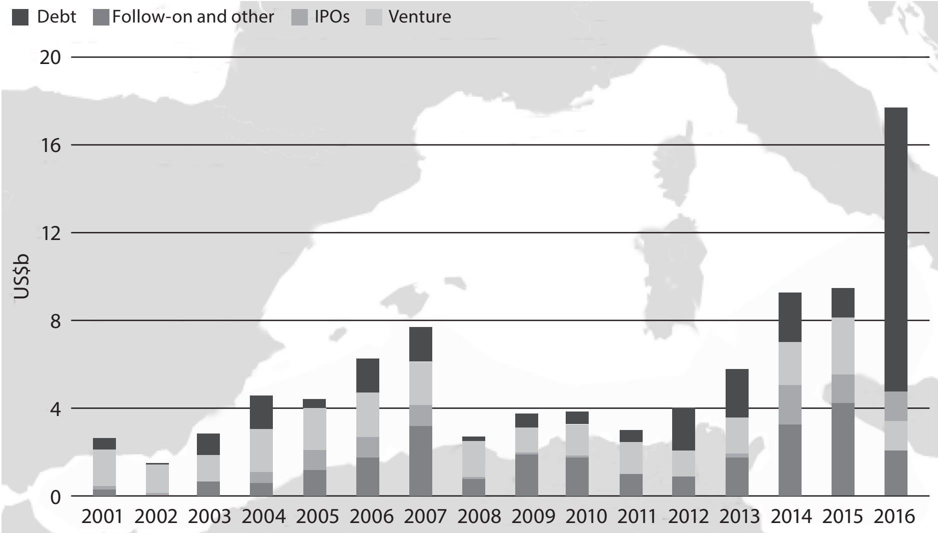
Venture Capital Funding

Over the past decade, the number of total investment in Europe's biotechnology firms has doubled from $5.1 billion in the period from 2005 to 2011 to $11.9 billion in the period from 2012 to 2017. A major share of this new investment, nearly 60%, went to Belgium, Switzerland, and the United Kingdom. The share of Germany, one of the leading European patent contributors, went down to just 8%, in comparison to 31% before 2012. In experts' opinion this was due to multiple reasons from the unfavorable regulatory framework related to start-ups, insufficient infrastructure for the development of start-ups to the soft factors such as insufficient innovative culture and poor social capital (Schrager 2018; Radu 2018).

In terms of the general innovation investment climate, the recent report by McKinsey & Company (2019) states that European biotechnology companies bring good value for investors. In fact, return profiles have been more advantageous in Europe. This can be seen especially when one compares pre-money valuations and structural costs of investments, which are 30% and 40%, respectively, lower than in the United States. The lower structural costs may be related to the more cost-effective operations and lower salaries for life sciences professionals in Europe. In addition, early-stage companies in Europe benefit from EU research grants and programs, as well as equity-free funding, and R&D tax credits from national governments (Figure 3.2).

From 2012 to 2018, European venture capital is estimated to have tripled, to $2.3 billion, thanks to the emergence of bigger, stronger European VC funds (McKinsey report 2019). The United Kingdom took the lead in venture capital ra-

Figure 3.2. European biotechnology financing by year, 2001–2016

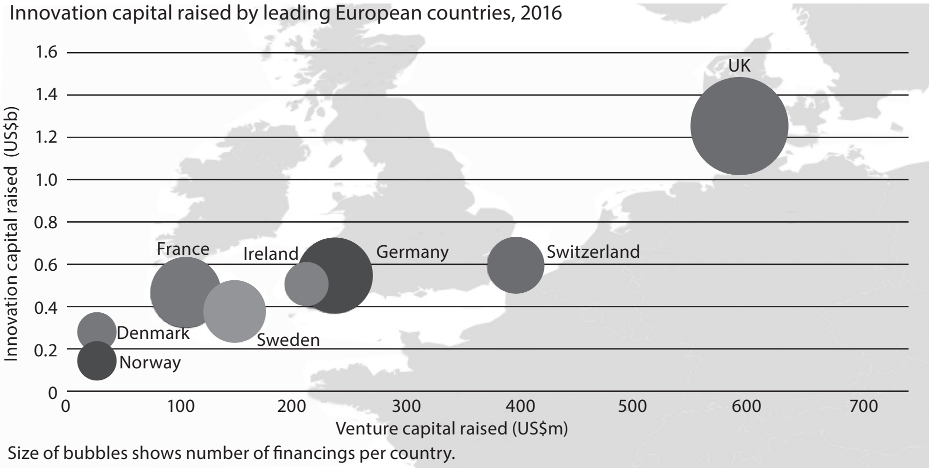


Source: *Biotechnology report 2017*, https://www.ey.com/.

ised. Nearly one-third of all Europe's venture capital went to UK-based biotechnology companies. Most experts agree that sufficient financing is now available for early-stage private venture rounds (Minsky 2019). In 2018, European start-ups, European biotech companies, and Israeli start-ups all received more money than ever from venture capital firms. In total, just under €28 billion of VC money was invested in Europe and Israel. In fact, it was a record-breaking year for VC funding in Europe and Israel. No less than 85% of VC funding investment went to smaller deals (Minsky 2019). The interest in investing in the late-stage drug development is growing, especially in niche therapies. Agreements beyond pure licensing accounted for up to 80% of deals in 2012, but for only 35% by 2018. Despite this positive dynamic, the financing gap with US biotechnology companies is significant. The gap is especially marked for biotechnology companies raising larger amounts in late-stage private venture financing rounds. In fact, the ratios between early and late financing vary considerably from country to country in Europe (Figure 3.3). For instance, in Switzerland, where the number of biotechnology companies has increased, there is a strong underlying imbalance between early- and late-stage financing.

As for public markets, biotech IPOs are three times larger on NASDAQ than on European exchanges, so European biotechnology companies tend to look to the United States for growth capital. As stated in McKinsey's report, in 2019, almost 30% of private-venture investment in biotechnology originates in the United States. The United Kingdom enjoyed the most financing of all markets in Europe, with

Figure 3.3. Innovation capital raised by leading European countries, 2016



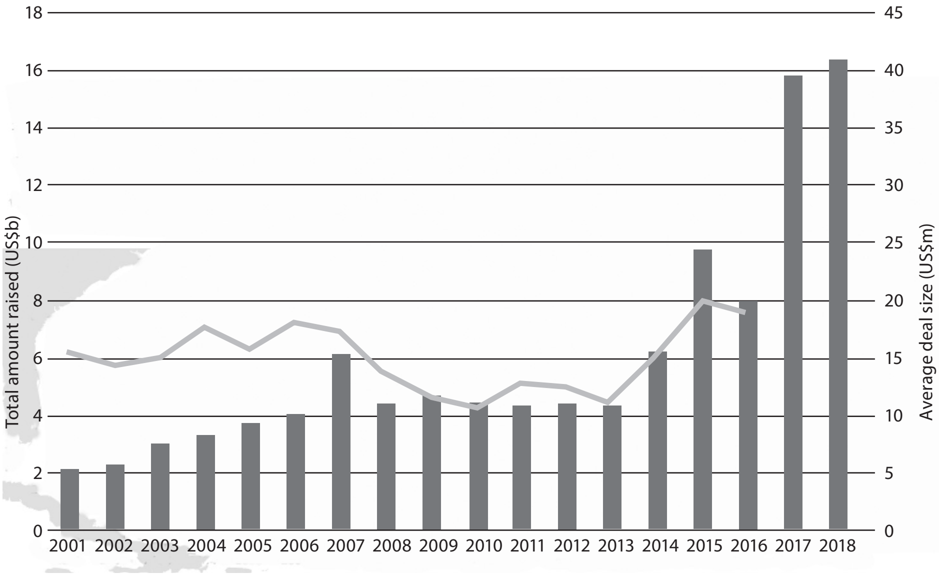
Source: *Biotechnology report 2017*, https://www.ey.com/.

innovation capital financing 25% of the total innovation capital, and the highest total venture financing, 30% of all European venture capital. The Nordic region (Sweden, Denmark and Norway) has rapidly emerged as top tier life sciences tech hub in Europe, right after the United Kingdom, Ireland, and Germany (Figure 3.3). The private VC funding market saw especially strong growth in the region in 2017. Specialist life sciences sVCs increased investments by 25%, in private Swedish, Danish and Norwegian companies (investing an estimated $95 million). In 2017, the pharmaceutical and biotechnology companies raised a total of $500 million through initial public offerings (IPOs), which was equivalent to 12% of the total US biotech/pharma IPO value, a record number for funding in the Nordic life sciences (Otmani 2018).

The continuous growth of VC funding allocated to the US life sciences sector is helping fuel the growth and development of biomedical and related industries. The value of VC investment in the life sciences industry in the United States during the years 2004–2018 have increased rapidly over the last decade (Statista 2020). In 2018, the VC investment in the US life sciences companies amounted to $23.25 billion, which is a 70% increase from the previous year (Figure 3.4).

Among firms that provide R&D as a service, the number of start-ups has almost doubled since 2007, accounting for over 80% of all R&D firms in 2017 (Kennedy 2018). Innovation capital raised in the United States fell by 36% from 2015's record year to $21.3 billion. The geography of high-tech startups remains extremely concentrated and unequal, with the Bay Area and the Boston-New York-Washington Corridor accounting for roughly two-thirds of all venture capital-backed investment across the United States. This is not surprising that most of the VC

Figure 3.4. US life sciences venture capital funding



Source: *Biotechnology report 2017*, https://www.ey.com/.

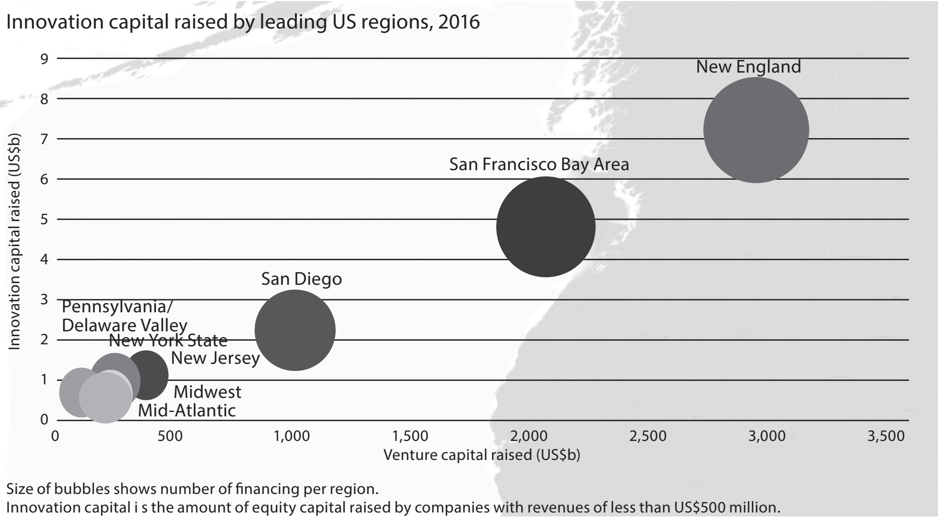
funding was directed to the locations with the highest life sciences commercial opportunities, such as Massachusetts (New England) and California (Figure 3.5). Most of the VC funding is being allocated to companies in these two states (74%). In fact, the MassBio report found that Massachusetts-based biotechnology companies dominated the initial public offering market last year, making up nearly half of all biotech IPO money and more than a third of biopharma venture capital funding (www.biopharmadive.com/).

Nevertheless, experts state that the share of VC investments in the US leading high-tech industry locations, i.e. the San Francisco Bay Area, Boston-Cambridge, started to drop as investors seek companies on new markets. One of the reasons for this trend is the rising cost of living in these top locations, which forces many start-ups to move to less expensive places.

Global Supply of Talents in Life Sciences

It is clear that the talent of key scientists fuels innovation in the industry. Therefore, companies often struggle to attract and retain talented graduates. In Europe, an analysis of the number of graduates in biological and related sciences shows that over 70% of them originate from the United Kingdom, France, Germany, Spain, and Italy (as for 2017). Their universities were most highly ranked by the World University Rankings 2020 in the biology and related sciences (Table 3.1). Among the 200 of the top universities in the QS World University Rankings (2017) for me-

Figure 3.5. Innovation capital raised by leading US regions, 2016



dicine and life sciences, there were 41 in the United Kingdom, 35 in Germany, 23 in Italy, 12 in France and 2 in Spain. The Netherlands is home to 11 of the world's top universities for life sciences and medicine. The Nordic countries, Sweden, Finland and Denmark, have 10, 5 and 5 representatives each, while Norway has 4. From these countries, the highest-ranked institution for life sciences and medicine is the University of Copenhagen in Denmark, which is ranked 27th. Finally, in the Central and East European countries, Hungary (with 3 entries), the Czech Republic (with 2 entries), and Croatia, Estonia, Poland, and Slovenia (with 1 entry) are among the world's best education institutions for life sciences and medicine.

Table 3.1. Number of Bachelor's or equivalent level graduates in biological and related sciences in the International Standard Classification of Education (ISCED) 2011, level 6

Country	Leading educational institutions	2017
Belgium	KU Leuven, Ghent University, Université Catholique de Louvain	374
Czech Republic	Charles University in Prague	841
Denmark	University of Copenhagen, Aarhus University	1,173
Finland	Helsinki University	320
France	Paris Sciences et Lettres – PSL Research University Paris; Sorbonne Univeristy; École Polytechnique, University of Paris,	11,397
Germany	University of Heidelberg, Technical University of Munich, Humboldt University of Berlin; Free University of Berlin; RWTH Aachen University; University of Tübingen, University of Göttingen	6,397

Greece	University of Crete	659
Ireland	Trinity College Dublin	1,992
Italy	Scuola Normale Superiore di Pisa, University of Bologna	5,982
Netherlands	Delft University of Technology, Leiden University, University of Amsterdam; University of Groningen,	2,327
Norway	University of Oslo, University of Bergen	515
Poland	Adam Mickiewicz University, Poznań, Jagiellonian University, University of Warsaw	2,166
Portugal	Catholic University of Portugal, University of Lisbon	1,750
Slovak Republic	Comenius University in Bratislava	506
Spain	Autonomous University of Barcelona	5,197
Sweden	Karolinska Institute, Lund University, Uppsala University, Stockholm University	398
Switzerland	ETH Zurich; École Polytechnique Fédérale de Lausanne, University of Bern	850
United Kingdom	University of Oxford, Univeristy of Cambridge, UCL, University of Edinburgh; King's College University; University of Manchester; Imperial College London	43,514

Source: based on OECD Statistics (2020) and the University Rankings (2020).

In the past decade, several top European universities[1] have started to integrate systems biology into their curricula, either by creating dedicated MSc programs or by incorporating systems biology components in their existing programs. The latter approach was in the accordance with the rising technological convergence in science and importance of educating life scientists to be able to collaborate with physicists, mathematicians and engineers. Moreover, educating scientists with a biological, medical, physical or mathematical background will make it possible to develop and exploit predictive computational models of biological systems and obtain deep insight into biological systems.

Despite the range of local, national and transnational training and education activities on the lower tertiary level of education, not many researchers in Europe follow further academic/scientific career in biological and related sciences on doctoral level (Table 3.2). The United Kingdom, Germany, Spain and France are the most active countries in Europe in the life sciences, offering scientific degrees in Molecular Biology, Biotechnology, Biomedical, Health studies and others.

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[1] KU Leuven, Belgium, http://onderwijsaanbod.kuleuven.be/opleidingen/e/CQ_50269018.htm; ETH, Zurich, http://www.cbb.ethz.ch/; University of Copenhagen, http://studies.ku.dk/masters/bioinformatics/; Stockholm University, http://www.sbc.su.se/masters/; Universities in Netherlands, www.nbic.nl/education/msc-programmes/; TUM, Munich, Germany, http://www.mastersportal.eu/studies/865/bioinformatics.html, and others.

Table 3.2. Number of doctoral or equivalent level (ISCED 2011, level 8) in biological and related sciences

Country	Leading educational institutions	2017
Belgium	KU Leuven, Ghent University, Université Catholique de Louvain	221
Czech Republic	Charles University in Prague	237
Denmark	University of Copenhagen, Aarhus University	–
Finland	Helsinki University	113
France	Paris Sciences et Lettres – PSL Research University Paris; Sorbonne Univeristy; École Polytechnique, University of Paris,	1,870
Germany	University of Heidelberg, Tecnical University of Munich, Humboldt University of Berlin; Free University of Berlin; RWTH Aachen University; University of Tübingen, University of Göttingen	2,956
Greece	University of Crete	65
Ireland	Trinity College Dublin	169
Italy	Scuola Normale Superiore di Pisa, University of Bologna	–
Netherlands	Delft University of Technology, Leiden University, University of Amsterdam; University of Groningen,	–
Norway	University of Oslo, University of Bergen	49
Poland	Adam Mickiewicz University, Poznań, Jagiellonian University, University of Warsaw	197
Portugal	Catholic University of Portugal, University of Lisbon	174
Slovak Republic	Comenius University in Bratislava	131
Spain	Autonomous University of Barcelona	2,173
Sweden	Karolinska Institute, Lund University, Uppsala University, Stockholm University	398
Switzerland	ETH Zurich; École Polytechnique Fédérale de Lausanne, University of Bern	498
United Kingdom	University of Oxford, University of Cambridge, UCL, University of Edinburgh; King's College University; University of Manchester; Imperial College London	3,934

Source: based on OECD.Stat (2020) and the World University Rankings 2020.

The United Kingdom, being one of the most popular locations for the academic degrees in the life sciences, may have some slowdowns in the mobility of doctoral and postdoctoral researchers from the European Union, following the Brexit vote. In addition, the EU medical evaluating body, the European Medicines Agency (EMA) announced its relocation from London to Amsterdam, moving around 20% of its workforce out of the United Kingdom.

In the United States, according to the CBRE research report (2018), most of the key life sciences talents, such as biomedical engineers, biochemists, biophysicists and chemists, were concentrated in the Northeast Corridor (New York City and New Jersey) and the West Coast (the San Francisco Bay Area). More specifically, life sciences hubs that offer a growing source of life sciences talent include Seattle, Houston, Austin and Denver (Table 3.3).

Table 3.3. Top total life sciences graduates by US school (2018)

Rank	Institution Name	Market	Total
16	University of California – San Diego	San Diego	1,870
18	University of California – Davis	Sacramento	1,591
18	University of California – Los Angeles	Los Angeles	1,529
n/a	University of South Florida – Main Campus	Tampa	1,370
18	University of Wisconsin – Madison	Madison, WI	1,321
39	University of Minnesota – Twin Cities	Minneapolis	1,296
23	University of Washington – Seattle Campus	Seattle	1,252
27	The University of Texas at Austin	Austin	1,186
73	University of Florida	Gainesville, FL	1,149
39	Ohio State University – Main Campus	Columbus	1,136
73	Rutgers University – New Brunswick	New Jersey	1,127
62	Texas A & M University – College Station	College Station, TX	1,099
1	University of California – Berkeley	San Francisco Bay Area	1,086
23	University of Michigan – Ann Arbor	Ann Arbor, MI	1,073
46	Michigan State University	Lansing-East Lansing, MI	1,067
33	University of Colorado Boulder	Denver	926
46	University of Arizona	Tucson, AZ	893
6	Johns Hopkins University	Washington, D.C. – Baltimore	891
85	Boston University	Boston-Cambridge	868
62	Arizona State University – Tempe	Phoenix	867

Source: CBRE Research Report (2018).

These and other markets have premier educational and medical institutions to drive continued industry growth. Smaller life sciences locations, such as Houston, St. Louis and Dallas, showed the highest growth trends and catching-up potential toward the leading Boston-Cambridge, MA and San Francisco-Bay, CA clusters.

In 2018, California-based research organizations received $3.9 billion in National Institutes of Health grants, ahead of Massachusetts with $2.7 billion. Additionally, the CLSA found that California companies had more than 1,300 medicines in the pipeline and roughly 130,000 employees working for 1,500 biopharmaceutical and medical device companies in 2018 (2018 Report from California Life Sciences Association). In contrast, Massachusetts-based biotechnology companies dominated the initial public offering market, making up nearly half of all biotech IPO money and more than a third of biopharma venture capital funding in 2018 (MassBio report 2019).

In fact, the top three US-based schools produce most of the life sciences graduates: the University of California in Los Angeles, Davis and San Diego (Table 3.3). However, when evaluating life sciences talents based on the Ph.D. degrees in biomedical and biological sciences, the greater proportion of talents emanates from Boston-Cambridge, Philadelphia and Washington, DC. Interestingly, Seattle's metropolitan region scores much higher in doctorates than in general degree graduates (CBRE Research Report, 2018).

Table 3.4. Top total life sciences doctorates by US school

Rank	Institution Name	Market	Doctors
6	Johns Hopkins University	Washington, D.C. – Baltimore	170
4	Harvard University	Boston-Cambridge	162
18	University of California – Davis	Sacramento	151
18	University of Wisconsin – Madison	Madison, WI	147
33	Universtiy of North Carolina at Chapel Hill	Raleigh-Durham	142
10	Duke University	Raleigh-Durham	140
18	University of California – Los Angeles	Los Angeles	139
23	University of Pennsylvania	Philadelphia	125
23	University of Michigan – Ann Arbor	Ann Arbor, MI	124
1	University of California – Berkeley	San Francisco Bay Area	123
73	University of Florida	Gainesville, FL	120
27	Vanderbilt University	Nashville	113
39	University of Minnesota – Twin Cities	Minneapolis	108
39	Ohio State University – Main Campus	Columbus	106
16	University of California – San Diego	San Diego	105
1	Stanford University	San Francisco Bay Area	102
23	University of Washington – Seattle Campus	Seattle	94
13	Washington University in St. Louis	St. Louis	94
73	University of Texas Health Science Center at Houston	Houston	92
18	Columbia University in the City of New York	New York City	91

Source: CBRE Research Report (2018).

According to the data provided by The National Science Foundation (NSF), life sciences has attracted the largest share of doctorates awarded in 2016, nearly 23%, followed by engineering (17%), and psychology and the social sciences (16.5%). John Hopkins University, Harvard University, University of California (Davis), followed by University of Wisconsin-Madison and University of North Carolina hosted the highest number of doctorates (Table 3.4). Women and foreign nationals account for most of the increase in the number of Ph.D. recipients over the last 10 years in the US higher education institutions. The top three countries – China, India and South Korea – accounted for 54% of the doctorates awarded to temporary visa holders.

3. Clinical Trials in the European Union and the United States

Major Regulations and Trends in Clinical Trials in the European Union and the United States

Behind every innovative product in biomedicine, there are thousands of patients who have volunteered to participate in clinical trials, which led to the breakthroughs in disease prevention and treatment. Citing the World Health Organization definition (2019), "a clinical trial is any research study that prospectively assigns human participants or groups of humans to one or more health-related interventions to evaluate the effects on health outcomes." In other words, "clinical research is that component of medical and health research intended to produce knowledge valuable for understanding human disease, preventing and treating illness, and promoting health" (https://www.ncbi.nlm.nih.gov/books/NBK22620/). All in all, clinical research brings real meaning to basic biomedical discoveries, by addressing patient's care from the physical, behavioral, and social perspectives. Therefore, the *goal of the EU Clinical Trial Regulation* – (Regulation (EU) No 536/2014) *is to create an environment that is favorable to conducting clinical trials in the European Union, with the highest standards of safety for participants* and increased transparency of trial information (European Medicines Agency 2020). Currently, the conduct of clinical trials in the EU must conform to Directive 2001/20/EC of the European Parliament (hereinafter referred to as the Directive), a document providing trial requirements and guidelines aimed mainly at guaranteeing the highest possible patient safety, enforcing the use of good clinical practice (GCP), and striving for high scientific value and usefulness of the data generated, among other goals. The Directive is considered an important step toward the harmonization of laws in the European Union. Nevertheless, it is each member state's responsibility to implement the contents of the Directive in their own national laws. Thus, different interpretations of the document result in slight discrepancies between the laws of each EU member state. As a result, the authorization of a clinical trial (after being reviewed by the national Ministry of Health or Health Agency, Ethics Committee, and other relevant, authorities responsible for genetically modified organisms (GMO)) is specific for each member state.

Furthermore, clinical trials involving new drugs are commonly classified into four phases (the preclinical phase refers to the testing of a drug on non-human subjects). If the drug passes through Phases I, II, and III successfully, it will usually be approved by the national regulatory authority for use in the general population. Phase I is the testing of the drug on healthy volunteers for safety; Phase II is the testing of the drug on patients to assess efficacy and side effects; Phase III involves testing the drug on patients to assess efficacy, effectiveness and safety; Phase IV is a post-approval studies phase related to the "post marketing surveillance" (DeMets et al. 2010). In Europe, all registration must take place before recruitment begins (Phase I).

According to the report by the Alliance for Regenerative Medicine (2019), approval times for a new trial in Europe can vary from fewer than 30 days to more than a year (three to six months on average). For example, in France or Germany, the average time would be from six to 12 months, while in Belgium and the United Kingdom, the decision would be made in 60 days. The report further says that GMO approval is particularly long in the Netherlands. In sum, differences in clinical trial requirements among various EU member states have made it difficult to conduct trials in two countries simultaneously. This has resulted in a significant drop in clinical trial applications in recent years. The introduction of the Clinical Trial Regulation (Regulation (EU) No 536/2014) into force will place all EU member states under the same regulatory blanket.

In the United States, the Food & Drug Administration (FDA)[2] regulations for the purpose of conducting clinical trials, which have been in effect since the 1970s, addresses both subjects which are essential for clinical research: "good clinical practice" (GCP) and human subjects protection (HSP). Adherence to the principles of GCP, including human subjects protection (HSP), is universally recognized as a critical requirement for the ethical conduct of research involving human subjects. The Office of Good Clinical Practice (OGCP) serves as the focal point for both GCP and HSP issues related to clinical trials and sets priorities for the development of the clinical trials policy. All clinical trials must be registered at ClinicalTrials.gov run by the United States National Library of Medicine (NLM) at the National Institutes of Health (NIH). In general, Section 801 of the Food and Drug

[2] The Food & Drug Administration (FDA) is responsible for protecting the public health by ensuring the safety, efficacy, and security of human and veterinary drugs, biological products, and medical devices; and by ensuring the safety of the nation's food supply, cosmetics, and products that emit radiation.

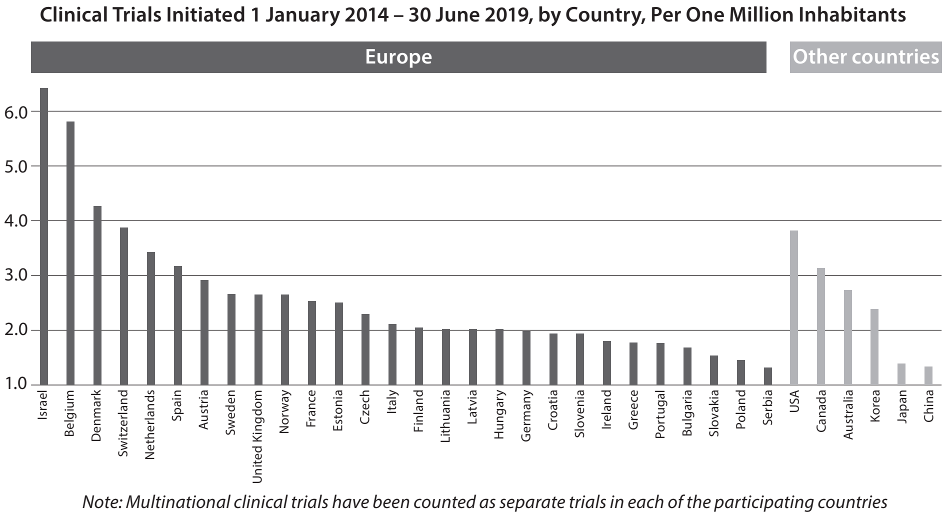
Administration Amendments Act (FDAAA 801) requires applicable clinical trials (ACTs) to be registered within 21 days after the enrollment of the first participant, yet there is no specific legal requirement to register Phase I of the trials at ClinicalTrials.gov (Clinical-Trial-Requirements-Reference-Guide-2012). The biggest challenge in the US clinical trials policy lies in the excessive regulatory burden. Even though the federal government (through the FDA) dictates the rules regarding the registration and reporting of clinical trials, many additional requirements come from the state level. The latter requires a simultaneous study of any change in both state and federal regulations, which can be an extra time-consuming and cost-related burden for research sponsors. One interesting legislative fact that is worth mentioning is the FDA Reauthorization Act (FDARA), signed on August 18th by President Trump. The Act reauthorizes user fees for pharmaceuticals and medical devices for five years as an attempt to lower drug prices. In experts' opinion, the new requirements may provide an opportunity for collaboration across the industry, academia and government, as well as closer collaboration between NCI, the COG, other collaboratives, the FDA, industry, and advocacy groups (https://www.emergobyul.com, August 2017).

Major Trends in Clinical Trials

In general, the United States initiates nearly three times more of new interventional clinical trials than Europe (on average) does. According to the report by the Alliance for Regenerative Medicine (2019), during the last five years (2014–2019) there were 2,097 new clinical trials initiated globally. The majority of these new clinical trials originated from North America (845) and Asia (736), followed by Europe (323), South America (26), Oceania (17), and Africa (11). Some 139 multi-regional clinical trials involved countries both in Europe (131) and North America (122). Additionally, the number of new clinical trials with advanced therapy medicinal products (ATMPs) increased by 32% during the 2014–2018 period, with the highest growth in North America (+36%) and Asia (+28%), but not in Europe (<2%). In Europe, big countries, such as the United Kingdom (112), Spain (102), and France (101), initiated the highest number of new ATMP clinical trials, followed by Germany (83) and Italy (66), during the years 2014–2019 (Figure 3.6). However, when the number of new clinical trials by country is examined in relation to the size of the country, smaller countries, such as Belgium, Denmark, and Switzerland, attract proportionally more new ATMP clinical trials per capita than other countries, including the USA and Canada. Country-by-country variability in the number of clinical trials in Europe results mainly from different speeds of assessment, and the time necessary for the approval of clinical trials in the different countries.

Notwithstanding, while the number of new ATMP clinical trials has grown significantly over the last five years (by more than 35%) on a global scale (with notable growth in North America and Asia), this trend has not been present in Europe, where the number of new clinical trials remained consistent. Furthermore, there were proportionally more new gene therapy clinical trials (utilizing gene delivery, gene editing, and gene modified cell therapy technologies) in North America (71% of all new trials) than in Europe (55% of all new trials).

Figure 3.6. Clinical trials initiated in Europe, the United States and other countries during 2014–2019, per one million inhabitants



Source: Report by the Alliance for Regenerative Medicine 2019, https://alliancerm.org/wp-content/uploads/2019/10/Trends-in-Clinical-Trials-2019-Final_Digital.pdf

The interview survey conducted by the Alliance for Regenerative Medicine (ARM), initiated since January 2014, revealed that the most important criteria for selecting a clinical trial site and a country for ARM members was "the expertise and the skills of the clinical centers and healthcare professionals, followed by the speed of approval, the quality of review, and the expertise of regulatory authorities" (Report by the Alliance for Regenerative Medicine, 2019).

4. Policies Supporting Innovation Networks and Collaboration in Life Sciences in the European Union and the United States

In Europe, the European Commission's (EC) Framework Programme (FP) contributes an important share of R&D expenditure. The Horizon 2020 (https://ec.europa.eu/programmes/horizon2020) is the biggest EU research and innovation program ever launched which makes nearly €80 billion available for over seven years (2014 to 2020). In addition to financing science and technology (S&T) development, one of the main objectives of the FP is to foster international collaboration among research organizations and private firms, both large and small ones. Collaboration is a key conduit for innovation-related knowledge flows for both firms that use R&D and those that are not R&D-active. In fact, the main idea behind the FP is that innovation often results from the interaction and cooperative efforts of different organizations devoted to the achievement of a common goal (European Commission 2013). In terms of the life sciences, the European Union has the holistic and multi-sectoral approach. The EU policy in the life sciences is driven by the European Commission. The EU European Bioeconomy Strategy (https://ec.europa.eu/research/bioeconomy/pdf) was defined in 2012 in the Communication of the EC 'Innovating for Sustainable Growth: A Bioeconomy for Europe' (EC 2012; *Life Sciences and Biotechnology – A Strategy for Europe*, 2002). The strategy is intended to be multi-sectoral and support of knowledge flow between scientific disciplines. Institutional arrangements, such as the organization of teaching and the organization of research activities in public sector research organizations, along with interdisciplinary and not only disciplinary dimensions, are crucial in this context (Reiss et al. 2003, Enzing et al. 1999).

The EC approach to promoting collaboration and networking in the life sciences comes from its strategic documents – the European Research Area (ERA) and European infrastructures for 2020 (European Strategy Forum on Research Infrastructures, ESFRI).

The European Research Area (ERA) aims to unify fragmented research efforts in the internal EU market via free circulation of researchers, scientific knowledge and technology (https://ec.europa.eu/info/research-and-innovation). Partnerships with member and associated countries and the Commission is represented by the European Research Area and Innovation Committee (ERAC), while partnership with stakeholder organizations is achieved via the following organizations: the European Association of Research and Technology Organisations (EARTO), the European University Association (EUA), the League of European Research Universities (LERU), NordForsk (www.nordforsk.org) and Science Europe (www.scienceeurope.org).

The European Strategy Forum on Research Infrastructures (ESFRI, https://www.esfri.eu/) plays a key role in policy-making on Research Infrastructures in Europe. It is composed of national delegates nominated by research ministers of EU countries and countries associated with Horizon 2020. One of the most important ESFRI missions is to optimize the use of the national facilities by integrating them into networks and opening their doors to all European researchers. This is a continuity of the so-called Integrating Activities under 7th Framework Programme (FP7) for Research and Technological Development (2002–2013)[3]. Another important mission is to support further deployment and development of ICT-based e-infrastructures to enable remote collaboration, and massive data processing in all scientific fields. Under the ESFRI initiatives, Industrial Biotechnology Innovation and Synthetic Biology Accelerator (IBISBA) was established, aiming to bridge the gap between academic research and industrial R&D needs. IBISBA is designed to accelerate end-to-end bioprocess development, linking best-in-class R&D facilities to provide seamless multi-technology services.

Science Europe is a European association representing the interests of major public research performing and research funding organizations, with an impact on research, interdisciplinarity, but also cross-border research collaboration priorities (to allow research communities to work together). 37 members from 28 European countries bring together national EU member states' research funding agencies and prominent research performing organizations (Academies of Sciences). They are among Europe's major players in public research funding. Together they spend over €18 billion on research each year.

Considering the convergence and interdisciplinary character of research in the life sciences sector, support of the EU framework for international mobility and networking events is very important. This is especially the case of smaller EU countries which might depend to a greater extend on an external input due to (natural) limitations in the diversity of their domestic knowledge base.

The EC launches many programs helping people build links between their organizations, including universities, research institutes and SMEs, training researchers and driving scientific excellence and innovation. The biggest program initiatives include: MSCA Actions (including Innovative Training Networks (ITN), Individual Fellowships (IF), Research and Innovation Staff Exchange (RISE), Co-funding of regional, national and international programs (COFUND) and European Researchers' Night (NIGHT, https://ec.europa.eu/research/mariecurieactions)), European Cooperation in Science and Technology (COST) Actions, Erasmus+.

Erasmus+ internationalization strategy aims to develop, stimulate and promote new cooperation pathways and sustainable networks with other universities and research institutions within the European Union and worldwide. The key objectives are: to support the whole range of international research and technological development activities, to expand the number of programs offering an international experience, to enhance mobility opportunities for students and staff, to internationalize the curriculum in order to reflect its comprehensive European dimension (https://ec.europa.eu/programmes/erasmus-plus).

[3] The main EU funding instrument for research and innovation.

The EC COST Actions is a funding organization for the creation of research networks among scientists across Europe (and beyond), and thereby give impetus to research advancement and innovation. COST is an attempt to create a bottom-up possibility for the researchers to create their own networks – based on their research interests and ideas – by submitting a proposal to the COST Open Call. Short-term scientific missions (STSM) are exchange visits between researchers in COST Actions, allowing scientists to visit an institution or a laboratory in another COST member state (www.cost.eu).

The EC European Territorial Cooperation (ETC) program – Interreg – aims at removing cross-border obstacles and supporting interregional innovation projects. Interreg Europe co-finances up to 85% of research and innovation project activities carried out with cross-border EU partners (www.interregeurope.eu). One of the excellent examples of such a support framework is the "voucher scheme" of the Danish cluster organization BioPeople (https://biopeople.eu), which is a part of the IN2LifeSciences project that is financed under the Interreg 4B program for Northwestern Europe (funded by the EU Structural Funds).

In parallel with public sector non-profit initiatives associated with the European Union, governments and industry take actions in both facilitating cooperation between professionals in biotechnology and the life sciences all over Europe, as well as industry lobbying. They include: the European Biotechnology Network (https://european-biotechnology.net); the Euroleague for Life Sciences (www.euroleague-study.org/en/network); EuropaBio (www.europabio.org) organizing a week-long series of events – the European Biotech Week since 2013 (www.lifescience.net/events), the European Confederation of Agronomists Associations (CEDIA, http://cedia.eu). There are also numerous regionally oriented non-profit organizations, including Nordic Life Science (www.nordiclifescience.org), the International Association of Students in Agricultural and Related *Sciences* (IAAS), and others. The biggest network of life sciences universities (more than 60) is the Association for European Life Science Universities (www.ica-ls.com). ICA supports networking in the life sciences, in order to share expertise and represent the general interest of EU university members at the European and global levels.

In the United States, the National Science Foundation (NSF) funds research and education in most fields of science and engineering and supports cooperative research between universities and industry. The mission of the Directorate for Biological Sciences (BIO) is to enable BIO-supported research, to advance the frontiers of biological knowledge, to increase our understanding of complex systems, and to provide a theoretical basis for original research in many other scientific disciplines. The Directorate of Biological Sciences is organized into divisions: the Division of Biological Infrastructure (DBI), the Division of Environmental Biology (DEB), the Division of Integrative Organismal Systems (IOS), the Division of

Molecular and Cellular Biosciences (MCB) and the Emerging Frontiers (EF). The last division supports multidisciplinary research opportunities and networking activities that arise from advances in disciplinary research. As of 2019, the BIO invested $783 million in biological sciences.

The NSF recognizes the importance of international collaboration in science. AccelNet program was established with the aim to accelerate the process of scientific discovery and prepare the next generation of US researchers for multi-team international collaborations. The NSF has invested over $11.5 million in 9 new projects to tackle grand scientific challenges that require significant coordinated international efforts. Research collaboration in networks is increasing in all fields of science, engineering, and STEM education. The awards are funded through the new NSF-wide Accelerating Research through International Network-to-Network Collaborations (AccelNet) program. These first AccelNet awards include 4 catalytic efforts to identify key knowledge gaps and 5 large-scale networking plans for innovative collaboration on research priorities and enhancing professional skills of students and early career researchers in international networks. Through these nine projects across 25 institutions, US research networks will connect with research networks across the globe to enable research advances at scales larger than the ones which are currently possible (https://www.nsf.gov/funding/).

The US National Institutes of Health (NIH) is the largest public funder of biomedical research in the world, investing more than $32 billion a year to enhance life. The Vascular Interventions/Innovations and Therapeutic Advances (VITA) and the Small Business Technology Transfer (STTR) schemes provide grants for academics which allow them to further develop their understanding of fundamental pathways and targets by resourcing the creation of antibodies, cell-based therapies, viral vectors or small molecule drugs by contract research organizations (CRO). The United States has been promoting these capabilities in academia through programs, such as Harrington (www.jmhmedicine.com) and SPARK (www.sparkprogram.org).

In terms of the research training and mobility, the United States offers less institutional support. Some mobility-related grants are offered by NSF Earth Sciences Postdoctoral Fellowships; Postdoctoral Research Fellowships in Biology and SBE Postdoctoral Research Fellowships, as well as the AccelNet). Furthermore, the National Institutes of Health (NIH) Office of Extramural Research, the National Institute of General Medical Sciences (NIGMS) and Grants.gov list all current discretionary funding opportunities from US agencies, including the National Institutes of Health, the National Science Foundation and the Department of Energy. Many non-profit, non-government organizations offer information on research mobility and research grants: the Grants Resource Center (GRC) run by the American Association of State Colleges and Universities (AASCU); Sponsored

Programs Information Network (SPIN) run by InfoEd International; Funding Opportunities Database (COS, www.cos.gdb.org/) and Newton's List: Creating Opportunities for International Scientific Collaboration (www.crdfglobal.org/success-stories/newtons-list-creating-opportunities-international-scientific-collaboration).

The federal government prioritizes technological convergence, encouraging multidisciplinary approaches, and prioritizes the implementation of the National Quantum Initiative Act which was passed in December 2018. In the case of the life sciences sector, the 2012 *National Bioeconomy Blueprint* (White House 2012) describes the strategic objectives. The blueprint stresses the importance of genetic database sharing, domestically and internationally. It does not explicitly support interdisciplinary and cross-sectoral R&D investments in the life sciences. It rather offers R&D support to highly-ranked universities and research teams in the field of life sciences, that further promote knowledge flows across various disciplines. In fact, academic research contracts in the life sciences sector tend to be pursued by well-established and well-connected scientists who are more advanced and have wider social networks, more publications and thus more government grants (Hicks et al. 2012; Wallerstein and Duran 2010). Furthermore, the US National Science Foundation (NSF) launched CREATIV – Creative Research Awards for Transformative Interdisciplinary Ventures (2012) – a pilot grant mechanism to support bold interdisciplinary projects in all areas of science, engineering, and education research. Since the future life sciences relies on creative interdisciplinary efforts, this new funding mechanism promises to provide funding opportunities for life sciences related efforts.

Many non-profit private initiatives promoted life sciences research collaboration and networks in the United States. Just to mention the Bill & Melinda Gates Foundation (www.gatesfundation.org), Priscilla Chan and Mark Zuckerberg's Biohub (Biohub) and the Chan Zuckerberg Initiative (www.chanzuckerberg.com) or opportunities offered by The Rockefeller Foundation (established by business magnate and philanthropist John D. Rockefeller). In establishing public partnerships for food security, the NSF8 partnered with the Bill & Melinda Gates Foundation to invest a total of $48 million over 5 years to support research carried out at US academic institutions, while the Gates Foundation supports international partners via sub-awards from the US awardees. While Priscilla Chan and Mark Zuckerberg committed $600 million over 10 years to fund the Chan Zuckerberg Biohub (in September 2016), an independent non-profit research center that brings together physicians, scientists, and engineers from UCSF, Berkeley, and Stanford University to encourage collaborations between these universities, especially in the in early-stage research and interdisciplinary projects.

Finally, many non-government organizations working collaboratively with industry leaders, key policymakers and other stakeholders to advance medical technology and promote innovation networking between biotechnology companies, academic institutions and biotechnology research centers include PhRMA (www.phrma.org), BIO (www.bio.org), Advanced Medical Technology Association (AdvaMed, www.advamed.org), California Biotechnology Foundation (www.cabiotech.org).

5. Conclusions

Europe still lags behind the United States and China when it comes to patenting commercially relevant innovations. One of the reasons behind this slow dynamics is lower innovation capital investments. The innovation capital investment in European life sciences industry clusters is increasing, but that is in late-stage financing, whereas European companies lag behind their US counterparts by a large margin in terms of early research funding. Europe, however, is highly scored on its overall level of talent base – life sciences.

Europe records higher geographical disparities in terms of distribution of venture (innovation) capital and talent opportunities related to life sciences, across and within the states. In Europe, the regions that attract most of such capital are Western and Nordic (the United Kingdom, Switzerland, Germany, Belgium, Sweden, Norway, Denmark), whereas regions with the highest number of life sciences talents are found in West, South, Central and Eastern Europe (France, Germany, Italy, Spain, Poland, Ireland, Portugal, and the Czech Republic). In means that Europe does not take full advantage of its talent and skills in the life sciences sector. The United States, on the other hand, does not record such huge disparities, with same regions recording highest concentration of innovation capital and talent opportunities, covering mainly North-East, South-East and West Pacific regions (Boston-Cambridge, the San Francisco Bay Area, San Diego, New Jersey, Raleigh-Durham and Washington, D.C. – Baltimore).

In the European Union, the common practice is the top-down model of research collaboration support via FPs and the latest Horizon 2020, allows for keeping some geopolitical balance, allowing for the partial mobilization of the talent mobility from the less advantageous regions, with requirements such as the creation of a research consortium for multinational teams. Yet, that "top-down networking" approach may infringe natural knowledge and resources sharing, as many consortia are being created to receive the research grant. In the United States, on the other hand, from the beginning of public research funding, a bottom-up model was established, funded by government agencies and favoring researcher-originated projects over thematically defined grants to promote technological and scientific innovation. The EU research funding procedures appear to be more complex. The United States relies on a strictly centralized process through one agency (the

FDA), whereas the European Commission synchronized the regulations of 28 different countries. The FDA historically developed as a consumer protection agency, whereas the regulations from the EC arose out of the need to harmonize interstate political interests. Thus, whereas the FDA has the advantages of centralization and common rules, the European Union regulates medical drug and device approvals through a network of centralized and decentralized agencies throughout its member states. Apart from differences in funding policies, the EU and the US policies differ in the technology transfer and innovation diffusion process. In the European Union, public policies tend to stimulate specific forms and strategies of technology transfer and innovation diffusion, whereas in the United States, the policy is focused on creating requirements and incentives for research organizations, as well as on stimulating them to intensify their commercialization efforts. Thus, the EU research funding process appears to be more political, regulated, controlled and bureaucratic. Nevertheless, the US life sciences clusters ecosystem suffers from the differences in the local regulations and taxation policies that hinder the growth innovative industries. Last but not least, in terms of technological convergence and interdisciplinary research efforts in the life sciences sector, many EU countries policies seem to be neglecting the promotion of knowledge flow between scientific disciplines. This is because in the European Union, unlike in the United States, policy instruments need to be adapted to the stage of the industry life cycle in each country as well as the global evolution of the life sciences industry. When it comes to the area of education and the promotion of basic and applied research, relevant policy actions in the EU countries seem to be targeting very well. For example, some EU new member states (e.g. Poland and the Czech Republic) took actions to offer business studies courses in university science degrees in biotechnology.

PART II

SOCIAL CAPITAL IN THE UNIVERSITY-BASED INNOVATION ECOSYSTEMS

Chapter 4

Life Sciences Cluster in Cambridge

Małgorzata Runiewicz-Wardyn

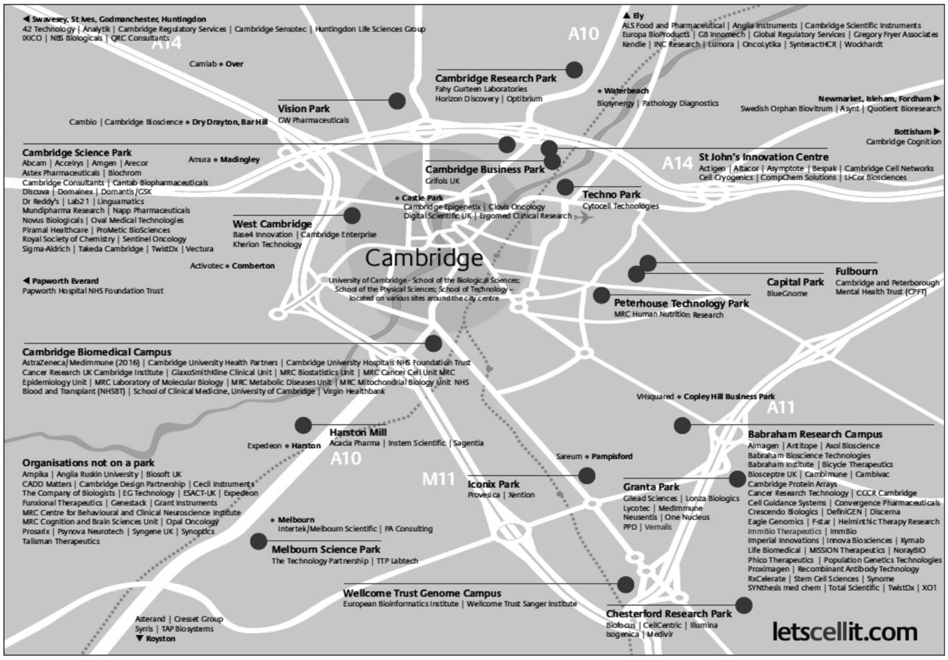
1. A General Overview of the Cambridge Life Sciences Cluster

The UK-based Cambridge University ecosystem is one of the oldest and most successful ecosystems in the world. It is focused on one of the top academic and research institutions in the life sciences sector. The early records of the Cambridge University academic activity can be traced back to the 12th century, when scholars and students began to settle into town and gradually started to be recognized officially. The modern Cambridge cluster began in 1960 with the foundation of Cambridge Consultants (www.cambridgeconsultants.com). The foundation started to strengthen the connection between the University brain power and industry. While Cambridge was already home to several well-established engineering firms, such as the Cambridge Scientific Instrument Company, the Pye Group, and Marshall of Cambridge (www.cam.ac.uk/research/innovation-at-cambridge), it was still viewed by many as a small country town. It is with the establishment of Cambridge Science Park by Trinity College (www.trin.cam.ac.uk) in 1970 that the cluster began to grow rapidly, with 39 new companies formed between 1960 and 1969, and 137 more in the 1970s. By 1990, company formations had reached an average of two per week. Today, Cambridge is Europe's largest technology cluster, often viewed as a part of 'the Golden Triangle' – the Greater London-Cambridge-Oxford bioscience cluster is the strongest in Europe. Around 57,000 people are employed by more than 1,500 technology-based firms in the area, which have combined annual revenue of over £13 billion (https://www.cam.ac.uk/research).

The Structure of University-Based Life Sciences Ecosystem

The university plays a fundamental role in the success of this place. The University is a major employer, technology provider, and a source of knowledge and skills in the region. It is organized in 6 schools, with four of them related to the life sciences sector. They are: School of the Biological Sciences, School of Clinical Medicine, School of the Physical Sciences, and School of Technology. In parallel to the structure of the Schools and Faculties structure, there are 31 colleges, which are granted their own status and regulations, where students live and can socialize. The colleges also guarantee supervision and small teaching sessions to undergraduates. Altogether Cambridge serves more than 18,000 students from all cultures and corners of the world and the total staff account for over 10,000 employees. Nearly 4,000 of the institution's students are international and hail from over 120 different countries. In addition, the University's International Summer Schools offer 150 courses to students from more than 50 countries. The university is split into 31 autonomous colleges where students receive small group teaching sessions, known as college supervisions. In addition to the Science Park, the University and its Colleges have been integral to the infrastructure which enables the cluster to continue to grow, including St John's Innovation Centre, Peterhouse Technology Park, the Cambridge Judge Entrepreneurship Centre (including Accelerate Cambridge).

Map 4.1. The Cambridge life sciences cluster



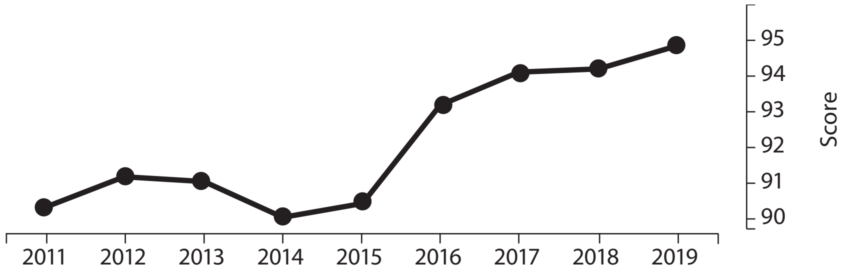
Source: https://www.cam.ac.uk/sites/

In terms of the location, the boundaries of the Cambridge life sciences cluster extend to the whole city, with the colleges and the faculties being spread out in its area, and so are the innovation and science parks, the offices of the venture capitalists and the business angels, and everything that is connected to the innovation process. Even though it is not possible to draw a detailed map of the ecosystem, one can approximate its extension to that of the city, or at least the parts of it that are important for innovation and entrepreneurship, which are all easily reachable by bicycle (Map 4.1). The Cambridge bioscience cluster directly employs some 13,800 people, and it is geographically spread between 18 parks (or subclusters) within approximately 10 miles of Cambridge, with outliers in Ely, Newmarket, Huntingdon and Godmanchester, and Royston.

Scientific Impact

The Cambridge academic system is well-renowned internationally and for several subjects, it is considered one of the best places in the world. The University is in top 10 of Reuters' top 100 most innovative universities in Europe (2018). The methodology of the ranking draws on several indicators, including patent filings and research paper citations. It aims to identify institutions that are doing the most to advance science, invent new technologies and help drive the global economy (www.reuters.com). Considering only scientific fields, the Times Higher Education World University Ranking 2019/2020 ranks the University of Cambridge 3rd in the field of engineering, 2nd in Life Sciences, 3rd in the category Clinical, Pre-clinical & Health. The highest growth of the University's rank was observed in the last several years (Figure 4.1).

Figure 4.1. The growing rank of the University of Cambridge in the life sciences sector, 2011–2019

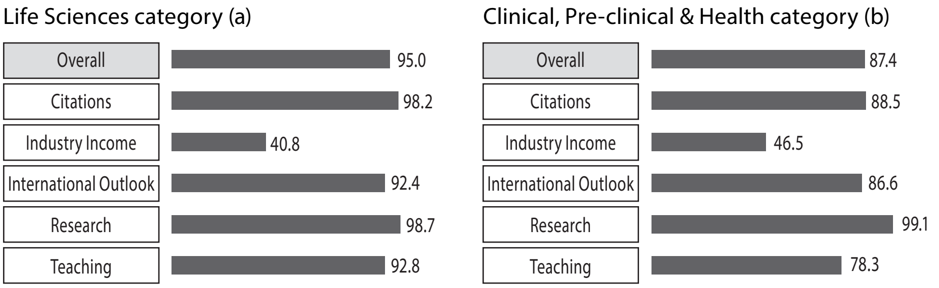


Source: https://www.timeshighereducation.com/world-university-rankings/

Another world ranking institution – QS World University Rankings – places Cambridge University 7th in the overall ranking and 1st in Biology sciences. Lastly, Cambridge has a strikingly high number of Nobel prize winners: since 1904, there have been 96 affiliates of the University who were awarded the prize.

Cambridge University stays high in the expert opinions regarding teaching and research quality, the number of citations per faculty, and employer reputation which is reflected in the industry income, citations and international outlook scores in both overall life sciences and the category Clinical, Pre-clinical & Health (Figure 4.2(a) and 4.2(b)).

Figure 4.2. Cambridge University's overall scores in the categories Life Sciences, and Clinical, Pre-clinical & Health



Source: The World University Rankings (2019); www.timeshighereducation.com/university-rankings/

The University also provides a steady supply of science graduates, many of whom find employment in the firms and institutes that make up the cluster. Over the years, a synergy has developed between the University-based science research and the technological and scientific base of the cluster. A key feature of the innovation system that is the Cambridge cluster is its focus primarily on 'analytical' knowledge (developing new knowledge of natural systems by applying scientific laws and techniques), which can be distinguished from 'synthetic' knowledge and 'symbolic' knowledge (applying or combining, in novel ways, existing knowledge; know-how). Cambridge scientists play an essential role in the research helping to bridge the gap between patients and scientific research. One way to do that is via clinical trials. The Wellcome Genome Campus in Cambridge is home to the Sanger Institute and the European Bioinformatics Institute. There are five areas of excellence of Cambridge: medtech, small molecules, antibody engineering, cancer, genomics. The Campus is one of the largest concentrations of genomics and biodata in the world, bringing together over 2,600 people working in specialist and innovative genomics and bioinformatics companies. Collectively, 45% of the Institutes' personnel are from outside of the United Kingdom, bringing together a unique combination of international knowledge, experience and scientific networks. One of its most important partnership projects is The 100,000 Genomes Project will sequence genomes from around 70,000 National Health Service (NHS) patients.

Technology Transfer

The development of a cluster with a constant entrepreneurial activity has been partly made possible by the active role of the University. Since the early 1970s, it became a fundamental provider of technology, ideas, and people, and started to actively engage in technology transfer, firstly through the Wolfson Industrial Liaison Office (https://www.enterprise.cam.ac.uk). Now the University has a wholly-owned subsidiary in charge of transferring technology, Cambridge Enterprise which engages in TT activities, seed funding, and consulting services, currently managing nearly 1,000 active IP, licensing and consultancy projects, together with 65 equity contracts. As the Cambridge University ecosystem provided more and more positive results, engagement in entrepreneurial education increased as well. Today, the University offers many activities in support of entrepreneurship. One example is the creation of the Centre for Entrepreneurial Learning within the Judge Business School, which provides electives on entrepreneurial practice and open programs for aspiring entrepreneurs, such as Enterprise Tuesday (www.jbs.cam.ac.uk/entrepreneurship), and Ignite Enterprises (www.jbs.cam.ac.uk/entrepreneurship/programmes/ignite). Together with these tailored programs, the creation of other organizations with similar missions proliferated, such as IdeaSpace (www.ideaspacefoundation.org), which provides office space and resources to those who want to start a new venture, preferably with innovative and potentially high-impact business models. Another notable sign of the continuing nourishment of the ecosystem is the creation of both Cambridge Network (www.cambridgenetwork.co.uk) and of St John's Innovation Centre (https://stjohns.co.uk). Thus, Cambridge Enterprise is the channel suggested by the University to commercialize new technologies. The academics, however, are not obligated to ask for its services. They can choose their own technology transfer backer.

Although patents are often used as an indicator of innovation, they are not unproblematic, since not all firms patent their 'inventions', and even if they do, a considerable amount of time may elapse before the invention is commercialized, and some inventions may never come to market. Furthermore, there is some evidence that in the medical field, licensing is often a preferred alternative to patenting. However, licensing data are difficult to obtain, whereas information on patenting activity is available much more readily.

Table 4.1. Cambridge technology transfer data, 2017–2018

	Commercial and research licenses signed	Patents applications	Contracts of industry collaborations	Start-ups
Total number	14	258	401	350

Source: www.enterprise.cam.ac.uk

According to the OCED data available for Cambridgeshire, where most of the life sciences research and development activity in Cambridge and 15-mile radius within the city, the most rapid growth in life sciences patenting activity started in the early-1990s onward. This growth was led by biotechnology and pharmaceuticals. Secondly, since the mid-2000s, the overall level of patenting appears to have somewhat leveled off, and more recently, it has fallen back a little. This appears to have been mainly due to biotechnology. While the sector has experienced a decline in patenting activity, patenting in pharmaceuticals and medical technology has remained more or less steady. As a consequence of these different trends, the latter two sectors account for most of the cluster's patent activity now.

The University's people and ideas are at the heart of many companies in the life sciences cluster (both spin-outs and start-ups). The University also contributes to the growth of the cluster by providing solutions to business problems through consultancy activity and through the licensing of discoveries to new and existing companies (Table 4.1). More than 1,000 IP licensing, consultancy and equity contracts are currently under management by Cambridge Enterprise, the University's commercialization group (www.enterprise.cam.ac.uk/ as of 16/10/2019). In 2018, there were 86 companies in the Cambridge Enterprise portfolio. As spin-outs grow and succeed, they exit the portfolio, either via sale or public listing. Collectively, this process has generated billions of pounds in value.

2. The Empirical Analysis

Considering the importance of Cambridge University in the scientific impact and technological transfer in the field of life sciences, the section below discusses the empirical survey findings on the role that social networks and networking play in the Cambridge University ecosystem. In the university-based innovation ecosystems, formal relationships among organizations and their actors merge with the personal networks. Just as Krugman (1991) points outs, "knowledge flows are invisible." Thus, the identification of the channels, boundaries and the true value added of knowledge flows within a particular personal network is both important and challenging. The author conducted 14 in-depth interviews with the Heads and Deans of Departments, the technology transfer offices (TTO), related educational institutions and companies in the following life sciences cluster ecosystems in Cambridge. The questionnaire was addressed to different groups of representatives from public research organizations (universities and government laboratories), nonprofit research institutes, research hospitals, science-based biotechnology firms, multinational pharmaceutical corporations and biotech clusters/networks organizations (Cambridge Medical School, Trinity College; Cambridge Enterprise Limited, Cambridge Academic Alliances, Cambridge Networks; Cambridge School of Clinical Medicine, Addenbrooke's Hospital; School of the Biological Sciences, the

Bioscience Impact Team; the MRC Laboratory of Molecular Biology, Academic Health Science Centre, Babraham Bioscience Technologies Ltd (BBT), AstraZeneca PLC, MedImmune Cambridge). The survey consisted of 13 questions concerning the organizations' strategy, network interaction, competition, R&D-projects and future plans. The questionnaire contained mixed questions (open and closed ones) and was composed of three parts: (1) the mission, structure and types of social networks; (2) the methods of social networking, the intensity of interactions and different dimensions of social capital, (3) the impact of social networks on R&D collaboration, innovative performance and future plans. A summary of the most important questionnaire findings on the role played by each type of proximities in each ecosystem (with some original statements of the respondents are written in quotation marks) can also be found below.

The Mission, Structure and Types of Social Networks (1)

All the respondents agreed that the core mission of the networks is to "share knowledge and information." This was followed up by their second choice – to "exchange ideas for the new common R&D projects/initiatives." Few respondents emphasized that participation in the networking events gives an "opportunity to learn what's happening in the fields not directly related to one's research field, but may be important for the implications in one's field". The exchange of best practices and promotion of one's research unit was the least important cause for the networking. Both networking with public and private organizations were equally important for the respondents. On average, Cambridge life sciences cluster's representatives devoted some 25–30% of their weekly work time on networking events (both formal and informal ones). Furthermore, the institutional dimension of social networking – interaction with other networks that are not part of one's local/regional network, such as other universities/labs/hospitals/medical institutions networks, but also business leadership programs/events, was important for all respondents. This was especially relevant for the participation in the regional and national networking events organized by the UKSPA networks (www.ukspa.org.uk/our-association), the UK BioIndustry Association (www.bioindustry.org) and to a lesser extent, the EU-based scientific networking events devoted to the life sciences. The purpose of such networking was to increase diversity, interdisciplinarity and different approaches in the life sciences. In the view of two-thirds of the respondents in the sample, "the ongoing technological convergence, enforces close collaboration between representatives of diverse knowledge bases within their local university-based innovation ecosystems." Therefore, participation in the EU-based networking events, such as BioEurope (or other pharma events), was more subject specific. In terms of the intensity of informal and formal social interactions between partners, jointly participating in R&D projects the survey show very regular interaction, occuring more than once, usually 2–3 times, a month. Two respondents mentioned that such interaction is based on the needs and the problem-specific situation ("demand-based"). In terms of the nature of partnerships within the established network, informal interpersonal interactions were important for 90% of the respondents.

The Methods of Social networking, Expectations toward Partners, the Intensity of Interactions and Different Dimensions of Social Capital (2)

Physical and face-to-face formal and informal meetings on site were the most frequent communication methods in the networking, whereas electronic communication methods, such as email, telephone and Skype, served as a means of maintaining the established network relationships. Furthermore, the respondents from Cambridge life sciences cluster admitted that "being institutionally proximate facilitates knowledge transfer and research collaboration." They also pointed out the "important role of TTOs and other intermediary-networking agents and institutions facilitating social networking and collaboration between various actors within their ecosystems." Moreover, once established network of formal relationships among Triple Helix organizations merges with the informal social networks, the institutional proximity becomes less important. Thus, the respondents agreed that "intermediaries and institutional proximities play an essential role in narrowing the social distances" at the beginning of any collaboration process. The role of the geographical dimension in the expansion of the social networks was rather limited and driven by a transaction-based interest approach. There was a much higher interest in expanding one's collaboration with the London life sciences cluster than other countries. In reference to the new innovative investors (e.g. from China), one respondent said that "before we do the R&D project, we explore it closer to build a trust and not damage our reputation." The respondents thought of trust and social norms as important in a network. This can influence both the obligations and expectations that people have on each other. For the same reason, the Cambridge respondents chose the geographical proximity – within the same region or the neighboring regions – as an important attracting factor for future collaborations and further networking. In this context, the interviewees from the Cambridge University ecosystems emphasized the importance of "social infrastructure – sport centers, clubs, bars and coffees – that create opportunities for informal interactions." "Having a brief chat over a cup of tea or coffee" was an especially popular attitude for the respondents of the Cambridge University ecosystem.

When asked about other expectations towards partners in the networks or attempted networks, a similar pools of expertise was considered important for 60% of respondents. As one of them said, "practical approach is predominant here – they know something I know or want to know." No finance-related aspect was considered important for the networking or possible future collaboration, In turn, trust was considered to be a very important factor for such long-term collaboration. Ideally, a new partner would be a friend of a friend (and would not be in conflict with the others). Generally speaking, people referred of a shared culture of "giving", knowing that being in that ecosystem, sooner or later they will get something back. Following the statement of one respondent, "usually, there is one or two of the key persons that one knows that can put things together and connect people. In other cases, such organizations as Cambridge Alumni groups (www.alumni.cam.ac.uk), Cambridge Innovation Capital (www.cicplc.co.uk) or Cambridge Cluster Network (www.cambridgenetwork.co.uk), would be a major platform for network expansion".

Almost everybody in the Cambridge university-based innovation ecosystem mentioned "openness (in sharing ideas and meeting people) as essential for strong and long-lasting social networks." Moreover, in the view of the interviewed scientists, managers and administrators, such behavioral components as "trust, openness, professionalism and complementarity become key drivers behind the social relationships and knowledge flows within the Cambridge ecosystem." Nevertheless, they also pointed out the potential problem of "putting too big pressure on scientists to attend to social events, as well as bridging and bonding efforts". As one faculty member put it, "Why widen one's circle of casual acquaintances when one has established a well-functioning network already and has other important tasks?" Another respondent expressed his fear that attending social events "may infringe the privacy and risk of someone scooping one's ideas." In a similar manner, digital forms of social networking "can facilitate communication but can limit one's privacy as it leaves traces." Moreover, all the respondents acknowledged the common behavioral components, such as "trust, professionalism and openness, as key for the social networks creation and connections to relevant stakeholders." A longer period of adoption may be needed for a distant partner. However, cognitive proximities and similar experience may offset geographical distances. In fact, as the survey outcome shows, distance in terms of knowledge base is both an enabler and an obstacle for the knowledge and innovative networking activities among the aforementioned respondents. The corporate-related respondents emphasized "the key role of Cambridge University and other local schools, and R&D centers as an incredible opportunity for the knowledge spillovers and innovative activity." Moreover, staying with the "close proximity to the best universities in the world enabled them to acquire high competence when dealing with the latest technologies." In this sense, limited competence and poor absorptive capacities of other non-local actors made the successful research interaction harder. This was particularly emphasized by both the faculty and business respondents from the Cambridge life sciences cluster. These respondents found technological proximities to be a "major challenge when expanding the innovation-driven social networks with the partners from Poland or Hungary." To some (limited) extent, the gap created by cognitive and technological distances was bridged by intermediaries (e.g. individual faculty members, TTOs), institutional and cultural proximities. Furthermore, even though the respondents agreed with the importance of diversity, heterogeneity, and complementarity in enriching the capabilities and knowledge of actors involved in the innovation processes, the Cambridge faculty and business respondents pointed out that "advancing from the same well-established knowledge base and knowledge networks creates more opportunities." Referring to the physical proximity may be also more important at the early stage of R&D project collaboration. As one respondent said about the early stage of research, "it is easier to do in one country." The networking with the EU member sates institutions may be discouraging because the strategic/administrative top-down decision-making process, which imposes partnerships where no cognitive proximities are present. Instead, participation with the EU networks or EU projects is determined by funding and political reasons. Lastly, the respondents were unwilling to open themselves to random networks. One of them mentioned that "there must be good reasons for it to happen." Most of the Cambridge cluster networks would be described as a small-world networks, suggesting that the networks exhibit the small-world phenomenon. Therefore, the speed of information transfer is higher than it is in a randomized network.

The Impact of Social Networks on R&D Collaboration, Innovative Performance and Future Plans (3)

For all the respondents, the participation within the national scientific and academic formal networking events played a very important role, from the perspective of personal development, the advancement of our institutions/organization and strategic development of a given scientific field. Similarly, when asked about the impact of networking on R&D/innovation performance approximately two-thirds of the respondents claimed that "information obtained from a member of one's close social network induces a stronger sense of trust and therefore may have an influence on their organization and personal opportunities development and choices," and in contrast, "one may be less amenable to update his or her beliefs on the basis of that information if the source of information is not familiar." The research or innovation opportunities grow even higher if networking leads to contacts with highly successful and influential people, e.g. star scientists or CEOs. In terms of personal development, social interactions, conversations between individuals who are familiar with the specific research problem, area or work more intensively in the area of applied science and innovations, enrich the practical knowledge and awareness of market related problems of innovations, etc. For the future plans, more than half of the Cambridge representatives would rather like to develop closer social interactions with existing partners. The aim is, as one person put it, to "construct and maintain a useful network" (vertical integration within the network), instead of enriching it with possible future social ties (horizontal integration within the network), or to become more international. This would include networking across their own Departments or organizations. As one researcher put it, "it is easier to expose problems and seek solutions within your own Department. Ca. one-third of the respondents would focus on enriching their current social networks with new personal contacts, research/business directions, as well as future partnerships. Finally, in terms of social networks, the respondents in the Cambridge ecosystem emphasized the need to further exploit the diversity within the local vertical networks rather than horizontal ones (between other university-based innovation ecosystems).

3. Conclusions

The Cambridge University ecosystem is rooted in the mature world-class cluster in life sciences. It is featured by more closed social networks with hierarchical structures and strong ties in the sense of Granovetter (1973). The intensity of networks is somewhat circulates around more powerful individuals or those who are of a higher status – Deans and Heads of Departments – interconnecting the other actors in the ecosystem, as well as holding control over information that originates from other networking groups. In this sense, their closed hierarchical network structure is in line with the spirit of Coleman (1988), it provides the ecosystem actors with greater trust which might be very important when deciding whether to exploit a research/business idea or not. The role of "triadic closures" was significant, as many of these actors formed collaboration links with partners' partners. The role of geographical proximity was great. Interactions with individuals, which do not originate from the local ecosystem, tended to occur at larger distances. The researchers and corporate representatives had a high degree of cognitive proximity – of common knowledge and understanding within their own organization/department. The latter had an especially positive influence on the researchers' willingness to interact with each other and create social capital, which, in turn, enhanced a higher level of trust in a given relationship. The physical proximity among Cambridge ecosystem actors allows them to engage in more informal interactions and serves as a precondition to strengthen social ties and trust. On the other hand, the geographic dimension can really matter when strong social networks already exist, so one could state that physical proximity enhances and strengthens personal relationships within the existing networks. The overall research findings showed that communication dimension is very important. In fact, analyzing the opinions of the respondents, one can notice that communication and 'social proximity' are mutually reinforcing. Communication, through its wide array of local workshops and informal events, enables socialization, whereas higher social proximity induces more frequent communication and the development of closer relationships.

Chapter 5

Life Sciences Cluster in Medicon Valley

Małgorzata Runiewicz-Wardyn

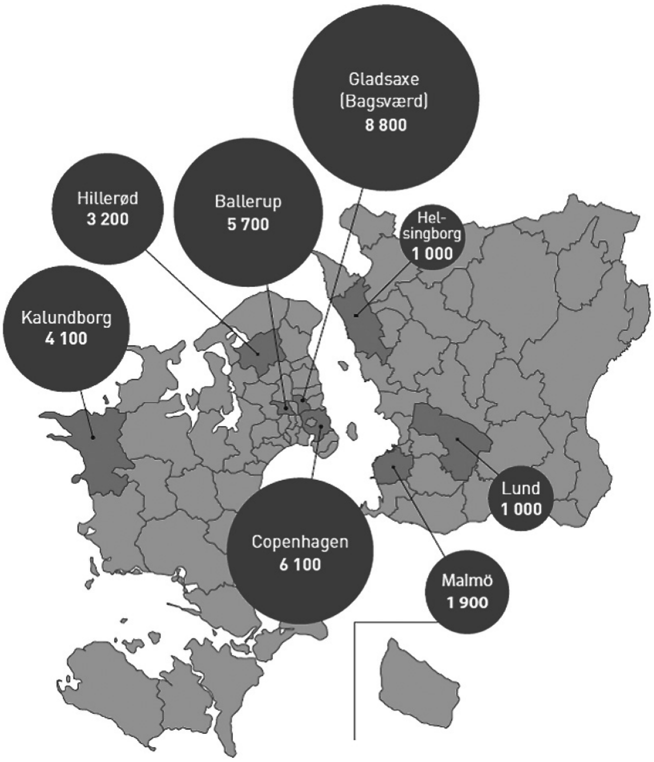
1. A General Overview of the Medicon Valley Life Sciences Cluster

Medicon Valley is a leading international life sciences cluster in Europe. It dates back to the 1990s, when the Swedish and Danish governments, inspired by the Silicon Valley, decided to join efforts in their national life sciences sectors. Today, the Medicon Valley bioscience cluster directly employs approximately 44,000 employees in the private life sciences sector, spread geographically on the cross-border Øresund area of 21,000 km^2. The area is occupied by approximately 3.5 million inhabitants and includes the Danish Capital Region, which naturally reinforces the strengths. The Danish Capital Region has the highest GDP per capita, but the Swedish side of the side, Skåne (81% of the Capital Region's GDP per capita), is growing at a fast rate. The Øresund Region is a technology hub with high innovation potential, and a good environment for start-ups. It accounts for a large share of total Swedish and Danish R&D: its R&D expenditure (5% of GDP), mainly of private origin, outperforms national figures. A total of 58% of those working in the Danish and Swedish life sciences sectors actually work in Medicon Valley (2016). As stated in the State of Medicon Valley Analysis (2019), the life sciences sector is the very dynamic and just in 2018, it recorded the highest growth in exports in the Danish life sciences industry's history. For instance, the export of medical products and devices reached over 15.4% of Denmark's total exports (this share has doubled since 2008). Life sciences exports were also record high in Sweden in 2018, having risen by 10.6% compared just to 2017.

The Structure of the University-Based Life Sciences Ecosystem

The university plays a fundamental part of the success of Medicon Valley. There are some 12 universities connected to 7 science parks, 5 of which provide life sciences-related education, 32 hospitals, of which 11 are university hospitals, are spread out in its area on the Swedish and Danish sides. The collaboration of these science parks plays an important role in the development of life sciences business in the region. In the early 1990s, a network organization – Medicon Valley Alliance (MVA) – enabling knowledge sharing and transfer of technology between the above-mentioned universities, was established. The main initiators behind the establishment of Medicon Valley were the universities in Lund and Copenhagen, strongly supported by the major pharmaceutical companies in the region: Novo Nordisk, Lundbeck and AstraZeneca. The idea was to create a platform where Danish and Swedish life sciences actors could meet (mva.org). MVA was founded in 1997 as an EU Interreg II project under the name Medicon Valley Academy. The establishment of this formal organization was preceded by the intense infor-

Map 5.1. The Medicon Valley life sciences cluster



Source: https://www.biopharma-reporter.com mal discussions about creating the organization already in 1992, when work on the bridge between Denmark and Sweden took off. As the bridge became a reality, expectations about closer interaction between research and business communities in the two countries grew. Today, the Medicon Valley life sciences cluster boundaries extended to Greater Copenhagen and southern Sweden (Skåne County), and were connected by the Øresund Bridge (Map 5.1).

Each university has a representative on the Board of Directors. One of the MVA initiatives concerns the attractiveness of Medicon Valley to international skilled scientists, experts and investors. MVA initiates, communicates, and encourages cooperation between companies, organizations, and public authorities. It is the only organization representing the entire health and life sciences sector in the cross-border region. MVA has strong ties with these universities, and influences the overall offer of life sciences-related education in the region. Two universities are especially active participants in the life sciences development in Medicon Valley – the University of Copenhagen in the Greater Copenhagen region and Lund University in the Malmö-Lund area.

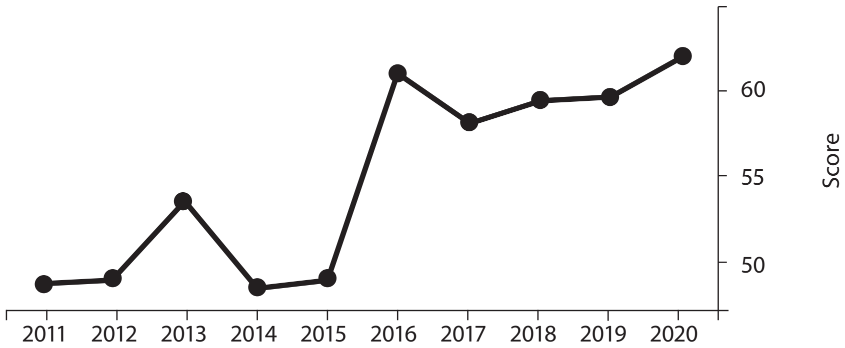
The University of Copenhagen is the oldest and the largest higher education institution in Denmark. The university accounts some 39,000 students and employs more than 5,000 academic staff, about 80% of whom are research staff. The University consists of four main campuses, three of which – the North Campus, the City Campus and the South Campus – are in Copenhagen, with the Frederiksberg Campus, where the Faculty of Science and the Faculty of Health and Medical Sciences are located, being in nearby Fredericksburg. It has about 100 departments and research facilities and six faculties: the Faculty of Health and Medical Sciences, the Faculty of Humanities, the Faculty of Law, the Faculty of Science, the Faculty of Social Sciences, and the Faculty of Theology. In general, the University accounts for ca. 4.3 students per staff and hosts 17% of international students (www.ku.dk). Nine researchers associated with the University of Copenhagen have been awarded Nobel Prizes, including Niels Bohr who was awarded a Nobel Prize in Physics in 1922 for his work on the structure of atoms. Other notable alumni include Tycho Brahe, who made the first scientific documentation of supernovas, and the philosopher Kierkegaard.

Lund University is a public research university in Sweden located in the city of Lund. The university also has campuses in Malmö and Helsingborg. It is considered to be one of the biggest Nordic educational and research institutions, hosting over 41,000 students, of which 3,000 are postgraduates. More than 7,000 people are the University's staff members. It also boasts one of Scandinavia's most extensive educational programs, with over 300 degree programs, including medicine and science. With over 600 partner universities in more than 70 countries, Lund University belongs to the League of European Research Universities, and Universitas 21, a global network of research universities. It is also home to two important scientific facilities: MAX IV – an electron accelerator laboratory for research into radiation, nuclear physics and accelerator physics – and the European Spallation Source (ESS), for research into materials. The University has a significantly higher ratio of the number of students to staff – 12.1, compared to the University of Copenhagen, however, it has a higher share of international students (19%) (www.lunduniversity.lu.se).

Scientific Impact

The University of Copenhagen is the highest-ranking university in Denmark and one of the highest-ranking universities in the Nordic region. Internationally, the University of Copenhagen ranks at a level that corresponds to a position among the top 1% of the world's universities. Considering all scientific fields, the Times Higher Education World University Ranking 2019/2020 ranks Copenhagen University 1st in Denmark, 4th in the Nordic region, 38th in Europe, and 101st in the world. In view of the two other rankings of higher education institutions: ARWU Shanghai Ranking (2019) and the CWTS Leiden Ranking (2019), the University takes 26th place and 36th place, respectively. Reuters' ranking of top 100 most innovative universities in Europe in 2018 places the University of Copenhagen among the most advanced universities in terms of science and new technological inventions. More importantly, it has a strong regional and European academic reputation for the research and education in the life sciences. Across the biological science fields, the University observes the highest growth of its rank in the last several years (Figure 5.1).

Figure 5.1. The growing rank of the University of Copenhagen in the biological sciences, 2011–2019/2020

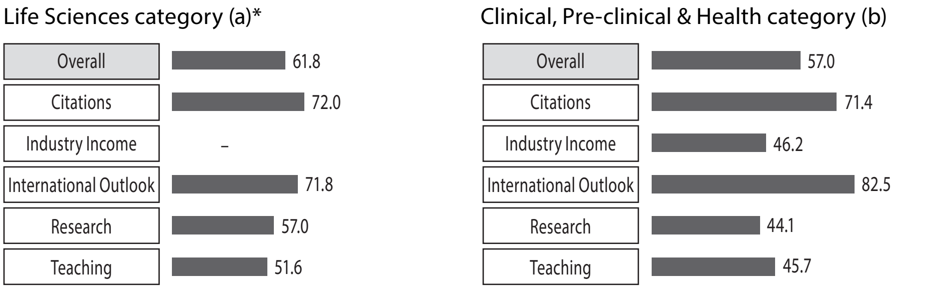


Source: https://www.timeshighereducation.com/world-university-rankings/

The life sciences ranking in the *Times Higher Education* (THE) World University Rankings 2019 assesses universities, using 13 indicators of excellence that evaluate teaching, research, research influence, innovation and international outlook.

The University of Copenhagen provides a high level of teaching and supplying of highly qualified science graduates in both life sciences and clinical, preclinical and health fields. Many of them find employment in the industry firms in Medicon Valley (Figure 5.2(a) and 5.2(b)).

Figure 5.2. The University of Copenhagen's overall scores in the categories Life Sciences, and Clinical, Pre-clinical & Health, 2019



Source: The World University Rankings 2019 by life sciences, www.timeshighereducation.com/university-rankings/

*2015/2016

The Department of Biology at the University of Copenhagen (BIO-UCPHs) is positioned among the top 2 to 9 best performing European academic institutions. The discipline-specific impact analysis confirms BIO-UCPHs research as leading across disciplines from molecules to ecology. The value of the teaching metric in the 2019 ranking is 45.7[1] (for the comparative purpose, the analogous value for Cambridge is 78.3, and 35.5 for Lund University). In the field of life sciences research, the University's programs annually attract 20–25 million euro in external funding, constituting about half of the total annual budget. Using co-publication as a proxy for collaboration with industry, the BIO-UCPHs registered more than 248 collaborative interactions with companies during 2010–2015. Yet, the University has a moderate position in the research metric (based on the reputation survey by academic peers; research income, and research productivity)—57.0 in life sciences research and 44.1 in clinical and preclinical research, which is significantly worse than Cambridge University (98.7 and 99.1, respectively) and slightly better than Lund University (54.6 and 39.7, respectively). According to the World University Rankings 2019 ranking data for citations, the University of Copenhagen achieved the value of 72.0 in life sciences research and 71.4 in clinical and preclinical research (with the 'citation' sub-index accounting for 30% of the total score in the Rankings).

[1] Both teaching and research metrics weigh 30% each in the total score in the life sciences and clinical, preclinical and health ranks (2019).

The ultimate test of the quality of research output is its impact. In terms of the reflection of the industrial value of the research, the University holds a score of 46.2 in clinical and preclinical research (this metric holds for 2.5% of the total rank), which is a level comparable to much stronger Cambridge University (see Chapter 4).The university-industry interactions have resulted in 178 joint publications with 139 unique companies from all over the world (35% from Denmark, 23% from the European Union, 34% from North America and 6.5% from Australasia).

Finally, for the international outlook (the ratio of international students to domestic ones, the ratio of international staff to domestic one, and the proportion of research that involves international collaboration), the University of Copenhagen reached the value of 82.5 for clinical and preclinical research, which is only slightly less than Cambridge University (86.6) and better than Lund University (72.6). In overall, around 75% of all BIOs publications include international collaborators. The genomics-based approaches and cell biology & genetics were the most popular fields of research for the above collaboration (36.3% and 19% of all papers). The collaboration of BIO-UCPHs with international companies has almost tripled within the past five years. We interpret this as the result of strong international relations and a demand for our research. In terms of national companies, BIO-UCPH is strengthening its communication with Danish companies. Thus, BIO has launched a strategic initiative aimed at offering open discussions concerning potential collaboration. The University's ties with major Chinese universities and research institutions have recently been expanded by the establishment of a Ph.D. degree program with BGI Shenzhen, the world's largest genomics research institute. A similar program has also been established with the National Institute of Nutrition and Seafood Research, Bergen, Norway.

Lund University is the highest ranked university in Sweden in the QS Ranking 2020. It is also consistently ranked among the world's top 100 universities in world university rankings. It is the top 101–150 university in the Shanghai Jiao Tong University's Academic Ranking of World Universities (ARWU 2019) and it has reached 88th place in the U.S. News Best Global Universities Rankings 2019.

The University is behind many innovations and new discoveries, e.g. including facial recognition technology, the wireless technology Bluetooth (named after a Viking chief) and Nicorette, the world's first nicotine medicine developed to help smokers quit their habit. The city of Lund has the youngest population of any in Sweden and its atmosphere is described as 'youthful and laid back.'

In the view of the experts from Times Higher Education regarding research excellence at the Lund University, a number of scores look as follows: 54.6 in the life sciences and 39.7 for the category Clinical, Pre-clinical & Health (Figure 5.4(a) and 5.4(b)). The situation looks different in the case of Copenhagen University where the above-given scores reach 57.00 for the life sciences and 44.1 for the category Clinical, Pre-clinical & Health (Figure 5.2(a) and 5.2(b)).

Figure 5.3. The growing rank of Lund University in the biological sciences, 2011–2019/2020

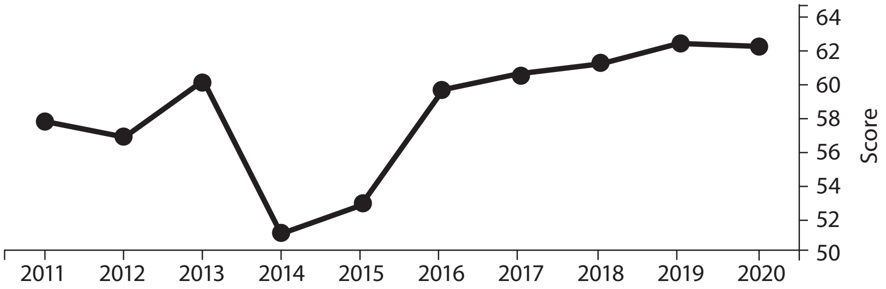
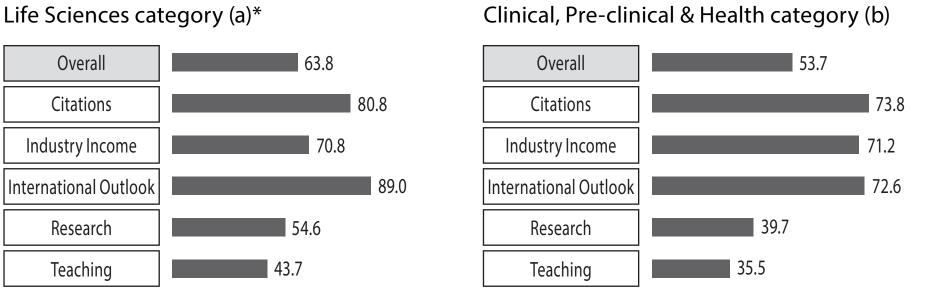


Figure 5.4. Lund University's overall scores in the categories Life Sciences, and Clinical, Pre-clinical & Health, 2019



Source: The World University Rankings 2019 by life sciences, www.timeshighereducation.com/university-rankings/

*2015/2016

The University stands high in terms of international collaboration and international-to-domestic-student/staff ratio—it scores 89.0 for the life sciences and 72.6 for the category Clinical, Pre-clinical & Health (which is different from Copenhagen University, which has got a higher score for the category Clinical, Pre-clinical & Health, i.e. 82.5, in comparison to 71.8 for the life sciences). Thus, the two universities seem to complement each another in the two fields above – life sciences and the category of Clinical, Pre-clinical & Health. The Lund University Alumni Network now offers one (LU alumni) the opportunity to start regional groups. These groups can be casual or formal, large or small, social or academic, or whatever makes one feel connected to the Lund University Alumni Network, one is part of a community with over 39,000 alumni scattered around the globe.

In sum, Medicon Valley, with its two major universities, Lund University and the University of Copenhagen, and over 15 smaller life sciences institutions – is a relatively younger ecosystem, which nevertheless has a stable generation of spin-offs and start-ups. The cluster is especially active in research and studying in the field of diabetes and neuroscientific research. Both universities are actively involved in attracting international faculty and students, with Lund University being more popular and thus more advanced in these efforts. Two cross-border universities have several areas of common specialization, such as life sciences and ICT, with complementary potential in universities and companies. The collaboration between Medicon Valley's universities contributes to the overall scientific impact and innovative potential of the region. According to MVA's study comparing Europe's ten most influential life sciences clusters, based on their scientific publication volume in the life sciences, during 2008–2018, Medicon Valley had a greater increase in the percentage of scientific publications in life sciences than any other cluster in Europe (a 23% increase, with 54% of the scientific publications resulting from international collaborations) (nordiclifescience.org).

Technology Transfer

The University of Copenhagen

The University's Technology Transfer Office at Research and Innovation (TT-UCPH) is responsible for negotiating various collaboration agreements between the University and external parties (www.fi.ku.dk/english/tech_trans). It was founded in 2003, with the mission to "ensure the exploitation of research results transferred to private companies" (www.fi.ku.dk/tech-trans). Apart from the director of Research and Innovation, there are currently 13 people employed at TT-UCPH: 5 business developers with scientific backgrounds and experience working in industry; 6 lawyers and 1 generalist managing the Copenhagen Spin-outs project. The basic mission of TT-UCOH is to identify research with commercial potential and to commercialize it, which firstly means building up relationships with industrial partners or potential investors. The University of Copenhagen and two other institutions (the Technical University of Denmark and The Hospitals of the Copenhagen Region) successfully applied for funding through EU-ERDF for the Copenhagen Spin-outs (CSO) project. In 2011, the CSO was established with the goal of fostering the transformation of life sciences research into the creation of sustainable spin-outs. The CSO involves a group of experts from companies or other organizations, such as Dansk Biotek and the Danish Association of the Pharmaceutical Industry, who provide help on particular issues related to commercialization. The CSO involves TTOs, science parks, innovation incubators, seed funds and spin-outs within the areas of medtech, diagnostics, biopharmaceuticals, industrial biotechnology and food. The stakeholders, funders and industrial partners in the Spin-outs project meet at least 4 times a year. Each TTO presents the current spin-out projects in their portfolio to the group. The Spin-outs project shows how collaboration between universities and other public research organizations with similar or complimentary research interests can be organized to provide the resources needed to bring research outputs to a market- and investor-ready stage. Developing an extensive network of partners, such as via the CSO project, in the early stages of the process is an important condition which is necessary to foster the growth of spin-offs/start-ups (*Copenhagen Spin-outs Program 2019*).

The creation of *spin-off* companies is one of the *technology transfer* mechanisms through which knowledge and/or intellectual property are transferred, by which research results are commercially exploited. Another technology transfer activity can either be a license agreement or a know-how agreement. The license agreement normally refers to the research licensing, patent applications, contracts of industry and start-ups. The number of life sciences-related patent applications to the EPO, in Denmark and Sweden, rose by 10% and 4%, respectively, just compared to 2018. The greatest increase was in pharmaceuticals, though most patents are still sought for biotechnology. Following the survey by the Centre for Science and Technology Studies (CWTS), concerning scientific publications and citations in the life sciences from 2006–2017, the region's researchers are cited significantly more often than average in 15 of the 20 largest subject areas for life sciences researched in Medicon Valley (2018). The quantified form of the technology transfer activities in the two universities is provided in Table 5.1.

Table 5.1. Copenhagen University's and Lund University's technology transfer data, 2018

	Commercial and research licenses signed number of invention disclosures	Patent applications	Contracts of industry collaborations	Start-ups/spin-outs
Copenhagen University	39	24*	382	7 spin-outs
Lund University*	206	16	-	21 start-ups

Source: https://www.innovation.lu.se; https://fi.ku.dk/english/tech_trans/

*2017

Lund University

The Technology Transfer Office at Lund University (LU Innovation) is the hub for innovation and commercialization (www.innovation.lu.se). The office supports researchers and students in developing and commercializing their research via company formations and/or licensing deals. LU Innovation's services include: business development through support and advice; verification support as well as market and IP screening. LU Innovation has patent engineers, a communications officer and a lawyer who help with the process with the research commercialization process. The LU Holding AB (owned by the Swedish state, but managed by Lund University), a company supporting newly-founded companies both operationally and financially, helping with agreement templates and providing representatives to the board. It has equity in over 60 spin-out companies (2019) which are highly dominated by the fields of life sciences and technology (such as medical engineering, diagnostics, drug development, and biotechnology). Other courses and initiatives of LU Innovation include: Commercialize Your Research in alliance with Sten K. Johnson Centre for Entrepreneurship; Interreg-funded Science for Society—a learning and networking platform for doctoral and postdoctoral students; Innovationskontor Syd (IKS), facilitating knowledge transfer between institutions and actors in the Blekinge Institute of Technology, Kristianstad University, Lund University, Malmö University, and the Swedish University of Agricultural Sciences; Leapfrogs project, providing students opportunities to develop their business ideas; the Interreg-supported Nordic Entrepreneurship Hubs project aiming to increase the collaboration between the Nordic universities; Swelife, the Swedish innovation program for life sciences stimulating generic models for innovation against widespread diseases (www.innovation.lu.se).

2. The Empirical Analysis

Taking into account the high role of the University of Copenhagen and Lund University's scientific impact and technological transfer in the field of life sciences in Medicon Valley, the section below discusses the empirical survey findings on the role that university-based social networks and networking play in Medicon Valley's ecosystem. The author conducted 12 in-depth interviews with the representatives of technology transfer offices (TTO) and heads and deans of departments of Copenhagen and Lund Universities, representatives of the labs (Copenhagen Bioscience Park), public and non-profit organizations (Medicon Valley Alliance, Copenhagen Capacity, Biopeople, Invest in Skåne), as well as with business sector representatives (AstraZeneca, MedImmune, MultiHelix AB). The questionnaire was addressed to all of the groups of the representatives. The survey consisted of 13 questions concerning the organizations' strategy, network interaction, competition, R&D-related projects and future plans. The questionnaire contained mixed questions (open and closed ones) and was composed of three parts: (1) the mission, structure and types of social networks; (2) the methods of social networking, the intensity of interactions and different dimensions of social capital, (3) the impact of social networks on R&D collaboration, innovative performance and future plans. The summary of the most important questionnaire findings on the role of each type of proximities played in each ecosystem (with some original statements of the respondents) are written in quotation marks.

The Mission, Structure and Types of Social Networks (1)

The major mission of the networks for the representatives of Medicon Valley was knowledge and information sharing, followed by potential research collaboration and common R&D. Both public and private organizations were included in the networks. In fact, the interviewed stakeholders emphasized they had rather close collaboration between the state and private organizations in Valley, via both formal and informal networks. This was particularly visible in the discussion about regional planning, development strategy and the implementation of public policies. One of such successful examples brought into the discussion was the cross-border public-private Danish-Swedish partnership 'ReproUnion,' where academia, hospitals and industry representatives from both countries meet formally and informally to discuss and find ways to develop Medicon Valley to the position of the world leader in the fertility field. The organization has also extended online networking activity on Instagram, Facebook and LinkedIn. Through its regular conferences, seminars and forums, it enables both formal and informal "social networking between different stakeholders and more importantly understanding in a simpler way what is happening in the field of reproduction."

Furthermore, the study shows that even though the Medicon Valley representative actors met face-to-face on regular basis informally (10–15% of their weekly work time). However, it was formal meetings that were the most effective driver for knowledge and information sharing. Formal meetings within one's business or academic networks, as put by the interviewees, were excellent channels for "knowledge, concepts and idea sharing" and "If someone has an idea to discuss, he or she shares without any particular secrecy." The need for the extra informal social and personal networking activity really "depends on the specificity of one's job and the problem one is trying to solve." Interaction with other networks that are not part of one's own regional or field-related networks was rather limited. The respondents appeared to trust the local regional environment more than fostering further collaborations out of the Scandinavian region. In this sense, one could say that "Scandinavians are closely related, and their populations feel close to one another." Any cooperative ties, related to establishing social trust, were heavily influenced by the effects of formal private or public institutions and their policies.

The Methods of Social Networking, Expectations toward Partners, the Intensity of Interactions and Different Dimensions of Social Capital (2)

The most preferable communication method of social networking was considered face-to-face formal meetings followed by communication by email and via Skype, whereas "informal physical meetings over coffee or a drink was not very popular, even more so after office hours." Online social networks were treated with caution, but appreciated for their contribution to the life sciences development, such as "when they allow providing data to speed up clinical trials" or when serving personal comfort, "the internet reduces cost and time when compared to the face-to-face meetings or discussion panels." The respondents were also reluctant to engage with companies, researchers or patients on social networks platforms, as these do not always allow for "establishing a proper kind of chemistry." Furthermore, the respondents admitted that "being institutionally proximate facilitates knowledge transfer and research collaboration." All representatives emphasized the important role of local intermediary organizations, such as Medicon Valley Alliance, "as facilitators for social networking and collaboration between various actors within their ecosystems." In the view of respondents, "once established extensive networks of formal relationships among Triple Helix organizations are further supported with informal social networks." As one of the actors stressed, "(..) it is a critical success factor to expand relationships and networks of partners from academia researchers, industry representatives and investors. Such collaborations create the critical mass that is needed to attract the interest of a wider pool of investors." Yet, when asked about the importance of networking, that person answered, "I do not avoid social networking, however, I allow myself to determine which relationships I want to cultivate." In terms of expectations toward partners in the networks or attempted networks, solid reputation and expertise were given the highest consideration. In fact, as someone pointed out, "due to the advancement and maturity of the Medicon Valley life science cluster," one has to "be careful and demanding, both contentwise and linguistically, when entering into new contracts with new companies, especially those without proven success in the market." When asked about other expectations toward partners, Once they have established common interest, further steps have to "be taken in a time-due, well-planned and constructive way." Common culture or physical proximity was the second important asset in the social networking or possible future collaboration. Trust and common social norms were considered to be very important factors for long-term collaboration. Long historical traditions of cross-border cooperation, linguistic and cultural proximity, along with internal accessibility (enhanced after the Øresund Bridge opening), ensures strong internal accessibility between the two main sides of Medicon Valley's stakeholders. In this sense, geographical and social proximities underline the importance of further "social contacts with Scandinavian colleagues." Yet, even though two nations share common Nordic values, habits and cultural traditions, their business culture differences could create potential asset difficulties for cooperation." As one respondent emphasized, "the potential for major collaboration projects over the border remains still underexploited." Furthermore, he showed concern that "while many local organizations, such as MVA and Øresund regional authorities, promote linkages to global knowledge hubs, the research collaboration potential across the border remains underexploited." The most important results so far concern international profiling of the region and internal and external networking. For universities, proximity is not so relevant in research activities, while the reverse is true for educational activities. Concerning the latter, "funding barriers for cross-border students have impeded cross-border cooperation." Another field where Medicon Valley stakeholders should work on is "facilitating cross-border patient mobility." In terms of the cognitive and technical proximity, the two sides of the cross-border region have several areas of common specialization, such as life sciences (i.e. diabetes, cancer, inflammation and neurosciences) and ICT, with complementary potential in universities and companies. The empirical findings indicated that the respondents utilized network ties to their old university colleagues, who knew the problem and spoke a common technical language, to discuss and develop their ideas, rather than looked for new contacts across the bridge.

Notwithstanding, the respondents from both sides of the Øresund Bridge gave an impression that despite the efforts to build one regional, culturally and linguistically similar identity in Medicon Valley, the population on the banks still seems to follow different cultural patterns. The Øresund identity appears to be much higher on the Swedish side. General problems of talent and highly skilled labor shortages lead to increased competition between the two sides. The problem slightly intensified after the bridge opened. "Labour market integration, which is commuting flows mainly from Sweden (of both Swedes and Danish nationals) to Denmark, jumped after the bridge opened." Differences in salaries and housing prices (higher on the Danish side), as well as employment opportunities revealed the asymmetric mobility patterns.

The Impact of Social Networks on R&D Collaboration, Innovative Performance and Future Plans (3)

In the view of the interviewed stakeholders, participation in the formal networking events, organized by MVA, "played an important role in building their R&D partnerships." Medicon Valley has high innovative potential. It has produced research breakthroughs in personalized medicine, gene therapy and biopharmaceuticals. "The region has finally reached the stage in which its life science sector covers the complete value chain activities, from basic research to industrial manufacturing." All respondents emphasized that information obtained from MVA members or their specific networks (for researchers, new enterprises, other specific fields) induced a sense of trust and contributed to the development of their professional opportunities. Many of the network groups initiated by or built around MVA became independent and self-reliant. Nevertheless, the role of social networking activity in the R&D collaboration is still limited. In particular, regional stakeholders should work more on joining forces for accessing EU competitive research funds and attract European and global investors. The Medicon Valley cross-bridge R&D collaboration was initially driven through the opening of the Øresund Bridge and the EU support for business and research cooperation in life sciences in early 2000. This early impulses did not transfer into the R&D partnership boost. This, however, depends on the willingness of stakeholders on both sides to introduce incentives and increase academic entrepreneurship and local industry-academia collaboration. It happened that Danish and Swedish companies pursued the research partnerships with academia in the United Kingdom (Cambridge and Oxford Universities) or the United States (Boston-Cambridge), while they could have accessed similar technologies in local universities. One way to improve is to engage TTOs in more active networking toward narrowing the technical knowledge and information gap between industry and academia, as well as to improve the social, entrepreneurial and leadership skills of local stakeholders.

For the future plans, more than half of Medicon Valley representatives think to further develop local and cross-bridge collaborative partnerships with government, academia, hospitals and the private sector with their existing partner by maintaining vertical integration within the existing networks, while at the same time expanding their horizontal integration within the European, Canadian and US networks. "The region is in a period of transition and it has finally reached the stage in which its life science sector covers the complete value chain activities, from basic research to industrial manufacturing." The future of Medicon Valley, as one of the respondents said, lies within both finding the ways to strengthen local identity and overcome cross-border socio-economic challenges, while promoting regional competitiveness and better integration into global life sciences hubs at the same time. Developing one regional identity and becoming a global life sciences cluster means that the governments on both sides of the Bridge must introduce common regional development strategies (reducing systemic differences and bureaucratic barriers) and regulations (i.e. the harmonization of tax regulations or lowering housing costs to encourage cross-border mobility), while entrepreneurs change their business attitudes from competitive to pro-collaborative.

Many of the Medicon Valley stakeholders have not explored fully the benefits of the social networking or social networking through social media technologies. On the other hand, many of them use technologies for various private purposes. Exploring the usage of social media technologies could promote global collaboration as well as increase interest and support social networks with our colleagues across the Bridge.

3. Conclusions

This point of view would imply that institutional engineering might indeed be used to foster social capital. The Øresund, most widely publicized model of cross-border integration in the European Union, is in need of a new chapter for its collaboration. The binational Swedish-Danish region has a long history of cross-border interactions and cooperation. The opening of the bridge between the two countries in 2000 gave a strong boost to the integration process.

Medicon Valley is considered to be one of the strongest mature life sciences clusters in Europe. Its development and cooperation in life sciences was given a major boost in 2000 thanks to the European development funds, which resulted in the opening of the Øresund Bridge, joining Denmark and Swedish life sciences clusters in one dense innovative cluster.

This provides benefits both from the learning perspective and exploitation of innovation perspective. In the last decade, many new partnerships have been formed by a mix of Danish-Swedish, public-private, academic-industrial representatives, as both countries share quite similar culture and institutions. Nevertheless, the existing differences in culture and language between Denmark and Sweden affect their differences in social set-ups. The relationships between the researchers and colleagues at the cross-border firm and university levels are based on educational and professional backgrounds rather than personal friendships and territorially contained trust and understanding. As in the view of Granovetter (1973), one could say that social networks in the Medicon Valley are characterized by the weaker ties, but greater openness, as in the sense of Coleman (1988). For this life sciences ecosystem, physical proximity remains a necessary condition for the social proximity to evolve and sustain.

Chapter 6

Life Sciences Cluster in the San Francisco Bay Area

Małgorzata Runiewicz-Wardyn

1. A General overview of the Bay Area Life Sciences Cluster

California and particularly the San Francisco Bay Area have a long tradition of entrepreneurship and innovation, usually associated with the successful story of the IT industry in Silicon Valley. Although the biopharmaceutical industry is not discussed as often as Silicon Valley, the Bay Area's life sciences story is equally extraordinary and important. In fact, San Francisco is considered to be the birthplace of the modern biotech industry. The Bay Area has produced many pioneers in the industry. By the mid-1970s, the entire Bay Area became a fast-growing technology cluster, with growing the venture capital industry. It was then that venture capitalist Robert Swanson initiated a meeting with UC San Francisco biochemist Herbert Boyer to discuss the idea of commercializing the recombinant DNA technology that Boyer helped invent (Zhang 2005). The event led to the birth of the first biotechnology company in the world –Genentech. Two years later, Genentech scientists cloned human insulin, and a year after that, the human growth hormone. The company's success inspired other Bay Area scientists. In 1980, Professor Raymond Valentine from the University of California, Davis, and Norman Goldfarb founded Calgene, specializing in the application of genetic engineering techniques in agriculture, whereas Kary Mullis and his colleagues at Cetus invented the polymerase chain reaction (PCR) technique that enables scientists to produce billions of copies of a DNA molecule in only a few hours (Rabinov 1996; Zhang 2005). The invention of PCR has been an important discovery that is often referred to as "the most revolutionary new technique in molecular biology in the 1980s" (*Ad-*

vances in Biotechnology and Genetic Engineering, 1996). In the summer of 1991, Cetus sold its patent of the PCR technology to Hoffman-La Roche for $300 million and agreed to be acquired by Chiron. Two years later, the invention of PCR won Kary Mullis a Nobel Prize in Chemistry. Another revolutionary discovery in the life sciences was brought in by Pablo Valenzuela and his colleagues. In 1981, biochemists Pablo Valenzuela, William Rutter and Edward Penhoet founded Chiron, which announced the first cloning and sequencing of the entire human immunodeficiency virus (HIV) genome three years later (see also Valenzuela et al. 1979).

The presence of Silicon Valley in the Bay Area provided a unique opportunity for biotechnology to merge with the IT sector. In the late 1980s, UC Berkeley's postdoctoral 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 (Yi 2010; Zhang 2005). Fodor founded Affymetrix, later on acquired by Thermo Fisher Scientific. Today, the company provides a widely used platform for analyzing the relationship between genes and human health. The history of the Bay Area has many other similar stories of companies started up by local biologists and venture capitalists (for more information, see *Advances in Biotechnology and Genetic Engineering*, 1996; Zhang 2005).

Currently, the San Francisco Bay Area is home to the largest biotechnology and biopharmaceutical community, with over 200 biotech companies, and 11.5 million square feet of space on 500 acres. Another five million square feet of new R&D space is under construction. According to the PricewaterhouseCoopers and CB Insights Healthcare MoneyTree report, in the second quarter of 2019, San Francisco led the country in new investing with $866 million going into 54 deals for biotech and medtech. The City and County of San Francisco is home to 234 life sciences companies that employ a workforce of 13,634 people. More than any other city in the world, San Francisco is deeply committed to actively recruiting, supporting and retaining biotechnology companies. Mission Bay is home to more than 38 life sciences companies including FibroGen, Nektar, Celgene, Bayer, and Pfizer. There are four life sciences incubators located in Mission Bay now. San Francisco's life sciences firms have attracted large amounts of investment. California attracts the most VC investment in its biotech industry in the entire country, amounting to $4.4 billion in 2016, with more than 70% of that figure coming from the San Francisco Bay Area alone, $3.1 billion (this amounts to close to 50% more than the next state on that list, Massachusetts). VC investment in the life sciences sector is only second to the computer industry in San Francisco.

Being historically rooted in both computer, IT, life sciences and media industry (more than 300 digital media companies operate in the Bay Area; they are, among others, YouTube, Electronic Arts, Zynga, Twitter, Dolby Laboratories, Pixar, Sony, Sega of America, Konami Digital Entertainment America, and PDI/ DreamWorks SKG), the modern San Francisco Bay Area, cannot be considered a classical cluster in the sense of Michael Porter's early definition, but rather a "cluster of clusters" or "cluster of tech startup innovations."

The Structure of the University-Based Life Sciences Ecosystem

While industry is responsible for the largest share of R&D expenditures in the Bay Area life sciences cluster, most of that funding is spent on product-related R&D. Basic research (without an immediate commercial objective) provides a critical and necessary foundation for technology breakthroughs that underlie the region's and the nation's economic leadership comes from government sources, and almost half of basic research is performed by the higher education sector (49.1% in 2015). California received $15.3 billion in federal support for science in 2015, 93% of which came from the Department of Defense, the Department of Health and Human Services, NASA, and the Department of Energy California also leads the nation with the highest level of state government R&D expenditures ($573.9 million in 2016).

The key components of the Bay Area life sciences ecosystem includes universities, federal labs, independent labs, joint research facilities, incubators, corporate labs, accelerators, and venture investment companies, along with more recent players, such as federal innovation offices, corporate innovation centers, and industrial innovation centers (BASIC's report 2018).

The Bay Area life sciences cluster's ecosystem boundaries extend to the whole Bay area, from north to south, with the universities, colleges and the faculties being spread out in its area, so as the innovation and science parks, the offices of the venture capitalists (Map 1). It includes three world-class research universities: the University of California in San Francisco, Stanford University and the University of California, Berkeley, which offer highly skilled talents and a very entrepreneurial and innovative culture. UC San Francisco, Stanford, UC Davis, and UC Berkeley all rank among the top 30 universities in the United States for R&D expenditures, with UCSF and Stanford both ranking in the top 10. Each of the three academic institutions has a long history of developing biomedical technologies, with combined strengths in medicine, engineering and the basic sciences. These universities has been responsible for many of the most transformative commercial breakthroughs.

On the east side of San Francisco's Mission Bay, a number of leading life sciences research institutions, including UCSF's Mission Bay Campus and Medical Center, the California Institute for Quantitative Biosciences (QB3), Gladstone Institutes, and the California Institute for Regenerative Medicine (CIRM) are anchored. In addition, the Bay Area is home to four U.S. Department of Energy labs

– Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, the California campus of Sandia National Laboratories, and the SLAC National Accelerator Laboratory – as well as NASA's Ames Research Center (whose focus includes space and earth science, and astrobiology). Lawrence Livermore National Laboratory, with an annual operating budget of approximately $1.5 billion, hires 6,586 employees (2017), with nearly half of them holding doctorates) does research i.e. in biosecurity, energy, and environmental security. Its campus is home to the National Ignition Facility, the largest laser in the world, and the world's fastest computers. Other federal facilities include the San Francisco Veterans Affairs Medical Center, the Veterans Affairs Palo Alto Health Care System, and the Joint Genome Institute (managed by Lawrence Berkeley National Laboratory). The Joint Genome Institute (JGI) at Lawrence Berkeley National Laboratory supports about 250 scientists and technicians sequencing and analyzing more than 60 terabases of DNA per year. The San Francisco VA Medical Center has the largest funded research program in the Veterans Affairs network, which includes research in fields of cardiovascular disease, post-traumatic stress disorder, and advanced medical imaging.

Representative laboratories and research institutes of independent status in the Bay Area include, among others:

- SRI International: founded as the Stanford Research Institute, spun off from Stanford University in 1970, the Institute is an independent, non-profit research center with focus on biomedical sciences, computing and information technology, and technology in learning.
- Children's Hospital Oakland Research Institute (CHORI, with an annual budget of $50 million) supports over 400 clinical trials and 200 scientists researching problems in such areas as immunobiology, infectious disease prevention, and oncology.
- Buck Institute for Research on Aging (annual budget: $38 million) is the first independent research facility in the United States focused solely on understanding the connection between aging and chronic disease, with the goal to increase the healthy years of life (research on Alzheimer's disease, Parkinson's disease, cancer, stroke, osteoporosis, heart disease, diabetes, macular degeneration, and glaucoma).
- Gladstone Institutes (annual budget: $80 million) is an independent biomedical research institution with close academic affiliation to UCSF, employing 350 scientists and trainees to focus on cardiovascular biology, immunology, neuroscience, and stem cell biology.
- Ernest Gallo Clinic and Research Center is a non-profit multidisciplinary research institution affiliated with the Department of Neurology within the UCSF School of Medicine. It is one of the world's preeminent academic centers de-

voted to the study of the biological basis of alcohol and substance use disorders (Bay Area Economy 2019).

Apart from the bigger universities and research laboratories, it is important to mention smaller educational institutions, such as community colleges, which boost the Bay Area life sciences ecosystem with professional education and training. These include the California State University, the East Bay (College of Alameda), Berkeley City College, American River College, City College of San Francisco, College of San Mateo, Contra Costa College, De Anza College, Folsom Lake College, Laney College, Merced College, Merritt College, Skyline College, Solano College, and Ohlone College. Approximately 70% of California's higher education students are enrolled in a community college and 48% of UC baccalaureates with degrees in STEM make the community college transfer students. These colleges offer degrees and certificates in Biotechnology and Biological Sciences, and therefore make an important transition from high school to the job/career market or further university education. As Josie Sette, Life Sciences/Biotechnology Deputy Sector Navigator–Bay Area Region, said: "Colleges quickly adapt to the needs of employers and market by offering new courses, seminars, recently the common request areas." The colleges cooperate through the formal and informal networks and meetings via the California Community Colleges organization, which brings the Bay Area life sciences sector's program, "Doing What MATTERS for Jobs and the Economy" (DWM). All colleges networking within the DWM program collaborate together to offer academic and applied technology skills to students and prepare students for the workforce (www.doingwhatmatters.cccco.edu).

According to the California Life Sciences Industry Report (2019), over 4,900 science and engineering Ph.D. recipients graduated from California institutions and are leading the state in the transfer of new technologies from the lab to the commercial sector. The state was number one in NIH research grants (Bay Area Economy 2019). One especially interesting initiative, introduced by the National Laboratories[1], was to include private partnerships and has led to the formation of new companies that impact the economies of their local communities. One example includes Sandia's entrepreneurial leave program that allows employees to leave the lab to start a new company, giving them the option to return to the lab within two years. Another example of the public authorities initiating multidimensional collaboration in the life sciences is Bay Area Science and Innovation Consortium

[1] The United States Department of Energy National Laboratories and Technology Centers are a system of facilities and laboratories overseen by the United States Department of Energy (DOE) for the purpose of advancing science and technology to fulfill the DOE mission. Sixteen of the seventeen DOE national laboratories are federally funded research and development centers administered, managed, operated and staffed by private-sector organizations under management and operating (M&O) contract with DOE–with the National Energy Technology Laboratory being the exception (https://www.energy.gov/national-laboratories).

(BASIC) which is the science and technology affiliate of the Bay Area Council and the Bay Area Council Economic Institute. A collaboration of major organizations in the Bay Area's scientific research community, it brings together leaders from the region's university, national laboratory and business communities to facilitate collaboration and address key issues and opportunities impacting the region's research base and its ability to support technology-led growth.

Map 6.1. The Bay Area life sciences cluster (by number of companies)

Source: Google Maps.

The collaborative model also extends to multipartner institutions, such as the Joint BioEnergy Institute (JBEI), a U.S. Department of Energy facility that focuses on advanced biofuels–liquid fuels derived from the solar energy (stored in plant biomass that can replace gasoline, diesel, and jet fuels). Managed by Lawrence Berkeley National Laboratory, JBEI's research partners include the Sandia, Lawrence Livermore, Pacific Northwest and Brookhaven national laboratories; UC Berkeley; UC Davis; UC Santa Barbara; and Iowa State University (Bay Area Economy 2019). The California state authorities also acknowledge the importance of accumulating cross-campus research efforts. The California Institutes for Science and Innovation (CISI) was created by the State of California in 2000 to maximize the impact of research being conducted at the UC system's ten campuses. Some $400 million in seed funding was initially made available for research partnerships coming from federal or industry sources. The four CISI were created: Calit2 (the California Institute for Telecommunications and Information Technology, a partnership of UC San Diego and UC Irvine) and the California NanoSystems Institute (a partnership of UCLA and UC Santa Barbara) in Southern California; and QB3 (the California Institute for Quantitative Biosciences, a collaboration of UCSF, UC Berkeley and UC Santa Cruz) and CITRIS (the Center for Information Technology Research in the Interest of Society, a collaboration of UC Berkeley, UC Santa Cruz, UC Davis, and UC Merced) in Northern California. In all, in the sense of the recent concept of 'innovation district,' there are four of such districts in the Bay Area: the Stanford Research Park (historical Silicon Valley) in Palo Alto, second in Mission Bay (San Francisco), the Livermore Valley Open Campus (an innovation hub between Lawrence Livermore and Sandia National Laboratories), and NASA Research Park at NASA's Ames Research Center (Mountain View).

Incubators and accelerators play a critical role in the Bay Area life sciences ecosystem and biotechnology industry. Citing a Silicon Valley bank analysis, "23 percent of life science startups that raised at least $4 million in 2017 and 2018 are currently involved with or have been involved with accelerators or incubators" (Venture Monitor 2019). Likewise, the "data shows that about 33 percent of all startups that successfully raise funding go through an accelerator or incubator. (…) The involvement with incubators 'plays a significant role by providing early-stage support and sometimes a follow-on round" (Keown 2019). Universities are active in this space. Some notable examples include: Stanford's StartX incubator (originally started as Stanford Student Enterprises), founded in 2011 is an on-campus business and entrepreneurial organization funded by Stanford University, corporate sponsorships and other donations (with $1.2 million annually); the Garage@UCSF is the first technology incubator in the UC system, launched in 2006; Berkeley Lab's Cyclotron Road and i-GATE (a partnership of Lawrence Livermore and Sandia National Laboratories with the East Bay cities of Livermore, Pleasanton, Dublin and Danville) – incubator programs developed by the federal laboratories. In addition, corporate incubators and accelerators from overseas also help nurture new talent and ideas. For example, in the past five years, the US Market Access Center has worked with more than 1,500 start-ups from 41 countries, including 23 of 28 EU members, and conducted programs in 35 of them.

Furthermore, the Bay Area ecosystem supports local knowledge spillovers and innovation diffusion efforts through establishing Industrial Innovation Centers. These Industrial Innovation Centers beyond corporate R&D performed in company laboratories or collaboratively with universities or federal labs. Private companies are advancing manufacturing through open platforms that enable start-up companies to test new technologies. Emerging companies can access at no cost a wide range of advanced manufacturing equipment, shop facilities, and workspaces to design and test new ideas, with support from academic researchers.

Stanford University has created the Stanford Entrepreneurship Network (SEN) – a working group of faculty and student organizations, a single point of contact, offering opportunities to gain entrepreneurial knowledge/experience via advice, mentoring, networking opportunities, etc. The SEN brings over 30 entrepreneurship-related programs together.

Last but not least, an important component of the Bay Area life sciences ecosystem is professional networking and brokering services both in companies and academia, promoting its life sciences community and networks within it. There are two major organizations worth mentioning here: Biocom: Life Science Association of California (Biocom) and California Life Sciences Association (CLSA).

California Life Sciences Association (CLSA) is the state's largest trade association representing California's life sciences industry, advocating for effective national, state and local public policies and supporting entrepreneurs and life sciences businesses. With offices in Sacramento, San Diego, South San Francisco, Los Angeles and Washington, D.C., CLSA works closely with industry, government, academia and others to shape the public policy, improve access to innovative technologies and grow California's life sciences economy (www.califesciences.org).

Headquartered in San Diego, Biocom works on behalf of over 1,300 members to drive the public policy, build an enviable network of industry leaders, create access to capital, introduce cutting-edge workforce development and STEM education programs, as well as create robust value-driven purchasing programs. Biocom provides the strongest public voice for research institutions and life sciences companies that fuel the California economy. Biocom offices are located in the heart of several California life sciences clusters and areas key to the active public policy initiatives and international collaboration in the life sciences, such as in Los Angeles, the Bay Area, Washington, D.C., and Tokyo (www.biocom.org/about-biocom).

Scientific Impact

Stanford University

Since its early history, Stanford's biological sciences department has promoted independent, self-directed research and interdisciplinary collaboration. In the mid-1960s, biological research shifted focus to the molecular level. At the same time, leaders within the City of Palo Alto and Stanford University forged a seminal partnership by creating the Stanford Research Park, which started an incredible number of breakthroughs in the field of biotechnology and medicine. For example, its spin-off, Varian Medical, developed radiation oncology treatments, medical devices and software for medical diagnostics. The 700-acre research park is home to about 150 diverse companies focused on scientific discovery, technological innovation and commercialization of groundbreaking research. It also includes existing biotechnology companies and the School of Medicine lab space focused on precision medicine.

Stanford University receives nearly two-thirds from federal funding, which is significantly more than the UC Berkeley – half of federal funding (2017). About two-thirds of Stanford's R&D expenditure funds came from the U.S. Department of Health & Human Services (HHS) and the Department of Defense (DOD) providing the largest shares. The largest federal funders in UC Berkeley were NASA, the National Institutes of Health, and the National Science Foundation.

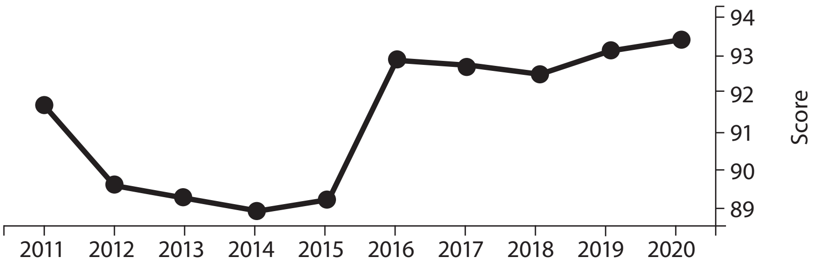
Stanford University is uniquely positioned to conduct interdisciplinary studies. There are seven schools in Stanford, including the School of Medicine and 13 independent laboratories, centers and institutes, including the innovative Stanford Program for Bioengineering, Biomedicine and Biosciences, known as Stanford Bio-X, which networks the following schools: the School of Humanities & Sciences, the School of Engineering, the School of Medicine, the School of Earth, Energy & Environmental Sciences, and the School of Law. The program facilitates interdisciplinary research and teaching in bioengineering, biomedicine, and biosciences. The related Biodesign initiative, which started as a course in Bio-X, focuses on the invention and early testing of health technologies. Another inter-disciplinary initiative is Innovative Medicines Accelerator – an initiative that arose out of Stanford's long-range planning process, which aims to help basic and applied researchers from across the Schools of Medicine, Engineering, and Humanities & Sciences translate their research discoveries into new therapies and diagnostics. Alexandria LaunchLabs at the Stanford Research Park is expected to open in spring 2021. Quoting the words of Tiffany Griego, managing director for *Stanford* Research Park, "As a University-affiliated research park, we recognize we have a unique mission–to bridge academia and industry in an effort to launch solutions that will have an enduring positive impact in our community and world." (www.med.stanford.edu/news/all-news/2019). Stanford's Hasso Plattner Institute of Design offers a non-degree program that teaches students from across the campus how to use design methodology to address real-life problems in their own fields. The Institute currently works with students of law, business, education, medicine, and engineering. Classes focus on real-world projects, with partners such as Facebook, Procter & Gamble, Electronic Arts, Kaiser Permanente, Google, Walmart, Mozilla Foundation, etc.

Stanford University has strong collaborative research practices with local and other world's leading institutions. The s. Stanford University has established an alliance – the Life Science Alliance (LSA) – with the European Bioinformatics Institute (EMBL-EBI) which is part of EMBL, Europe's flagship laboratory for the life sciences and leading research institute in molecular biology. "By bringing together the best researchers from clinicians to engineers, chemists and biologists, we can gain a global understanding of the problem and create breakthroughs in biomedical research" (sic!). In bridging these two institutions, the LSA leverages complementary strengths and creates interdisciplinary research networks for the benefit of the life sciences communities worldwide.

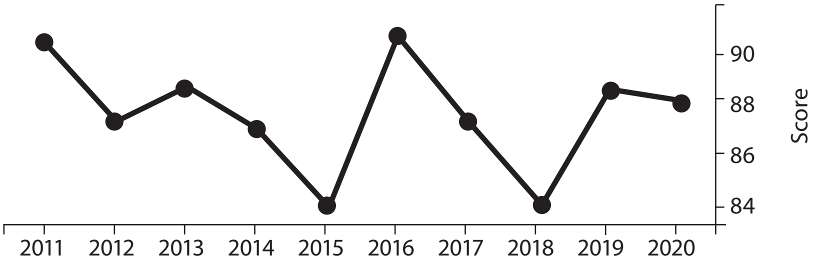
Stanford University has a high teaching and research quality in life sciences, which is also depicted in students' high perception of teaching quality, high teacher/student ratios and valuable education for the worldwide employment market, and an overall positive rank of the University in the life sciences sector (Figure 6.1 (a) and (b)). The Biology Department is at the center of life sciences research at Stanford, with a mission to lead in understanding life, from molecules to cells, and organisms to ecosystems.

Figure 6.1. The rank of Stanford University (a) and the University of California, Berkeley (b), in the life sciences sector, 2011–2020

a)



b)



Source: www.timeshighereducation.com/world-university-rankings/

Stanford has led the nation in developing programs tailored for entrepreneurs. These include the Lean LaunchPad – an experiential learning course offered to graduate student teams by the School of Engineering's Stanford Technology Ventures Program (STVP), the ten-week Launchpad course for graduate students offered by the Stanford d.school (www.dschool.stanford.edu), and The Spirit of Entrepreneurship course offered by STVP. According to the 2011 Stanford Innovation Survey, technical innovators – who have created new products, processes, or business models – are more likely than other Stanford alumni to have participated in these entrepreneurship courses and programs. 60% of founders who received venture investment within three years of graduating had participated in an entrepreneurship course at Stanford. The same survey found that 35% of technical innovators and 40% of founders had participated in entrepreneurial competitions. Stanford University has also created the Stanford Entrepreneurship Network (SEN) – a working group of faculty and student organizations, a single point of contact, offering opportunities to gain entrepreneurial knowledge/experience via advice, mentoring, networking opportunities, etc. The SEN brings over 30 entrepreneurship-related programs together (www.sen.stanford.edu).

The University of California, Berkeley

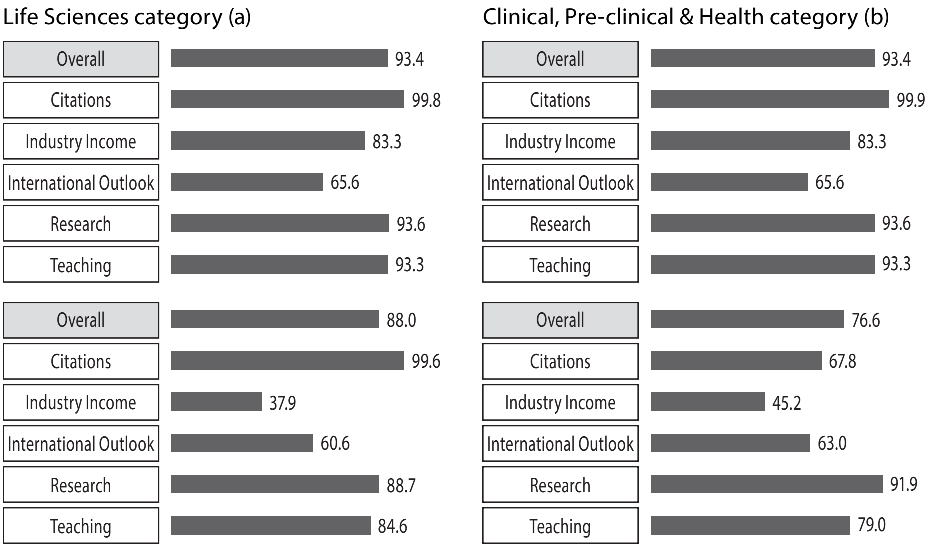
Founded in 1868, the University is the oldest of the ten campuses of the University of California. The university is located in San Francisco's Bay Area, where it is home to about 27,000 undergraduate students and 10,000 postgraduate students in numerous disciplines. As of October 2019, Berkeley alumni, faculty members and researchers include 107 Nobel Prize laureates, 25 Turing Award winners, and 14 Fields Medalists. Berkeley maintains close relationships with three U.S. Department of Energy National Laboratories – Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, and Los Alamos National Laboratory – and is home to many institutes, including the Mathematical Sciences Research Institute, and the Space Sciences Laboratory. Through its partner institution, the University of California, San Francisco (UCSF), Berkeley also offers a joint medical program at the UCSF Medical Center.

The Berkeley-Emeryville corridor is home to more than 150 biotech and life sciences firms, contains more than 1.45 million square feet of commercial wet lab space, and hosts research centers, such as QB3-Berkeley, QB3-East Bay Innovation Center, the U.S. Department of Energy's (DOE's) Joint BioEnergy Institute (JBEI), and the Molecular Biophysics and Integrated Bioimaging (MBIB) and Biological Systems and Engineering (BSE) divisions at Lawrence Berkeley National Lab. Berkeley and Emeryville benefit from immediate proximity to a nearly $1-billion pipeline of R&D at UC Berkeley and Lawrence Berkeley National Lab and state-of-the-art equipment and lab space.

The University of California, Berkeley, is well-renowned internationally and for several scientific fields, it is considered one of the best places in the world, including: Engineering & Technology, and Life Sciences. Considering only scientific fields, the Times Higher Education World University Ranking 2019/2020 ranks the University of California, Berkeley, 13th in Life Sciences and Medicine. The highest growth of the University's rank was observed in 2016 and the lowest drop in 2018 (Figure 6.2). The World University Rankings is a global university ranking examining both a university's teaching and research environment. It places Berkeley University 13th, several positions below Stanford University (4th place). Yet, according to the Shanghai Ranking's Global Ranking of Academic Subjects 2019, UC Berkeley is ranked in the top five in Biotechnology. Moreover, UC Berkeley ranks 4th in its overall ranking of global universities, and has consistently been ranked in the top 5 across many subject areas, including: Biology and Biochemistry.

The University's position remains high when it comes to expert opinions regarding the teaching and research quality, the number of citations per faculty and employer reputation in overall life sciences and clinical and preclinical research. However, its performance in the index of industry income – a given university's ability to help industry with innovations, inventions and consultancy – is significantly lower than in the case of Stanford University (Figure 6.2(a) and 6.2(b)). This situation can be also explained by less of the university's ability to attract funding in the commercial marketplace.

Figure 6.2. The overall scores of Stanford University (a) and the University of California, Berkeley (b), in the categories: Life Sciences and Clinical, Preclinical & Health



Source: The World University Rankings (2020), www.timeshighereducation.com/university-rankings/

Berkeley University actively supports research and teaching practices in cross-disciplinary collaboration between its schools and departments. UC Berkeley's College of Engineering and the Haas School of Business bring engineering and business education together through the Management, Entrepreneurship, & Technology Program (M.E.T.). This four-year program, offered to those UCB freshmen allows students to earn two bachelor's degrees at once: a business degree and one of five engineering tracks: bioengineering (BioE), civil engineering (CE), electrical engineering and computer sciences (EECS), industrial engineering and operations research (IEOR), or mechanical engineering (ME) degrees. The program includes industry internships and career coaching for future industry leaders who understand technology innovation from idea to impact. The University is also a part of academic collaboration consortium between UC Berkeley, UC San Francisco, and Stanford–The Bay Area NSF Innovation Corps (based on a three-year $3.75 million grant from the NSF), which focuses on innovation and commercializing universitiy research through partnerships with industry.

Technology Transfer

Since the U.S. Bayh-Dole Act of 1980, US universities and other non-profit institutions to obtain title to inventions developed from federally funded research, provided that they protect (when appropriate) and commercialize the discoveries. University is able to retain the title to the patents and create revenue by licensing the patent or selling it entirely to a private company. Prior to this act, the government retained ownership of all patents granted, using the government's money. The government also retained the right to license out the inventions to the private sector, which it did non-exclusively. The economic output of these regulations was impressive. As a result, over 2,200 new companies have been formed that were based on the licensing of an invention from an academic institution, about thirty billion dollars of economic activity per year and 250,000 jobs can be attributed to technologies born in academic institutions since 1980 (web.mit.edu/lawclub/www/Bayh-Dole%20Act.pdf).

According to the BASIC Stanford's Office of Technology Licensing (OTL), in 2018, there were $40.96 million in gross royalty revenue from 813 technologies, with royalties ranging from $11 to $11.1 million. Fifty-three of the 813 inventions generated $100,000 or more in royalties. Seven inventions received $1 million or more. The Office evaluated 560 new invention disclosures and signed 150 new licenses. Seventy-six (76) of the licenses were non-exclusive, 41 were exclusive, and 33 were option agreements. Twenty-eight (28) of the 150 agreements were with Stanford start-ups and 24 of them involved equity.

Nevertheless, historically only approximately 10% of total OTL licenses are used to start the companies. Here is the number of inventors by Stanford schools: medicine 2,611, engineering – 2,473, humanities and sciences – 889, dean of research – 223, SLAC – 69, earth sciences –29. The pace of the start-up licenses activities seems to increase in recent years with start-ups comprising over 20% of licenses during 2015–2016. These companies include Alexo Therapeutics, Capp Medical, Circuits Therapeutics, Google, Verinata Health, Oculeve, Forty Seven, etc. Table 6.1 presents the selected technology transfer data for the Stanford University and University of California, Berkeley compared.

Table 6.1. Selected technology transfer data, 2017 (*2018)

	Licenses signed	US patent applications	New invention disclosures	Start-ups
Stanford University	150*	204	477	22
University of California, Berkeley	261	188	192	11

Source: BASIC Stanford's Office of Technology Licensing (OTL); Berkeley Intellectual Property & Industry Research Alliances (IPIRA).

UC Berkeley has often been cited as one of the leading universities worldwide in producing entrepreneurs and attracting funding for start-up companies. Its alumni and faculty have founded a large number of companies, and its degrees are among the most valuable in Silicon Valley. The Office of Intellectual Property & Industry Research Alliances (IPIRA) is committed to nurturing and managing Berkeley's IP portfolio, supporting Berkeley's research enterprise by fostering research collaborations among scientists, entrepreneurs and corporations to speed innovation and catalyze the commercialization of game-changing technology solutions. Following the data provided by the IPIRA and the University, since 2005, over 600 products have been commercialized from discoveries licensed through the IPIRA (such as methods of treatment for malaria and cancer, biofuels, robotic legs, DNA sequencing, surgical tools, forensic tools, handheld diagnostics, gene editing, mobile microscopy, nanowires, RFID, internet security software, search engines and more); 238 start-ups founded to commercialize inventions and copyrights under licenses from the IPIRA (attracting $1.6 billion in venture funding and $51 million in SBIR/STTR). Ca. 29 of them have had a successful exit via merger or acquisition, generating $8.1 billion in cash and stock options, while 66 Berkeley start-ups which are currently in the Bay Area employ 1,543 Californians and generate $195 million in annual revenue. Last but not least, over 1,300 companies served through negotiated agreements with the IPIRA, including $500 million in industry-sponsored research from British Petroleum for the Energy Biosciences Institute, $5 million in industry-sponsored research from Aduro, and $89 million in licensing revenue from Bristol-Myers Squibb.

The industry-university collaboration resulted in the sponsorship of four institutes, including the Energy Biosciences Institute (formed in 2007 with sponsorship from the global energy company BP), California Research Alliance (with the largest chemical producer in the world, BASF), Innovative Genomics Institute (co-funded by Ka Shing Foundation), and the Immunotherapeutics and Vaccine Research Initiative (established as a multi-disciplinary research unit in 2008, with the support of a generous donation by Henry H. "Sam" Wheeler Jr.).

Many of the region's best-known companies have been started by faculty or graduates of Berkeley, UCSF, or Stanford. Examples include Genentech, Chiron (since then acquired by Novartis), Agilent Technologies, Cisco Systems, Dolby Laboratories, Apple, eBay, Alphabet (Google), Hewlett-Packard, Electronic Arts, PayPal, NVIDIA, LinkedIn, Netflix, Sun Microsystems (since then acquired by Oracle), Tesla, Instagram (acquired by Facebook), Yahoo!, Varian, VMWare, NetApp, and Intuit.

2. The Empirical Analysis

Considering the solid research base, strong industry-university networks and the highly innovative performance of the San Francisco Bay Area life sciences ecosystem, the following section discusses the empirical survey findings on the role that social networks and social capital play in the Bay Area ecosystem's success performance. The author conducted 24 in-depth interviews with the heads and deans of departments, the technology transfer offices (TTO), related educational institutions and companies in the following life sciences cluster ecosystems in the San Francisco Bay Area. The questionnaire was addressed to different groups of representatives from public research organizations (universities and government laboratories), non-profit research institutes, research hospitals, science-based biotechnology firms, pharmaceutical firms, including start-ups, and biotech clusters/networks organizations (Stanford University, Stanford Medical School, Ohlone College, California State University, East Bay, Solano College, Biocom, Women in Bio, a Polish trade union, Biomedical Manufacturing Network; NuMedii, Unnatural Products Inc., Ingenium, TwoPoreGuys, Thermo Fisher Scientific, BioSurplus, 2D Genomics). The survey consisted of 13 questions concerning the organizations' strategy, network interaction, competition, R&D projects and future plans. The questionnaire contained mixed questions (open and closed ones) and was composed of three parts: (1) the mission, structure and types of social networks; (2) the methods of social networking, the intensity of interactions and different dimensions of social capital, (3) the impact of social networks on R&D collaboration, innovative performance and future plans.

The Mission, Structure and Types of Social Networks (1)

For the interviewed faculty representatives, networking (both formal and informal) meant expanded contacts, which might eventually lead to new grants, publications and awards. Moreover, younger faculty members were keener to go networking than their senior colleagues, who have already had well-established careers and innovation networks, and were more cautious when establishing new relationships "from scratch." They were also more concerned about the digital forms of social networking, which, as one speaker put it, "leave traces." Another concern was expressed toward "social obligations and too big pressure toward social events, bridging and bonding activities, which may be hard for some researchers who value privacy." Senior researchers were also more interested in knowing more about the networking event program, i.e. going through the list of participants.

The core mission of the networks for two-thirds of the Bay Area business representatives was to be able to "share information and ideas" as well as "meeting interesting people." In fact, the expression "information sharing" was more frequently mentioned than "knowledge sharing" by the business representatives in comparison with the faculty members. What is more, the faculty members were more willing to conduct the discussion about their current and future research activities than their corporate colleagues who limited the discussion to more general facts. Furthermore, Stanford University's ecosystem representatives (university faculty and business managers) valued time and physical proximity as an important attracting factor for both formal and informal social networks. Networking for the exchange of best practices and promotion of one's research unit was the least important for the faculty members of Stanford University. This was not the case for smaller the Bay Area colleges and universities representatives. For instance, naturally emerging formal and non-formal problem groups via bottom-up initiatives by faculty members at Solano and Ohlone Colleges used digital platforms focusing on sharing and disseminating information associated with education-related challenges as well as professional career support for teachers in the field of STEM (Science, Technology, Engineering and Mathematics). What is more, the platform groups took their private initiatives to meet informally, at academic researchers' homes, in order to further exchange the ideas, experiences and problems related to the teachers' training process. Similar initiatives were launched by East Bay University's faculty members. Their aim was to solve a wide range of problems, starting from improving STEM teaching for teachers and faculty, helping students acquire the STEM knowledge and finishing with finding solutions to the administrative issues related to STEM students' immigration (visas, language and social skills). What has been an informal problem group grew into the formally structured Institute for STEM Education (www.csueastbay.edu).

As far as smaller, start-up companies are concerned, the reason for the networking started with searching and then developing their business ideas, but intensified at their maturity stage, when selling or upgrading their technologies. For these firms networking meant "promotion of oneself and one's skill set." Yet, since the early stage of "idea development" was very often filled with certain precautions, smaller companies had also demonstrated the preoccupation for "not saying too much and to be not scooped up your ideas." Less common, smaller firms were networking to get involved in the new R&D projects and gaining new practices. In the words of small companies representatives "networks work for start-ups," as they allow to gain "feedback and recommendation" as well as "connections to the important people in the field," which may be very helpful, especially at the stage of developing ideas.

In addition to information sharing and self-promotion, bigger companies emphasized the important role of networking in "strengthening their organizations' social capital." Bigger organizations used networking events to integrate internally, e.g. via networking events and digital channels, e.g. Facebook and Twitter. The respondents from these organizations mentioned social networking events, organized by their partners or intermediaries as "strengthening their intra- and inter-organizational networks and thus organizational proximity." They also admitted that "informal meetings between colleagues stimulated interorganizational knowledge sharing as well as enriched their competences, skills and ideas." Although business respondents emphasized the important role of a local knowledge base–such as local universities and R&D centers–they did not precondition their success in the opportunity for knowledge spillovers from these universities. Many of the business founders and managers studied at the local universities, and have solid educational and research backgrounds. what was "more important [was] to have access to t*acit knowledge and resources, especially to other experts and researchers in the area.*" As business respondents pointed out, knowledge comes with "job mobility and start-up experience (*success* or failure)." They also emphasized that "in the era of technological convergence and technology dynamics, the ability to create business or innovative activities is determined by one's capacity to establish relationships with customers, suppliers, researchers and brokers."

Furthermore, academia-related respondents said that "technological convergence represents scientific and possibly commercial opportunity, yet also a challenge, especially when it comes to accessing talents or building a common vision in the interdisciplinary projects." Researchers coming from various fields have different cognitive experience (for example, research related to cancer etiology and prevention requires expertise from social, behavioral, biogenetic fields). They also agreed that "the need for social interactions, both among researchers, but also tech companies and investors, grow."

On average, the Bay Area life sciences cluster's representatives devoted some 30–40% of their weekly work time (100%) on networking events (both formal and informal ones). For small start-ups, networking took 30% of their weekly time (interaction with other R&D partners outside the Bay Area every two weeks), for the academia, that was less than 25%, whereas for the non-profit organizations (intermediary and TTOs), networking occupied 40–50% of their weekly time. In terms of the intensity of informal and formal social interactions between corporate and academia-based partners jointly participating in R&D projects, the survey shows a very regular interaction, usually 2–3 times a month, based on the needs and problem-specific situation ("demand-based"). In terms of the nature of partnerships within the established network, informal interpersonal interactions were important for at least 60% of the respondents. Less than 30% of the Bay Area academia representatives used social media for professional purposes. Faculty members, especially in the colleges, frequently had Facebook groups of their classes.

The distinction between public and private organizations had no relevance to the networking activity for the Bay Area respondents. Moreover, both the business representatives and the academia found it important to participate in private-public partnerships, particularly since it may lead to access to the national R&D/scientific networks and the participation in the federal and state-funded projects and initiatives. For instance, the "Doing What Matters for Jobs and the Economy" initiative (www.doingwhatmatters.cccco.edu/) and the Strong Workforce Program (www.cccco.edu), which connect local colleges to achieve a common goal, offer academic and applied technology skills. These initiatives enable faculty to meet informally to discuss the common problems and issues related to both academic work and administrative/funding-related issues. In the view of the colleges' representatives, these top-down initiatives reduced the feeling of competition and allowed to identify problems and strengths of each college concerned.

The Methods of Social Networking, Expectations toward Partners, the Intensity of Interactions and Different Dimensions of Social Capital (2)

All university and college faculty members chose formal and informal face-to-face meetings as the most adequate method of networking. In fact, university and college networks via formal and informal faculty meetings, usually at the campus, but also at private residences (at friends' and families' homes) were mentioned as the first way to start "personal introduction that can help get the attention of proper partners and investors." A close physical, organizational and social distance among actors enhanced people's willingness to participate in coffee-like events and meet new people from academia and industry both formally and informally. In addition, interactions between local community colleges were initiated through the formal networks of the California Community Colleges (CCC) (www.foundationccc.org) and informal problem groups via social media:

- California Community Colleges Facebook Page: www.facebook.com/CAComm Colleges
- Financial Aid Facebook Page: www.facebook.com/icanaffordcollege
- California Community Colleges Twitter Feed: www.twitter.com/CalComm Colleges).

For the Bay Area business representatives, physical and at site face-to-face formal and informal meetings were the most frequent communication method in the networking (especially for smaller companies), whereas electronic communication methods, such as email, telephone and Skype, served as a means of maintaining the established network relationships, "physical contact face-to-face is important the first time, then it can be electronic." Furthermore, they pointed out that the local labor market was the source of building strong social networks. "Job mobility is very important for the development of professional and social networks in the Bay Area life sciences cluster; (…) you get new knowledge, experience and technical application; (…) in fact, the success of the Bay Area life sciences cluster lies within openness and courage in changing jobs as well as in start-up activity; (…) through such experience, you get to know people, which will help you to start your business." Furthermore, the respondents in the Bay Area mentioned that "staying on average 4–5 years within one company is an optimal period for the successful career and professional networks development." Interestingly, when asked about the challenges related to the disclosures for IP, they said "it was not an important factor."

When asked about other expectations toward partners in the networks or attempted networks, "cognitive proximity and similar pools of expertise" were considered important for 60% of business respondents. As one of them put it, a "practical approach is predominant here–they know something I know or want to know." Interaction with other networks, especially in other countries, was important, but was determined by a specific problem (research, business, etc.). As one of the representative pointed out, "it is important to look beyond the local area (as one of the business strategies), but trust had to be there." Then, he gave an example of a "company in Sofia, Bulgaria, which was about to manufacture part of software infrastructure for some biotech-related data." However, the Bay Area company did not agree to do it without building a trial version first. "Building trust was essential."

Moreover, staying in close proximity to the best universities in the world enabled them to acquire high competence when dealing with the latest technologies. "Being institutionally close (universities and colleges, public and non-profit organizations, etc.) facilitates knowledge transfer and research collaboration." In this sense, limited competence and poor absorptive capacities of other non-local actors made a successful interaction harder. The role of physical proximity was higher at the early stage of R&D project collaboration. As one respondent put it, the early stage of research "is easier to do in one's country." On the other hand, as the message of the previous paragraph demonstrates, cognitive proximity and trust may offset geographical distance.

Furthermore, the respondents acknowledged that common behavioral components, such as "trust, professionalism and openness, are of key importance for the social networks creation and connections to relevant stakeholders"; (…) for the distant partner the longer period of adoption may be needed." The respondents also added that "many companies watch toward China, but are still reluctant to join any formal or informal networks independently, without the help of one the Bay Area intermediaries." The expectation mainly concerns trust. As one representative said, "(..) formal networking meetings are very useful, but one has to be careful not to say too much without legal protection." In fact, one corporate respondent mentioned that empathy and trust were important for the networking and bonding. Consequently, he found it challenging to use digital forms of social networking. He also added that companies' representatives with the mission to expand their networks internationally must "consider cultural differences and adapt to local organizational and social culture."

Furthermore, even though the respondents agreed with the importance of diversity, heterogeneity, and complementarity in enriching capabilities and knowledge of actors involved in the innovation processes, they also pointed out the important role of TTOs and other intermediary-networking agents and institutions facilitating social networking and collaboration between various heterogeneous actors within their ecosystems. The presence of intermediary and brokering organizations was especially important for the small life sciences companies, who attempt to connect with possible partners and investors. As one respondent pointed out, "by doing their job they are saving our time and money." He also added that there are "important skills for CEOs of both smaller and bigger companies to network and show up; one never knows where the idea may come from." Moreover, once an established network of formal relationships among organizations merges with the informal social networks, the institutional proximity becomes less important. Thus, the respondents agreed that intermediaries play an essential role in narrowing the social distances. The expectations of networking and brokering organizations toward partners were looser, following the motto: "There is not one size that fits all." What matters is to "achieve mutual benefit." This is unlike the university TTOs, which were more committed to networking with "the appropriate companies." The best candidate companies "should have not only expertise, resources, but, above all, business networks"; "(...) well-established companies were preferred to smaller companies that may have focus, but no sufficient experience and resources."

The role of socio-cultural proximity is another important expectation related to the successful networking in the Bay Area life sciences cluster ecosystem. This dimension does not refer to the language and traditions, but rather to the entrepreneurial attitude and openness. As one respondents pointed out, "speed is important if you want to survive. (…) Once you have an idea, just do it! If it doesn't work, reshape it, find other ways to use your assets, don't wait until it gets better, it may not (…)."

Another important socio-cultural view in the Bay Area cluster ecosystem is "to stay positive and never give up," which meant, as an interviewed entrepreneur said, "Do not mourn, start up the company after it falls." According to a TTO representative dealing with technology transfer in the academia, "technologies at their early stage require a significant investment to bring them to the market place. Therefore, most of the successful companies' initiators must demonstrate irrational optimism, faith in the technologies, and be eager to commit their own time and resources." Moreover, the openness also referred to the academic relationship between students and teachers. One respondent mentioned a situation related to "the visit of a group of European students at Stanford, who asked the University's authorities to organize a meeting with Noble Prize winners, afraid that the winners might not respond to their request." Surprised, as they tried to do it themselves, all the 5 Noble Prize winners answered and showed their interest in coming and meeting them.

Cultural and language proximity may also contribute to the successful building of networks. One respondent, with a cultural background in India, pointed out that a "cultural background was important when going for the outsourcing from companies in India over the European companies." The findings identified three culturally related groups of networks in the Bay Area life sciences ecosystem: Chinese, Korean and Polish. The Chinese life sciences community group has grown especially in the last decade. In the view of the respondents, "this group of people watches and learns fast how the ecosystem of the Bay Area works."[2] These groups of networks enhance outsourcing activities and other innovation networks with their countries and beyond[3].

Polish network organizations founded in order to facilitate the professional scientific and social networking of Polish professionals, entrepreneurs, researchers and other beyond national borders, include such organizations as: Klub Inżynierów Polskich, US-Poland Scientific and Technical, US-Poland Innovation HUB, established in 2012 by the US-Polish Trade Council. One of noble initiatives of the HUB was to support talented and experienced Polish companies in the IT, creative in-

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[2] Many of this group's representatives are members of the Chinese American Biopharmaceutical Society (CABS), a non-profit organization joining more than 3,000 members and subscribers in the life sciences industry. About 70% of its members have a Ph.D. degree related to life sciences, and hold senior research and management positions in the multi-national life sciences corporations. The CABS is also the largest and most active Chinese biopharmaceutical association in Northern America. It organizes many activities to promote Sino-US collaborations in life sciences and to provide life sciences companies in China with an excellent platform to promote researchers mobility, business and scientific social capital in both the United States and China (www.cabsweb.org).

[3] Korean Pharmaceutical and BioScience Society, International (PBSS) is a non-profit professional organization of scientists and other professionals in the life sciences sector, working in diverse organizations, such as the biotechnology and pharmaceutical industries, instrumentation and scientific product suppliers, academia, government laboratories and contract research organizations. The PBSS has over 5,000 members and is active through five member organizations in the San Francisco Bay Area, the San Diego area, Boston, Vancouver and Korea.

dustries, biomedicine, green technologies, and smart energy industries in expanding their business and innovation networks in the unique ecosystem of the Bay Area and Silicon Valley–the Top 500 Innovators Program (in collaboration with Stanford University and the University of California, Berkeley, 2011–2017)[4]. Another initiative promoting Polish achievements and ideas in the area of high technology and innovation in IT, life sciences, artificial intelligence and smart technologies is so-called Poland's Days.

The Impact of Social Networks on R&D Collaboration, Innovative Performance and Future Plans (3)

When asked about the impact of networking on R&D collaboration and innovative performance, different actors had different perspectives. For all the respondents, the participation in formal professional networking events played a very important role, both from the perspective of career development, increasing organizational proximity and strategic development of scientific/business fields. For start-up representatives, networking opened new business opportunities (by helping them sell out their companies and start new business). Big companies used networking organizations (i.e. Biocom) to lobby power (federal state authorities) and enabled access to new technology. One respondent referred to the recent case of a big company contacting a networking institution with a request to organize a networking and technology demonstration event, with the aim to access specific technology. "The reaction to the call was immediate and over 80 best technologies, both from public and private labs, were presented, out of which the company chose the one that was the most appealing to their needs." This is an example of the impact of social networking on a company's business development and R&D collaboration. In the Bay Area life sciences ecosystem, there are two leading intermediary organizations: Biocom: Life Science Association of California (Biocom) and California Life Sciences Association (CLSA)[5] (n.b. in the opinion of the representatives of

[4] The intensive program, covering interactive workshops, training, presentations and meetings with recognized and experienced business experts, strategic partners, and investors from the United States and Poland. Until 2017, 91 companies have applied to the program, 35 companies participated in the first stage of the program (workshop sessions in Poland), and 33 companies moved to the second stage (business meetings in Silicon Valley). Poland's Days: May 26–29, 2015, Silicon Valley; November 16–21, 2014, Los Angeles; November 17–23, 2014, Santa Monica; March 21–23, 2018, San Francisco) and Polish-American Science and Technology Symposium (November 15–17, 2012, Silicon Valley; June 28, 2017, San Francisco).

[5] Until 2015, there were three organizations Bay Area Bioscience Association (BayBio) and the California Healthcare Institute (CHI) merged. California Life Sciences Association (CLSA) is the state's largest and most influential life sciences advocacy and business leadership organization. With offices in Sacramento, San Diego, South San Francisco, Los Angeles and Washington, D.C., CLSA works closely with industry, government, academia and others to shape public policy, improve access to innovative technologies and grow California's life sciences economy, whereas Biocom focuses more on networking for the companies, by facilitating meet-ups, organizing educational events and

networking organizations, they do not compete, but complement each other and find their common ground, by lobbying legislation for developing the Bay Area life sciences hub).

Using university or college networks helped researchers start personal introduction to the professional communities, attracted the attention of angel and venture capital investors. Through their participation in the professional associations, alumni groups, and personal interest communities (networking with friends and family), researchers and business representatives gained new perspectives that allowed them to advance in their careers. As one respondent put it, "social proximity and ongoing dialogue among faculty, industry experts, entrepreneurs and non-profit professional organizations are invaluable to inspiring innovation, new companies and new technologies within the Bay Area." Although some scientists and academic representatives shared the concern that social networks might have a reputational impact, they did not have definite opinions on whether that would have a positive or negative impact on their professional careers. For the academia, networking allowed for the "quicker adaptation to the needs of employers and market requirements," which resulted in the new courses, seminars, which in the last years included courses developing social skills[6]. Such courses were especially important for students with different cultural backgrounds such as Chinese and Indian. An example of such a course is 'Communication, problem solving, team work, customers support skills.' Informal networks also supported academia entrepreneurs who actively draw on alumni and faculty members who mentor and support local companies by serving on their boards. The interviewed faculty member emphasized that half of his students chose Stanford for its entrepreneurial environment. Yet, the impact of social networking on the local innovative environment is also determined by the close physical proximity. In the view of the HUB, the success of the Top 500 Innovators Program was moderate. The forum for discussion between their US and Polish leaders was related to the challenges of education and the application of the latest technologies, but did not follow up with any concrete action projects or investments. The latter was explained by the fact that "networking worked best with physical contact and cognitive proximities."

In terms of the future plans, corporate respondents emphasized the importance of expanding the networks with existing partners (vertical integration within the network), while simultaneously enriching horizontal and cross-disciplinary integration within the network. The respondents pointed out the important role of intermediaries, non-profit organizations and TTOs in maintaining the future growth

offering its members opportunities to encourage mutual communication and collaboration, https://califesciences.org/chi-baybio-merger-announcement/.

[6] The employers often appreciated young engineers and graduates to have some sort of student job experience (i.e. McDonalds), which would allow them to develop social abilities and team work experience prior to taking up their professional career.

of the Bay Area life sciences ecosystem, by carrying on its operational and educational roles, by the vertical and horizontal integration of the ecosystem players, as well as by promoting the active involvement of community both as inventors and users of the state of art technologies. They also indicate that the important role of intermediaries is actually promoting the life sciences and biotech industry on state and international levels.

3. Conclusions

The Bay Area life sciences ecosystem is a mature but dynamic cluster, with a high entrepreneurial spirit and courage in the exploitation of new innovative opportunities. Geographical, cognitive, organizational and cultural proximities between the life sciences ecosystem's actors in the Bay Area intensify their social interactions and the interchange of ideas. The Bay Area life sciences ecosystem is characterized by the diverse and open culture, in which personal contacts have great value. This creates a model rooted in the open innovation paradigm, collaborative workspaces and horizontal structures. It recombines the features of both social networks models – a closed network (Coleman 1988) and a network rich in structural holes (Burt 1992). This way, the life sciences ecosystem in the Bay Area reminds one the experience of the IT sector in Silicon Valley (even though the locations of both clusters do not entirely overlap, with the first being located more in San Francisco and the East Bay, and the second in Santa Clara and Sunnyvale). Furthermore, as the study shows, the social networks within the Bay Area actors are characterized by the strength of the weak ties in the sense of Granovetter (1973), which are expanded via both vertical and horizontal interlinkages within the cluster and promote firms' specialization in the life sciences, while enriching them with new emerging (i.e. interdisciplinary) research and commercialization opportunities. The environment of dense networks and bonding social capital, driven by the geographical, interorganizational and cultural proximities also resembles social networks with closure in the sense of Coleman (1988). The research study demonstrated that when the technological dynamics-bridging type of social capital takes an active role (especially via intermediary organizations and personal contacts from one's previous jobs), the role of indirect ties to external collaborators ("triadic closure" that occurs through the shared collaborator inside and outside the cluster ecosystem) becomes active, too.

Chapter 7

Life Sciences Cluster in Seattle in Washington State

Zbigniew Bochniarz

1. A General Overview of the Life Sciences Cluster in the Seattle Region

The life sciences cluster ecosystem in Washington state (WA, United States) embraces over 1,100 organizations located in 110 cities, however, 440 of them are located in Seattle, and the next over 330 units are located in rather close proximity to the city (Life Science Washington – LSW: *Economic Impact Report 2019*). For this reason, the author uses "Seattle region" in the title of this section instead of "Washington state." This is an economic cluster, not a formalized or officially registered one because on the basis of the interviews conducted with cluster ecosystem leaders, without significant support from the state government, they could not fulfill all cluster functions performed in the other states, where such support was delivered (e.g. North Carolina or Massachusetts). For that reason, this largest and oldest organization coordinating activities within the cluster since 1990 describes itself as "(…) an independent, non-profit 501(c)(6) trade association serving the life sciences industry in the state of Washington" (www.lifesciencewa.org). Currently, Washington state's life sciences industry is serving over 500 members, bringing together research institutions, investors and innovators to grow the state's life sciences economy. Its mission emphasizes "[s]timulating life science innovation, job creation and ecosystem vibrancy across Washington state through engagement, collaboration, promotion, and advocacy." In order to follow its mission, the Washington state's life sciences industry elaborated its strategic plan focusing on three main initiatives: (1) ensuring life sciences companies to have access to talents and workforce training programs necessary for investing and growing in the state; (2)

ensuring life sciences entrepreneurs to have access to mentoring and to resources required to start up and grow; (3) elevating the visibility and conditions of existing and emerging life sciences clusters.

The LSW is a typical institution of collaboration (IFC) in Porter's cluster concept based on strong and continuing investment in social capital that integrates its network facilitation and builds trust among its members. Based on the concept of social capital elaborated by the team led by the author (Bochniarz and Faoro 2016), the LSW association is the main non-governmental actor facilitating investments in social capital for the whole life sciences cluster in this state by providing series of well-designed and systematic activities throughout the years. They offer the venue where representatives from academia, business and governmental organizations could meet comfortably and regularly to exchange their knowledge, experiences or work together for solving emerging problems for the life sciences industry. For that reason, the LSW is the key partner for Washingtonian universities in building social capital for this industry.

The life sciences industry in Washington state encompasses top world-class universities (e.g. the University of Washington (UW)) and non-profit research organizations (e.g. Fred Hutchinson Cancer Research Center), start-ups, global corporations and governmental laboratories. All those organizations were distributed in the following branch groupings: Biotechnology & Non-profit Research (347 units), Medical Devices and Equipment (316), Digital Health/Health IT (197), Life Sciences-related Distribution (118), Drugs & Pharmaceutical (100) and Agricultural Feedstock & Industrial Bioscience (66) (*Economic Impact Report 2019*). It is worth mentioning that Washington state is regarded as a national leader in innovation and discovery, particularly in the following areas: biotechnology, medical devices, digital health/health IT, bio-agriculture, biofuels, and veterinary medicine. Those over 1,100 organizations offered directly 35,914 jobs and were supported by additional 90,401 jobs related to the life sciences industry, which together contributed to Washington's GDP of about $11.5 billion, with wage and benefits only of $6.7 billion). Finally, in terms of wealth creation in Washington state, the life sciences cluster is a significant contributor, with the average annual wage about 30% higher in 2017 than the average wage in the state's private sector – $93,146 vs. $62,274 (*Economic Impact Report 2019*).

The main roots of the life sciences cluster in the Seattle metropolitan area are coming from the over 150-year-old (ca. 1861) public University of Washington with its 59,252 students and 4,369 core full-time faculty members on three campuses (Seattle, Bothell and Tacoma) ranked 14th globally and 3rd as the public university in the United States with 7 Nobel Prize winners (UW *Annual Report* 2019). In addition, Reuters' information agency ranked the University (2019) as the most innovative public university in the world. One of the less known of the University of Washington history facts is that since 1979 (with the exception of the post-recession year 2009), no other US public university has received more federal research funding than the University of Washington. For that reason, the University has been leading knowledge and technology foundation of more than 100 life sciences industry companies.

There is the second public university – Washington State University (WSU) since 1890, with its main campus in Pullman (South-Eastern part of Washington) contributing to life sciences mainly in bio-agriculture, biofuels and veterinary medicine. Both public universities belong to the US top 131 research (R1): doctoral universities. In addition to these two public research universities, there are several important knowledge-generating hubs, which have been established in the process of the emerging of the life sciences cluster, in addition to emerging business organizations as spin-offs of research institutions or as organic inventors' start-ups. One of the first such organizations was Seattle Children's Hospital, originally established as Children's Orthopedic Hospital by Anna Herr Clise in 1907. It is now known as Children's Hospital and Regional Medical Center. It was the first pediatric hospital in the Northwest. Today, it is a well-known organization serving communities from at least four states – Alaska, Montana, Idaho and Washington – with 11 regional clinics, 21 outreach sites and clinics, and their main affiliation with the UW School of Medicine, in addition to 13 other collaborative partners (www.seattlechildrens.org). Seattle Children's – as it is popularly known – is the workplace for over 7.8 thousand active employees, 960 physicians in training and 758 medical students in training in the academic year 2017/2018. It was for many years at the top of the National Institutes of Health (NIH) funding recipients due to its high-quality performance in clinical research (ranked 5th by the NIH in 2018) and hospitalization (ranked 5th by *U.S. News & World Report*). Its main research venue is Seattle Children's Hospital Research Institute established in 2006 around research centers with a common thematic focus and an identifiable core set of programs with faculty members from different disciplines affiliated with the following centers: Immunity & Vaccines, Translational & Clinical Science, Developmental Therapeutics, Childhood Infections & Prematurity; Childhood Cancer; Tissue and Cell Biology; Genetics & Development; and Health Services & Behavioral Science. Its mission says: "We provide hope, care and cures to help every child live the healthiest and most fulfilling life possible," and its vision includes "(…) serving all children without consideration that they parents could pay for?" (www.seattlechildrens.org).

Far away from Seattle (over two hours of driving today) – in Spokane (Eastern Washington), Hollister-Stier Laboratories – now known as Jubilant Hollister-Stier – was established in 1926. This is the oldest brand in allergy science founded by chemist Guy Hollister and physician Robert E. Stier to cure the "summer cold" allergy caused by grasses in the area. They developed a vaccine to cure it, and over the years, their company became the world leader in allergenic immunotherapy products and devices, in addition to manufacturing sterile injectable pharmaceuticals and biotechnology products (www.lifesciencewa.org).

There were also important government actors in shaping Washington state's life sciences industry at the federal and state levels. The first group made of two U.S. Senators, Henry "Scoop" Jackson and Warren G. Magnuson – nicknamed "The Gold Dust Twins" by Washingtonians – for their ability to attract federal money to the State from 1941 until 1983. Both were very influential in the U.S. Congress and big supporters of development in the US West. Senator Jackson was particularly successful in passing critical US legislations for the environmental protection, nature conservation (including establishing several national parks in the West), quality of life and international legislations. Senator Magnuson was particularly successful in introducing legislation creating the National Cancer Institute (NCI) in 1937 and a National Research Foundation – now known as the National Institutes of Health (NIH) – in 1945. Later, in the 1960s, he was instrumental in establishing the Medicare and Medicaid programs, civil rights legislation and consumer protection legislation. Finally in 1972, Senator Magnuson helped secure federal resources through the NCI for establishing the Fred Hutchinson Cancer Research Center in Seattle, which became the leading bone marrow transplant facility in the world until these days (ibid.). For that reasons the UW Health Science Center, established in 1970, was renamed Warren G. Magnuson Health Sciences Center in 1978 (www.lifesciencewa.org).

The 1950s marked the development of Washington state's life sciences industry by two companies established around medical devices invented by Washingtonians. The first, Quinton Instruments, was founded by the University of Washington's biomedical engineer Wayne Quinton in 1953. He developed the first treadmill for cardiac stress testing and later invented over thirty biomedical devices ranging from treadmills to Quinton catheters for hemodialysis (ibid. and Wikipedia). The second, Physio-Control, was founded by Dr. K. William Edmark, a Seattle cardiovascular surgeon, to reduce the number of sudden deaths during cardiac surgery. Physio-Control's products present mainly a line of defibrillators including both advanced units for trained personnel and automated external defibrillators for first responders and the general public (ibid.).

In 1956, a new institution emerged – the Pacific Northwest Research Foundation – now known as the Pacific Northwest Research Institute (PNRI) – founded by Dr. William Hutchinson (www.pnri.org). It was one of the first private nonprofit basic biomedical and clinical research institutes in the Northwest, and set the "corner stone" for establishing the Fred Hutchinson Cancer Research Center as a spin-off in 1972.

Later in the 1950s, two research organizations important for Washington state's life sciences industry cluster were founded. The first, in 1956, was the Virginia Mason Research Center –now known as Benaroya Research Institute at Virginia Mason (BRI) in Seattle. The Institute "is one of the few research institutes in the world dedicated to discovering causes and cures to eliminate autoimmune and immune system diseases. At BRI, our scientists aren't focused on eliminating one or two autoimmune diseases – we're taking on all 80. Because autoimmune diseases are connected, so is the way we're fighting them. We're applying the breakthroughs we make against individual autoimmune diseases to make progress against them all. Through collaboration and cooperation between researchers, across clinical trials and with other institutions, we connect laboratory research to clinical trials and translate discoveries to real-life applications. As a world leader in scientific innovation, we're leveraging this progress to eliminate autoimmune and immune system diseases in the future" (www.benaroyaresearch.org). The Institute leads two international collaborative networks: (1) the Immune Tolerance Network (ITN), "(…) for clinical research focused on the development of therapeutic approaches that lead to immune tolerance in asthma and allergy, autoimmune diseases such as type 1 diabetes, and solid organ transplantation" (ibid.) and (2) type 1 diabetes TrialNet for conducting "(…) clinical studies that evaluate new approaches to preventing, delaying and reversing the progression of type 1 diabetes" (ibid.).

The second organization was the Reconstructive Cardiovascular Research Laboratory as a branch of the Providence Seattle Medical Center, founded by Dr. Lester R. Sauvage in 1959, and later renamed as the Hope Heart Institute. The institute was particularly successful in the world's first successful experimental coronary artery bypass graft operation, using the patient's own vein as a bypass graft in 1963. In 1965, Dr. Mark Dedomenico joined Dr. Sauvage and together in 1969, "(…) [they] were able to bypass blockages in all the main coronary arteries" (…), "using only the pat[i]ent's internal thoracic (chest wall) arteries." "The invention of coronary Artery Bypass Surgery opened the era of introducing dilating balloons and stents to correct coronary disease" (www.hopeheart.org).

The 1960s brought two important organizations to Washington state's life sciences industry cluster. The first, in 1962, was the Seattle Artificial Kidney Center – now Northwest Kidney Centers – founded by Dr. Belding H. Scribner of UW and by James W. Haviland, President of the King County Medical Society to be the world's first out-of-hospital outpatient hemodialysis treatment center. This not-for-profit community-based organization promotes "(…) the optimal health, quality of life and independence of people with kidney disease, through patient care, education, and research" (www.nwkidney.org). The second was Battelle Pacific Northwest Division founded from the US Energy to deal with environmental, energy, and health issues (www.battelle.org).

Also the 1970s are marked by establishing two organizations with global recognition. The first one (1975), already mentioned above, is the Fred Hutchinson Cancer Research Center, commonly called "Fred Hutch" – one of the world most prominent organizations in creating knowledge and innovation on "(…) bone marrow transplantation and its spinoff, immunotherapy, which harnesses the power of the immune system to kill cancer with minimal side effects" (LSW: *Economic Impact Report 2019*). With its three winners of the Nobel Prize in Physiology or Medicine, Fred Hutch is one of 41 national comprehensive cancer centers and the source of over 20 life sciences spin-off companies. The Center is also home of the oldest and largest cancer prevention program. Today, with over 300 scientists organized in five divisions, the Hutch represents a cutting-edge academic organization with clinical research and teaching proceeding with its "(…) mission to eliminate cancer and related diseases" and partnering with top-caliber institutions, companies and philanthropic organizations worldwide (www.fredhutch.org). It joined forces with its local partners, UW Medicine and Seattle Children's, to establishSeattle Cancer Care Alliance (SCCA) in 1997. These days, it also works with technology companies to use "(…) novel patient-engagement tools that employ biosensors and mobile apps, artificial intelligence and computer vision applications in radiology."

The second institution founded by Drs. Ruth Shearer and Ken Stuart in 1976 was the Issaquah Group for Health and Environmental Research – later renamed as the Center for Infectious Disease Research (CIDR) – the first global health organization in this region. In 1986, it moved from Issaquah to Seattle and became Seattle Biomedical Research Institute. This non-profit organization was internationally recognized center not only for research, but also for training excellence, with connections to more than 100 partners and collaborators around the world, including the World Health Organization. In 2015, the Institute changed its name to Center for Infectious Disease Research (www.bizjournals.com/seattle/blog/health-care-inc).

The beginning of the 1980s brought a huge institutional change for American universities – the Bayh-Dole Act (H.R.6933, Public Law: 96–517, December 12, 1980) provided for university technology transfer. This law created the legal base for the American universities and federal laboratories to transfer their research and technologies for commercialization to private companies. This way, the universities became financially interested in sharing the results of their research and technological innovations with business companies and in becoming a "launching pad" for many spin-off companies, particularly in the life sciences industry.

The 1980s in the Seattle metropolitan area were marked by establishing many companies, which had a significant impact not only on the life sciences industry, but on the global communities. The first two came out as spin-offs of the Hutch: the first one, in 1980 – Genetic Systems – was founded by Robert Nowinski, with capital raised by David and Isaac Blech, to serve as a monoclonal antibody-based diagnostic company. The second – Immunex Corporation – was founded in 1981 by two researchers from Fred Hutch – Steven Gillis and Christopher Henney, joined by businessman Stephen Duzan – became publicly-owned in 1983 and soon became the largest biotechnology corporation in the Pacific Northwest, listed in both S&P 500 and NASDAQ 100. The main goal of the corporation – developing immune system science to protect human health – has been materialized in many products, e.g. the drug Leukine approved by the FDA in 1991 for patients undergoing bone marrow transplants, Novantrone for multiple sclerosis, and Enbrel, an anti-inflammatory drug used to treat arthritis. At the end of 2001, Immunex was bought by one of the world's largest biotechnology companies, Amgen from California, for $16 billion (archiveswest.orbiscascade.org).

As mainly the University of Washington's spin-off came ZymoGenetics, founded in 1981 by Professors Earl Davie and Benjamin Hall in collaboration with the Nobel Prize-winning Professor Michael Smith from the University of British Columbia. This innovative company served from 1988, as the primary US discovery lab for Novo Nordisk contributing to the development of their products (LSW, op. cit.).

In 1983, MDRNA (later Marina Biotech) was founded for the purpose of developing therapeutic products based on RNA interference and in October 2018, it changed its name again to Adhera Therapeutics (www.pharmajournalist.com).

Although Microsoft has been based in Redmond (Washington state) since 1975, it is not a life sciences company, but it was a significant event in 1986 for the state's life sciences industry when the corporation completed its IPO, and its founders – Bill Gates Jr., and Paul G. Allen –became strong supporters and investors in the life sciences initiatives.

Another spin-off from the University of Washington and ATL – Heart Technology – was founded in 1988. A few year later, in 1993, the company introduced Rotoblator into the market – a medical device invented by the University of Washington's Professor David Auth to reopen clogged arteries. Two years later, the company was bought by Boston Scientific Corporation (xconomy.com/author/dauth/).

Finally, some institutional development critical for the emerging of the Seattle region's life sciences cluster started at the state level in 1989. First, the Washington State Legislature created Governor's Biotechnology Advisory Committee to assess the state of biotechnology industry and elaborate a program with the Department of Trade and Economic Development (DTED) to increase employment, capital investment and sales, simultaneously developing an evaluation procedures for the program's effectiveness. The Governor invited private and public leaders from the biotechnology and medical devices industries to the Committee. They prepared numerous policy recommendations, including improving the state's tax structure for encouraging company development, supporting investment in higher education and hands-on training programs, establishing a state-supported biotechnology investment fund, and the creation of incubator facilities and shared equipment programs (www.lifesciencewa.org). Another recommendation included the DTED's assistance in funding the Washington Biotechnology & Biomedical Association (WBBA). In 1989, it soon materialized and the Association became an active partner for dialogue with the Washington State Legislature producing the Washington State Sales Tax Exemption for High Technology R&D/Manufacturing in 1994. Fortunately, this initial tax legislation was further expanded and modified (LSW: *Economic Impact Report 2019*). It is worth adding that the WBBA became Life Science Washington (LSW) trade association (1990).

In 1989, Icos Corporation was established by Robert Nowinski, Christopher Henney and George Rathmann. It was directed at developing and commercializing treatments for inflammation and other serious diseases. It was the largest life sciences start-up with $33 million in private financing, mainly from Bill Gates as the largest shareholder. After a successful initial public offering in 1991, Icos Corporation was bought by Eli Lilly & Co. for $2.1 billion (ibid.).

In 1990, Microsoft's co-founder, Bill Gates, was also instrumental in enhancing human capital at the University of Washington by his gift of $12 million that enabled hiring a famous scholar from the California Institute of Technology, Dr. Leroy Hood. He became well-known for developing an automated DNA sequencer and four other game-changing instruments. Soon after, he founded and chaired the UW's Department of Molecular Biotechnology, and co-founded several life sciences companies and institutes, including, among others, Darwin Molecular (1992), Institute for Systems Biology (2000), and Arivale (2015) (LSW: *Economic Impact Report 2019*). These two examples of Bill Gates's involvement indicate how important the proximity and cross-discipline inspirations, particularly between life sciences and IT clusters, are. This case clearly confirms the presence of positive Jacobsian externalities, discovered by Jane Jacobs in her extensive urban research (Jacobs 2000).

In 1992, two University of Washington professors, Edmund Fischer and Edwin Krebs, were awarded the Nobel Prize in Physiology or Medicine for their discoveries concerning reverse protein phosphorylation (www.uw.edu).

The history of the life sciences cluster in the Seattle region and in Washington state in general shows how important individuals are for the development the whole industries, particularly talented inventors. Here is the name of Robert Nowinski mentioned for the 3rd time as a founder of PathoGenesis Corporation in 1992 (LSW: *Economic Impact Report 2019*). Also in 1992, Targeted Genetics Corporation was founded by Stewart Parker as a spin-off from Immunex Corporation, with technologies licensed from Fred Hutch, targeted at developing and commercializing cutting-edge gene and cell therapy products. A year later, it became the first company to begin human clinical testing using gene therapy to combat HIV infection. In 1999, the cluster was recognized globally by over 5,700 participants representing national and foreign organizations (30% from abroad) at the world's first BIO'99 International Biotechnology Meeting & Exhibition held in Seattle (LSW: *Economic Impact Report 2019*).

The year 2000 was important for the global community at large, and particularly for life sciences, with establishing the Bill & Melinda Gates Foundation in Seattle – the world's largest private foundation, with the endowment of over $46,8 billion today (Warren Buffett has also contributed with over $3 billion to the trust fund). From the very beginning, life sciences projects – public or private – seem to be a favorite target for this foundation in the United States or abroad, particularly in developing countries. Total grant payments since inception until 2018 was over $50 billion (www.gatesfoundation.org).

This year, Institute for Systems Biology – ISB – was also founded by the above-mentioned Leroy Hood from UW in collaboration with Alan Aderem, and Ruedi Aebersold, as a non-profit research institution focusing on studies and applications of system analysis for resolving secrets of human biology. After 20 years of successful operations, ISB described them as "(…) a collaborative and cross-disciplinary nonprofit biomedical research organization based in Seattle. We focus on some of the most pressing issues in human health, including brain health, cancer, sepsis and aging, as well as many chronic and infectious diseases. ISB is an affiliate of Providence St. Joseph Health, one of the nation's largest not-for-profit health care systems." (isbscience.org).

One of the best examples of the Seattle region life sciences cluster activities, supporting Porter's cluster concept (Porter 2008) and his positive externalities, took place in 2001 when the Seattle Cancer Care Alliance (SCCA) was founded by Fred Hutch, UW Medicine, and Seattle Children's, becoming the cancer treatment center which "(…) has turned thousands upon thousands of cancer patients from all over the world into cancer survivors" (LSW, op. cit.). This year also marked the most prestigious global recognition of a scientific achievement – the Nobel Prize in Physiology or Medicine for Leland H. Hartwell of Fred Hutch for his discoveries of key regulators of the cell cycle.

One of the most important events for the idea of networking in life sciences took place in Seattle in September 2003 with establishing the Allen Institute for Brain Science by former Microsoft co-founder, the late Paul G. Allen, who initially contributed seed money of $100 million (www.alleninstitute.org). After 16 years, the Institute grew up from 5 original employees to 500 employees and assets of over $345 million at the end of 2017 (ibid.). Today, the Allen Institute is composed of two other institutes besides the original Brain Institute – the Institute for Cell Science (December 2014) and the Institute for Immunology (December 2018), and of the 4th very innovative component (March 2016) – the Paul G. Allen Frontiers Group – "(…) to identify and fund pioneering, transformative bioscience around the world" – a collaborating network of Allen Discovery Centers at the most prominent US universities and research organizations, including Stanford University and Tufts University, Boston Children's Hospital and Harvard Medical School and at the University of Washington School of Medicine (ibid.). The Allen Institute brought a new quality to the LSC of connecting bioscience with medical sciences, making an open access to the research results for researchers worldwide and an effective collaborative network of discoveries centers. In addition, this is a showcase of unique combination of an exceptional generosity of its founder with his long-term transdisciplinary vision and passion to implement it in order to serve the global community better.

On February 6, 2019, *The Puget Sound Business Journal* published an article entitled "Washington's Life Science Posted Massive Growth despite the Death of State Fund," commenting what the LSW January 2019 *Impact Report* mentioned above. The staff writer, Casey Coombs, cited Dr. Leslie Alexandre, the President & CEO of LSW, who credited the fast growth of life sciences industries to the earlier support from the state government, including the Life Science Discovery Fund that has disappeared in recent years. She indicated that life sciences industries are mature and bringing significant investments to the state. For instance, one of the Hutch spin-offs, Adaptive Biotechnologies, licensed their technology for $2 billion in January and the another – Juno Therapeutics – was acquired for $9 billion last year. So Dr. Alexandre argued that the life sciences industries have huge development potential in WA, which should be recognized by the State Legislature and further enhanced by necessary support, including reintroduction (or re-filling) of the Life Sciences Discovery Fund and investment in public universities and life sciences infrastructure.

As the results of years of educating and lobbying legislators, finally, on April 28, 2019, good news for the life sciences came from the Washington State Legislature in Olympia – "all of the major elements of Life Science Washington's legislative agenda had been enacted! The agenda included investments in workforce, research, growing the life science ecosystem, university research facilities, transportation, as well as managing drug pricing legislation" (www.lifesciencewa.org/page/2019PolicyRecap_). In addition, the package includes support for emerging life sciences clusters around Bothell and Canyon Park, Spokane and the Tri-Cities[1].

[1] Bill SB5490 Transferring duties of the life sciences discovery fund was passed and should be effective by July 28, 2019 (https://legiscan.com, visited on September 5, 2019). The first paragraph stated:NEW SECTION. Sec. 1. A new section is added to chapter 43.330 RCW to read as follows: (1) The department must contract with a statewide nonprofit organization to either provide services

To sum up, the brief journey over the development of LSC in WA, from simple health care organization to complex and deeply interconnected collaborative networks, heavily depended on humans and social capital has developed over decades in Washington state, and particularly in the Seattle metropolitan area.

The Structure of the University-Based Life Sciences Ecosystem

As it has been already mentioned at the beginning, the University of Washington (UW) is the largest and the most prominent actor in the Washington life sciences cluster (WALSC), which covers the whole state, as an economic unit. According to the data from the Financial Report 2019 (www.uw.edu, op. cit.), the University of Washington has over 59,000 students (including 14,498 graduates) and over 31,000 faculty and staff (including 4,364 core faculty) produced almost 19,000 degrees (including 4,687 master degrees and 915 doctoral degrees) in the academic year 2018/2019. The University raised over $1.5 billion funds from all sources for research during that period.

The University's academic structure is based on 18 schools and colleges, of which 10 are directly and indirectly connected with the life sciences cluster: The School of Medicine (UWSOM), the School of Pharmacy (UWSOP), the School of Dentistry (UWSOD), the School of Public Health (UWSOPH), the School of Nursing (UWSON), and with the other, including the College of Arts & Sciences, College of Engineering with the Paul G. Allen School of Computer Science & Engineering, the College of Environment, the School of Information and Graduate School. The life sciences are present in the academic activities of at least 80 of 151 the University departments, making inter- and transdisciplinary teaching and research possible.

The School of Medicine belongs to the US top providers of medical education with training of primary-care physicians. It has been ranked 1st 23 times in the last 26 years and 1st in family and rural medicine for all consecutive 26 years. In the early 1970s, UWSOM was recognized as the national leader in federal biomedical research grants and research achievements and has sustained this position until now. Today, UWSOM is a part of the UW Medicine ecosystem (see Map 7.1), which is "(…) governed and administered as an enterprise of the University whose mission is to improve the health of the public" (UW 2018 Financial Report). It includes eight organizations dedicated to patient care, medical education and re-

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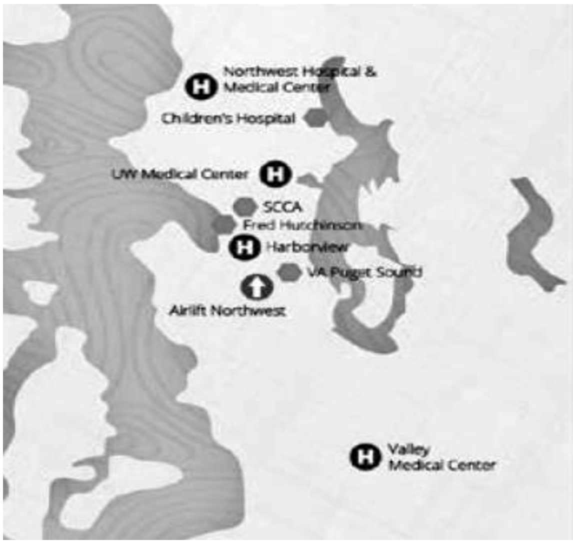
or make grants, or both, to entities pursuant to a contract to foster growth of the state's life science sector and to improve the health and economic well-being of its residents. The statewide nonprofit organization must be a statewide organization established with a primary mission of growing and sustaining the life science ecosystem within the state of Washington by supporting life science entrepreneurs and connecting life science researchers, and biopharmaceutical, medical device, digital health, and health information technology companies to the resources they need to accelerate life science innovation (https://www.lifesciencewa.org/page/2019PolicyRecap).

search: Airlift Northwest, Harborview Medical Center, Northwest Hospital & Medical Center, UW Medical Center, UW Neighborhood Clinics, UW Physicians, and Valley Medical Center. UW Medicine represents 2,388 full- and part-time regular faculty, 4,670 clinical faculty, 454 affiliated faculty, 27,487 employees and 4,800 students (UW Medicine Facts Book).

Map 7.1. The UW Medicine Ecosystem



Source: The UW Facts-Sheet 2019, p. 44, www.uw.edu

UWSOM is also a center of one of the world's largest ecosystems of advancing medical knowledge through scientific research, recognized by external donors in terms of raised funds. For instance, in 2017, the UWSOM was second in the United States when it comes to total federal research grants, with $850.6 million in total revenue, according to the Association of American Medical Colleges. UWSOM is reaching out to other states, being the hub for providing a training program for physicians in five states to care for patients and communities throughout Washington, Wyoming, Alaska, Montana, and Idaho (WWAMI program). This is a powerful network organization building human capital of critical importance in rural areas which are heavily dependent on social capital. Today, the WWAMI program is recognized as one of the most innovative medical education and training programs in the country.

Finally, UW Medicine created the world's largest network of scientific research by establishing the Institute for Health Metrics and Evaluation (IHME) in 2007 with a long-term grant from the Bill & Melinda Gates Foundation. Since that time, it has grown rapidly and now includes nearly 450 faculty, staff and students in Seattle and more than 3,700 collaborators in nearly 150 countries around the world, focusing their research on 190 countries (UW Medicine Fact Book).

Summing up the role of life sciences, particularly in the case medical sciences at the University of Washington, in financial terms, one could notice their dominant position – on this side, the medicine-related revenues were the highest and made 31% of total revenues in comparison with the 2nd highest revenues from contracts, grants and gifts, which made 29%. On the side of expenses, the 1st position was taken by academic activities – instruction and research amounting to 35% of the total – followed by medicine-related 29% (ibid.). Therefore, there is no doubt that life sciences played the leading role at the University of Washington.

Map 7.2. Seattle life sciences cluster

Source: Google Maps.

Scientific Impact

The fast-growing intellectual capacity of the life sciences cluster (LSC) in Washington state (WA) described earlier produced an enormous scientific impact coming from both its basic and applied research, conducted mainly at UW, WSU, Fred Hutch and the Allen Institute. One example of the highest recognition of the significance are five Nobel Prize winners from the University of Washington and Fred

Hutch (three of them had joint appointments) for the following achievements (www.uw.edu, op. cit.):

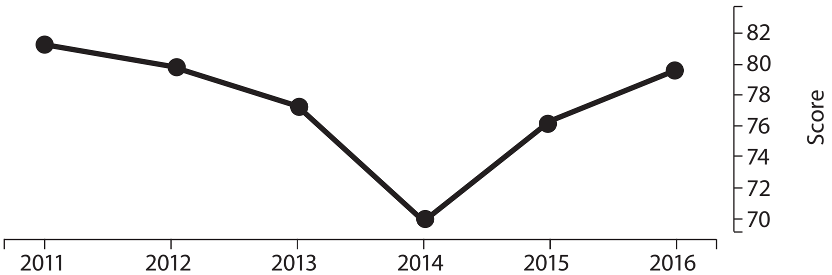
- E. Donnall Thomas for discoveries concerning organ and cell transplantation in the treatment of human disease (1990).
- Edmond H. Fischer and Edwin G. Krebs for discoveries concerning reversible protein phosphorylation as a biological regulatory mechanism (1992).
- Leland H. Harwell for discoveries of key regulators of the cell cycle (2001).
- Linda B. Buck for discoveries of odorant receptors and the organization of the olfactory system (2004).

The individual recognition of the scientific impact of the University of Washington's faculty members is also marketed by the prestigious awards by the academic peers or special institutions (ibid.):

- National Academy of Science: 33 elected members
- National Academy of Medicine: 34 elected members
- National Academy of Engineering: 6 elected members
- Canada Gairdner Foundation Awards: 12 recipients
- Howard Hughes Medical Institute: 11 investigators
- Lasker Foundation Awards: 6 recipients.

Besides the selected individual recognition and the general ranking described above, here is the evaluation the life sciences sector based on internationally renowned rankings – the Times Higher Education World University Ranking 2019/2020, and the QS World University 2018/2019 ranking, among others.

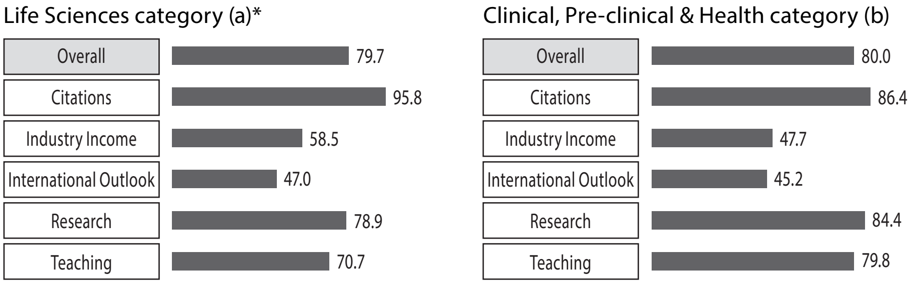
Figure 7.1. The growing rank of the University of Washington in the life sciences sector, 2011–2019



Source: https://www.timeshighereducation.com/world-university-rankings/

The University is ranked in the expert opinions regarding teaching and research quality, number of citations per faculty and employer reputation, which is reflected in the industry income, citations and international outlook. The scores are presented for both overall life sciences and the category Clinical, Pre-clinical & Health (Figure 7.2(a) and 2(b)).

Figure 7.2. The overall scores of the University of Washington in the Life Sciences category and the Clinical, Pre-clinical & Health category, 2019



*2016

Source: World University Rankings 2019/2020 by life sciences, www.timeshighereducation.com/university-rankings/

The above-presented figures, in addition to other pieces of information and data, indicate a strong global position of the University of Washington, particularly in the quality of research works producing an exceptionally high number of citations. For that reason, the National Taiwan University ranked the UW 6th overall and 2nd among public universities worldwide for the quality and impact of research activities (www.uw.edu).

This way, the University of Washington makes critical contributions to the life sciences industry cluster in the Seattle region and the whole state economy. It is worth mentioning that the University is concerned with its sustainability by investing in developing research skills of their students. According to *Annual 2018 Report*, "(…) 8,411 unique students worked under the close guidance of UW faculty mentors (…) spending 1,450,259 hours devoted to research." Another 2,561 students completed university-affiliated internships. Over 2,600 graduate students received grants or contracts, including 173 from the most prestigious source–the National Science Foundation. Finally, the sponsored research projects supported 5,583 full-time equivalent employees. Taking into account an economic multiplier provided by the Washington Higher Education Board, the University of Washington's research funding generated about 24,500 jobs in the state (ibid.).

Technology Transfer

The life sciences cluster in Washington is regarded as one of the most innovative and entrepreneurial clusters in several reports and publications for years (e.g. Cortright and Mayer 2002 or *Future at Risk*, 2018). There is no doubt that a strong entrepreneurial spirit is present in the cluster and there are many actors, who are involved in it. Let us start with the University of Washington (UW) listed as number 1 public university and number 5 overall on the Reuters Top 100: *The World's Most Innovative Universities*, released on October 23, 2019. This is the third consecutive year, when the University maintains its position as the top-ranked US public institution among universities doing most for advancing science, inventing new technologies and driving the global economic development (www.uw.edu, op. cit.). Here is the comment of the University of Washington's President, Ana Maria Cauce: "It's an honor to once again be recognized for the culture of innovation that infuses the University of Washington, a culture that contributes to the enormous impact that our research, scholarship and discovery have on our students and the public we serve" (ibid.).

Looking at the record of the last 10–15 years, the University directly supported carefully selected between 10–12 start-ups every year. The current data on start-ups and technology transfers is illustrated in Table 7.1.

Table 7.1. The technology transfer of the University of Washington, 2018–2019

	Commercial and research licenses signed	Patent applications	Contracts of industry collaborations	Start-ups
Total number	353	183	420	14

Source: The University of Washington.

There are several other players involved in technology transfer and boosting start-ups. First of all, these are the life sciences research institutes or centers, particularly Fred Hutch, the Allen Institute and Seattle Children's Research Institute. Each of them has a significant number of spin-offs. Some of them have grown tremendously fast, reaching their capitalization in billions of dollars, e.g. Juno Therapeutics sold for $9 billion in 2018 and another Fred Hutch spin-off – Adaptive Biotechnologies – for almost $2 billion in 2019.

The second important players are nongovernmental organizations (NGOs), playing the role of institutions for collaboration (IFC) – critical for facilitation of cluster development (Porter 2008). Washington state is rich in numbers of such organizations indicating a high level of social capital, but three of them are particularly important for the facilitation of entrepreneurship, innovations, commercialization, and start-ups. These are Life Science Washington (LSW) trade association and its Life Sciences Institute, and independent healthcare hub – Cambia Grove. Each of them has a great variety of programs supporting these activities.

For instance, Life Science Washington Institute (www.lswinstitute.org) belongs to the national prestigious DRIVe Accelerator Network composed of 13 centers. The Network is the Division of Research, Innovation, and Ventures (DRIVe) established in 2018 by the Biomedical Advanced Research and Development Authority (BARDA) for "(…) building portfolio of products representing disruptive and innovative approaches to transforming health security." The mission of the Institute is assisting "(…) life science researchers, entrepreneurs, and companies in bridging the gap between discovery and commercialization by providing a broad range of activities, including consulting services, regular educational and company showcase events and the creation of resources pertinent to the issues associated with technology commercialization in Washington state" (ibid.).

Established in Seattle by Cambia Health Solutions in 2015, Cambia Grove (www.cambiagrove.com), is an interesting NGO connecting a community of health care changemakers "(…) toward building a more person-centric and economically sustainable health care system" (In recent years, they have focused on "(…) system-wide opportunities to drive large scale health care transformation" (ibid.). One of the most interesting forms of its activities is its original program, 5 Points of Health Care – "(…) a framework designed to better understand the health care system by breaking the system into five distinct sectors: Patient, Payers, Providers, Policymakers and Purchasers (…)" and through series of workshops, meetings and other networking events contribute to the transformation of the system for excellent performance (ibid.).

The list of Washington life sciences-related NGOs includes two other important associations–Global Washington (www.globalwa.org) and the Washington Global Health Alliance (www.wghalliance.org), contributing to the internationalization of the life sciences cluster, delivering its services worldwide, solving the most urgent global problems.

Finally, the list of NGOs is closed by the Polish American Chamber of Commerce – Pacific Northwest established in 2010 to facilitate bridging Polish and American business communities for closer collaboration, particularly in high-tech industries, including aerospace, IT and life sciences.

Summing up the role of the life sciences-related NGOs, it is worth emphasizing that the organizations make acritical contribution to building social capital in the life sciences industry by building bridges among the major stakeholders in a very neutral way.

The third important player is financial institutions starting with the public funds (e.g. Washington's The Life Sciences Discovery Fund), business angels, venture capital, investment banks or private investors. The presence of the world's largest foundation–the Bill & Melinda Gates Foundation–and both charity and business investing by multi-billionaire Pall G. Allen are just leading examples of the funding availability. For all those reasons, Washington state belongs to the top

3 states regarding the availability for start-up funding and venture capital after California and Massachusetts, which are always on top of the ranking (clustermapping.us/region, visited on November 8, 2019).

2. The Empirical Analysis

The empirical analysis conducted was based on 10 in-depth interviews with the top leaders or managers from the following organizations within the Seattle region life sciences cluster: the University of Washington's Life Sciences Corporate Relations, and its UW Medicine, Institute for Health Metrics and Evaluation (IHME), Life Science Washington the non-profit organization; Life Science Washington Institute; the Washington State Department of Commerce; the Fred Hutchinson Cancer Research Center; the Allen Institute; Cambia Grove, and the Polish American Chamber of Commerce – Pacific Northwest. Although the interview structure followed the standardized 12 questions (the 13th question, typical for the European Union, was skipped), several other issues associated with the cluster activities and particularly the future prospects were discussed.

The Mission, Structure and Types of Social Networks (1)

There are minimal differences in selecting the top four "mission of social networks" priorities by the interviewed life sciences cluster leaders, which were "knowledge and information sharing, common projects and innovation initiatives, commercialization of innovation and promotion of the network." Surprisingly for a cluster, the best practice exchanges received a rather low ranking. Only non-governmental organizations (NGOs) ranked the best practice exchange as one of their top priorities.

The number of private and public actors involved in their collaborative networks differs, depending on the size of the lead organization starting from minimum 500 through about 1,000 members to over 3,000 for the biggest leaders.

There are many types of networks, in which the Seattle life sciences cluster and Washington state's life sciences organizations participate, starting with global networks, such as Institute for Health Metrics and Evaluation, collaborative research network with over 3,700 researchers from 150 countries, or BIO – the Biotechnology Innovation Organization – the world's largest trade association of biotechnology companies, academic organizations and state biotechnology centers operating in over 30 countries through American and interstate networks, such as WWAMI – the UW School of Medicine's one-of-a-kind, multi-state medical education program for rural doctors from five northwestern states at the University of Washington or seven Allen Discovery Centers in California, Massachusetts and Washington state, to very local ones, such as the SCCA of four organizations or UW Medicine composed of eight organizations.

The most important and, at the same time, the most popular thing was face-to-face meetings, which absorbed around 25% of the leaders' time, then there was electronic communication (20–25%), followed by joint projects and conferences, workshops and seminars. The least popular were joint trainings (10%) and other forms of collaborative activities (5%). Again, for the NGOs workshops, seminars and trainings were much higher ranked comparing with other actors.

All of the interviewed leaders indicated that the most important interaction with other networks were universities and R&D organizations, followed by networks of clusters and scientific parks. International networks indicated only by two of the leaders, were the least important for them.

The Methods of Social Networking, Expectations toward Partners, the Intensity of Interactions and Different Dimensions of Social Capital (2)

The expectations toward partners were highly diversified. The top three priorities indicated by most of the respondents were: "excellence in education leading to high-quality graduates"; a "high quality of basic research producing discoveries, invention, innovation and facilitation of their commercialization"; and "delivering [to] the nation the highest quality of academic services as one of the US top university."

The other expectations included a high level of expertise in R&D, significant time commitment for joint activities, willingness to share resources, including best practices, and bringing new values to collaborative efforts.

Most of the leaders indicated very regular interactions within the cluster – more than once a month. They were followed by the second group characterized by regular interactions. It is interesting that only one of the leaders pointed out few interactions within her networks. Taking the whole group of the leaders into account, one could state that the Seattle life sciences industry cluster is an "effective cluster." The high intensity of interactions contributes to the high level of social capital, which, measured by the time spent together by the cluster participants, would make its high monetary value, as it was calculated for another Washingtonian cluster – Aerospace in 2015 (Bochniarz 2016).

As the consequence of face-to-face preferences in building relations – social capital – within the life sciences cluster, the most popular geographical proximities were metropolitan and neighboring areas for their partners, followed by national, cross-country locations. The third, equally popular proximity was state and pan-American, and global allocation of their partners.

It is worth mentioning that most of the interviewed organizations were located in the close proximity (less than 5–7 km) mainly in South Lake Union, in the University District and at Lake Washington. One could find an excellent description of this area on the website of Institute for Systems Biology, which occupies an environment-friendly building (LEED Platinum certified) in the place "(…) where leading-edge anchor institutions and companies cluster and connect with start-ups, business incubators and accelerators (…) They are the ultimate mash up of entrepreneurs and education institutions, start-ups and schools, and mixed-use development and medical innovations, bike sharing and bankable investments – all connected by transit, powered by clean energy, wired for digital technology, and fueled by caffeine" (isbscience.org). In this relatively limited area, there are many organizations playing important roles in the Seattle life sciences cluster, such as the University of Washington with its own enterprise called UW Medicine, Amazon, Fred Hutch, the Center for Infectious Disease Research, some offices of Microsoft, Novo Nordisk, the Allen Institute, and many others.

The Impact of Social Networks on R&D Collaboration, Innovative Performance and Future Plans (3)

All of the interviewed leaders indicated that both formal and informal forms of partnership were equally important. They also fully agreed that the networking activities within the cluster's ecosystem activities had an impact on R&D and academic collaboration between different departments and schools. This success is well-reflected in the Washington University academic curriculum, in which "from 30% to 50% of graduate teaching – on master and doctoral levels – are of inter- or transdisciplinary character." Furthermore, the transdisciplinary evaluation teams are institutionalized to assess the academic level of master or doctoral dissertations or projects. Networking and team-building capabilities are also strongly promoted by faculty members. Students are encouraged to resolve complex real-life problems, explore different disciplines and/or collaborate with other students from different disciplines.

Combining answers to several questions on critical issues, one could find an interesting phenomenon – there are no financial or funding problems for any of the UW organizations due to the recognition of the University of Washington as the world's top-ranking university. Although the large and mid-size organizations did not experience problems with funding, this was not the case for small organizations and start-ups. They suffered from the lack of sufficient public support before the well-working state Discovery Fund was refilled until April 2019, when the State Legislature renewed its commitment to support the life sciences industry by refilling the Fund through the Commerce Department. This group of respondents emphasized the need for further networking efforts in building a common vision of the Seattle and Washington state's life sciences industry. One example could be the dialogue related to the "unclear Washington state priorities for the whole life sciences industry," as one of the interviewed leaders stated.

For the several other organizations, the main problem was "securing research scalability" and finding "more effective ways of identifying new partners" – according to the interviewees.

Three other problems were raised by leaders representing small organizations: "overcoming high risk aversion and strong competition from mainly larger organizations and securing safe ways of conducting business against growing crime."

3. Conclusions

Summing up historical development and conducted interviews with the selected life sciences leaders, one could find striking similarities among the Seattle region's life sciences cluster's organizations – a high level of social capital represented by the main participants of the cluster producing a strong innovation ecosystem based on networking. This phenomenon of a high level of innovative performance in the Seattle life sciences cluster was earlier confirmed by other researches. Although all of them underlined the high innovative character of the cluster's activities, they did not explain its roots fully. One of the reasons for that could be the fact that all these reports were elaborated by American scholars for whom certain characteristics of the academic culture in the United States or Canada were obvious. However, comparing the American academic culture and recent trends with the European one, particularly with European continental universities, one could find a significant difference in the level of academic freedom, openness to innovation, and particularly interdisciplinary and transdisciplinary education and research, which are not encouraged in Europe that much, keeping most of their scholars within their disciplinary silos. Here, at UW, from 30% to more than 50% of graduate teaching – at master and doctoral levels – is inter- or transdisciplinary. The transdisciplinary evaluation teams are institutionalized to assess the academic level of master or doctoral dissertations or projects. Teams are encouraged to resolve complex real-life problems. This way, students are early exposed to exploring different disciplines and/or to collaborating with other students from different disciplines. As a result of such an academic culture, the graduates are accustomed to collaborating with other disciplines and to taking challenging, real-life projects. This way, American universities, including the University of Washington, shape a custom not only to collaborate with other disciplines, but also to practice entrepreneurship (Bochniarz 2019). All these lead to a high level of invention and innovation. Following the major social capital theories initiated by the studies of Coleman (1988, 1990) and Burt (1992), applied in the context of the Seattle region, by types of social capital – "bonding" and "bridging" – they are present in the Seattle life sciences cluster ecosystem, where the University of Washington's faculty and alumni, along with many local non-government organizations representatives, act as partners and intermediaries among the Triple (Quadruple) Helices.

From the very beginning of the emerging of Seattle's life sciences cluster, invention, innovation and entrepreneurship have been formative forces shaping the life sciences industry This is also linked to the general characteristic of the State's long tradition in the global cluster leadership and rich social capital around the aerospace and IT industries. Although when it comes to the size and mixed – global and local activities – the life sciences cluster was not listed in the US Cluster Mapping as one of the top five trading clusters in WA (clustermapping.org), its role in contributing to the people's well-being goes far beyond the state, or even America. As the authors of the early reports on live sciences in metropolitan areas stated, the Seattle-Tacoma area belonged to the top five metropolitan areas, which accounted for 75% of venture capital and for 74% of contract value with biopharmaceuticals (Cortright and Mayer 2003) in the 1990s. It means that the Seattle metropolitan area belonged to the few regions in the United States, generating new knowledge and boosting the growth of the life sciences industry in a very similar way, as it was happening in the European Union (Runiewicz-Wardyn 2013). Since then, the situation has not changed much.

The most recent news confirm the leading role of the WALSC in the most urgently needed areas of life sciences – meeting the challenges of the emerging catastrophe coming from climate change. Here are just two examples from BIO press releases (on January 10, 2020):

> *"Alaska Airlines' support of Washington's low carbon fuel legislation signals that transportation companies who look to the future are embracing renewable fuel policy. Alaska is the dominant carrier at the rapidly expanding Sea-Tac Airport and has been at the forefront of utilizing sustainable aviation fuel to lower carbon emissions. Standing with Governor Inslee, Climate Solutions, the American Lung Association, and the Auto Alliance, the aviation industry is working to decarbonize the skies"* (www.bio.org/press-release/green-energy-solutions-unleashed-through-new-partnership);
>
> (on November 21): *"Since implementing its low carbon fuel standard in 2011, California has prevented over 50 million tons of carbon pollution from being emitted on its roadways," said Graham Noyes, co-founder and Executive Director of the Low Carbon Fuels Coalition. "We know that states across the country–from Washington to Minnesota to New York–are looking at policies to decarbonize and diversify their state's transportation sectors, and this new joint initiative will work within those states to help lawmakers realize the potential of low carbon fuel policies"* (www.bio.org/press-release/green-energy-solutions-unleashed-through-new-partnership).

Finally, the best way to value social capital and its major products – networks and trust – is to assess its performance in the crisis situation caused by COVID-19. Since January 21, 2020, when the first case of 2019 novel coronavirus (COVID-19) in the United States was officially announced by the Center for Disease Control and Prevention (CDC) and the Washington State Department of Health (DOH) in Washington State, of a passenger who arrived at the Seattle-Tacoma Airport from

Wuhan, China, on January 15, 2020, many key life sciences stakeholders undertook intensive activities which resulted, among others, in novel coronavirus home test kit before the end of March 2020 (Doughton, Sandi, *The Seattle Times*, March 20, 2020). This new product is provided by the Seattle Coronavirus Assessment Network (SCAN) which capitalized two years of research efforts of the Seattle Flu Study initiative that is now dedicated to better understanding the spread of the novel coronavirus and is funded by Microsoft's co-founder Bill Gates' private Gates Ventures investment arm, with technical assistance from the Bill & Melinda Gates Foundation. As reported by CNBC, the Seattle-based Amazon Corporation will assist with at-home COVID-19 testing swabs delivery and collection – this way avoiding visits of people who are concerned about being infected by the virus – to swab those individuals' noses and send samples for analysis (Statt, Nick, *The Verge*, March 23, 2020). This is an excellent example of how collaborative networks (SCAN), in partnership with corporations and academia, are taking lead when the federal government failed with providing available COVID-19 testing.

These three examples show that the Seattle life sciences cluster ecosystem leadership meets emerging challenges by providing innovative solutions. It is an illustrative example of both – the cross-sectoral fertilization of different scientific disciplines and industries, and the practical functioning of the Triple (Quadruple) Helix concept. The latter was possible due to the years of building social capital that resulted in high trust, and confidence in partnering with other industries and sectors.

PART III

POLAND'S LIFE SCIENCES ECOSYSTEMS ENVIRONMENT

Chapter 8

Life Sciences Clusters in Poland: Drivers, Structure and Challenges

Barbara Kozierkiewicz

1. A General Overview of the Life Sciences Ecosystem in Poland

Research in life sciences leading to new, innovative methods of treatment is a very important part of the development of medicine. Today, people live some 30 years longer than they did in the previous century, and medicine is able to effectively treat most of the serious diseases that were once considered to be incurable. This, among other factors, can be attributed to progress in the development of new and innovative methods of treatment. However, innovations do not arise in isolation, but require collaboration between various complementary players in this sector. This complementarity consists, among other things, in connecting scientists creating innovations with an industry that has structures and resources enabling the introduction of these innovations into the market. This type of cooperation (known as Triple Helix) supported by regulatory governmental institutions and potentially also by other complementary valuable contributors is crucial and enables the transfer of the benefits of innovation to society.

The aim of the present section is to draw the picture of the Polish biotechnological and pharmaceutical innovation sector by describing the key organizations and institutions playing an important role in this sector, and interlinkages between them.

There are several important stakeholders in this sector in Poland: universities, global biotechnological and pharmaceutical companies, small and medium-size biotechnological and life sciences companies, as well as other institutions, organizations and associations.

Universities, especially medical universities, have a very long history in teaching and science generation expressed in scientific publications and managing non-commercial research, but a limited history of commercialization and cooperation with biotechnological and pharmaceutical business which started in Poland only in the 1990s, when the socialist economy collapsed, allowing for the development of innovation, functioning of international biotechnological and pharmaceutical companies, and at the same time, cooperation between Polish scientists and the biopharmaceutical industry. Global biotechnological and pharmaceutical companies which value Polish sites, cooperation with Polish scientists, and therefore allocate their global commercial clinical research activity, using local research sites in public and private centers.

Small and medium-size biotechnological and life science companies, frequently allocated in life sciences clusters or special zones that operate in Poland, or at a close proximity to the research institutes. Two Polish innovative biotechnological companies – Selvita, based in Cracow, and OncoArendi Therapeutics from Warsaw – deserve particular attention. Both companies succeeded in initiating the clinical phase of new, innovative investigational products, though both of them conduct their research in early clinical phases outside Poland. OncoArendi Therapeutcs is the third company in the history of Poland to introduce an innovative investigational drug to clinical trials. The company gathers experts from such domains as biology, chemistry, medicine, process chemistry. However, as the following study shows, preparing the application documentation at the early stage of the project development was quite challenging. The company sought feedback from the officers in registration offices in order to be able to adjust its research plans at the early stage of its innovative project. The Polish Office for Registration of Medicinal Products, Medical Devices and Biocidal Products does not organize consultation meetings, which is why the company reached out to a German office (Bundesinstitut für Arzneimittel und Medizinprodukte, BfArM) and received useful information. The company cooperates with a contract research organization (CRO) which runs a specialized center for early clinical phases with its own diagnostic and bioanalytical laboratory (Lipner et al., 2018).

Selvita (https://selvita.com/) is a Polish biotechnology company and a member of the Cracow Life Sciences Cluster. The company has been very successful on a global market and effectively initiated the clinical phase with its own innovative investigational product. The company runs its clinical trials in the United States, since only there was it able to find a proper center for conducting their phase I trials. The company faced the challenge of finding a proper partner for running the trials and did not manage to find one in Poland or in Europe.

Finally, institutions, organizations and associations, governmental, academic or independent, play a role in shaping and supporting the life sciences innovations in Poland. The content of this section is based on the review of literature and online sources about the innovation sector in Poland and qualitative research carried out in the form of qualitative surveys with selected people playing an important role in the sector or representing key institutions and organizations.

2. The History and Key Life Sciences Sector Trends in Poland

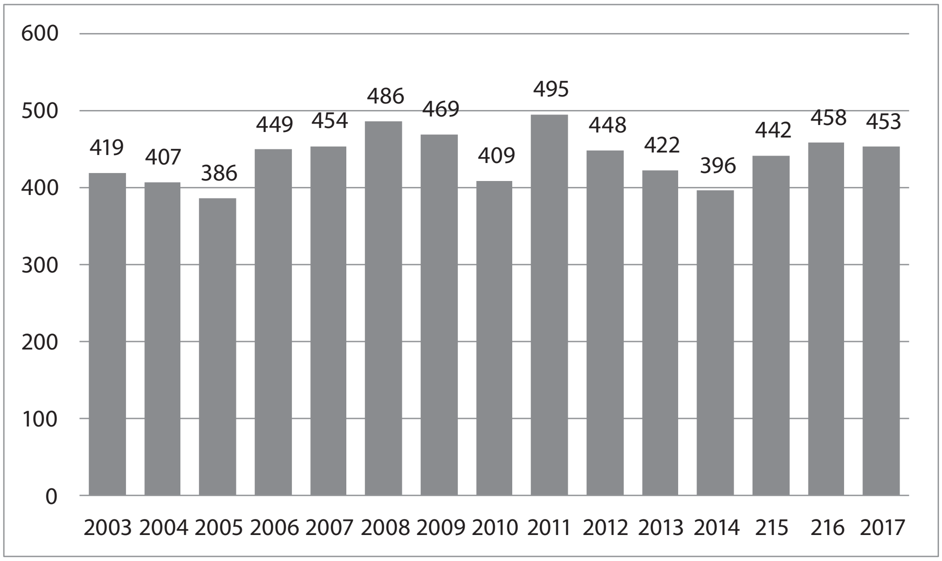
The following section starts with the history of the life sciences sector development, and is followed by the description of key country-level institutions and organizations. Next sections are dedicated to the extensive analysis of the role of universities in the life sciences ecosystem development, as well as the empirical analysis based on the author's qualitative surveys and related conclusions.

The first research in medicine was probably carried out in the 16th century. In the 18th century, it was already common practice among scientists, and rapid advancements in medicine that occurred in the 19th century led to further improvements in methodology.

Large-scale clinical trials, i.e. commercial trials, have been conducted in the world from the beginning on the previous century, however, until the 1990s, they were conducted mainly in the United States, Canada, Japan and in the countries of Western Europe. The countries of Middle and Eastern Europe, in the times of the socialist economy, were not a market allowing for the development of innovation, the functioning of international biotechnological and pharmaceutical companies and, at the same time, cooperation between national scientists and the biopharmaceutical industry. In fact, the sector of clinical trials in Poland developed as late as at the dawn of the previous century, due to increasing competition on the market and the pharmaceutical industry's search for new markets for its activity. First clinical trials were initiated in Poland in 1984, however, significant development took place in the mid-1990s. In 1998, the Polish Ministry of Health published a global recommendation regarding the conduct of clinical trials – the Good Clinical Practice (ICH GCP Guidelines). Later, those guidelines became incorporated in the Polish law.

After the Polish accession to the European Union and the adoption of European directives regulating the principles of conducting clinical trials, Poland became a reliable market for conducting them. Its membership in the European Union additionally facilitated the practical side of this activity, also by helping the transfer of investigational products, lab and medical equipment between the countries. The above-described political and economic situation encouraged the pharmaceutical industry to become active in this part of Europe, and thus it facilitated the development of a new branch of clinical trials emerging in Poland. From 2003, the number of registered clinical trials remains more or less constant and oscillates between 400 and 500 trials, which is represented on the graph below.

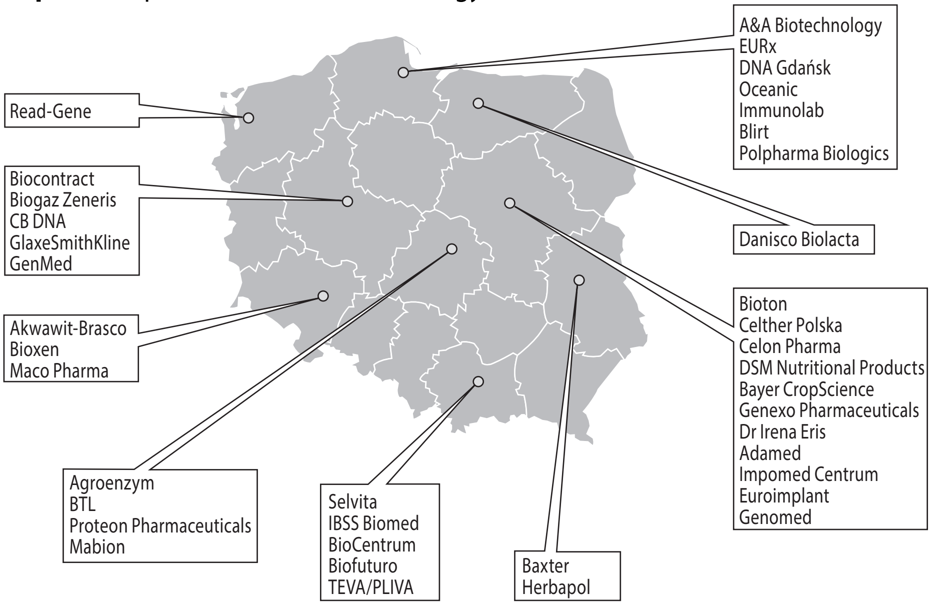
Figure 8.1. Number of clinical trials in Poland, 2003–2017



Sources: The Office for Registration of Medicinal Products, Medical Devices and Biocidal Products; Clinical Trials in Poland 2010; 2015, en.infarma.pl/reports/infarma-reports; The data on the clinical trials market in Poland was extracted from various primary and secondary sources: *Clinical Trials in Poland – Key Challenges* (*Badania kliniczne w Polsce – Główne wyzwania*), PwC, November 2010;˙ the Office for Registration of Medicinal Products, Medical Devices and Biocidal Products; Clinical Trials in Poland (*Badania kliniczne w Polsce*), PwC, December 2015; the interview with the President of the Office for Registration of Medicinal Products, Medical Devices and Biocidal Products, published in *Badania Kliniczne*, No. 1, 2018.

The history of innovations developed at Polish universities is parallel to the increasing effectiveness in patenting and cooperation with business in their commercialization and/or licensing. At the end of the last century, the first university technology transfer centers started to operate at Polish universities with a goal to coordinate commercialization processes at universities and support utilization of a given university's scientific potential in the socio-economic environment. University technology transfer centers are now working at almost all universities. Since 2015, they have been collaborating in harmony, combining all centers and acting as a one-stop shop for business partners potentially interested in commercialization deals. As claimed by the Polish Investment and Trade Agency (PAIH), Poland now offers perfect conditions for the development of life sciences and biotechnology not only for the big global pharma industry, but for all players of the life sciences sector, which consists in the network of 110 scientific institutions, 2,800 researchers dealing with biotechnology, grants and European co-funding opportunities, and six mature biotechnological or life sciences clusters (Warsaw, Łódź, Tricity, Wrocław, Poznań, and the biggest one, the Cracow Life-Science)[1] (Map 8.1).

Map 8.1. Map of the Polish biotechnology sector



Source: The Polish Investment and Trade Agency, https://www.paih.gov.pl/search/biotechnology.

Biotechnological companies or other companies from the life sciences sector function quite frequently within life sciences clusters present in Poland. Special Economic Zones and biotechnological clusters associating scientific institutions and small and medium-size enterprises started to emerge in the 1990s and at the beginning of this century, and they were a means to invest and speed up transformation in times when Poland did not have its own capital, technology or know-how. The Cracow LifeScience Cluster is one of the biggest, the most active clusters and it is dedicated to the life sciences sector. It will be described in more detail in the section devoted to the Cracow region.

3. Policies and Institutions Playing a Key Role in the Development of the Life Sciences Industry in Poland

Universities in Poland operate on the basis of the Act of July 20, 2018 – the Law on Higher Education and Science (Journal of Laws 2018, item 1668). The Nation-

[1] https://inwestor.newseria.pl/newsy/w-ciagu-roku-liczba,p168295524

al Centre for Research and Development (NCBR), which is an executive agency of the Minister of Science and Higher Education, works on the basis of the Act of April 30, 2010 on the National Centre for Research and Development (Journal of Laws of 2010, No. 96, item 616). There are several laws and ordinances regulating the principles of conducting clinical trials, i.e. research involving people, in Poland. The most important ones are listed below with links to the full texts of these legal acts. Work is underway on a draft Act on Clinical Trials for Medicinal Products for Human Use. The new regulations have a chance to come into force in 2020. The work on this law is coordinated by the Medical Research Agency.

- The Pharmaceutical Law of September 6, 2001, Journal of Laws of 2001 No. 126, item 1381; (Notice of the Marshal of the Sejm of the Republic of Poland of October 30, 2017, on the Publication of the Consolidated Text of the Act – the Pharmaceutical Law, Journal of Laws of 2017, item 2211)
- Act of December 5, 1996 on the Medical Profession, Journal of Laws of 1997 No. 28, item 152; (Notice of the Marshal of the Sejm of the Republic of Poland of March 1, 2018on the Publication of the Consolidated Text of the Act on the Medical Profession, Journal of Laws of 2018, item 617)
- Regulation of the Minister of Health of May 2, 2012 on Good Clinical Practice, Journal of Laws of 2012, item 489
- Regulation of the Minister of Health of November 21, 2012 on the Central Register of Clinical Trials in the Field of Examined Veterinary Medicinal Products, Journal of Laws of 2012, item 1363

On the Polish market, there is a number of institutions and organizations supporting research in the field of life sciences, both of commercial and non-commercial character, as well as the ones supporting innovation and science commercialization.

The National Centre for Research and Development (NCBR) is an executive agency of the Minister of Science and Higher Education, financed from the resources of the Polish and EU funds. It was established in the summer of 2007 as a unit that carries out tasks in the fields of Polish science, science technology and innovation policy in Poland. At the time of its creation, it was the first unit of this type, created as a platform for effective dialogue between the science and business communities. In addition, on September 1, 2011, the National Centre for Research and Development expanded its scope of activity with new initiatives and opportunities. By taking over the function of an Intermediate Body from the Ministry of Science and Higher Education in three operational programs: Human Capital, Innovative Economy and Infrastructure and Environment, it has become one of the largest innovation support centers in Poland. In the EU financial perspective 2014–2020, the NCBR acts as an Intermediate Body in operational programs: *Intelligent Development and Knowledge, Education and Development.*

Currently, almost all university technology transfer centers participate in the "innovation incubator" program, which is a program of the Ministry of Science and Higher Education, implemented as part of the Ministry's project. "Support for scientific research management and commercialization of results of R&D works in scientific units and enterprises," co-financed by the EC under the name *Intelligent Development Operational Program 2014–2020.* The purpose of this program is to support the process of managing the results of scientific research and development works, in terms of their commercialization. The implementation of the program should contribute to the promotion of scientific achievements, increase their impact on the development of innovation and strengthen cooperation between the scientific and economic environments.

The initiation and strengthening of cooperation between the scientific and economic environments, including entities interested in implementing the results of R&D works. These activities at a university level will include: the preparation and development of projects implemented at the university toward their commercialization (this process includes carrying out pre-implementation works for projects with high implementation potential, the development of expert opinions on the market potential of inventions and their readiness for implementation, and the valuation of industrial property rights) and technology portfolio management.

The mission of the National Centre for Research and Development is to support Polish scientific units and enterprises in developing their ability to create and use solutions based on the results of scientific research in order to give a development impulse to the economy and for the benefit of society. Thus, the main task of the Centre is the management and implementation of strategic programs of R&D works, which directly translates into the development of innovation.

The Medical Research https://abm.gov.pl/) Agency is a Polish agency responsible for the development of scientific research in the field of medical and health sciences and creating an innovative healthcare system. Its functioning brings measurable benefits to patients as it allows one to assess which new medical technologies and therapeutic methods should be used to meet the needs of society. Supporting the development of medical sciences and health sciences as well as contributing to the increase of the innovativeness of Polish medicine are the most important goals set for the Agency whose main role is to provide financing for clinical analyses and research in healthcare. The Agency was established to make better use of the potential in Poland for the development of medical research and health sciences. One of the most important areas is development in the field of non-commercial clinical trials which account for about 1% of all registered studies in Poland and still have untapped potential. For comparison, in Western Europe, this indicator is about 40%. Ultimately, the Agency wants its research to reach 20–30%. The President of the Agency, Grzegorz Cessak, claims that recent legislative changes, thanks to which medical services and medicines examined in non-commercial trials may be financed by the National Health Fund (NFZ) if they are covered by standard healthcare. Moreover, the reduction of fees for filing a motion for initiation of clinical trials caused the number of such trials to increase from one to several percent. Nevertheless, there is still much to do. This refers to, for instance, the scope of financial support of the compulsory insurance of the sponsor and of the investigator, since these costs exceed the capacities of Polish research centers willing to run non-commercial trials (Olszewski, 2018).

In 2019, the Agency received 77 applications with a total value of nearly PLN 1.5 billion in a competition for support of non-commercial clinical trials (the pool of funds allocated for this purpose was PLN 100 million). Such a great interest in the competition and exceeding the allocated budget nearly 15 times shows a strong mandate and the need to establish a Medical Research Agency. The Agency's activities in the following year will largely focus on the creation of a Clinical Research Support Center as a model for an effectively operating unit coordinating administrative processes and logistics, serving its own healthcare entity. As a consequence, the Agency plans to create a network of research centers in Poland and their integration with international networks. The Agency coordinates work on the draft Act on Clinical Trials of Medicinal Products for Human Use. The key task of the team established for this purpose is to improve the functioning of the legal environment of clinical trials. The agency offers various programs to support innovation in Poland, such as support for start-ups through a dedicated mentoring program. Over 200 companies applied to both previous editions, of which 70 benefited from the help and knowledge of experts. A mentoring program is targeted at start-ups and young companies that need support from experienced experts in developing one of the five main business competences: team creation, business development, marketing, product management, investor relations.

The Clinical Research Support Center cooperates with various entities from the area of R&D:

1. In March 2019, the Medical Research Agency signed a memorandum of cooperation in the development of clinical trials with the leading cancer center, MD Anderson, one of the world's most respected centers dedicated to the treatment of cancer. The letter of intent assumes the creation of joint research and scientific programs and conducting joint clinical research, with emphasis on non-commercial research.
2. The agreement between the Medical Research Agency and pharmaceutical companies (cooperation agreements were signed by 13 companies) relates to supporting enterprises in conducting and developing innovative activities in the field of medical sciences, health sciences and interdisciplinary projects in healthcare, with particular emphasis on artificial intelligence, and it also in-

cludes joint actions aimed at developing new technologies and scientific research in healthcare. As part of the cooperation, the parties envisage, among other things, the joint organization of workshops, conferences, seminars and trainings, as well as the creation of initiatives at expert level in the form of think tanks.

The main institution regulating the conduct of clinical trials on the Polish market is the Office for Registration of Medicinal Products, Medical Devices and Biocidal Products. Apart from its activity associated with the registration of clinical trials conducted on the territory of Poland, the Office organizes meetings with social organizations from time to time, e.g. with associations of companies and expert groups. It also strives to maintain transparency with data and information on required documentation regarding the registration of both clinical trials and medicines.

The Polish Association for Good Clinical Practice (GCPpl) (https://www.gcppl.org.pl/)[2] is the only association of a number of various members, from the field of both commercial and non-commercial clinical trials, which strives to unify and activate the entire environment of the clinical trials sector in Poland. The mission of the Association is to create a forum for discussion for all the entities engaged in the domain of clinical trials in Poland and to create and support initiatives favoring implementation of the principles of the ethics and reliability of clinical trials, in particular in the scope of full compliance with the Good Clinical Practice. The Association has around one thousand members working in pharmaceutical companies, CROs, investigators, lawyers, coordinators and pharmacists from research centers, and for the past 20 years of its operation, it has been actively participating in the public debate on clinical trials, regarding legislation in this scope, cooperation between various actors in the sector, particularly with the Ministry of Health and the Office for Registration of Medicinal Products. The cooperation entered a very intense phase after the publication of the European regulation of April 2014. Common priorities for key institutions working in the sector of clinical trials in Poland, the Ministry of Health and branch associations were established at that time. The following factors were prioritized: (1) Stable development of clinical trials in Poland; (2) Ensuring the safety of participants of clinical trials in Poland; (3) Closer cooperation between stakeholders of clinical trials in Poland (at this point, many institutions and organizations which should cooperate with one another were mentioned) (Jędrzejowski 2018). Companies or specialists employed by parapharmaceutical companies or CROs closely cooperate with each other and with other entities active on the market in specific sectors through GCPpl, INFARMA, PolCRO associations.

[2] Stowarzyszenie na Rzecz Dobrej Praktyki Badań Klinicznych w Polsce, https://www.gcppl.org.pl

The Employers' Union of Innovative Pharmaceutical Companies INFARMA) (http://en.infarma.pl/) was established in 2006 by the member companies of the Association of Representatives of Innovative Pharmaceutical Companies. That Association was set up much earlier, in 1993. The Association represents 28 leading innovative companies from the pharmaceutical sector, conducting research and development activity and producing innovative medicines. INFARMA is a member of an international organization which is an association of the innovative pharmaceutical sector – the European Federation of Pharmaceutical Industries and Associations (EFPIA) – and Employers of Poland, and the National Chamber of Commerce. The objective of INFARMA is to launch initiatives which have a positive impact on creating systemic solutions in the scope of health protection in Poland. Such solutions should make it possible for Polish patients to use the most modern and the most efficient therapies, so that the Polish standards of treatment would correspond to the global ones.

The Polish Association of Employers of Clinical Research Companies (PolCRO) (http://www.polcro.pl/) inis the association of companies conducting clinical trials in Poland on behalf of other sponsors. PolCRO closely cooperates with GCPpl and participates in a number of initiatives aiming at stimulating the sector of clinical trials in Poland.

Portal of Polish Healthcare Innovations Database (Innomedbook) is a solution by Szymon Biernat, recently awarded during the conference Life Science Open Space (http://lifescienceopenspace.pl/en/badania-nad-lekami/baza-danych-polskich-innowacji/). Pharmaceutical companies need innovation to meet the challenges of a rapidly changing environment. Polish scientists and start-up environment has a lot to offer to Polish and international corporations. However, there is a lack of space where it would be easy to find projects of interest to companies. Innomedbook provides access for companies to Polish innovators. Innomedbook constantly monitors the market for medical innovations, keeping in mind the needs of the corporate world.

4. The Role of Universities in the Life Sciences Ecosystem Development

4.1. Academic Ecosystem in Poland

Medical universities in Poland operate on the basis of the Act of July 27, 2005 – the Law on Higher Education (Journal of Laws of 2017, item 2183, as amended). The university has a legal personality and is autonomous in all areas of activity – on the principles set out in the above-mentioned Act. The Minister of Health oversees the compliance of medical universities with legal regulations and the statute, as well as the proper spending of public funds. There are ten medical universities in Poland[3]:

1. Medical University of Białystok
2. Medical University of Gdańsk
3. Medical University of Silesia
4. Medical University of Lublin
5. Medical University of Łódź
6. Poznań University of Medical Sciences
7. Pomeranian Medical University in Szczecin
8. Medical University of Warsaw
9. Wrocław Medical University
10. Jagiellonian University Medical College

There is an annual ranking of universities in Poland published by *Perspektywy*[4]. This list assesses all universities operating in Poland, not only those that conduct medical studies. The universities in this ranking are evaluated according to several criteria. One of them is innovation, which in this ranking has a weight of 8% of the total rating. In assessing this criterion, the following factors are considered:

- Patents, protection rights – the number of patents and protection rights granted in Poland and abroad in 2017–2018 in relation to the number of academic staff: professors, assistant professors and PhD recipients employed full-time at the university.
- EU funds obtained – a criterion measured by the value of projects implemented under the European Union's programs (3%).

Technical universities excel in the innovation category[5]. The first places among the universities with medical faculties are occupied by the following places: 9, 10 and 11 (in general, i.e. it is not known whether the number of assessed patents comes from the medical faculties of these universities). These places are occupied by the Jagiellonian University, the Medical University of Silesia and the Medical University of Warsaw, respectively.

[3] https://www.gov.pl/web/zdrowie/uczelnie-medyczne

[4] http://ranking.perspektywy.pl/RSW2019/ranking-uczelni-akademickich (8.12.2019).

[5] http://ranking.perspektywy.pl/RSW2019/ranking-uczelni-akademickich/rankingi-w-grupach-kryteriow/innowacyjnosc

Entering the detailed rankings for individual fields of medical studies, the rankings are as follows[6]: Medical faculty – 1. Jagiellonian University Medical College; 2. Medical University of Warsaw and 3. Wrocław Medical University; Pharmacy – 1. Jagiellonian University Medical College, 2. Medical University of Gdańsk and 3. Medical University of Warsaw; Dentist faculty – 1. Jagiellonian University Medical College, 2. Medical University of Łódź, 3. Poznań University of Medical Science and 4. Medical University of Warsaw; Nursing – 1. Jagiellonian University Medical College, 2. Wrocław Medical University, 3. Medical University of Gdańsk and 4. Medical University of Warsaw.

As a result of a competition from the Ministry of Science and Higher Education, 10 universities received the status of research universities for the years 2020–2026[7]: the University of Warsaw, the Gdańsk University of Technology, the AGH University of Science and Technology in Cracow, the Warsaw University of Technology, the University of Poznań, the Jagiellonian University in Cracow, the Medical University of Gdańsk, the Silesian University of Technology in Gliwice, the Nicolaus Copernicus University in Toruń, and the University of Wrocław.

The Medical University of Warsaw and the Jagiellonian University in Cracow usually appear at the top of the rankings of medical fields described above, and therefore Warsaw and Cracow, as two regions, have been selected for a further, in-depth analysis in this study. Yet, the organization of universities in Cracow and Warsaw differs in relation to medical faculties, which is why one cannot directly compare their places in rankings, especially when one wants to focus on achievements in the field of life sciences.

In Cracow, the Medical College of the Jagiellonian University has been an organizational unit of the Jagiellonian University since 1993, bringing together three medical faculties, functioning similarly to several other faculties of the Jagiellonian University.

There are two separate universities in Warsaw, the University of Warsaw and the Medical University of Warsaw, which are separate organizational units and the rankings are listed independently from each other. Both universities strive to strengthen cooperation and formalize it in the form of university federations. In October 2018, a letter of intent, regarding the creation of the university federation, was signed. This federation is to start operations in 2020. Federalization is expected to bring several benefits, including easier initiation of interdisciplinary projects, access to libraries, scientific infrastructure and partner's research datasets, a wider offer for doctoral students, and in the future, a higher position of the university in rankings.

[6] http://ranking.perspektywy.pl/RSW2019/ranking-kierunkow-studiow/kierunki-medyczne-i-o-zdrowiu

[7] The Ministry of Science and Higher Education, https://www.gov.pl/web/science/leaders-of-the-excellence-initiative--research-university-competition---the-best-universities-in-poland

4.2. A General Overview of the Warsaw and Cracow Life Sciences Ecosystems

The University of Warsaw (http://en.uw.edu.pl/) was founded in 1816 under the name Royal University of Warsaw. As for 2018/2019, approximately one thousand people studied on bachelor and master degree programs, 2.7 thousand people studied on postgraduate programs and over 2.9 thousand people engaged in doctoral studies. Over 4.9 thousand foreigners study at the University of Warsaw on complete degree programs or as scholarship holders of academic exchange programs The percentage of foreigners studying at the University of Warsaw in relation to the total number of students increased to 6.6%. In 2018, foreigners constituted 10.0% of the total number of doctoral students. In total, the University employs 7.3 thousand academic teachers plus additional 3.7 thousand people of administration staff and librarians. The University has 21 faculties, including the Faculties of Biology, Chemistry, and others.

The University implements six strategic programs aimed at strengthening the University of Warsaw's position as the best research center in Poland, which means maintaining a high position among Central European universities and joining the leading universities on the continent; strengthening its international recognition and enhancing its strong impact on the environment, by undertaking socially important research topics (www.en.uw.edu.pl). Some 1,000 foreign partners cooperate with the University, and 531 of them have signed a direct cooperation agreement. The University develops dynamic scientific cooperation with non-EU countries from Asian countries, Russia, Brazil and Azerbaijan. In the European Union, the University is a part of scientific cooperation of European research universities forming the 4EU + Alliance: the University of Warsaw, Charles University (the Czech Republic), Heidelberg University (Germany), Sorbonne University (Sorbonne Université, France), the University of Copenhagen (Denmark), the University of Milan (Italy).

The Medical University of Warsaw (WUM) is one of the oldest medical schools in Poland. For over 200 years, it has provided education and training in medicine and pharmacy at undergraduate and postgraduate levels. WUM's programs meet the highest international standards of university education and are based on the principles of good clinical and pharmaceutical practice. The University provides both general and specialty training. Students learn at the University's six clinical teaching hospitals which provide general and tertiary medical care for patients. The students and staff also conduct scientific and clinical research at these hospitals as well as get involved in several clinical academic departments located in other hospitals in Warsaw.

WUM offers 19 degree programs, including three full-time degree programs in English: Dentistry, Medicine, and Pharmacy. Moreover, the Medical University of Warsaw has an international dimension based on its international educational standards and the exchange of scientific thought among higher education and research institutions (i.e. via 114 Erasmus+ agreements and 34 international cooperation agreements with research centers around the globe), and it invests in the development of its research infrastructure and continues the expansion of its facilities. The latest projects include the Library and Information Center, the Center for Preclinical Research and Technology, the Paediatric Hospital, and the Sports and Rehabilitation Centre – the most modern facility of its kind in Poland. The construction of a modern University Center of Dentistry began in September 2017.

The Jagiellonian University in Cracow is the oldest university in Poland and one of the oldest in this region of Europe. It was founded on May 12, 1364 and renovated as the Jagiellonian University after bankruptcy on July 26, 1400. Both at the time of its establishment and renewal, the university contained medical faculties (www.uj.edu.pl).

In 1950, the Faculty of Medicine was excluded from the Jagiellonian University and a separate university was created. In 1973, the Medical University in Cracow was named after Nicolaus Copernicus (Regulation of the Council of Ministers of September 8, 1973 on the Name of Nicolaus Copernicus Medical University in Cracow (Journal of Laws of 1973 No. 36, item 215). The Academy was re-incorporated into the Jagiellonian University on May 12, 1993 as a Medical College (Collegium Medicum) (Act of April 16, 1993 on the Inclusion of the Nicolaus Copernicus Medical University in Cracow into the Jagiellonian University in Cracow (Journal of Laws of 1993 No. 44, item 200).

Currently, the Jagiellonian University has 16 faculties, including medical ones (the Faculty of Health Sciences, the Faculty of Medicine, the Faculty of Pharmacy, the Faculty of Biochemistry, Biophysics and Biotechnology, which reunited with the Jagiellonian University in 1993 and formed the so-called Jagiellonian University Medical College. In accordance with the principles of the Bologna Process, studies are divided into three degrees: bachelor, master and doctoral ones. The European ECTS credit system is in force at all faculties, enabling the combination of studies at the Jagiellonian University with studies at other foreign universities. The nationality structure also changed, in addition to students from EU countries, the University welcomes new students from Asia and Africa, as well as from new Eastern European countries (the Ukraine, Belarus).

Scientific Impact

Polish universities stand relatively low in the field of life sciences, judging from the evaluation prepared by the internationally renowned rankings – the Times Higher Education World University Ranking 2019/2020 and the QS World University Rankings 2018/2019.

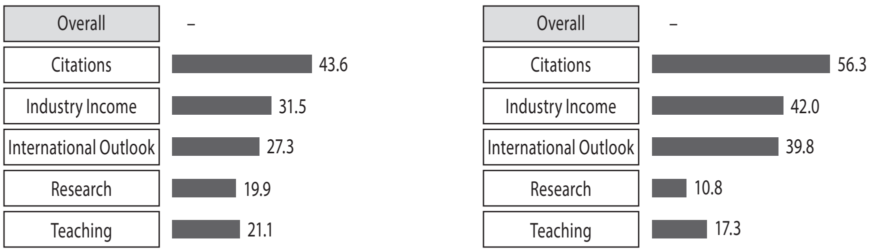
The first one includes the Jagiellonian University (401–500), Warsaw University (401–500), followed by Adam Mickiewicz University (501–600).

Furthermore, the experts' opinions regard teaching and research quality as rather low in all the above-mentioned universities (Figure 8.2(a) and Figure 8.2(b)).

Figure 8.2(a). The Jagiellonian University's overall scores in the life sciences and the category Clinical, Pre-clinical & Health, 2019

Life Sciences category (a)

Clinical, Pre-clinical & Health category (b)



Source: The World University Rankings 2019/2020 by life sciences, https://www.timeshighereducation.com.

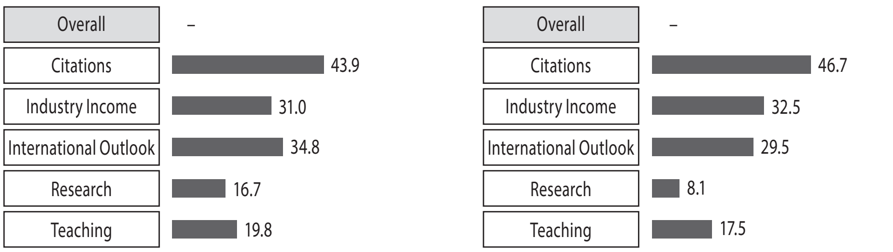
The score for teaching for the Jagiellonian University is 21, for the University of Warsaw – 19.8, with the best score on the list for the Massachusetts Institute of Technology, i.e. above 90 points. In the research quality ranking, the Jagiellonian University scored 19.9 and the University of Warsaw scored 16.7, while the best academia in this category, the University of Oxford, got almost 92 points.

Figure 8.2(b). Warsaw University's and Adam Mickiewicz University's overall scores in the life sciences ranks, 2019

Life Sciences category

Warsaw University

Adam Mickiewicz University



Source: The World University Rankings 2019/2020 by life sciences; https://www.timeshighereducation.com.

The strongest category for Polish universities is the number of citations per faculty in both overall life sciences and the category Clinical, Pre-clinical & Health rather high, especially for Jagiellonian University. It is consistent with the method of evaluating academic activity presented in the Polish law, described below, which places the greatest emphasis on the number and type of publications originating from universities.

Technology Transfer

The main institutions supporting technology transfer between universities and business are centers of technology transfer (CTTs), like for instance UOTT active at the University of Warsaw (http://uott.uw.edu.pl/), and CITTRU at the Jagiellonian University in Cracow (http://www.cittru.uj.edu.pl/), which operate at the majority of the Polish universities and scientific institutions and coordinate commercialization processes. They are based in the regions, but cooperate closely at the national level.

University representatives in Poland, especially their representatives dealing with technology transfer, understood that in order to increase the competitiveness of the offers of the Polish universities, they must act jointly throughout the country. As a result, the Polish Association of Centers for Technology Transfer (PACTT) was established. This network of academic technology transfer centers has been operating in Poland since December 2015. Currently, it consists of 66 units that deal with the transfer of knowledge both at public and private universities and at the institutes of the Polish Academy of Sciences. The agreement between PACTT is a voluntary association of the representatives of university units responsible for the management and commercialization of intellectual property. The agreement is nationwide, and its members are successively joined by new members. PACTT's goals are (www.pactt.pl):

- Integration of the professional environment dealing with the transfer of knowledge and technology in academic settings.
- Exchange of knowledge, experience, operating standards and good practices.
- Development of professional competences of employees of technology transfer centers.
- Cooperation in the commercialization of scientific research results.
- Joint representation of the members of the agreement before public administration bodies, employers' associations and other entities acting for innovation and cooperation between science and business.
- Initiating and giving opinions on legal changes, giving opinions on strategic documents and actions taken by authorized bodies in the field of the state's innovation policy.

Universities and scientific units represented in PACTT through technology transfer centers offer access to over 65,000 scientists in Poland and over 14,000 patents and patent applications.

PACTT supports business dialogue with the world of science through brokers who, as dedicated company guardians, collect data on available patents and discoveries. On the basis of the preferences and expectations of enterprises, brokers prepare collective presentations in which scientific teams, selected from 66 Polish universities, scientific units and investment committees from enterprises, participate. One of the elements of this process is PACTT's support of scientists–in the preparation of presentations and companies – in building relationships with the research teams of interest to them. Cooperation with PACTT means that the business/investors can count on ongoing updating of information in accordance with the profile of interest, receive a dedicated broker who collects information from universities and research units, presenting them in a convenient form, and can have access to the intellectual property of universities and scientific units in one place (one-stop shop).

There are several most common types of commercialization at universities in Poland: direct commercialization, sale of intellectual property and indirect commercialization. The direct commercialization (sales and license) consists of selling the results of the research work or grant a license to use the results of research. The sale of intellectual property rights is related to the one-time transfer of all rights to the results in exchange for a fixed price (by transferring the rights to research results, researchers also get rid of all risks associated with further commercialization). In the case of granting a license to use the results of research, their owner – the licensor – obtains revenues in the form of license fees from the entity that acquires the license (the licensee). The license fees can be set based on one-off payments, periodic payments or in relation to the licensee's revenues from the implementation of research works. Finally, the indirect commercialization requires creating or using an existing company (usually a capital company) to bring research results to it for commercialization. Such an appeal may be made in the form of an in-kind contribution, but it may also be in the form of a license. At the University of Warsaw, this process will be supported by a special purpose organization of the University of Warsaw – UWRC Sp. z o.o. Operating in the form of a capital company also opens the possibility of obtaining external capital from private and institutional investors. At the same time, this form of commercializing research results is associated with greater involvement of the owners of research results and with many risks associated with running a business (www.uwrc.pl).

According to the Patent Office of the Republic of Poland (www.uprp.gov.pl) Jagiellonian University including Collegium Medicum in the period 2001–2019 filed 628 patent applications (239 in Poland, 389 abroad) and received 267 patents granted (132 in Poland, 135 abroad). University of Warsaw at the same period filed 162 patent applications in Poland and 314 abroad.

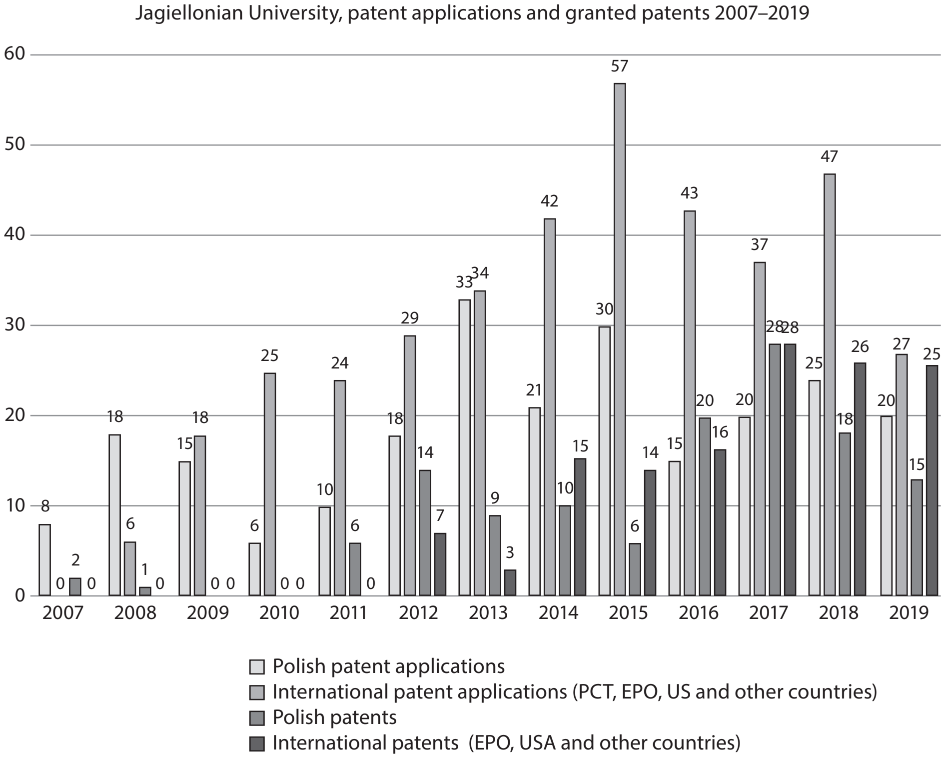
Table 8.1. The Jagiellonian University's and Warsaw University's technology transfer data, 2017–2018

	Commercial and research licenses signed	Patents applications (in Poland and abroad)	spin outs/spin offs
Total number:	24	198	23
Jagiellonian University	22	129	13 start-ups in 2018
Warsaw University		69	10 spin-offs

Source: the data was achieved from various primary and secondary sources: the University of Warsaw Patent Bureau, the Jagiellonian University CTT CITTRU annual report 2017, 2018 updated later by Jagiellonian University CTT CITTRU (number of licence and sale agreements).

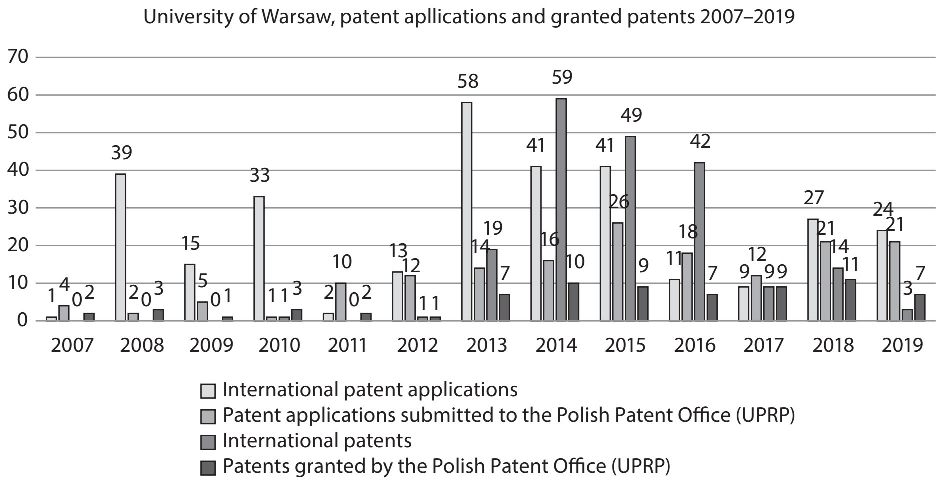
Statistics of patent applications and patents granted from previous years for both universities are presented in Figure 8.3 and Figure 8.4.

Figure 8.3. Patent applications and patents granted by the Jagiellonian University, 2007–2019



Source: *CTT CITRU Annual Report 2018*, http://www.cittru.uj.edu.pl/documents/1587933/142756691/2019+Raport+CITTRU+dla+wszystkich+FINALNA.pdf/aef71608-878e-49c6-9303-361eb094329d (updated on 26.03.2020 by Jagiellonian University CTT CITTRU).

Figure 8.4. Patent applications and patents granted by University of Warsaw in 2007–2019



Source: data achieved from University of Warsaw – University Center for Technology Transfer on 6.03.2020.

Supporting Infrastructure for Innovation and Technology Transfer

There are two other important initiatives in the Warsaw region which are based at the University of Warsaw and managed by the Technology Transfer Centre, supporting innovations and science-business cooperation, which also manage two institutions directed at students, scientists and business: the University of Warsaw Innovation Club and the University of Warsaw Incubator.

The University of Warsaw Innovation Club[8] is a kind of networking club. Meetings are organized once a quarter in a convenient location in Warsaw. During them, one can learn about the best emerging or existing projects at the University of Warsaw in the chosen field. For business, this is a unique opportunity to build relationships with key science representatives who are keen to commercialize their discoveries and solutions. These are people actively seeking contacts with representatives of companies interested in cooperation. Thus, the UW Innovation Club is a space in which the world of business connects with the world of science for the benefit of both parties, e.g. to conduct joint development activities.

The University of Warsaw Incubator[9]' has a goal of creating conditions for the development of a practical approach to the results of scientific work and practical projects at the University of Warsaw, such as start-ups, NGOs, and the develop-

[8] Inkubator UW, https://www.en.uw.edu.pl/uw-incubator/

[9] Klub Innowacji UW, http://pactt.pl

ment of people who create change in companies and local communities. The University of Warsaw Incubator was launched in March 2017, as the joined initiative of the University's Technology Transfer Centre and a special purpose company (UWRC Sp. z o.o.) of the University of Warsaw. It operates on all University of Warsaw campuses as a creative space for newly-created start-ups.

The University of Warsaw Incubator is a section of the University's Technology Transfer Centre and is established to support entrepreneurial attitudes and behavior in the academic community by enabling the verification of practical, scientific, technological or social ideas in cooperation with experienced experts in safe business conditions. The Incubator helps in the development of business and social projects in various stages of market maturity, organizing workshops, training sessions, meetings with experts, as well as providing modern infrastructure and workspaces. It offers co-working spaces, quiet workrooms, conference rooms, a 3D design and printing center, an electronic workshop and a modern workshop. As part of the University of Warsaw Incubator, students and individual scientists or their teams, as well as newly-established technology companies, including the University of Warsaw's spin-off companies, receive substantive support (mentoring, consulting, valuations, etc.). In addition, they receive an opportunity to rent space in selected facilities of the University of Warsaw.

This offer is addressed to everyone who would like to develop entrepreneurially – both for those seeking inspiration and those who already have an idea for a business. The offer includes various workshops that will allow one to improve or acquire technological, soft and business skills, but also to stimulate creativity. In addition to expert support for each project, there is an opportunity to get support in pre-incubation, i.e. setting up one's own business under the wings of a limited liability company that UWRC raised at the University for this purpose. There are a few already completed projects in the Incubator:

- Brave Camp Summer School: thanks to cooperation with the sponsor which was a pharma company, over 70 submitted student projects were given the opportunity to go to a training center to work on business models, marketing and soft skills.
- Przedsiębiorczość – Otwórz Głowę! (Entrepreneurship – Open Your Head!): general university classes which have been attended by 100 students so far.
- MatchIT: a weekend start-up marathon at the University of Warsaw, during which students built preliminary versions of applications that solve business and social problems.
- Skillbox: a series of workshops on about 50 topics, covering three sectors of competence: business, technology and personal skills: every month, they launch another pool of classes for the next 30 days. The workshops are very popular, there are about 1,000 entries to the workshops every month.

- Mentoring with experts from various fields related to entrepreneurship and business who support participants in the development of their projects.

The Jagiellonian University pursues a policy of openness to entrepreneurship. In 2002, the University founded the Centre of Technology Transfer (CTT CITTRU) which is a unit comprehensively supporting the university and the academic community in cooperation with the economic environment, promoting knowledge transfer and entrepreneurship. The Centre of Technology Transfer CITTRU is a unit of the Jagiellonian University responsible for comprehensive cooperation between the science and the business environments. CITTRU is responsible for:

- Identifying innovative solutions emerging at the Jagiellonian University,
- Providing comprehensive legal protection for research results
- Analyzing market potential of research results
- Choosing the optimal commercialization method for scientific achievements, through licensing, sale or creation of spin-off companies, in cooperation with creators and interested entrepreneurs,
- Developing the Jagiellonian University's invention offers, including innovative solutions for industry, and the offer of Jagiellonian University's research services commissioned by external institutions,
- promoting the technological offer during trade fairs, business conferences and direct meetings with potential technology recipients
- Identifying potential business partners interested in cooperation in the commercialization or purchase of technologies developed by the Jagiellonian University researchers and building a network of contacts with industry
- Negotiating, preparing and supervising the implementation of contracts related to commercialization
- Coordinating the implementation of research services at the Jagiellonian University, including creating an offer of research services, and its promotion among potential recipients and negotiating relevant contracts
- Cooperating with external entities, including foreign partners, in the field of innovation and the creation and implementation of pro-innovation activities

CITTU CTT brokers shared their experience in knowledge and technology transfer, while simultaneously promoting the university's offer at many events, such as conferences, study visits and expert panels. In 2018, 14 conferences or events took place with participants from Poland, but also with European and global partners, with active CITTU CTT brokers' engagement.

The Academic Incubator of Entrepreneurship of the Jagiellonian University (AIP UJ), operating within the CTT CITTU structures, has conducted over 45 individual meetings, as well as trainings for organized groups of students. In 2018, 13 new companies concluded pre-incubation agreements. The number of supported AIP UJ startups increased to 34.

The university, like most universities in Cracow, is also a minority shareholder of a well-functioning Kraków Technology Park (KPT). It is a place that not only manages the economic zone and its buildings in which one can use the space and conduct business, but it also provides the opportunity to use support programs. Now, for example, Skylab program is working, i.e. it is an initiative thanks to which start-ups or groups planning to kick off start-up activity can work with mentoring, coming from an experienced entrepreneur, for several weeks.

The region also has the Małopolska Center of Biotechnology (MCB), which is a research and development park which was established as a project aimed at creating an interdisciplinary research center enabling comprehensive research at various levels of body functioning. The MCB consists of 6 research centers and 5 laboratories of independent research groups.

In 2004, the Jagiellonian Center of Innovation (JCI)[10] was established by the Jagiellonian University with the view of creating a life sciences technology park. Two years later, the Cracow LifeScience Cluster[11] was created which was a network of institutions and companies from the macroregion of Southern Poland, linked by common objectives and vision of developing innovation in the scope of biotechnology and life sciences. As of the date of its launch, the cluster gathered 32 entities and was not fully directed. The creators were seeking a force to drive it in a specific direction, which proved to be life sciences.

The activity of the Cracow LifeScience Cluster currently covers two domains derived from biotechnology and life sciences: products and technologies for health and life quality (covering research on medicines, medical diagnostics, e-health and telemedicine, therapeutic technologies and medical devices, medicinal products as well as medicinal and cosmetic devices) and products and technologies for sustainable development and bioeconomy (covering modern sustainable agriculture, healthy foods and nutrition, environment and bioeconomy).

The main objectives of the creators of the cluster were:

1) to create a network of subject in the scope of life sciences, enabling the effective connection and use of the existing potential of people, enterprises, universities, research and development facilities, business environment institutions, and local and regional authorities
2) to link and develop resources and competencies in the scope of life sciences in order to both effectively use the existing opportunities and create new op-

[10] Jagiellońskie Centrum Innowacji, https://www.jagiellonskiecentruminnowacji.pl

[11] Klaster LifeScience Kraków, https://www.lifescience.pl

portunities associated with the development of innovative knowledge-based economy

3) to support entrepreneurship and innovation in the scope of life sciences and creating conditions for effective commercialization of the results of research and development works.

The project is currently coordinated by the Cracow LifeScience Cluster Foundation, set up in 2013 as a separate and independent entity dedicated to the development of the cluster. The objectives of the Foundation consider the perspective of both bio-region, which is international economical promotion of the bio-region of Mazowsze and partnership within the cluster. Three main areas of the cluster's activity are as follows: to inform and educate, to integrate and coordinate activities.

The researchers working on their subjects gain necessary knowledge, experience and various types of resources, but they hesitate quite often to share them with others or to make use of knowledge, experience and resources developed in other places. This is due to many reasons. Learning what the others are working on, making contacts, looking for partners is time-consuming, however, if successful, it may lead to increasing various types of resources for either party. One ambition of the cluster is to integrate activities within and across functions, across entities in the scientific environment, of science and business or of business with business, which is done through numerous meetings organized by the cluster. Another cluster activity includes the coordination of activities where integration is not possible for various reasons. The cluster's goal is also to coordinate activities of scientific partners in the region, in the country and in Europe, and to coordinate efforts of various actors within social activities and political, lobbying ones.

The initiative of the Cracow LifeScience Cluster currently connects 75 entities. The largest group consists of small and medium-size enterprises (50%), followed by big enterprises, including hospitals (20%) and scientific facilities (universities and research and development institutes) which amount to 15%. The managers of the cluster search for indicators on which the evaluation of the cluster's activity could be based, whereas the manner of evaluating international clusters, such as, for example, the Boston cluster, served as the point of reference. The effectiveness of activities undertaken by the cluster may be evaluated on three levels: (1) through the evaluation of the development of the entire ecosystem of the region, expressed in the number and quality of workplaces existing and created in the region and the value of tax paid by those companies; (2) through influencing key success factors, such as increase in the research activity. Such an indicator can also hardly be assigned solely to the activity of the cluster, as it is often other activities, such as, for instance, changes in legislation regarding higher education, that can have a stronger impact; (3) through the evaluation of direct activity of the cluster, expressed in the number and quality of the meetings, initiatives and projects organized by the cluster.

The Cracow LifeScience Cluster takes pride in participation in many international, national and regional projects, such as, for example: Anti-Microbial Coating Innovations – AMiCi – to prevent infectious diseases; the Baltic Fracture Competence Centre – the BFCC – the improvement of the outcomes of treating fractures and quality in the scope of their understanding, analyzing, diagnosing and optimization of social and economic costs; the Centre for New Methods in Computational Diagnostics and Personalised Therapy.

The life sciences business start-up essentials[12] initiative of the Cracow LifeScience Cluster aims to: facilitate the initiation of new business undertakings through enabling networking in the domain of life sciences (networking), develop specialized knowledge about the market and its needs, niches and opportunities (exploration), identify, verify, test and integrate ideas (ideation), gain competence and knowledge necessary to effectively develop new undertakings (education), and inspire to act, change attitudes and development goals (inspiration).

One of the important initiatives of the cluster is the Life Science Start-up Scene program, which is dedicated to the cooperation of companies from the region and which consists in monthly meetings during which individual start-ups are presented, various aspects important for those start-ups are discussed, and to which experts from various domains are invited to comment on the presentations.

An important indicator of the success of the cluster is the achievements of its partners. One example of such an achievement is the above-described success of Selvita, which is a member of the Cracovian life sciences center and which initiated the clinical phase of trials for its own medicine. Apart from the cluster members, the institution cooperates with similar clusters from the region of Southern Poland, MedSilesia, Lublin, Wrocław. The cooperation consists in, for example, study visits during which the partners exchange experiences and inspire one another by presenting their projects.

SOLARIS is a Polish national research center located in Cracow providing scientists with synchrotron radiation (https://synchrotron.uj.edu.pl/en_GB/centrum/o-centrum-solaris).. Synchrotrons open up completely new research possibilities. Thanks to them, we can carry out analyses which were previously impossible. Synchrotrons also allow us to obtain better results than those from studies carried out using traditional methods. The synchrotron beamlines are currently the most versatile research tools possessed in the natural and technical sciences, such as biology, chemistry, physics, materials engineering, nanotechnology, medicine, pharmacology, geology or crystallography.

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[12] https://lifescience.pl/wydarzenie/life-science-business-startup-essentials/

Finally, in terms of cooperation between the Jagiellonian University and the government, one of the goals of the Marshal's Office of the Małopolska region is to utilize the scientific potential of the region and build connections between small and medium-size business from the regions and academia aiming to develop the region. A few years ago, the voivodeship authorities commissioned the development of a model technology transfer system and in this way, the SPIN model project[13] was created. A theoretical study of what technology transfer is and how to do it was created, and it was also recognized that the best supporting tools are the creation of units that focus their competences within the industry and those that can support entrepreneurs. The Jagiellonian University is a beneficiary of the SPIN project, specifically the biotechnology center which carries out audits, gives advice on how to develop and change biotechnology companies and other projects related to the life sciences ecosystem. This is financed by the Marshal's office. They also organize a SAFARI program[14], designed to support cooperation between academia in Cracow and small and medium-size business companies from the region.

5. The Empirical Analysis

The section below discusses the findings from the review of data available on the official websites of the most relevant institutions, and the survey performed with representatives of key institutions and organizations dealing with technology transfer or supporting collaboration between business, science and supporting organizations. The author reviewed the official websites of the institutions, the official documents and performed 12 in-depth interviews with people representing public institutions and organizations related to the university ecosystem: technology transfer centers from the University of Warsaw and the Jagiellonian University, their heads and brokers directly looking for collaboration deals, life sciences cluster, the company SYNERGIA WUM at the Medical University in Warsaw; people representing pharma business associations, such as the Association of Innovative Pharmaceutical Companies INFARMA, the Good Clinical Practice Association in Poland, and business representatives – the head of one pharmaceutical company, one representative of a Polish biotech company and a company of clinical research centers, GP4Research. The survey consisted of 13 questions (open and closed ones). The focus was on three groups of topics: (1) the mission, structure and types of social networks and methods of social networking, (2) expectations toward partners, the intensity of interactions and different dimensions of social capital, (3) the impact of social networks on R&D collaboration, innovative performance and future plans and challenges.

[13] https://www.spin.malopolska.pl

[14] https://www.malopolska.pl/

The Mission, Structure, Types of Social Networks and Methods of Social Networking (1)

The majority of people active in the domain of life sciences in Poland who agreed to share their experiences belong to more than one network of entities cooperating on the market, including national and European networks, as well as networks reaching beyond the Old Continent and engaging members from all around the world. In several cases, even if the speaker described a national network, of which he was a member, at the same time, he drew attention to the fact that the network has equivalents in other European countries and that similar networks are associated under one flag at the European level. The majority of them are official networks. The most important and the most frequently mentioned reasons for which the networks are created and which are contained in the network mission are: common projects and initiatives in the scope of R&D, sharing knowledge and information, followed by exchange of best practices.

In the view of respondents, networking also helped promote one's organization and region as a top logistic location for potential technology recipients, as well as identify potential business partners interested in cooperation with universities (partners for new projects or commercial research services). Approximately two-thirds of the interviewees mentioned formal meetings face-to-face as well as participation in conferences, and workshops as the most common methods of networking. Just in 2018, CTT CITTRU representatives took part in 22 regional, national and European events: industry meetings, partnering, fairs and meetups presenting university offers and searching for partners for new projects or commercial research services. These networking events enabled the representatives to share their experiences and related problems in knowledge and technology transfer. The representative from the Cracow CTT CITTRU mentioned that networking with people from the life sciences cluster in Cracow was important for promoting one another's activities, inviting one another to events, such as conferences, meetings, or organizing something together. The cluster promotes university's technology offer through the cluster's channels.

The cluster plays an important intermediary role in informing and educating its regional members and stimulating networking on various levels. The cluster organizes various meetings with its scientific partners or open days of the cluster, to which scientists from various domains and universities are invited and during which complementary partners often meet for the very first time. It also happens that during those meetings, the scientists learn that others conduct works approximated to what they are involved in themselves, which makes it possible to mutually inspire each other and join forces, if such is the will of both parties. Meetings of this kind make the researchers aware of the complementary value of the presented works or, on the contrary, of the fact that they work or plan to work on something already covered by someone else. The managers of the cluster claim that it is "a perfect example of self-taught organization and they seek to support this model of activity. "They also organize a program designed to support cooperation between academia in Cracow and small and medium-size business companies from the region: "There is also a SAFARI program, in which the organizers invite companies from the Cracow region to the Cracow city and show institutions around universities, scientific laboratories, units such as CTT CITTRU and show that this is the place where you can come and find some support for yourself, whether you are buying research services or technologies, or developing new products. This shows small businesses that the university is not some mythical creation that you'd better not get close to, the great walls that you can't break through, only that it is a place where you can really get specific support that also develops their own business."

Expectations toward Partners, the Intensity of Interactions and Different Dimensions of Social Capital (2)

Polish networks usually attracted members with similar knowledge, interest or those involved in a similar activity/project. Those who were invited to join or joined the network, also expected to maintain long-term relations. In the majority of cases, contacts within the network were regular. Some people mentioned daily or weekly contacts, fewer people mentioned at least monthly contacts.

It is impossible to determine the dominant form of contact. The respondents mentioned both electronic forms, phone calls, face-to-face meetings and variety meetings, workshops and conferences that usually have a formal character.

As mentioned above, institutions designed to enhance technology transfer in Poland are located at a given university in the region. They do cooperate with other similar institutions in the region, but a regional network is not the first one being mentioned by them in relation to partners in a technology transfer network. The main network connecting people working with technology transfer is a nationwide association of technology transfer sites (PACTT) which seems to be more important for members and has strong regional connections. In the view of its representatives, "PACTT was originally, and partly still is, an informal association – a living organism (…). We founded the foundation in the last year, but as an additional element that will allow us to do additional things, we do not give up this informality. It is the most active network operating in the area of technology transfer at the interface between the academic community and business in Poland (…). The association's meetings are held twice a year, we have joint ventures, we can give opinions on documents regarding technology transfer centers, lobby for new ventures, share knowledge and clients. (…) In PACTT, we expect from our partners not only keeping relationships, but mainly sharing knowledge and resources. We realized that if we want to be visible as Poland, we don't get much if we all play for our goal. What we try to do at PACTT is, if someone goes to an event, to function together as Polish universities and leave such self-promotion."

There are also activities done on a regional level with the same spirit of inter-institutional cooperation. An Example of such an activity is a joint activity initiated in Cracow or the earlier described cooperation with regional governmental bodies that naturally have a local nature: "We also do similar things on a smaller scale in Cracow, CTT directors, and CEOs of special purpose companies, we regularly meet every 1–2 months, where we undertake joint initiatives: e.g. a joint acceleration program. In the past, each university used to implement an innovation incubator program separately. Now, instead of separating, we will have a joint 'demo day' – 5 universities or 10 entities – because there is a center of technology transfer and a special purpose company at each university. We think it is worth it because investors will come to one event, and we will show them the Cracow offer together and not separately. I am a huge supporter of doing things together and for now, I manage to spread these ideas to colleagues from other universities."

Geographical proximity is important for some activities. In this empirical work, this perspective was expressed specifically by a person representing the University of Warsaw Incubator. As one of the respondents emphasized, "(…) scientists involved at the same time in entrepreneurial activities don't want to change their lives dramatically and move to another city or region or commute extensively. They want to stay close to the university they are working at, the laboratory or institution supporting them, like an incubator or a technology park. The immediate proximity of these institutions is important to them."

For many interviewed stakeholders of the R&D activities in Poland, international collaboration was crucial. Scientists from the life sciences sector participate in European or global professional associations in their disciplines. Big companies operating in the life sciences sector in Poland also have global roots. For example, people working in sites dealing with technology transfer belonged to the European professional association for knowledge transfer professionals, ASPT Proton (www.astp4kt.eu). ASTP was established in 2000 with the focus on providing outstanding training and practice exchange among technology transfer professionals and members via participation in conferences and exchange of knowledge and experience. PACTT members also belong to the ACT Network that is associated with ASTP Proton–a European organization associating employees of technology transfer centers. This is a network of national networks operating in Europe. As stated by one member, "We use the knowledge of what our colleagues are doing in the world, we have a chance to look for partners for the projects there and, whether it's a prosaic thing to have discounts on trainings or we can attract these trainings to Poland, they have very good intensive workshop trainings.

The Impact of Social Networks on R&D Collaboration, Innovative Performance and Current Challenges and Plans (3)

The majority of the speakers emphasized the significant role of networking in the development of innovation in their areas of interests. It was noted that due to the large complexity of innovative research projects and their multidisciplinary character, their effective implementation was very often impossible without the networking support, and that networking played a major role in innovations. Networking and all types of cooperation were mentioned by all players working with innovations in life sciences: scientists, business representatives and people directly mediating technology transfer in Poland. One of the interviewees emphasized the importance of "creating a fund similar to the one in the innovation incubator from the budget set by the university for pre-implementation research. (…) The university gets mini-grants in projects that we want to commercialize. Sometimes you have to earn some extra research, make a quote or obtain external analyzes, and these are pre-implementation studies that we can finance from an innovation incubator, and now additionally from the funds allocated for this purpose by the university." The respondents were also aware of challenges for the development of innovation in their area of interests, barriers of different types, which hindered their cooperation in the networks For example, the respondents emphasized the importance of too much individualistic approach in collaboration networks. There is a huge effort of people directly involved in technology transfer to join forces and cooperate between each other on the national level. Yet, in the Polish life sciences university-based ecosystems, "sometimes opposite behavior was very visible. (…) A high level of individualism, which is also a characteristic of the nation. Some activities of public institutions active in the sector, as well as institutions associating scientific institutions are fragmented, act independently, do not unite for a single common goal, do not share one major direction (…). Lack of cooperation and organization of networks of public institutions. For example, in some aspects, representatives of universities, institutions, hospitals, who do not cooperate in a single network, do not speak with one voice and are not vocal in matters which are of concern to them, such as the question of non-commercial trials." A similar situation, in the view of the respondents, occurred when fragmented teams worked at universities, and each scientist kept focused on their own project–large organized and targeted teams directed at their implementation of common research projects were missing. Furthermore, there was also lack of interdisciplinary cooperation mentioned by some speakers, where doctors could meet representatives of other professional groups active on the life science market, such as chemists, biologists, biotechnologists, and representatives of engineering fields dealing with medicine. The doctors met at medical congresses in their own circle, and there was little interdisciplinary discussion which is nowadays indispensable for the development of innovation.

Jan Filip Staniłko, Deputy Director of the Department of Innovation in the Ministry of Development pointed out that there were many innovations at medical universities that never entered into force, and the universities needed to learn how to "do business." Large, interdisciplinary, potentially virtual teams needed to work on innovations. It was also important to build dialogue between universities and biopharmaceutical companies (International Clinical Trials Day 2018, Clinical Trials, Common Goals, Warsaw, May 24th, 2018).

In sum, efforts to incorporate all players of the sector into one game aiming to increase innovation in Poland are still in progress. Apart from the activities of CTTs and PACTT described above, there are also some goals on a regional level. A good example was described by a representative of CTT in Cracow, whose goal for the nearest future was organizing academic activity – CITTRU manages the innovation incubator, but at the Jagiellonian University, similar activities are also carried out by the career office, student circles, and the management department. The plan is to try to coordinate all these initiatives for the benefit of all.

Moreover, the interview study with the Polish academia representatives revealed that intellectual property at the Polish universities was fragmented and thus, it was difficult to set up cooperation or prepare an interesting offer to a business partner based on only one university's innovation proposals: "People working with technology transfer in Poland strongly believe that cooperation and networking on a country level is the key to support development of innovations and technology transfers in Poland. They have a strong country level network that, in their opinion, helps to develop cooperation with business partners (…). If a client approaches us, and we are not able to sort out his problems completely, and if he agrees to send his question to others, we send it to other units and there will always be someone in Poland who is able to support his undertaking (…). We offer a 'one-stop shop'–it's a solution in which companies/investors get one broker who will scan the offers from all Polish universities based on the agreed criteria and prepare an answer to the company so that it does not have to contact 50 entities in Poland separately."

Another challenge mentioned by the respondents is the "discrepancy between the objective of scientists and business, along with the fact that the Law on Higher Education that does not promote the commercialization efforts of scientists in academia. The goals of academics were numerous, including highly scored publications. The goal of business was to commercialize innovation. The academics were not rewarded and stimulated to seek the practical application of their innovative ideas. There were also no mechanisms stimulating them to seek cooperation with other centers or with business aiming at the practical implementation or even the commercialization of innovation.

The Polish Association of Centers for Technology Transfer (PACTT) raised comments on the draft Regulation on the Evaluation of the Quality of Scientific

Activities of July 30, 2018. The proposed regulation did not motivate scientists to commercialize the results of scientific research. Furthermore, achievements in the commercialization of ideas and scientific discoveries has a very limited impact on the assessment of a given university. In fact, in the view of respondents, "currently, the number and type of scientific publications are the most important factors influencing the university's assessment, and the successes in commercialization affect the university's assessment much less (…)." Therefore, PACTT argued that "in order to encourage the academic community to intensify cooperation with the socio-economic environment, and particularly to commercialize the knowledge generated, it is necessary to radically raise the rank of indicators related to this activity (…)." In the view of the Association members, "without increasing the score for patents obtained, and in particular for successful commercialization, we will not mobilize scientists to be more active in taking actions to create and transfer solutions that contribute to the growth of innovation in the economy and have a positive social impact. The proposed changes by PACTT postulated that the value of individual indicators related to commercialization, including patents, should be similar to the value of indicators related to scientific publications. Unfortunately, ultimately the regulation did not cover all postulates and the advantage of the publication value over successes in commercializing discoveries in university assessments remained."

Another challenge in this category is a general attitude and belief of some scientists that 'the science is not for sale.' As one respondent said, "there is a general belief among many academics or representatives of the authorities of a university that there are technical universities to cooperate with, and universities are universities for basic research." A positive attitude toward cooperation with business is not something obvious and natural.

Another challenge consists in insufficient cooperation between the scientific environment and business. The Deputy Director of the Institute of Experimental Biology of the Polish Science Academy emphasizes the necessity of cooperation between the world of science, the government administration and business, which would translate into the development of the entire biotechnology sector[15]. The problematic issue mentioned by the interviewee was the lack of trust, which again can be explained to some extent by the low level of social trust described in Poland, partly shaped over the years of the socialist economy. Scientists often fear that cooperating in a project with a company will end in the loss of control over it. There is a kind of fear of such cooperation, possibly resulting from a historically negative approach to cooperation between science and medicine and pharmaceutical business. Contrary, companies avoid cooperation with universities on the basis of stereotypical notions that these are ossified organizations with which cooperation

[15] https://biznes.newseria.pl/news/polskie-firmy,p161601405

is very difficult. The challenge is to convince an increasing number of companies that a university is not a place that should be handled from afar, but with which it is worth cooperating. "We are constantly encountering such situations that companies are very surprised that some processes, such as signing a contract for carrying out commissioned tests, for example, can also be carried out in part thanks to CITTRU, and it doesn't take, I don't know, half a year. So the challenge is the stereotypical belief that if it is a university, it will last a long time, and if we ask how many times you have faced it, then never – it is necessary to disenchant the myth."

In the view of corporate respondents, there was little motivation of business to promote Polish innovations: "This part of Europe, including Poland, also has not been an obvious market for business, especially global companies operating in the life sciences sector seeking innovation, but it changes. Business increasingly seeks innovation in Central and Eastern Europe, however, Poland is not an obvious market, the attitude of business toward Polish innovations is weaker when compared to, for example, the Hungarian market."

The speakers also note that too early patenting was sometimes an issue. Patent application is made early from public funds, and the reflection over the purpose of a given solution or product comes second: "After obtaining patent protection, a valuation may take place, which is sometimes overstated, since the assessors do not account for all the elements significant for the investors, such as the quality of conducted operational procedures which are decisive in the possibility to fully use gathered data for commercial purposes by the investor." Inflated expectations restrained the originator in his negotiations with the investor, which in Poland may be multiplied by the low level of social trust. The speakers suggested that the earlier business verification took place, the better it was for the prognoses regarding the commercialization of products. On the other hand, it seemed to be natural that the researchers attempted to obtain patent protection for their ideas as early as possible. There were also opinions that scientists often waited too long for the patent, trying to improve their invention without end.

Furthermore, the respondents also mentioned that legislative gaps and excessive bureaucracy were impeding collaborative efforts, especially at the EU level. The need for legislative changes was emphasized. The latter especially concerned the necessity to adjust the Polish law and practice of clinical trials to Regulation No 536/2014 of the European Parliament and of the Council of 16 April 2014 on clinical trials on medicinal products for human use, which was applied, starting from the second half of 2019: "The Regulation is binding for all the European countries, without the necessity to implement its provisions in the national legal orders, which this time gives the chance for uniform application in the entire EU. Work on this Regulation constitute a challenge for the entire EU. For Poland, the main challenge is to create principles of common policy of the Office for Registration of Medicinal Products, Medical Devices and Biocidal Products and the Bioethical Commissions for the evaluation of a motion for initiating a clinical trial and getting ready for common substantial evaluation led by the reporting state and to perform the function of the reporting state." Furthermore, as the speakers emphasized, "even though the Regulation is binding for all the EU member states, some areas are left out to be regulated on local markets. In recent years, work on those areas constituted the main subject of very intense cooperation between various actors on the market of clinical trials in Poland."

All in all, the representatives of the Polish life sciences ecosystem saw the new directive as a great hope for the environment of innovative clinical trials in Europe; as another step toward the unification of requirements, simplification of the procedures and, as a result, maybe reducing the time of obtaining consents and lowering administrative costs. Attempts at standardization on international level started in 1996 by introducing ICH E6 GCP, which yet failed to slow down the increase of the costs of clinical trials resulting from administrative reasons and extending the time of introducing innovative therapies into the market in Europe (Directive 2001/20/EC of the European Parliament and of the Council of 4 April 2001 on the implementation of GCP and the Directive of 8 April 2005 on detailed guidelines for GCP). The Directive was adopted by the European countries in a non-uniform way, with a number of additional local provisions, which ruined chances for standardization and lowering the costs and time, and as consequence, conducting innovative research became less interesting for sponsors.

The imperfection of laws in the scope of clinical trials in Poland causes many people to notice problems associated with excessive bureaucracy, which, for example, is manifested in the necessity to submit to the Office for Registration of Medicinal Products, Medical Devices and Biocidal Products documents that are not required in other European countries. Another problem reported by the respondents was the long waiting time for decisions regarding approval for the initiation of a given clinical trial (Olszewski 2018; Jędrzejowski 2018).

Another difficulty is the lack of institutional support and scientific advice at early stages of works on a new medicine within the Polish Office for Registration of Medicinal Products, Medical Devices and Biocides (Lipner et al. 2018). Biocidal Products. Such institutions were present in other European countries, such as ANSM in France (www.ansm.sante.fr) or BfArM in Germany (www.bfarm.de). The latter, for example, issued around 290 answers to over 300 applications for scientific advice in the last 3 years. As one study respondent said, "(…) such an institution is particularly in demand right now, when we can witness an increasing number of innovative trials, combining I- and II- or II- and III-phase trials, basket- or umbrella-type trials. The work on creating such an organ are in progress, and there is a strong will to initiate its activity and faith in the fact that its functioning could support innovations and assist in the course of designing the implementation of medicines at early stage, however, by now, realistic plans of its creation are nowhere near completion (…).” In addition, frequent personal changes in the management boards of organizations and public agendas, including the Ministry of Health, are not beneficial for creating solid legislative and institutional support.

In the view of the respondents, the complicated procedures for obtaining EU grants discourage seeking participation in the further networks: “The Polish biotechnological sector is only starting to develop, it has large potential, however, at the same time, it faces challenges associated with the legislative environment and complicated access to financing.” Some experts also pointed at administrative obstacles associated with obtaining financial grants for scientific works. The requirements were very high and funds required for conducting scientific research often failed to be obtained for administrative reasons, complicated application forms, required documentation. As a result, the Polish biotechnological sector is underfunded, which was a big challenge that the researchers active on the non-commercial Polish market had to face.

Some speakers also noted that the European Union limited the financing of projects to the amount of €200,000, which excludes life sciences projects: “This kind of money only allows to run early tests, such as toxicological ones, while business potentially interested in commercializing the idea makes its decisions much later, when the project is initiated or heads for the initiation of its clinical phase, by which time it would have required significantly larger funds.” Yet, others mentioned that since recently, there have been a lot of more easily accessible Polish investment funds, and the researchers were less inclined to use European funds.

Some speakers pointed out too easy access to public funds and thus little motivation to access funds through the professional or private networking. The supply of public funds exceeded the supply of projects, which resulted in the chasing of projects. The latter resulted in the low quality of some projects that were eventually awarded funding: “It is too easy to obtain money for a project through easy access to Bridge Alfa funds. The researchers obtain financing for the implementation of projects, however, they lack operational knowledge or the opportunity to use professional project managers which could lead the project in operational terms. As a result, the money from the European Union or from other public funds is misused.” One speaker mentioned that one example for the lack of operational experience in managing projects is a too optimistic plan of research: “Experts from various fields of medicine or related areas, highly qualified in their domain, are unaware of a number of operational requirements associated with project implementation which must be met and which require proper time, such as certifications, permissions of various offices, statistical requirements, etc. The lack of operational experience and external control sometimes leads to neglecting elements which are significant from the point of view of future commercialization, including proper certification of the laboratory, which is sometimes forgotten by scientists focusing on the medical and scientific side of the trial."

Moreover, the interviewees share their concern that "a project financed from public funds may be subject to insufficient control, with no milestones, no independent assessment of the legitimacy of continuing the project or the need to correct or stop the project (…)." This leads to the situation where a scientist who is operationally inexperienced and at the same time emotionally engaged in his own research seeks to continue the project, regardless of signals suggesting a different solution. Some speakers suggested that one's own input in financing projects would allow for a better assessment of the value of the conducted project and for advocating the introduction of objective control points which can indicate a potential necessity of correcting, ending or continuing the project. One of the speakers pointed out that "introducing control is opposed and is sometimes referred to as 'an attack on the freedom of science' by some scientists," whereas in his opinion, a scientist's freedom does not go with commercialization.

6. Conclusions

The study shows that the Polish life sciences university-based innovation ecosystem stakeholders appreciate the role of social networks and collaboration within the Triple/Quadruple Helix in the development of the life sciences sector in Poland. Nevertheless, the role of social capital and network capital in the university-based innovation ecosystems is rather low. There are numerous challenges and barriers to the social networks and social capital formation in the life sciences university-based innovation ecosystem in Poland. The most prominent ones are: the low level of trust and the low level of organizational, social and cultural proximity between the scientists and business, little motivation and no mechanisms stimulating research co-operation, patenting and commercialization, legislative gaps and excessive bureaucracy in the scope of clinical trials, the lack of intermediary institutions, brokering university-industry collaboration, as well as supporting innovations via giving scientific advice at early stages of research works, a high level of individualism and lack of interdisciplinary cooperation, especially at the university level, and little competition over the European research funds.

The development of networks differs in various environments related to the development of life sciences technology in Poland. Scientists from the academic environment participate in scientific associations relevant to their specialization. The need for cooperation with business and the need to commercialize their scientific ideas 'is not obvious,' especially for scientists coming from universities, who believe that commercialization should be the domain of technical schools. The academic community, motivated mainly by publications, tends to work in narrow teams of specialists in a given field. In the academic community, the scientific position of high-level professors in a given topic is very strong and often decisive, which may hinder any commercialization efforts if anyone from this group proclaims the view that 'the science is not for sale.'

From the end of the last century, technology transfer centers began to emerge at Polish universities, whose task was to find entrepreneurs interested in investing in the discoveries of Polish scientists. It was a milestone that increased the chances of commercialization of the discoveries of Polish scientists. Several years later, they noticed that the offer of individual universities in Poland was too fragmented to interest larger investors who would have to contact dozens of institutions in search of a solution to their problem. Thus, representatives of individual technology transfer centers thus initially created an informal network between technology transfer centers and began to act together for the benefit of all. Informal relations in this network remain and still play a very important role, supporting trust thanks to which the network offers investors a one stop shop, i.e. one selected person, a broker located in one of the centers/universities, represents all other centers, taking care of everyone's interests equally. Currently, a formal foundation has already been established, which enables the implementation of additional tasks of the agreement, but everyone emphasizes the importance of remaining good informal relations.

On national and regional levels, a "top-down networking" approach may be seen. In some regions, the local government understands important networks and organizes actions linking academia with regional small and medium-size business. This enabling function of local governments is something that completes the structure of Triple/Quadruple Helix. On the other hand, there is still few informal, "bottom-up" initiatives for networking events, using digital platforms for the purpose of building problem groups, discussing various challenges in life sciences education and research in the related fields.

Conclusions and implications

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Despite substantial differences between the analyzed life sciences university-based ecosystems, they also share many emerging properties, similar to the other typologies of ecosystems. These include: the co-specialization and complementarity of participants, as well as co-creation, co-evolution, innovation and positive externalities within the ecosystems as their greatest value sources.

All the analyzed university ecosystems have their own internal technological and social dynamics. Considering the intensity and scale of their interlinkages, the Cambridge and Medicon Valley clusters conform with Porter's concept of the 'functional clusters,' with the close synergy between the three Triple Helix components, namely university-industry-government. These ecosystems demonstrate close links between research and faculty staff in medical and related departments of the universities and local bioscience companies, either in the form of collaboration, funding or the employment of graduates as the commercialization channels of university-based research. In reality, both clusters could qualify as Quadruple Helix models.

Furthermore, in the case of the two US-based ecosystems – in the Bay Area and Seattle – the clusters involve the mutually reinforcing interaction between several components in Porter's terms, which are characterized by "rich social capital" that leads to the positive externalities that contribute to building collaborative synergy, knowledge spillovers and increase of innovations within, in the sense of Bochniarz and Faoro's concept of an "effective cluster" (2016). Both offer high-skilled talents and a very entrepreneurial and innovative culture. Both provide a multinational and diverse environment, facilitating exchange of best practices and beliefs, in which universities take the lead in the establishment of university-industry collaborations, result in cutting-edge developments and inventions which, in turn, attract more talent, firms, and investments. Table 8.2 summarizes the basic features, differences and similarities of all five case studies, related to their university/science base, financial capital, entrepreneurship, social capital and networking.

Table 8.2. Summary of the basic features, differences and similarities of all five case studies

	Cambridge	Medicon Valley	San Francisco Bay Area	Seattle	Poland
University and science base	World's leading university/ Nobel Prize winners	Attracting and retaining international talent (through EU programs)	World's leading university/Nobel Prize winners	World class university/Nobel prize winners, attracting international talent	Underinvested science base and recruiting talent
Financial capital	High in governmental and venture capital funding	High research funding from the EU and university	High in governmental and venture capital funding	Rising research funding and venture capital	Rising research funding opportunities from the EC and university
Entrepreneurship	Incubative entrepreneurship new ideas and ventures within the organization.	Incubative entrepreneurship new ideas and ventures within the organization	Opportunistic and mass entrepreneurship	Opportunistic and mass entrepreneurship, but rather on SME scale	Emerging and individual entrepreneurship
Social capital	Valuable social capital for innovation and competitiveness	High level of social capital not related to innovation collaboration	Rich social capital for innovation, collaboration and fair competition	Rich social capital for innovation, collaboration and fair competition	A different kind of social capital
Networking	Moderate networking/direct and indirect links between industry, venture capitalists and research institutions	Loose networking/ indirect links between industry, venture capitalists and research institutions	Tight networking/ direct links between industry, venture capitalists and research institutions	Tight networking/ direct links between industry, venture capitalists and research institutions	Little networking/ direct and indirect links between industry, venture capitalists and research institutions

Source: own elaboration.

The diversity, interdisciplinarity and connectivity of these university-based innovation ecosystems create natural "bottom-up" environments for the technological convergence in the life sciences sector. These ecosystems have social and institutional mechanisms allowing new ideas to move from one domain to another, strengthening innovative potential of the local life sciences industry. In Cambridge, Medicon Valley and Poland's universities-based ecosystems, in turn, research collaboration was stimulated in the sense of the top-down approach. There is a relatively low level of cross-disciplinary research initiatives and grants supporting diverse research teams working in collaboration toward a common goal (this phenomenon is nearly non-existent in Poland). For the Medicon Valley and Cambridge life science clusters, the government has been an important provider of both human capital and financial support. In contrast, academic spin-offs and venture capital were the two major sources for human and financial capital in the Bay Area and Seattle clusters.

Furthermore, the key differences between the two Western European and US clusters are grounded in their entrepreneurship, social capital and network patterns which develop interdependently in the evolution of their cluster ecosystems. In the Bay Area, a strong entrepreneurship culture, history and social capital promote tight and dynamic networking. In contrast, social capital formation, entrepreneurship and network dynamics in the Medicon Valley and the Cambridge clusters ecosystems have been initiated to the significant extent by the intermediary organizations and "star" scientists. Moreover, Scandinavian ecosystem members seem to have higher social trust when approaching via both physical and digital contact in comparison to the UK-based cluster.

Finally, the research study demonstrates the different configuration of clustering and networking in the evolutionary processes of the EU and US clusters ecosystems. In the Bay Area and Seattle clusters, companies are linked to research institutions and venture capital firms in the initial stage. At the mature stage, these links shift toward more tight connections between companies themselves. In contrast, companies in the Medicon Valley and Cambridge clusters have better links with research and the government institutions (public funds supporting the primary healthcare sector in their regions within university) from the early state of their growth. This is because both clusters are linked to the various public and EU funding schemes. In Poland, the role of entrepreneurship in the social capital formation is still at the emerging stage, and thus, it results in the loose networks in the life sciences ecosystem. Poland's life sciences clusters are still young and need time to demonstrate their ability to adapt to their complex environment.

Last but not least, the following comparative research findings show that even though all four university-based life sciences cluster ecosystems evolve from different origins and follow different evolutionary paths, their success factors lie not only in human and financial assets, but also in the dynamic forces generating and sharing these resources, which depend on the social networks and social capital.

The Implications for the Academia

The process of technology transfer is a continuous cycle, starting from the discovery in the lab, through the development into licensed product in the marketplace. At each of these stages, networking plays a great role. Throughout the start-up process of a successful business, advice and mentorship are invaluable. Following the experience of Stanford University and its OTL unit, the University's authorities could help with networking and provide guidance for commercialization. Stanford formal programs and entrepreneurship classes (especially for the life sciences and engineering faculty and students), combined with informal advice from advisors, friends, colleagues, can help to guide early entrepreneurs through all stages of the start-up process.

The scientific potential of the Polish life sciences sector has not been fully utilized. In recent years, commercial research has demonstrated some rising trend, and hopefully this will provide results in the nearest future. Moreover, Polish cooperation between technology transfer centers is an example of a network in which joint representation increases the chances of all Polish universities to compete on the global innovation market in life sciences. It seems that with the growing number of European projects and the growing number of non-commercial research, one can expect an increase in the number of innovations, and more strength will be needed to support their commercialization. The current technology transfer centers, despite the fact that they work well, cooperate well in the nationwide network, are under-resourced (for example, at the University of Warsaw, only 10 brokers work for 3,500 scientists).

The paradox is that many universities received a significant grant, which was mainly invested in buildings and other hardware, and this is why investment in human capital necessary for efficiently utilizing them lags far behind. The results can be seen in closing well-equipped labs with expensive technologies after 4 or 5 p.m. and in preventing the commercial use of their capacities. This is also an example of poor social capital and mistrust toward business partners.

University and other higher education institutions should undertake major curricular and organizational reforms to restructure teaching and research in the field of science and engineering. These new skills and knowledge are needed to integrate previously separate disciplines around common goals, principles and visions. The existing regulatory, organizational and behavioral barriers, preventing universities from undertaking interdisciplinary or transdisciplinary and team research programs for master and doctoral degrees, should be overcome. In the light of the world's leading US universities' experiences, keeping the habilitation degree (mainly within one discipline) as a requirement for a scientific career in Poland seems to be a thing of the past, preventing young scholars from investigating emerging and complex real problems which are multi- and transdisciplinary.

Engineers and scientists at every career level should gain skills in at least one of the converging disciplines – nanotechnology, biotechnology, information technology, communication and cognitive science – and advance collaboration with colleagues in other fields. Yet, systemic understanding of how to generate successful inter- and transdisciplinary research teams consistently is a difficult task. The central element of the collaborative research (both with industry and academia) is the development of a shared vision, mutual knowledge and building trust. This paradigm shift from competitor to collaborator has been absolutely tectonic with pharmaceutical collaborations emerging as the new imperative. Behavioral components, such as trust, professionalism, openness, transparency and complementarity become key for an entrepreneurial university to lead and prosper in the academia and become an attractive partner for business or governmental organizations.

In sum, the success factors of the two US life sciences cluster ecosystems are intertwined – a strong science and industry base is interlinked with entrepreneurship and social capital, and the glue that holds them together is trust. Even though the first factor can be somewhat initiated by the government funding the other factors – entrepreneurship, social capital, and networking–it can hardly be provided by governmental policies. There is a common saying in the Bay Area that they succeeded because they are far away from the federal government.

The other factor of success of the two analyzed US universities is capitalizing on already accumulated social capital in the form of powerful networks of alumni associations, which not only provide financial capital, but also facilitate communication among existing or potential cluster partners, leading to cluster integration and synergies. Finally, American universities are run by mainly professional leaders, usually selected for global research with autonomy greater than in Europe (also at their school or college levels), but also with greater responsibilities, including balancing their budgets. They have to perform, to be competitive to raise funds to support education and research, including public/state universities, which receive only about 25% of their budgets from their states.

The Implications for the Business

The rising importance of interdependence and integration between various technologies and disciplines in life sciences requires collaboration with external partners, and largely depends on both in- and out-house research. Yet, since new technologies are integrated into traditional ones, internal corporate R&D capabilities determine real knowledge absorption. Therefore, the modern life sciences reshape the current business models toward greater innovation openness, focus on downstream activities, operational capability and technological diversification. Manufacturing, information, biotechnology, and medical service corporations need to develop partnerships of an unparalleled scope to exploit the tremendous opportunities from technological convergence, as well as invest in production facilities based on entirely new principles and with increased emphasis on human and social capital development. In fact, in the past decade, pharmaceutical companies have been aggressively acquiring biotech companies in order to take collaborative agreements on learning and research in much smaller discovery units, in an effort to marry the strengths of the biotechnology and pharma industries. Furthermore, developing converging technologies within the life sciences university-based ecosystem has risks and uncertainties that companies need to consider along the way, e.g. cost-related, operational, regulatory and ownership issues. In terms of the last one, it may cause legal battles over the ownership of intellectual property as convergence leads to the formation of new partnerships and alliances. Hence, companies need to evolve new models of licensing and profit sharing with affiliated partners, as well as to adopt a more effective approach to generate innovations based on open innovation and open collaborative networks (see Chesbrough (2006) on "open business models"). In regard to the last one, traditional private-public partnerships should be further complemented with other open innovation strategies, i.e. outsourcing and crowdsourcing of knowledge generation to external actors (industry experts, scientists, researchers, Ph.D. students, etc. as well as supporting researchers), supporting open-source innovation platforms and virtual R&D. This can create substantial cost saving and value creation for the companies. Yet, these open innovation strategies may suffer, at least at the earlier stages of collaboration, from underdeveloped communication potential and socio-cultural barriers. Thus, pharma business managers must have not only a comprehensive knowledge of the research fields, but also good communication and social skills, as well as sufficient time devoted to mobilize the network partners' knowledge and resources sharing. Collaboration networks take time and do not always depend on financial support, but more on common interests, communication and above all trustful and open discussions between the actors involved.

In sum, executing an open innovation model may help the smaller life sciences clusters, including Poland, to spur product development, speed time to market, reduce costs, and increase competitiveness. Yet, the transition from the traditional, closed R&D model, which stifles true innovation to an open and collaboration driven innovation model requires a greater social trust and cooperation-based attitude. Companies that adopt a cooperative, open innovation framework are likely to succeed. In terms of the technology commercialization process, it is important to become attractive and to partner with appropriate companies. The best candidate companies should have not only expertise and resources, but above all, business networks to bring the technology to market and gauge commercial potential.

The Implications for the Government Policies

Poland is ranked at the bottom of the EU social capital rankings (with relatively high level of bonding, yet low level of bridiging social capital) (Social Capital Ran kings 2019; World Economic Forum 2019; European Social Survey 2016).

As the collected evidence from the world class university-based clusters clearly indicate, life sciences industry is heavily depended on effective knowledge-based governmental policies, good academic and business environments that encourage creativity, drive excellence, entrepreneurship, innovation and knowledge sharing.

A sound and visionary governmental policy design should follow several principles. The first principle of an effective governmental policy is “do not make any harm” to natural processes going on in the life sciences industry. The government should facilitate these processes through well-designed incentive system support national priorities. This should be a two-way communication path. Unfortunately, numerous past experiences indicate that too much centralization of decision power and bureaucracy prevented the commercialization of many successful innovation projects in Poland. The cluster policy, initially implemented by France and Poland, resulted in the misuse of about 75% of grant funding in 2007–2012 (Czyżewska 2013). The introduction of the Key National Cluster Policy in 2015 should improve this policy, but a very bureaucratic requirement of the cluster definition as a formalized organization by PARP prevents funding for the Polish largest knowledge-generating cluster (a three-star cluster, according to the European Cluster Laboratory) in Warsaw where universities are organized by disciplines (Warsaw University or the Warsaw University of Technology), and have rather informal collaborative relations, particularly in life sciences, and for that reason, they are not counted as national key clusters with privileged access to grants.

Achieving the full impact of the Polish life sciences sector on the economy and a wider society requires a policy framework that can address technological, economic, institutional and social challenges in this sector. This includes greater flexibility in the use of current government funds and additional efforts to support inter- and multidisciplinary R&D projects. Moreover, in order for the life sciences research to be successful, in terms of improving the quality of human life, it should consider the full range of scientific innovations in various related and non-related disciplines. Therefore, additional government institutional efforts must be put to support inter- and multidisciplinary R&D projects. The latter will require greater flexibility in the use of new and existing funding mechanisms in and across governmental agencies. As the life sciences industry continues to evolve, more researchers and companies within the clusters of fields related to the life sciences see opportunities for innovations within this dynamic sector. There are more and more examples of cluster organizations that lift their cooperation to a higher institutional level by creating formal strategic cluster partnerships. Many of strong and prosperous specialized clusters have multiple linkages to other clusters and industries in a region (see Delgado, Porter and Stern 2014).

The implementation of the ‘smart city’ concept means learning how to support the circulation, interaction and combination of knowledge and creative ideas – not just through random interaction, but also through institutions that help to orchestrate and channel the knowledge in useful ways (see Mazzucato (2018) on “mission-oriented innovation policy”). Public and other non-profit institutions should therefore be more active in brokering, encouraging and reinforcing that cross-sectoral cooperation at local, regional and global levels. Furthermore, the experience from the Western life sciences clusters shows that knowledge intermediaries are more effective when they are disposed to the bottom-up than to the top-down culture of decision-making systems. The government could contribute significantly more to the development of knowledge networks, in general, and particularly of Triple Helix networks, via the active promotion of market-oriented intermediaries to provide bridging and closure services in the network development.

Furthermore, the study outcome demonstrates the role of social capital in generating positive externalities in the life sciences cluster ecosystems that contribute collaborative synergy, knowledge spillovers and the increase of innovations. Yet, that social capital building is also a self-reinforcing, culturally defined long-term process. The social trust and the capacity of citizens to build cooperative ties heavily depend on the government institutions and policies which can create, channel and influence the amount and type of social capital. Yet, designing policies targeting social capital in clusters seems to be a challenging process. Any polices should consider a complex set of factors, such as human capital, long-term research strategies, and the innovative profile of research institutions, the technological maturity of industries, the business strategies of firms, along with the institutional, cultural and social realities of each cluster ecosystem region. A policy based on the imitation or replication of the supposedly best practices of other European and US leading clusters should consider the local variation of social capital and go beyond one-size-fits-all solutions.

To conclude, this publication reaches its readers during one of the biggest pandemics in the world's history, related to the spread of COVID-19. The latter shows that the biggest challenges that we face today cannot be solved by isolated groups of scientists and their knowledge. It is imperative that policy regulators, academia and business representatives start exploring how to bring together researchers and experts from different disciplines to make a path for breakthrough innovations. One of the ways to achieve this is through sharing high-quality research tools and platforms, to be able to co-create with colleagues from all sectors and disciplines, i.e. Open Science resources. Thus, the effective policies should focus on the transition from the traditionally "closed and compartmentalized approach" to the research outcome to a more "open and holistic approach," harnessing the added value of Open Science, and yet promoting the investments needed to transform open initiatives into real technologies addressing societal challenges.

Research Limitations and Implications for Future Research

Although the results of the following study are somewhat consistent with the findings of other research studies on social networks in the location-specific context, and role of clusters in the localized knowledge spillovers, they have a largely exploratory nature (Feldman 2006; Boschma 2005; Porter 2008; etc.). There are several limitations in the following study. The first one refers to still very generalized university-based innovation ecosystem terminology applied in the project. The term has been used in the MIT Skoltech Initiative (Graham 2013), but, regretfully, research on the term is still scarce and fragmented. Another limitation is linked to the qualitative method applied in the discussed study which has several constraints, mainly resulting from the rather small and unequally distributed sample of clusters and their representatives considered. 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 social and relational capital behind the origin, growth and evolution of life sciences clusters; second, determine the role of social networks in strengthening the capacity of clusters players to respond, deal and transform as conditions in the clusters' ecosystems change; third, determine the role of local, national and global networks and partnerships in maintaining clusters' internal technological dynamics. Moreover, the future studies should adjust their findings to the life sciences industry's dynamics. The life sciences industry goes through technological maturity in some fields and considerable growth in others. Industries at different phases of their life cycles need different externalities to generate innovations within their specified environments. The impact of social networks and partnerships on the innovative capacity of the life sciences clusters' ecosystem may also be determined by the actors' absorptive and knowledge transfer capacities, which, on the other hand, may be determined by their talents and previous innovations. Furthermore, future research is needed to identify whether cultural proximity takes precedence over personal and social characteristics and motives in determining behavior in the networking. Last but not least, further research on the role of social proximity in moderating the nature and dynamics of interactions within the life sciences university-based innovation ecosystems must consider an increasing technological convergence and an overall globalization process within the life sciences sector.

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Annex

Survey questionnaire

I. Mission, structure and types of social networks

1. The core mission of the networks (why organizations seek value creating relationships?):

1.1. Knowledge/information sharing
1.2. Common R&D projects/initiatives
1.3. Exchange of best practices
1.4. Promotion of one's university/organization/region as a top logistic location

2. The number and types (public/private) of organizations included in the network?

3. Methods of cooperation/networking and time allocated:

3.1. Electronic (email, telephone and Skype)
3.2. Face-to-face (formal meetings)
3.3. Face-to-face (informal meetings)
3.4. Conferences, workshops, seminars projects (official and unofficial)
3.5. Projects related

4. Total percentage of your weekly work time devoted to networking (from 1 to 100%):

5. The percentage of your weekly work time (100%) devoted to networking via:

5.1. Electronic (email, telephone and Skype) (%)
5.2. Face-to-face (formal meetings) (%)
5.3. Face-to-face (informal meetings) (%)
5.4. Conferences, workshops, seminars (%)
5.5. Projects related (%)

6. Interaction with other networks (that are not part of the own network or regional cluster):
6.1. Networks of universities, R&D institutions and labs
6.2. Networks of hospitals/medical institutions
6.3. Networks of clusters/scientific parks
6.4. Business networks
6.5. Other networks (e.g. NGOs, non-profit organisations, etc.)

II. Methods of social networking, expectations towards partners, intensity of interactions and different dimensions of social capital

7. What are the expectations towards partners? (please renumber accordingly from the most important to least important (1–5)
7.1. Similar pools of expertise
7.2. Financial contribution
7.3. Long-term relationships
7.4. Same social and ethical values
7.5. Other expectations

8. What is the intensity of interactions between partners jointly participating in R&D projects – valuation:
8.1. No interaction at all
8.2. Very few interactions (less than once a year)
8.3. Few interactions (more than once a year but less than once trimester)
8.4. Regular interactions (but less than once a month)
8.5. Very regular interaction (more than once a month)

9. Nature of partnerships within networks: formal or informal?

10. What is the geographical proximity of the partners involved (geographically close or distant):
10.1. Same cluster/university ecosystem
10.2. Same metropolitan area (MSA)/region (NUTS2)
10.3. Same state or country
10.4. Overseas

III. The impact of social networks on R&D collaboration, innovative performance and future plans

11. What is the significance of the participation within the national R&D/scientific networks and programs? (*why is it so important?)
11.1. very high*

11.2. moderate
11.3. low
11.4. none

12. What is the impact of networking on R&D/innovation performance?

13. Future plans and other specific problems, challenges of the network

13.1. developing cooperation with existing partners (vertical integration within the network)
13.2. enriching with possible future (horizontal integration within the network)
13.3. becoming more international
13.4. focusing on national/state/local networks and partnerships

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