

# Chapter 1

## The Networked Nature of R&D in a Spatial Context

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### 1.1 Rising Interest in the Geography of R&D Networks

Starting with the seminal works of Feldman (1994) and Audretsch and Feldman (1996), the *Geography of Innovation* has – without doubt – evolved to one of the main research fields in Economic Geography and Regional Science. A great deal of theoretical and empirical literature has been followed in this area, drawing on significant methodological advancements in spatial analysis, spatial statistics and spatial econometrics as well as on the availability of novel, systematic information sources on the innovative activity of firms, regions and countries. The Geography of Innovation literature describes the role of proximity and location for innovative activity. It is emphasised that spatial studies of innovation provide pivotal anchor points for understanding and explaining the space-economy (see Feldman and Kogler 2010).

Over the past decade, we have observed an increasing research interest within the Geography of Innovation literature on the spatial dimension of networks and collaborations between actors conducting joint Research & Development (R&D) activities. This subfield has meanwhile become an essential and fascinating domain for advanced research on the spatial and temporal evolution of innovation systems at different spatial scales. Special emphasis is placed on interactions between organisations performing joint R&D, for instance in the form of collaborative research projects, joint conferences and workshops, or shared R&D resources in the form of labour and capital. Such interactions have attracted a burst of attention in the last decade, both in the scientific and in the policy sector (see, for instance, Autant-Bernard et al. 2007). With the focus on networks and R&D collaborations, the Geography of Innovation literature clearly has become more interdisciplinary – in particular in methodological terms – involving a multiplicity of scientific fields

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such as economics, geography, social sciences, physics and complex systems research (see Reggiani and Nijkamp 2009).

The research focus on the geography of R&D networks has been triggered by various considerations in theoretical and empirical literature in Economic Geography and Regional Science in the 1980s and 1990s (see, e.g. Clark et al. 2000). When we recapitulate the development of this literature stream, two arguments for the focus on networks are central:

*First*, innovation, knowledge creation and the diffusion of new knowledge are the key vehicles for sustained economic growth of firms, industries or regions, and, thus, are essential for achieving sustained competitive advantage in the economy (see, e.g., Romer 1990; Lucas 1988; Grossman and Helpman 1991). The theory of endogenous growth and the geography-growth synthesis both consider that economic growth and spatial concentration of economic activities emanate from localised knowledge diffusion processes (Autant-Bernard et al. 2007). The fundamental neoclassical assumption of constant or decreasing returns to scale is contested, assuming that knowledge may be subject to increasing returns because of the externalities inherent in its production and use. In this respect, the value of the geographically localised knowledge base increases due to network effects and the characteristics of knowledge. Network effects come into play, since a diversified set of local actors may gain access to new knowledge. The properties of knowledge crucial for this argument are non-excludability – knowledge is accessible to actors that invest in the search for it – and non-rivalry – knowledge can be exploited by different innovating actors simultaneously (see Feldman and Kogler 2010).

*Second*, interactions, research collaborations and networks of actors have become an essential element for successful innovation (see, for instance, Fischer 2001). Long viewed as a temporary, inherently unstable organisational arrangement, R&D networks have become the norm rather than the exception in modern innovation processes (Powell and Grodal 2005). Organisations must collaborate more actively and more purposefully with each other in order to cope with increasing market pressures in a globalizing world, new technologies and changing patterns of demand. In particular, firms have expanded their knowledge bases into a wider range of technologies (Granstand 1998), which increases the need for different types of knowledge, so firms must learn how to integrate new knowledge into existing products or production processes (Cowan 2004). It may be difficult to develop this knowledge alone or acquire it via the market. Thus, firms form different kinds of co-operative arrangements with other firms, universities or research organisations that already have this knowledge to access it faster.

The fundamental importance of networks for generating innovations is also reflected in the various systems of innovation concepts (see Lundvall 1992 among many others). In this conception, the sources of innovation are often established between firms, universities, suppliers and customers. Network arrangements create incentives for interactive organisational learning, leading to faster knowledge diffusion within the innovation system and stimulating the creation of new knowledge or the combination of pieces of existing knowledge in a new way. Participation in innovation networks reduces the high degree of uncertainty present

in innovation processes, providing fast access to different kinds of knowledge, in particular tacit knowledge (see, for example, Kogut 1988).

Science, Technology and Innovation (STI) policies have recently followed this trend, shifting emphasis to the support of networks and collaborative arrangements between innovating actors, in particular between universities and firms. At the European level, the Framework Programmes (FPs) for Research and Technological Development (RTD) are the prime examples of policy programmes to support collaborative knowledge production across Europe. This has led to the establishment of a pan-European network of actors performing joint R&D (see, e.g., Scherngell and Barber 2009). From this background, not only the scientific domain, but also the policy sector shows increasing interest in network structures and network dynamics driven by public funds. In a European policy setting, particular interest is devoted to the geography of such networks, bearing in mind the overall policy goal of an integrated European Research Area (ERA).

The focus of this volume is on the geographical dimension of interactions in networks and R&D collaborations. While early contributions to the Geography of Innovation literature highlight the localised character of knowledge production and diffusion, one of the most fundamental questions of current research is how the structure of formal and informal networks modifies and influences the spatial and temporal diffusion of knowledge (see Autant-Bernard et al. 2007). As highlighted by Reggiani and Nijkamp (2009), the foundation for an interpretation of the economy as an interdependent complex set of economic relationships has long been underpinned by the “first law of geography” (Tobler 1970), stipulating that everything in space is related to everything else, but nearby things are more related than distant things. However, advances in network theory may challenge or – at least – extend this statement, assuming that in certain network typologies distant things may be more related than near things.

In the Geography of Innovation literature, such considerations are referred to as the local buzz vs. global pipelines nature of knowledge creation. This concept describes the interplay between the interaction behaviour of localised innovating actors, mainly driven by spatial proximity, and the access and transfer of more distant knowledge, mainly distributed via alternative channels, often in more formalised form as, for instance, by networks of joint R&D projects between firms providing complementary, highly specialised knowledge (Bathelt et al. 2004). Assuming that the relative importance of such geographically dispersed and more distant knowledge sources – transferred over network channels – increases, certain network structures may be considered as essential determinants of how knowledge diffuses in geographical space, and why some actors, regions or countries benefit more than others due to certain network positions.

However, these theoretical considerations rest on a small base of empirical evidence (see Feldman and Kogler 2010), which may be related to methodological limitations as well as to a lack of data and insufficient information on different types of R&D networks and collaboration patterns. In methodological terms, we need to combine existing spatial analytic tools with methods coming from sociology, in particular Social Network Analysis (SNA) (see Ter Wal and Boschma 2009), or

from physics and complex systems research (see, e.g., Reggiani and Nijkamp 2009). However, until now it remains in many aspects unclear in which way and how these different methodological streams can complement each other in a meaningful way.

## 1.2 Motivation, Objective and Structure of the Book

From this perspective, the motivation of this book is to bridge the research gap discussed above. There are two objectives: *First*, the volume aims to advance the theoretical basis and the methodological toolbox for the investigation of the geography of networks and R&D collaborations. *Second*, it aims to provide novel empirical evidence on spatial network structures and the impact of R&D networks on knowledge creation and diffusion which is particularly to be interpreted in respect to current European STI policies. In this sense, the book brings together a selection of articles providing novel theoretical and empirical insights into the geographical dynamics of networks and R&D collaborations, using new, systematic data sources, and employing cutting-edge spatial analysis, spatial econometric and network analysis techniques. It simultaneously provides a collection of high-level recent research on the spatial dimension of R&D collaboration networks, and contributes to the recent debate in Economic Geography and Regional Science on how the structure of formal and informal networks modifies and influences the spatial and temporal diffusion of knowledge.

Given the focus of the book on the geography of networks and R&D collaborations, with the aim to methodologically advance analytic approaches for the analysis of such networks in a spatial context, and to provide novel empirical evidence on structure and impact of R&D networks, the volume comprises three major parts. Initially, Part II shifts attention to methodological advancements from an interdisciplinary perspective, while Parts III and IV are two thematic sections focusing on structure and impact of R&D networks in a STI policy context.

*Part II*, entitled *Analytic advances and methodology*, comprises a selection of articles providing insight into novel and advanced methodologies for the analysis of R&D networks – formally defined as a set of nodes, most often representing organisations, inter-linked by a set of edges, most often representing joint R&D activities – in a spatial context. One essential element of this section is to bring together methodological approaches from different disciplines, ranging from advanced spatial analysis tools to network analysis approaches coming from statistical physics, sociology and complex systems research. Part II highlights different modelling approaches for investigating the spatial structure of R&D networks and how it changes over time. From this perspective, the section significantly addresses a research issue raised by many economic geographers and regional scientists in the recent past, inspiring a look at alternative methodological and analytical approaches coming from related disciplines for the spatial analysis of networks, such as, for

instance, Social Network Analysis (SNA) techniques (see, e.g., Bergman 2009; Ter Wal and Boschma 2009).

*Part III*, entitled *Structure and spatial characteristics of R&D networks*, shifts emphasis to the empirical analysis of real world R&D networks from a geographical perspective, employing advanced methods of spatial analysis, spatial econometrics and network analysis, some of them introduced in Part II in an abstract manner. By this, the articles gathered in Part III provide new insight into the research questions raised above, as, for instance, on the effects of different forms of proximity on the constitution of R&D networks at different spatial scales and in different economic sectors of activity. Another common focus of the articles in this section is that they use novel, systematic data and information sources on different kinds of R&D networks, such as, for instance, project-based R&D networks constituted under the heading of the European Framework Programmes (FPs).

*Part IV*, entitled *Impact of R&D networks and policy implications*, puts emphasis on the crucial question on how structure and dynamics of R&D networks affects knowledge creation and inventive behaviours of innovating actors. Since modern STI policies have shifted their focus on supporting such networks, this section provides important implications in a STI policy context, particularly at the European level. This is of crucial importance, since the realisation of an integrated ERA is one of the major goals of the STI policy strategy of the European Commission (see, e.g., Hoekman et al. 2013). Networks of actors performing joint R&D should span the territory of the EU – stimulating the circulation of knowledge and researchers in a Europe-wide system of innovation – and, thus, the analysis of the spatial dimension of European R&D networks shows direct European policy relevance. In this sense, the articles gathered in Part IV address the essential points: how to interpret results from empirical investigations of spatial R&D networks in a STI policy context, and how potential policy implications and measures may be derived.

### 1.3 Overview of the Chapters

As mentioned in the previous section, Part II of the volume focuses on analytic and methodological advances – from an interdisciplinary perspective – for the investigation of R&D networks and R&D collaborations in a spatial context. After this introductory chapter, Part II begins with a contribution by Autant-Bernard and Hazir (Chap. 2) focusing on different modelling approaches and underlying conceptions for network formation in a geographical context. The article provides a review – as a reasonable starting point for Part II – on recent works that investigate network formation in space and time but reveal a high variation in terms of methodological and analytical approaches. In doing so, the authors discuss the different aspects of the relationship between geography and networks, and discuss in some detail the distinct methodological approaches and their capability to investigate this relationship. Chapter 3 authored by De Montis, Caschili and Chessa

shifts attention to a complex systems research perspective for investigating spatio-temporal network dynamics, in particular for spatial systems with a very large number of nodes and vertices. The authors present a state-of-the-art summary in the field of complex network analysis, laying special emphasis on the issue of community detection in networks which is of crucial interest when describing R&D network structures (see also Chap. 9 of this volume by Barber and Scherngell). Communities, defined as homogenous, densely connected sub-networks, are a key element for understanding the network structure as a whole. The authors demonstrate this by means of a case study employing a network community detection approach to study the problem of regionalisation on the island of Sardinia (Italy).

Part II continues with two contributions introducing two distinct analytical approaches for the investigation of spatial network structures that have initially been applied mainly in an a-spatial context. Initially, Broekel and Hartog (Chap. 4) focus on exponential random graph models (ERGM) to analyse the determinants of cross-region R&D collaboration networks. The authors lay special emphasis on advantages and disadvantages of this approach in comparison to a spatial interaction modelling perspective that is often used to disentangle the influence of different types of proximities on R&D network structures (see, e.g., Scherngell and Barber 2009). The solidity of the ERGM approach is demonstrated by means of an illustrative example focusing on the structure of cross-region R&D networks of the German chemical industry. After that, Sebestyén and Varga (Chap. 5) develop a novel index, labelled Ego Network Quality (ENQ), for measuring the quality of network position and node characteristics in spatial R&D networks. The authors demonstrate that the ENQ is an integrated measure for the network position of a specific node in a spatial context, very much resembling to the solution applied in the well-established index of eigenvector centrality in an a-spatial context. Robustness and weighting schemes of the index are tested via simulation and econometric techniques.

Chapter 6, authored by Chun, discusses the notion of network autocorrelation, referring to a situation when network links from a particular origin may be spatially autocorrelated with other flows that have the same origin, and, similarly, network links into a particular destination may be correlated with other flows that have the same destination. The author argues that this invalidates the independence assumption of network flows, raising the need for a proper modelling method which can account for network autocorrelation. The eigenvector spatial filtering method is presented as an effective way to incorporate network autocorrelation in linear regression and generalised linear regression models. Chun illustrates these methods with applications to interregional commodity flows and interstate migration flows in the U.S.

Part II closes with a contribution by Crespo, Suire and Vicente (Chap. 7) on the assortativity and hierarchy in localised R&D collaboration networks. By this, the authors focus on two important structural properties and present a combination of two SNA measures, degree distribution and degree correlation, to study whether such localised networks are allowed to avoid technological lock-in.

The contributions gathered in Parts II and III comprise a selection of articles providing novel empirical evidence on real world R&D networks from a spatial perspective. Initially Part III shifts attention to the investigation of spatial network structures and dynamics. The section opens with a contribution by Lata, Scherngell and Brenner (Chap. 8) that puts emphasis on observing integration processes in European R&D from a network perspective. The authors investigate co-patent and project based R&D networks, and estimate the evolution of separation effects over the time period 1999–2006 that influence the probability of cross-region collaborations in these distinct networks. They use Poisson spatial interaction models accounting for spatial autocorrelation among network links. Chapter 9, authored by Barber and Scherngell, employs community detection (see Chap. 3 of this volume) to characterise the structure of the European R&D network using data on R&D projects funded by the fifth European FP (FP5). Communities are subnetworks whose members are more tightly linked to one another than to other members of the network. The identified communities are analysed with respect to their spatial distribution and by means of spatial interaction models.

Chapter 10, authored by Leitner, Stehrer and Dachs, focus on the global R&D network, proxied by R&D investment flows between countries. The authors analyse internationalisation patterns of business R&D for OECD countries and identify specific home- and host-country characteristics that are conducive or obstructive to cross-border R&D expenditure of foreign affiliates.

Chapters 11, 12 and 13 investigate spatial aspects of different networks constituted under the heading of the FPs at an organisational and R&D project specific level. Initially, Reinold, Paier and Fischer (Chap. 11) explore determinants of inter-organisational knowledge generation – proxied by joint publications or patents resulting from joint FP projects – by means of a binary response model using novel data from a survey among FP5 participants. Chapter 12 by Hazir presents an empirical investigation on the formation of multilateral FP collaboration networks in the Biotechnology field employing exponential random graph models (ERGM). The author focuses on the question how geography and heterogeneity in institution types affect the way organisations form R&D networks. Chapter 13, authored by Vicente, Balland and Suire, completes Part IV adopting a SNA perspective to analyse collaborative projects funded in FP5 and FP6. They study the properties both of the network of organisations and the network of collaborative projects, focusing on the particular case of Global Navigation Satellite Systems (GNSS) in Europe.

Part IV turns to the impact of R&D networks on knowledge creation and inventive behaviours of organisations, and its consequences for STI policy. As a starting point, the contribution of Hoekman and Frenken (Chap. 14) frames the geography of scientific research networks laying special emphasis on empirical studies that evaluate policy efforts to support the creation of ERA. The authors introduce a logic of proximity, intended to provide researchers with a way to coordinate their networks, and a logic of stratification, intending to provide pathways for researchers to get involved in networking. The chapter presents an overview of recent empirical findings to illustrate the interplay between proximity

and stratification of European R&D networks, and discusses potential implications for future ERA policies. Chapter 15 by Wanzenböck and Heller-Schuh connects very well to this discussion, as it stresses the importance of specific network positions to gaining access to knowledge located further away in geographical space. They analyse the position of regions in the European network of R&D collaboration within the FPs in the time period 1998–2006. By means of a panel version of the Spatial Durbin Model (SDM), the authors identify determinants that push a region in a specific, favourable network position to gain access to region-external knowledge.

Chapters 16 and 17 are among the first contributions that aim to establish a direct link between network structures and network impact in terms of knowledge creation and inventive behaviours of innovating organisations. Chapter 16 by Breschi and Lenzi analyses R&D networks among 331 US cities using patent data for the period 1990–2004. The authors investigate the impact of network participation in driving the spatial diffusion of scientific and technological knowledge. They propose new indicators that are intended to capture US cities' propensity to engage not only in local, but also global, knowledge exchanges, and relate these propensities to cities' inventive and economic performance. The contribution of Hidas, Wolska, Fischer and Scherngell (Chap. 17) is in a similar spirit in that it aims to explain inventive performance by means of network participation. The authors identify and measure effects of research collaboration networks on knowledge production at the level of European regions, using a panel data SDM relationship for empirical testing.

Chapters 18 and 19 focus on different types of policy induced R&D networks, and the impact of policy initiatives on network formation and innovative outcome. Cantner, Graf and Hinzmann (Chap. 18) analyse the impact of governmental funding on cooperation networks in Germany under the heading of the so-called Leading-Edge Cluster Competition. The authors identify the extent of policy influence for selected clusters on the network of the most important cooperation partners, its geographic reach, and network dynamics. Chapter 19 by Korber and Paier provides an alternative approach to investigate the relationship between STI policy funding schemes, R&D collaborations and innovative performance. The contribution presents an agent-based simulation model to explore the relationship between a specific type of policy-induced networking, so called competence centres, and innovative outcome in the Viennese Life Sciences innovation system.

The volume closes with Chap. 20, which provides a synthesis of the main empirical results, methodological advancements and policy implications. Furthermore, ideas for a future research agenda are presented, emphasising the need for further crossing of disciplinary boundaries for the future investigation of the spatial dimension of R&D networks and R&D collaborations.



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