Innovation Processes in Regional Innovation Systems

Classification, Network Structures, and Empirical Determinants

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Dipl.-Geogr. Jérôme Jürgen Stuck
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Tag der Promotion:	16. Januar 2015
Kommissionsvorsitz:	Prof. Dr. Gerald Kuhnt Institut für Physische Geographie und Landschaftsökologie Naturwissenschaftliche Fakultät der Gottfried Wilhelm Leibniz Universität Hannover
Erstgutachter:	Prof. Dr. Javier Revilla Diez Geographisches Institut Mathematisch-Naturwissenschaftliche Fakultät der Universität zu Köln
Zweitgutachter:	Prof. Dr. Knut Koschatzky Competence Center Politik und Regionen Fraunhofer Institut für System- und Innovationsforschung der Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V.
Weiterer Prüfer:	PD Dr. Stefan Hennemann Institut für Wirtschafts- und Kulturgeographie Naturwissenschaftliche Fakultät der Gottfried Wilhelm Leibniz Universität Hannover

“If one man starts a new idea, it is taken up by others and combined with suggestions of their own; and thus it becomes the source of further new ideas.“

ALFRED MARSHALL (1890:225)

Dedication

To my parents, who have given me the opportunity to receive the best education and supported me throughout my life.

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Abstract

Ever since the scientific community has agreed that innovation provides an important contribution to long-term macro-economic and regional economic development and competitiveness, extensive research on the creation of innovations has been conducted in the past decades. According to the current state of innovation research, innovations are generated especially by systemic, i.e. complex, non-linear, and cooperation-driven learning processes.

Economic geographic innovation research argues, moreover, that due to social components in the learning process, innovation processes are particularly embedded at the regional, i.e. sub-national level. In order to promote a better understanding of these regional innovation processes and to develop innovation strategies for regions, the ‘Regional Innovation System’ (RIS) approach has been established since the mid-/late-1990s. Despite numerous scientific studies that have since then dealt with the structure and functioning of regional innovation processes in the context of the RIS approach, there is still great need for research. In the light of an abundance of potential research fields, the present thesis focuses on three important aspects that have not yet been studied sufficiently.

In summary, firstly, based on conceptual and methodological modifications of an existing RIS-type classification scheme, I test the possibility to assign a large number of regions to different RIS types on the basis of core characteristics reflecting major innovation process structures in RISs. Then I theoretically discuss which role networks play in RISs and what kind of network structures are to be expected from a network-theoretical perspective in regional innovation processes of different RIS types. Finally, I analyse whether characteristics of RISs or sector-specific properties are associated with specific network structures in regional innovation processes.

The data basis has been formed by data from the Seventh European Framework Programme of the European Union (EU), regional patent data of the Organisation for Economic Co-operation and Development (OECD) as well as the German Patent and Trade Mark Office (= Deutsches Patent- und Markenamt; DPMA), and from the INKAR dataset provided by the German Federal Institute for Research on Building, Urban Affairs and Spatial Development (= Bundesinstituts für Bau-, Stadt- und Raumforschung; BBSR). In addition to unilateral, bilateral and multivariate methods from descriptive and analytical statistics also network analytical techniques are applied.

This PhD thesis gives a theoretical, methodological and empirical input to economic geographic RIS Research and contributes to a better understanding of regional innovation processes.

Keywords: regional innovation processes, Regional Innovation Systems, RIS, regional knowledge networks, social network analysis, SNA, network structures.

Kurzzusammenfassung

Seitdem in der Wissenschaft weitestgehend Einigkeit darüber herrscht, dass Innovationen einen wichtigen Beitrag zur langfristigen gesamt- und regionalwirtschaftlichen Entwicklung und Wettbewerbsfähigkeit leisten, entwickelte sich in den vergangenen Jahrzehnten auch eine umfassende Literatur über deren Entstehung. Dem aktuellen Verständnis der Innovationsforschung zufolge entstehen Innovationen vor allem im Zuge systemischer, d.h. vielschichtiger, nicht-linearer und durch Kooperationen geprägter Lernprozesse.

Die wirtschaftsgeographisch geprägte Innovationsforschung argumentiert darüber hinaus, dass Innovationsprozesse aufgrund sozialer Komponenten im Lernprozess insbesondere regional, d.h. auf subnationaler Ebene eingebettet sind. Um solche regionalen Innovationsprozesse besser verstehen und innovationsbasierte Entwicklungsstrategien für Regionen entwickeln zu können, hat sich seit Mitte/Ende der 1990er Jahre der ‚Regionale Innovationssystem' (RIS)-Ansatz etabliert. Trotz zahlreicher wissenschaftlicher Arbeiten, die sich seither im Rahmen dieses Ansatzes mit der Struktur und Funktionsweise von regionalen Innovationsprozessen beschäftigt haben, besteht weiterhin großer Forschungsbedarf. Vor dem Hintergrund der Fülle potentieller Forschungsfelder konzentriert sich die vorliegende Dissertation auf drei wichtige Aspekte, die bislang unzureichend untersucht wurden.

Kurz zusammengefasst wird zunächst die Möglichkeit untersucht, basierend auf konzeptionell-methodischen Veränderungen an einem existierenden RIS-Typenklassifizierungs-Schema, RIS-Typen-Zuordnungen für eine große Anzahl von Regionen auf Grundlage von wenigen zentralen Informationen über wesentliche regionale Innovationsprozess-Strukturen vorzunehmen. Anschließend wird theoretisch diskutiert, welche Rolle Netzwerke in regionalen Innovationssystemen spielen und welche Netzwerkstrukturen im regionalen Innovationsprozess aufgrund unterschiedlicher regionaler Charakteristiken aus netzwerktheoretischer Sicht in verschiedenen RIS-Typen zu erwarten sind. Abschließend wird empirisch analysiert, ob Charakteristiken regionaler Innovationssysteme oder sektorspezifische Eigenschaften mit spezifischen Netzwerkstrukturen in regionalen Innovationsprozessen zusammenhängen.

Die Datengrundlage bilden vor allem die Datenbank des 7. Forschungsrahmenprogramms der Europäischen Union (EU), regionale Patentdaten der Organisation für wirtschaftliche Zusammenarbeit und Entwicklung (OECD) sowie des Deutschen Patent- und Markenamtes (DPMA) und der INKAR Datensatz des Bundesinstituts für Bau-, Stadt- und Raumforschung (BBSR). Neben uni-, bi- und multivariaten Verfahren aus der beschreibenden und analytischen Statistik finden auch netzwerkanalytische Methoden in den Analysen Verwendung.

Durch die Bearbeitung der skizzierten Themenfelder leistet diese Dissertation einen theoretischen, methodischen und empirischen Beitrag zur wirtschaftsgeographischen RIS-Forschung und trägt zu einem besseren Verständnis regionaler Innovationsprozesse bei.

Schlagworte: regionale Innovationsprozesse, regionale Innovationssysteme, RIS, regionale Wissensnetzwerke, soziale Netzwerkanalyse, SNA, Netzwerkstrukturen.

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ABBREVIATIONS

Abbreviations

AMCER	Advanced Monitoring and Coordination of EU R&D Policies at Regional Level
BBSR	Bundesinstitut für Bau-, Stadt- und Raumforschung (= Federal Institute for Research on Building, Urban Affairs and Spatial Development)
BID	Business Innovation Dimension
BRICS	Brazil, the Russian Federation, India, China, and South Africa
CORDIS	Community Research and Development Information Service
DPMA	Deutsches Patent- und Markenamt (=German Patent and Trade Mark Office)
e.g.	Exempli gratia (= for example)
eds.	Editors
EPO	European Patent Office
ERA	European Research Area
ESPON	European Spatial Planning Observation Network
et al.	Et alii (= and others)
etc.	Et cetera (= and so forth)
EU	European Union
ff	Folio (= and following)
FP7	Seventh European Framework Programme
GDP	Gross Domestic Product
GID	Governance Innovation Dimension
GOF	Goddness-of-fit
H	Hypothesis
HEI	Higher education institution
HQ	Headquarter
i.a.	Inter alia (among others)
i.e.	Id est (= that means)
ICC	Interclass Correlation Coefficient

IPC	International Patent Classification
LMNE	Large *or* multinational enterprise
ML	Maximum likelihood
MNE	Multinational enterprise
NIS	National Innovation System
NUTS	Nomenclature of Territorial Units for Statistics
OECD	Organisation for Economic Co-operation and Development
PCT	Patent Cooperation Treaty
R&D	Research and development
RIS	Regional Innovation System
ROR	Raumordnungsregion (= German Planning Region)
RQ	Research question
SIS	Sectoral Innovation System
SME	Small and medium-sized enterprise
SNA	Social network analysis
TIS	Technological Innovation System
TL	Territorial Level
VIF	Variance Inflation Factor

Chapter 1

INTRODUCTION

1.1 BACKGROUND

Innovations are considered to be one of the key elements of economic growth (VERSPAGEN 2006; OECD 2007), as their application entails transformations through 'creative destruction' and considerably influences growth and development potentials (SCHUMPETER 1911; NELSON/WINTER 1982). Therefore, the ability to create innovations is commonly accepted to be a decisive core factor for long-term economic prosperity and competitiveness (ROMER 1986, 1990; HOWELLS 2005; WEF 2014).

According to the OECD (2005:46), innovations are defined as „the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organisation or external relations“. Following this definition, four major types of innovation can be distinguished: product, process, marketing, and organisational innovations. Innovations are to be understood as part of the technological progress. Technological progress describes changes in the inventory of knowledge (e.g. of a region) through innovations, i.e. a change or improvement of production processes and methods, products, services, and organisation forms (SCHÄTZL 2003:115).

The creation of innovations is assumed to be processual. In a simplified scheme, the innovation process can be characterised by three stages: development, implementation, and dissemination (KOSCHATZKY 2001; HENNEMANN 2006). In the first step, an invention is generated, for instance through R&D. If the invention is implemented in the market, it can be called innovation. Finally, the innovation process will be completed through the diffusion of the innovation. Innovation diffusion is a very broad term, "describing the temporal and spatial diffusion process of new products and processes, the knowledge incorporated in them, as well as the innovation-related information" (KOSCHATZKY 2001:95).

However, as of cause the creation of innovation is far more complex in reality, innovation research started early to develop different innovation models in order to be able to explain the complexity and processuality of innovations (for an overview see e.g. ROTHWELL 1994). Between the 1950s and 1970s, first attempts were made to derive explanatory models. In the framework of the 'Technology Push Model' and the 'Need Pull Model' the innovation process was assumed to be a sequential or a linear model, consisting of a series of individual phases (ibidem:7-8). The idea that the phases of an innovation process do not follow linear patterns was increasingly adopted in the 1970s and early 1980s within the framework of the 'Coupling Model' (ibidem:9ff). This model assumes that researchers, producers, and users are related (ROTHWELL/ZEGVELD 1985:50). However, according to the model, feedback loops were only possible between directly related actors or fields of activity, and the focus was placed on the integration of research and development (R&D) and marketing activities.

Since the mid-1980s and the beginning of the 1990s, the perception of non-linear innovation processes further intensified (ROTHWELL 1994:12ff). By now, innovation processes are seen as highly integrated, i.e. they are characterised by intense and actor-spanning exchanges and feedback effects. This view shapes the modern understanding of innovation processes. Key findings from research are that innovation processes are systemic processes which are coined by spillover and feedback effects in the process of learning as well as networking as a result of social interactions and cooperations between various types of actors (e.g. suppliers, customers, R&D partners, universities, research institutes etc.) (e.g. KLINE/ROSENBERG 1986; JAFFE 1989; CAMAGNI 1991; MALECKI 1991; ACS et al. 1992; LUNDVALL/JOHNSON 1994). In addition, it has become increasingly important that innovating actors are embedded not only locally but also extra-regionally (i.e. at a national and/or international level). This spatial diversification avoids lock-in effects and ensures access to new, global knowledge sources (BATHELT et al. 2004; MORRISON 2008; BRESCHI/LENZI 2013). The driving force behind this paradigm of innovation is the process of globalisation. It promotes shorter product life and innovation cycles as well as associated constant and intense pressure to generate innovations (for an overview see SCHÄTZL 2003, Section 2.4.3.1 and BATHELT/GLÜCKLER 2012, Section 15.2.3 and 15.2.4).

However, although globalisation has led to the development of non-linear, collaborative and geographically more distributed innovation processes, at the same time empirical findings repeatedly show that the regional level remains the crux of collaborative innovation processes (e.g. BOSCHMA/TER WAL 2007; BROEKEL/BOSCHMA 2011). This can be attributed to the fact that innovation activities are – at least in parts – social learning processes (ASHEIM 2000:413). In this respect, one major argument from the innovation literature is that collaborations in the course of innovation processes presuppose codes of behaviour as well as mutual trust between the innovating actors, both aspects which are particularly promoted by spatial and cultural proximity (LUNDVALL 1988; LUNDVALL/JOHNSON 1994). An additional argument is that innovation processes often require implicit or tacit knowledge. This type of knowledge is not codified, documented or articulated as it is the case with regard to codified knowledge (POLANYI 1966; NONAKA 1994). The transferability of such ‘sticky‘ knowledge is therefore only possible through personal contacts as well as verbal and non-verbal communication, whereby spatial and social proximity, a common knowledge base and a relationship of trust play an important role (KOSCHATZKY 2001; BATHELT/DEPNER 2003; ASHEIM/GERTLER 2005). In other words, as Cooke & Memedovic (2003:9) state, "[i]nnovation is a learning process that benefits from the proximity of organisations that can trigger this process".

Thus, due to proximity-driven and region-specific conditions necessary for innovation creation, even the growing pressure from globalisation on innovating actors could not significantly threaten the relevance of regions and their networks of interaction for innovation processes (Storper 1995, 1997a; for an overview of empirical evidence see e.g. Becheikh et al. 2006). Innovation processes continue to be particularly anchored at the regional level (Lundvall/Borrás 1997:39; Sternberg 2000a:391). Regions as geographical units are therefore central to the organisation of economic and innovative activities (Omae 1995; Storper 1997b; Dunning 2002; Scott/Storper 2007; OECD 2009b). However, studies continuously show that innovation outputs vary greatly amongst regions (e.g. Blind/Grupp 1999; Koschatzky et al. 2000; Porter 2003). The consequence is that competitiveness and long-term development perspectives vary greatly.

In order to find out the reasons for these differences and to develop regional innovation strategies, researchers developed the Regional Innovation System (RIS) approach (i.a. Cooke 1992; Cooke/Morgan 1994). Unlike other regional analysis approaches developed in the 1990s and early 2000s (for an overview see e.g. Koschatzky 2001, Chapter 5), the RIS approach particularly emphasises regional innovation processes. In this context, it is assumed that the regional innovation performance and competitiveness largely depend on the networking and the structure of the regional actors as well as on the way regions are constituted with respect to socio-economic and institutional framework conditions. The approach thus utilises the above described modern understanding of innovation processes. It is probably this view that has contributed to the circumstance that the RIS approach "[…] has evolved into a widely used analytical framework that generates the empirical foundation for innovation policy making" (Doloreux/Parto 2005:133). This is supported by the fact that institutions like the Organisation for Economic Co-operation and Development (OECD) or the European Union (EU) repeatedly use the approach or parts of it as a framework for the design of innovation policy activities (for information and studies see OECD 2014 and EC 2014a).

To understand regional innovation processes, the scientific focus of RIS Research is placed particularly on the structure and functioning of RISs. So far, this has especially involved discussions about RIS type classifications (e.g. Braczyk et al. 1998; Asheim/Isaksen 2002), the relevance of interactivity and networks (e.g. Cooke/Morgan 1993; Cooke 1996; Fornahl/Brenner 2003), the institutional and organisational dimensions of RISs (e.g. Cooke et al. 1997, 1998), their evolutionary character (e.g. Cooke et al. 1998; Uyarra 2010; Fu

2011), governance and policy aspects (e.g. COOKE et al. 2000; ANTONELLI/QUÉRÉ 2002; COOKE 2007), the importance of certain types of organisations in RISs (e.g. REVILLA DIEZ 2000; MULLER/ZENKER 2001; TÖDTLING/KAUFMANN 2002; AGRAWAL/COCKBURN 2003; REVILLA DIEZ/BERGER 2005; CANIËLS/VAN DEN BOSCH 2011), and the extent to which RISs exist in metropolitan areas, old-industrial regions, regions in transition, etc. (e.g. ASHEIM/ISAKSEN 1997; KAUFMANN/TÖDTLING 2000; REVILLA DIEZ 2002b; DOLOREUX 2003; DOLOREUX/DIONNE 2008).

However, although the RIS approach has obviously roused the sustained interest of scientists involved in analysing regional innovation processes in the last two decades, further research is necessary in order to improve the approach (for an overview see e.g. MARKUSEN 1999; MOULAERT/SEKIA 2003; DOLOREUX/PARTO 2005; TER WAL/BOSCHMA 2009). The present dissertation addresses three important topics related to the just briefly sketched research fields of RIS type classifications as well as RISs and networks that have yet not received adequate attention: (1) enabling the application of a RIS type classification framework for a large number of regions, (2) the theoretical discussion of network structures in RISs, and (3) the analysis whether regional network structures are associated with regional/RIS-related or sectoral characteristics. A detailed elaboration of these research gaps is given in the next section.

1.2 RESEARCH GAPS

This dissertation is a compilation of research papers that further investigate research gaps related to the analysis of regional innovation processes in the context of the RIS approach. With regard to this, the following three topics deserve a more detailed analysis. Firstly, the difficulties in applying a RIS type classification framework to a large number of regions, secondly the fuzziness and generic mode of knowledge network structures in RIS theory, and last but not least the uncertainty about whether the existence of specific knowledge network structures in regions is associated with regional/RIS-related or sectoral characteristics. By addressing these issues the RIS approach may receive inputs for further development. In the following, the above briefly described topics and the resulting research gaps will be explained in more detail.

The *first topic* concerns the assignment of a large number of regions to different RIS types according to their regional innovation process structures. Since the theoretical basis of the approach is conceptually very comprehensive, existing RIS type classification and analysis frameworks have high requirements for data availability regarding both qualitative and quantitative information (e.g. COOKE 1998, 2004; PADMORE/GIBSON 1998; ASHEIM/ISAKSEN

2000). This has in turn led to the circumstance that so far regional innovation process analyses and RIS type assignments were only applied to one or very few regions in the context of case studies (e.g. BRACZYK et al. 1998; COOKE et al. 2004; STUCK/REVILLA DIEZ 2013). As a result, it is difficult to conduct initial and quick comparisons between potentially large numbers of regions or to gain new, generalisable empirical findings which could be used to spur the long-demanded debate about RISs and their (un)known characteristics (e.g. MARKUSEN 1999; MOULAERT/SEKIA 2003; DOLOREUX/PARTO 2005). Research should therefore make RIS type assignments for a large number of regions possible.

The *second topic* is that the RIS approach can barely be applied to analyse regional knowledge network structures, although networks resulting from interactive learning and inter-organisational relations are fundamental to the RIS theory, as they constitute regional innovation processes (COOKE/MORGAN 1993; COOKE 1996; FORNAHL/BRENNER 2003). This is due to the circumstance that in the RIS literature relational structures and interaction networks are discussed in a rather fuzzy and generic manner with the ‘network term’ often being used rather metaphorically (GRABHER 2006; TER WAL/BOSCHMA 2009). As a result, the approach cannot be used to develop empirically testable hypotheses regarding network structures in regional innovation processes. In other words, so far, the RIS approach lacks theoretically precise and quantitatively measurable statements about structures and characteristics of inter-organisational interactions and knowledge exchange relations.

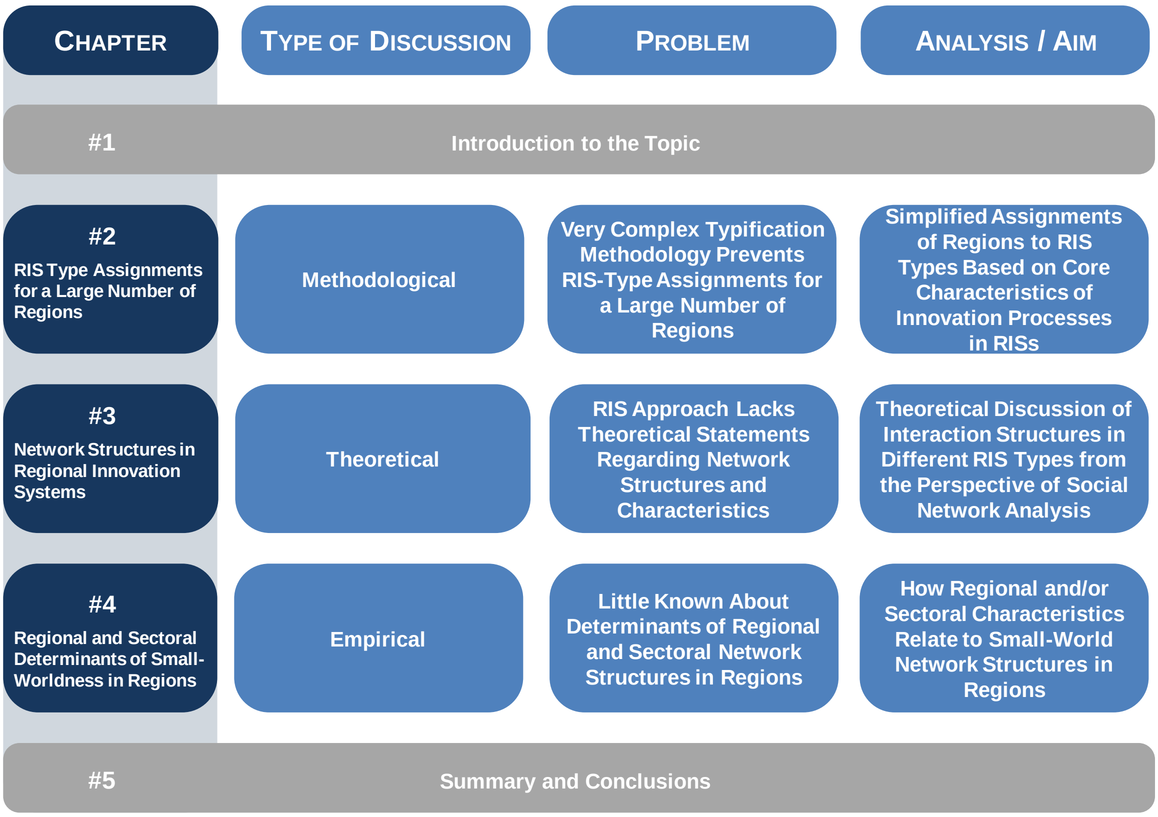
The *third topic* concerns the circumstance that until today it is empirically not proven whether the characteristics of regions are associated with certain regional knowledge network structures resulting from regional innovation processes. Although arguments from economic geographic RIS Research support this (e.g. BRACZYK et al. 1998; COOKE et al. 2004), arguments from Industry Research claim that sectoral characteristics are of major importance (e.g. MALERBA 2002, 2004; TER WAL/BOSCHMA 2011; BROEKEL/GRAF 2012). An empirical analysis applying a comparative view could thus gain new empirical insights and help to assess the role of RISs and sectors for the existence of regional network structures. This is of relevance, as research repeatedly shows that specific regional knowledge network structures are connected to innovation capabilities of regions (FLEMING et al. 2007; BRESCHI/LENZI 2011).

1.3 OBJECTIVES AND STRUCTURE

The present dissertation will explore the three research gaps briefly outlined in the previous section. In doing so, this work contributes to methodological, theoretical and empirical discussions related to regional innovation processes in the context of the RIS approach. In this dissertation each of these research gaps is dealt with in a single chapter. The research goals of the chapters are designed to fill these research gaps. ***Figure 1*** provides an overview of the chapters and the structure of this dissertation.

Chapter 2 is titled ***'Regional Innovation System Classification: An Approach to Assign a Large Number of Regions to RIS Types'*** and addresses the first research gap (see Section 1.2). The identified problem is that the conceptual comprehensiveness of existing RIS type classification and analysis frameworks and their related high requirements for data availability allows only conducting regional innovation process analyses and RIS type assignments in the course of case studies. However, this largely prevents performing comparisons between large numbers of regions, and gaining new, generalisable insights. Accordingly, the *objective* is to develop an approach to perform simplified RIS type assignments for a large number of regions. This will be realised through conceptual and methodological modifications of an existing assignment approach and by focussing on core characteristics and elements of innovation processes in RISs.

Figure 1: **Chapter Overview**



Author´s illustration; note: chapter boxes contain abbreviated chapter titles

Chapter 3 is titled ***'Network Structures in Regional Innovation Systems'*** and concerns the second research gap (see Section 1.2). At present, the RIS approach does not provide clear theoretical statements about structures and characteristics of inter-organisational interactions and knowledge exchange relations. As a result, knowledge network structures of regional innovation processes cannot be analysed. The *objective* of this chapter is therefore to contribute to the creation of an explicit 'Network Dimension' in the RIS approach that shows which knowledge network structures are to be expected in different RISs. To realise this, existing arguments about interactions and knowledge exchange relations from the RIS literature will be rendered more precisely by evaluating these from a network-theoretical perspective.

Chapter 4 is titled ***'The Regions or the Sectors: What Determines Small-World Network Structures in Regions?'*** and deals with the third and final research gap addressed in this dissertation (see Section 1.2). The deficit is that even though research already provides useful and enriching empirical insights with regard to the impact of knowledge network structures on regional innovation capabilities, very little is known about how the existence of knowledge network structures is determined in regions. As the third chapter will show, arguments from economic geographic RIS Research, on the one hand, suggest that especially regional characteristics relate to knowledge network structures of regional innovation processes. Arguments from the Industry Research literature, on the other hand, however point to the importance of sectoral characteristics. Empirical evidence considering both literature streams is missing. In order to contribute to this discussion, the *objective* of this chapter will be to apply a comparative approach that empirically analyses whether regional or sectoral characteristics relate to network structures in regional innovation processes. In addition, by using some of the arguments developed in the third chapter, this empirical investigation implicitly provides initial evidence regarding theoretically discussed network structures in RISs (see objective of the third chapter).

Chapter 5 provides a summary of each main chapter with the respective major contributions as well as a conclusion regarding the implications for future research and policy making.

Finally, it is worth mentioning that this dissertation follows a cumulative approach. This means each of the three main chapters comprises a theoretical background section, a methodological discussion, and an analysis including a discussion of the gained results. According to this approach, repetitions, especially between the theory and methodology parts of the main chapters as well as between the conclusions of the main chapters and the overall summary and conclusion in the fifth chapter, cannot be ruled out.

Chapter 2

REGIONAL INNOVATION SYSTEM CLASSIFICATION: AN APPROACH TO ASSIGN A LARGE NUMBER OF REGIONS TO RIS TYPES

Abstract[1]

PHILIP COOKE´s Regional Innovation System (RIS) analysis and classification framework is one of the most renowned concepts for assigning regions to different RIS types according to their regional innovation process structures. A look at the existing RIS literature shows, however, that RIS type identifications for a large number of regions are neither possible nor practicable. This is mainly due to the approach´s conceptual comprehensiveness and its high requirements for data availability regarding both qualitative and quantitative information. I argue that there is a crucial need to enable RIS type assignments for large numbers of regions, as subsequent analyses would have the potential to allow for new insights regarding RIS type specific empirics, theory, and policy measures.

Based on a simplistic interpretation of COOKE's two-dimensional RIS analysis and classification framework the present chapter provides an approach to perform approximate deductions of regional RIS types on the basis of core characteristics reflecting major innovation process structures in the R&D subsystem of regions´ RISs.

2.1 INTRODUCTION

Amongst the regional approaches that deal with the analysis of regional innovation processes, the RIS approach is one that attracts broad and sustaining interest by policy- and other decision-makers (e.g. CHARLES et al. 2000; DOLOREUX/PARTO 2005; OECD 2009a, b; STUCK/REVILLA DIEZ 2013). Based on the RIS approach, many RIS analysis and assessment frameworks have been developed in the last two decades (for an overview see THOMI/WERNER 2001 or DOLOREUX 2002) including the one established by the founding father of the RIS theorem, PHILIP COOKE (1992). COOKE´s (1998, 2004) concept has the advantage that it features a two-dimensional framework that allows assigning regions to nine different RIS types and to deeply investigate regional innovation processes with respect to their structures and regional context-specificities.

However, looking at actual and past RIS studies (e.g. COOKE et al. 2004; ASHEIM/COENEN 2005; STUCK/REVILLA DIEZ 2013) it can be easily seen that due to the concept’s comprehensiveness and high requirements for data availability regarding both qualitative and quantitative information, a comparative application of the framework for a large number of regions is neither possible nor practical. I argue that this prevents not only the possibility to identify and

[1] An earlier version of this chapter has been presented at the research colloquium of the Institute of Economic and Cultural Geography of the Leibniz Universität Hannover (2013), the 53rd European Regional Science Association Conference in Palermo (2013), and the Annual Meeting of the working group on Industry Geography in Naurod-Niedernhausen (2013).

compare innovation system types for a large number of regions but also impedes possibilities to gain new, generalisable empirical findings which could in turn be used to spur the debate about RISs in general and their characteristics in particular (MARKUSEN 1999; MOULAERT/SEKIA 2003; DOLOREUX/PARTO 2005; TER WAL/BOSCHMA 2009).

Given this motivation, based on a simplistic interpretation of COOKE's two-dimensional RIS analysis and classification framework, *the aim* of this chapter is to perform approximate deductions of regional RIS types on the basis of core characteristics reflecting major innovation process structures in the R&D subsystem of regions´ RISs. The approach is finally tested on the basis of German regions.

The chapter is structured as follows: In Section 2.2, theoretical issues regarding the RIS approach are briefly introduced, limitations and deficits are discussed, and, finally, the leading research questions are derived. Section 2.3 thoroughly discusses general conceptual and methodological aspects as well as envisaged simplifications. Thereafter, in Section 2.4, the revised framework is applied by performing a RIS type assignment for 96 German regions and the results are discussed. A conclusion is presented in Section 2.5.

2.2 THEORETICAL BACKGROUND

2.2.1 Regional Innovation Systems

Innovations are elementary for economic prosperity (ROMER 1986, 1990), as they lead to upheavals in the economy, which at the same time spur technological and organisational changes (SCHUMPETER 1911). While today there is a broad consensus concerning the importance of inventions and innovations for economic development (OECD 2007), since the 1980s questions on which prerequisites are required for innovation creation, and, especially, at which scale innovation processes and innovation governance is located, are in the focus (for a brief overview see MOULAERT/SEKIA 2003; CARLSSON 2007).

In this debate, apart from the national, technological, and sectoral scale (e.g. FREEMAN 1988; LUNDVALL 1992; NELSON 1993; CARLSSON/STANKIEWICZ 1991; BRESCHI/MALERBA 1997), particularly the regional level has gained relevance since the 1990s (OMAE 1995; STORPER 1997b; DUNNING 2002; SCOTT/STORPER 2007; OECD 2009b). Within different research fields on the geography of innovation (MACKINNON et al. 2002) researchers from various disciplines highlighted the importance of *the region* for the organisation of innovation processes and economic prosperity (e.g. BECATTINI 1990; MAILLAT/LECOQ 1992; SAXENIAN 1994; STORPER 1995, 1997a; FLORIDA 1995; PORTER 2000; SCOTT/STORPER 2007).

A very renowned approach to the analysis of regional innovation issues is the RIS approach (COOKE 1992, 1998, 2004; COOKE/MORGAN 1994). It attracted broad interest by scientists and policy-makers in the last two decades (e.g. CHARLES et al. 2000; DOLOREUX/PARTO 2005; OECD 2009a, b; STUCK/REVILLA DIEZ 2013), as it highlights that unequal innovation performances of sub-national units (e.g. states, cities, and municipalities) may be attributed to the innovative capabilities of its actors and on the ways they interact (DOLOREUX 2002:243).

Even though there is no common definition, RISs are generally known as „interacting knowledge generation and exploitation sub-systems linked to global, national and other regional systems“ (COOKE 2004:3) „in which firms and other organisations are systematically engaged in interactive learning through an institutional milieu characterised by embeddedness“ (COOKE et al. 1998:1581). RISs thus constitute the supporting institutional, organisational and technological infrastructure within a regional production system.

The RIS approach especially highlights the regional dimension of innovation processes. This means that innovative and economic competitive advantages of regions arise from geographical proximity, how actors and institutions are spatially interconnected, and the way RISs are constituted with respect to organisational and socio-institutional framework conditions. Such advantages promote access to local and extra-regional knowledge and allow for region-specific learning processes that ease coordination of joint projects and facilitate face-to-face contacts. This in turn stimulates inter-organisational knowledge spillovers[2] and promotes organisations’ capabilities to collaborate and/or cross-fertilise in networks. This supports the generation and diffusion of (tacit) knowledge, innovations, and technological progress among regional organisations, which ultimately increases the innovation performance of the region (CAMAGNI 1991; BATHELT et al. 2004; COOKE 2004; FRITSCH/FRANKE 2004).

A RIS hosts many different actors. Usually, such actors are understood as organisations. Actors in RISs are e.g. firms, universities, research institutes, mediating as well as political actors, technology-transfer agencies, consultants, skill development agencies, public and private funding organisations, and other non-firm organisations involved in innovation processes (COOKE et al. 1992, 1997; KOSCHATZKY 2001). Firms are *the* key players in market-based RISs, since they are constantly strived to improve products or services by using inventions and innovations in order to maintain or increase their level of competitiveness. Together with firms, universities and research institutes form the R&D subsystem within a RIS. Universities and research institutes complete the R&D subsystem. This is because on the one hand, they

[2] Based on the theoretical assumption that face-to-face contacts are important to transfer tacit knowledge, a number of empirical findings have found out that knowledge spillovers are to a significant extent a regional/local phenomenon (JAFFE 1989; JAFFE et al. 1993; ACS et al. 1992, 1994; AUDRETSCH/FELDMAN 1996; ANSELIN et al. 1997). Regarding this, FRITSCH & FRANKE (2004:245) state that “[t]herefore, it can be assumed, that knowledge spillovers constitute an important factor in shaping regional conditions for innovation activities”.

are conducting applied research in the context of e.g. contract research or collaborative research projects, and, on the other hand, they are providing new knowledge through basic research, which in turn can be taken up by the firms and developed into new marketable goods and services (HENNEMANN 2006). The R&D subsystem thus contains the most crucial actors for developing new knowledge and innovations, and reflects major research, technological development and innovation features and processes. Therefore, in the context of this work, investigations addressing RISs (and their dimensions) are always limited to the R&D subsystem of a RIS.

2.2.2 Classification of Regional Innovation Systems

Based upon the 'RIS-idea' a series of frameworks have been developed within the last two decades or so (for an overview see THOMI/WERNER 2001 or DOLOREUX 2002) that serve as the basis to the analysis and assessment of real-world RISs. Because the RIS concept designed by COOKE (1998, 2004) is probably one of the most widespread and has been extensively applied in empirical studies (CARLSSON 2007:860), I will exclusively concentrate on this RIS concept in the context of the present chapter.

Figure 2: Two-Dimensional RIS Classification Framework

Business Innovation Dimension	Governance Innovation Dimension		
	Grassroots	Network	Dirigiste
Globalised	Globalised grassroots RIS	Globalised network RIS	Globalised dirigiste RIS
Interactive	Interactive grassroots RIS	Interactive network RIS	Interactive dirigiste RIS
Localist	Localist grassroots RIS	Localist network RIS	Localist dirigiste RIS

Author´s illustration; based on COOKE (2004:15)

Using Cooke´s RIS concept, RISs can be analysed along two major dimensions – the '*Gov-*

ernance Innovation Dimension' (GID) and the '*Business Innovation Dimension*' (BID). Following THOMI & WERNER (2001:212), the BID especially depicts major characteristics and structures of the innovating actors as well as their spatial patterns in innovation processes, while the GID particularly aims to reveal how innovation processes are managed and controlled by innovating and political actors.

Along each of the two dimensions COOKE´s RIS concept distinguishes three RIS models (see ***Figure 2***) with distinct characteristics (described in detail in Section 2.3.1). The BID contains the localist, the interactive, and the globalised model. The GID differentiates between a grassroots, a network, and a dirigiste model. By combining these dimensions COOKE identifies nine theoretical RIS types. Which of the nine RIS types a region de facto has, depends on the manifestation of a group of different regional characteristics in both the BID and the GID.

2.2.3 Problem Definition and Research Questions

In practice, similar to other RIS analysis and assessment concepts, the above described framework emphasises qualitative processes of innovation activities as well as the institutional and cultural milieu in which a region and its actors are embedded (BRACZYK et al. 1998; COOKE et al. 2004; ASHEIM/COENEN 2005). This means, in addition to classical 'hard factors' particularly the "soft infrastructure" (THOMI/WERNER 2001:209) is a focal point of the analysis. This has contributed to the development of a very comprehensive, often qualitatively oriented analytical framework, with the advantage that it allows for deep analytical investigations of one or few regions.

The comprehensiveness and the focus on qualitative aspects is justified by the intention to unveil systemic and structural features of real-world RISs to the greatest extent and the view that the systemic nature of RISs can hardly be measured by quantitative indicators. Moreover, most representatives of this approach have the understanding that system performance differences are based to a large extent on mostly qualitative context- and region-specific conditions (MORGAN 1995; STORPER 1995, 1997a).

An *unresolved problem* is nonetheless that these advantages related with the comprehensive analytical framework turn out to become disadvantages when analysts or researchers are interested in the assignment of a large number of regions to different RIS types. COOKE´s comprehensive framework is dependent on the availability of a large amount of qualitative and quantitative information. But since such data is often not available to the desired extent and/or quality when regional analyses involve a large number of regions (esp. with respect to qualitative data), the assignment of a large number of regions to RIS types has not been possible so far. On top of that comes that – even if the needed data might be available for large numbers of regions – applications of the framework for a large number of regions would simply not be practical owing to the large amount of characteristics that have to be considered in order to account for the framework´s focus on in-depth investigations.

However, enabling RIS type assignments for a large number of regions might offer many possibilities. For instance, scientists and practitioners could carry out initial and quick comparisons between regions with different RIS types. Moreover, empirical evidence found in the context of analyses involving a large number of regions may even support new theoretical generalisations and/or stimulate the demanded discussion about RISs in general and their (un)known characteristics in particular (MARKUSEN 1999; MOULAERT/SEKIA 2003; DOLOREUX/PARTO 2005; TER WAL/BOSCHMA 2009).

In the light of this, I want to discuss and test an approach to perform RIS type assignments for a large number of regions. However, this makes conceptual and methodological modifications of COOKE's two-dimensional RIS concept necessary. The aim is to show how to perform *approximate* assignments of regions to RIS types on the basis of a simplified approach that utilises a few quantifiable core contents of the BID and the GID. However, as stated above, the investigations are limited to the R&D subsystem of regions´ RIS, as it contains the most crucial actors for developing new knowledge and innovations. Thus, RIS type assignment results will always reflect only the circumstances from the R&D subsystem, not from the entire RIS. Given that the R&D subsystem is probably the most important part of a RIS, I am convinced that this reduction is acceptable.

Derived from this aim, the first major research question that has to be dealt with is as follows:

> RESEARCH QUESTION 1 (**RQ1**): *How can a simplified BID and GID type deduction be achieved to assign regions to RIS types and which of the many characteristics describing the BID and the GID are necessary for this purpose?*

Thereafter, the modified conceptual framework has to be specified, i.e. appropriate indicators and methods have to be selected. The second major research question is thus as follows:

> RESEARCH QUESTION 2 (**RQ2**): *Which databases and indicators are appropriate to cover the selected characteristics of the BID and the GID and which method can be applied in order to operationalise them to uncover regions´ RIS types?*

In the final step, taking German regions exemplarily as an analytical base, the designed RIS type assignment approach needs to be tested and the results have to be discussed. The third major research question is thus as follows:

> RESEARCH QUESTION 3 (**RQ3**): *What are the results from the designed RIS type assignment approach, and how can the results be assessed?*

2.3 METHODOLOGY AND DATA

2.3.1 Conceptual Reduction and the Development of the Simplified RIS Assignment Approach

This section addresses the first research question[3], thereby targeting on how to realise *an approximate assignment of regions to RIS types* by conceptually focusing only on few characteristics from the BID and the GID. To answer this question, however, it is necessary to first discuss the contents of the BID and GID in more detail.

Table 1: The Business Innovation Dimension (BID)

BID Type	Structure- and Context-describing Characteristics			Spatial Patterns of Innovation Activities
	Enterprise Domination	**Research Infrastructure**	**Innovativeness and Innovation Culture**	**Research Reach and Collaboration**
Localist	- SMEs - Indigenous	- Few public research organisations	- Weak business innovativeness and innovation culture	- Local/regional innovation activities
Interactive	Balanced mix, i.e.: - Indigenous and externally-controlled actors - SMEs and LMNEs or large research institute(s)	- Mix of public and private innovation activities	- Sophisticated innovation culture - Strong business innovativeness	Balanced mix, i.e.: - Local/regional, and - Extra-regional innovation activities
Globalised	- LMNEs or large research institute(s) - Externally-controlled	- Public regional research infrastructure depend on and orieted toward needs of focal actor(s)	- Innovation activities and culture depend largely on focal actor(s)	- Extra-regional innovation activities

Table provided by author; based on COOKE (1998, 2004) and THOMI/WERNER (2001)

From Section 2.2, we know that the BID depicts characteristics and structures of the innovating actors as well as their spatial patterns in innovation processes. In order to depict this, the BID can be divided into four major property dimensions (see ***Table 1***): *'Enterprise Composition'*, the first property dimension, addresses the question on which role large or multinational

[3] RQ1: How can a simplified BID and GID type deduction be achieved to assign regions to RIS types and which of the many characteristics describing the BID and the GID are necessary for this purpose? (see also Section 2.2)

enterprises (LMNEs) and small and medium-sized enterprises (SMEs) play and whether they are indigenous in origin or externally-controlled. *'Research Infrastructure'*, the second property dimension, deals with the question on how the public and/or private research landscape (i.e. HEIs[4] and/or research institutes) is set-up and structured. *'Innovativeness and Innovation Culture'*, the third property dimension, reveals which role innovations and innovation activities play for public and private actors and how their innovation culture is constituted. *'Research Reach and Collaboration'*, the fourth and final property dimension of the BID, deals with the question of where innovation activities of regional actors take place and where their potential innovation cooperation partners are situated. The first three property dimensions can thus be grouped as 'Structure- and Context-describing Characteristics', whereas the fourth one can be considered as describing the 'Spatial Patters of Regional Innovation Activities'.

Table 2: The Governance Innovation Dimension (GID)

GID Type	Controlling and Managerial Competences-describing Characteristics		
	Initiation of Technology and Knowledge Transfer	Source of Funding	Innovation Process Coordination
Grassroots	- Local/regional	- Local/regional organisations	- Local/regional
Network	- Multi-level	- Mix of local/regional and extra-regional actors	- Mix
Dirigiste	- Extra-regional	- Extra-regional	- Extra-regional

Table provided by author; based on COOKE (1998, 2004) and THOMI/WERNER (2001)

Regarding the GID, we know from Section 2.2 that it aims to reveal how innovation processes are controlled and managed by regional actors. To depict this, COOKE´s GID can be divided into three major 'Controlling and Managerial Competences-describing Property Dimensions' (see ***Table 2***): *'Initiation of Technology and Knowledge Transfer'*, the first property dimension, deals with the question on whether technology and knowledge transfer activities are organised by regional actors or are induced from outside the region (e.g. national, supranational or international level). *'Source of Funding'*, the second property dimension, pays attention to the question from which spatial level and actors innovation funding comes from. *'Innovation Process Coordination'*, the third and final property dimension of the GID, addresses the question on whether innovation process coordination is made by the region and its actors or controlled from outside the region.

A closer look at the BID and the GID as well as the literature describing them (COOKE 1992; COOKE/MORGAN 1994; BRACZYK et al. 1998; COOKE et al. 2004) reveals, however, that

[4] HEIs are universities, applied universities, polytechnical universities or the like.

the authors who developed the framework more or less implicitly assume a distinctive, BID and GID type-bounded shaping of the characteristics in the property dimensions. This is indicated through the separating black bolded lines in ***Table 1*** and ***Table 2***. But what does that imply?

Regarding the BID – on the one hand – in the first instance this means, a *localist BID type* region is generally assumed to be dominated by SMEs, with only few (public) research capacities, and a generally weak business innovativeness and innovation culture. Furthermore, with regard to its research reach and collaboration (e.g. reach of research activities, sharing of knowledge etc.), the region´s actors are assumed to be especially integrated in innovation processes located at the local or regional level. In comparison, a *globalised BID type* region is assumed to be dominated by the presence of LMNEs or large research entities, and the public regional research infrastructure as well as the region´s innovativeness is assumed to be strongly oriented towards or dependent on the focal actor(s). At the same time, it is assumed that the actors of such a region are particularly integrated in innovation processes which are organised and implemented mostly at extra-regional (i.e. national and/or international) levels. A mixed or balanced case is an *interactive BID type* region, as it is assumed that the region is neither dominated by SMEs nor by LMNEs, has both strong private and public research actors, and has a sophisticated innovation culture and strong business innovativeness. Moreover, it is assumed that the region and its actors are integrated in innovation processes at local/regional, national, and international levels (COOKE 1998, 2004; THOMI/WERNER 2001).

Regarding the GID – on the other hand – in the first instance this means, that in case that the source of initiation and funding of technology and knowledge transfers as well as their coordination is mostly organised at or coming from the local/regional level, a region is assumed to be a *grassroots GID type*. If such managerial and coordination competences are usually situated at or influenced by extra-regional levels or actors, a region´s GID is assumed to be a *dirigiste* type. The *network GID type* is assumed to be a mixture of the former types, meaning that (innovation) governance decisions follow some kind of multi-level approach (ibidem).

However, regarding both the BID and the GID, in the second instance it becomes clear that the meaning behind the just described BID and GID-type-specific characteristics and the resulting *mutual dependencies* in the shaping of the property dimensions of the BID and GID types are much more important than could be suspected at first glance.

Why? Because from a theoretical and conceptual point of view it can be argued, that it is unlikely that a region with structure- and context-describing characteristics indicating the existence of for instance a localist BID type exists, which simultaneously shows spatial innovation activity patterns indicating a globalised BID type. Instead, both structure- and context-describing characteristics *and* innovation-process-orientation-describing characteristics are supposed to be correlated, i.e. they are conceptually intended to be from the same BID type. The same applies to the characteristics in the GID. For instance, if a region is characterised by locally/regionally initialised technology and knowledge transfers or by locally/regionally financed innovation activities – therefore indicating the presence of a grassroots GID type – it is conceptually ruled out that this region would simultaneously show innovation process co-ordination patterns that indicate a dirigiste GID type.

Following this logic, however, it is plausible to argue that it is possible to theoretically and conceptually approximately deduce a region´s entire BID and GID type on the basis of information about one core property dimension. However, the question remains which property dimensions in the BID and the GID represent the required core characteristics and are thus appropriate to serve as a basis for approximate assignments of regions to RIS types.

With regard to the BID, I decide to focus on the property dimension ‘Research Reach and Collaboration’ in order to deduce a region´s BID type. It depicts innovation process interaction patterns of a region’s actors and thus the ‘outcome’ or ‘product’ of the structural factors (see ***Table 1***). Therefore, it can be assumed that this property dimension embodies *the* major feature of a respective BID type. This is also manifested in the naming of the different BID types, i.e. if a region has particularly local/regional innovation activity patterns it is termed ’localist’, if a region is dominated by the existence of extra-regional innovation activity patterns it is termed ’globalised’, and if a region has spatially mixed innovation activity patterns it is termed ’interactive’.

In practice, the identification of BID types on the basis of the conceptually reduced framework has the consequence that a region showing in an analysis, for instance, particularly regional/local patterns of innovation activities would be typified as a localist BID type region. This is because according to COOKE´s RIS concept it is very likely that regions with regional/local patterns of innovation activities are simultaneously shaped by SME dominance as well as other firm-size structure related characteristics. This interdependence reflects quite clearly the concept´s understanding that the nature of the research reach and collaboration characteristics of a region are heavily dependent on the type and size-structures of the dominant, innovating actors. ***Table 3*** illustrates this argumentation.

Table 3: Theory-led Deduction Approach of Different BID Types

BID Type	Structure- and Context-describing Characteristics			Spatial Patterns of Innovation Activities
	Enterprise Domination	Research Infrastructure	Innovativeness and Innovation Culture	Research Reach and Collaboration
Localist	Theoretically and conceptually deduced ←			Has to be analysed
Interactive	Theoretically and conceptually deduced ←			Has to be analysed
Globalised	Theoretically and conceptually deduced ←			Has to be analysed

Table provided by author

With respect to the GID, I focus on the property dimension 'Innovation Process Coordination' in order to deduce a region´s GID type. The reason to do so is because this property dimension depicts the spatial level innovation activities or processes are usually organised at or coming from, therefore covering a large part of what the entire GID embodies (see also Section 2.2). In practice, this implies that a region which is identified to be particularly shaped by innovation coordination activities that are usually organised at or coming from the local/regional level would be typified as a grassroots GID type. This is because according to the above described logic inherent to the conceptual framework, it is very likely that these regions are additionally shaped by local/regional technology and knowledge transfer initiation and innovation financing patterns. ***Table 4*** visualises this argumentation.

Table 4: Theory-led Deduction Approach of Different GID Types

GID Type	Controlling and Managerial Competences-describing Characteristics		
	Initiation of Technology and Knowledge Transfer	Source of Funding	Innovation Process Coordination
Grassroots	Theoretically and conceptually deduced ←		Has to be analysed
Network	Theoretically and conceptually deduced ←		Has to be analysed
Dirigiste	Theoretically and conceptually deduced ←		Has to be analysed

Table provided by author

Finally, by bringing together the deduction results from the BID and the GID, it is possible to assign regions to RIS types (as shown in ***Figure 2***). However, both the results and the thereon based assignments of regions to different RIS types are rather ideal-typical and hypothetical, since a large part of what is called ‘RIS’ is theoretically deduced. Nonetheless, as the content of both dimensions and their types is based on extensive empirical research (CARLSSON 2007:860), at this time it is plausible to argue that the actual regional conditions should have at least essential similarities with the theoretical predictions (COOKE 1998, 2004).

2.3.2 Geographical Scale of Regional Innovation Systems

Territorial innovation systems are located at different levels. Most common in this respect is to distinguish the ‘National Innovation System’ (NIS) and the RIS. While NISs are clearly limited by national borders, in terms of RISs this is not so straightforward. In general, the regional level is understood as a sub-national level. This, however, raises the question as to which regional level RISs can be designated in Germany (CARLSSON et al. 2002).

To cut a long story short, this question cannot be fully answered at present due to a lack of conceptual unity resulting from the heterogeneity of regions and a number of theoretical aspects (see for instance discussions of COOKE 2001a, 2002a; KOSCHATZKY 2001, 2009; CARLSSON et al. 2002). Against this backdrop and since a continuation of this debate is far beyond the scope of this work, I will follow THOMI & WERNER´s (2001:210) recommendation and apply a flexible and pragmatic approach. In order to identify RISs I use the instrument ‘German Planning Regions’ (= Raumordnungsregionen; (ROR))[5]. In doing so, the present work follows studies conducted for instance by KOCH & STAHLECKER (2006) or FRITSCH & SLAVTCHEV (2011). Furthermore, linked to this approach is the fundamental assumption that “all regions have some kind of regional innovation system, including not only regions with strong preconditions to innovation but also old industrial regions, peripheral regions, rural regions and regions in transition” (DOLOREUX/PARTO 2005:141). This conceptualisation of RISs is inspired by works such as those of ASHEIM & ISAKSEN (1997), COOKE et al. (2000), BUNNEL & COE (2001), STUCK & REVILLA DIEZ (2013) or EC (2014b).

RORs are important instruments for the German ‘Federal Institute for Research on Building, Urban Affairs and Spatial Development’ (= Bundesinstitut für Bau-, Stadt- und Raumforschung; (BBSR)) in order to perform large-scale spatial analyses of specific structures, effects, developments and disparities. RORs depict large-scaled, functionally defined spatial units, thus representing economic centres and their related surroundings. RORs are defined on the basis of county-specific commuting relations of employees subject to social security deductions, and they largely coincide with the German Federal States (= Länder), i.e. they are

[5] Locations and names of the ROR units can be concluded by using ***Appendix A*** in combination with either ***Appendix B*** or ***Appendix C***.

also State-specific (except for ROR Bremerhaven) (see map in ***Appendix A***). According to the BBSR (2013), due to the definition of the RORs, they are particularly suitable for inter-regional, nationwide comparisons.

2.3.3 Databases and Indicators

In this section I discuss which databases and indicators are appropriate to cover the selected characteristics of the BID and GID. This section thus approaches the first half of the second research question[6].

Database for the Business Innovation Dimension

Along with the decision to focus on the property dimension ‘Research Reach and Collaboration’ in order to deduce a region´s BID type (see Section 2.3.1), the task is now to select a database that allows deriving indicators that depict spatial patterns of innovation activities and processes, i.e. they should enable to assess whether a region´s BID can be denoted as localist, interactive, or globalised. Thus, the database needs to provide information that shows the degree and extent to which a region and its actors from the R&D subsystem (see Section 2.2.1) are integrated in intra- and extra-regional knowledge or innovation generating processes. Patents meet these requirements by providing names of R&D actors (i.e. persons or organisations), their relations in co-patent projects, and the actors´ geographical information.

Patents provide information on the output and processes of inventive activities (OECD 2009c), and are therefore somewhere in between inventions and innovations. A patent protects new inventions and gives the owner the spatial and temporary privilege of exclusive use and exploitation of the invention. Simultaneously, the patent owner can prohibit unauthorised use of the patent and the knowledge contained therein. This monopolisation of the use and exploitation and the resulting possibility of exclusive economic exploitation is a major incentive to apply for a patent (DPMA 2014).

However, there is also a variety of limitations attached to patents (PAVITT 1985; GRILICHES 1990): For instance, patents only include a part of the totally produced knowledge (FRIETSCH et al. 2008:1), namely explicit, codified knowledge (GRUPP 1997). [7] The implicit knowledge resulting from learning processes is not considered. In addition, patents usually result from R&D activities. But, more than half of all innovating firms in the European Union (EU) and about 40% of all innovating firms from Germany are non-research and development (R&D)-

[6] RQ2: **Which databases and indicators are appropriate to cover the selected characteristics of the BID and the GID** and which method can be applied in order to operationalise them to uncover regions´ RIS types? (see also Section 2.2)

[7] Relative to the total knowledge, the proportion of explicit technical and technological knowledge produced within R&D activities is likely to be comparatively small.

performers (ARUNDEL et al. 2008; RAMMER et al. 2011). Moreover, according to their nature, patents tend to indicate only technical or technological knowledge created by the industrial sector. Only 3-5% of all patents come from service companies (FRIETSCH/SCHMOCH 2006:94). As a result, innovations from the service sector and organisational innovations are almost not considered (MAIRESSE/MOHNEN 2003).

A strong technology-oriented understanding of innovation may in particular have a distorting influence when regions have no significant industrial firms and/or research entities (HEIs and/or research institutes), or when they are marked by a strong presence of SMEs. The latter has a distorting effect, because SMEs are often either involved in non-technological innovation processes or in technological innovation processes that are not patented (e.g. MASUREL 2002). In addition, patents list only those innovating actors who have been directly certified. This means, in case regional actors have been involved only indirectly in the invention or innovation process – e.g. in the form of informal consultations – they would not be registered.

Furthermore, the validity of a patent may be limited by sectoral differences regarding patenting propensities. This means that in practice R&D activities of some sectors may not necessarily lead to patents, although innovation activities might have taken place and R&D processes might have been completed (MANSFIELD 1986:177). In addition, patents can also be registered for strategic reasons and not for bringing new products on the market. BLIND et al. (2009) point out that patents can be used to prevent competitors from registering their own patents or even to foreclose entire technologies. Additionally, the possibility exists to use patents as a quasi 'currency' in the context of exchange contracts (cross-licensing) in order to get access to foreign technologies.

With the peculiarities of patent data in mind, however, I finally decide to make use of patent application information from the OECD REGPAT Database[8] (January 2013 edition) in order to approximate regional spatial patterns of innovation activities and processes (see ***Table 3***). It is generally assumed that patents are predominantly registered with the goal of bringing new knowledge and new technologies to the market (OECD 2009c). Moreover, as all patent applications go through a formally prescribed procedure, patents have the advantage that the resulting databases are publicly accessible, consistent, and complete (GRAF 2011). In total, this makes patents one of the most widely used innovation activity and process indicators in innovation research (NAGAOKA et al. 2010).

The OECD REGPAT Database lists the patent applications to the European Patent Office (EPO; based on PATSTAT, October 2012) and Patent Cooperation Treaty (PCT) patents at

[8] Scientific access to this database can be gained by writing an email to sti.contact@oecd.org.

international phase (based on the OECD patent database, including patents published up to December 2012) and includes applicant and inventor addresses at a very detailed regionalised level (Nomenclature of Territorial Units for Statistics (NUTS) 3, for European regions, and Territorial Level (TL) 3[9] for other countries´ regions) for most OECD and EU27 countries, plus the BRICS[10] countries (MARAUT et al. 2008; EPO FORUM 2012; OECD 2013).

However, before working with the patent information of the OECD REGPAT Database I addressed some methodological aspects related to patents. Firstly, it is of interest which *time period* is used. I investigate patent applications which were first filed (priority year[11]) between 2004 and 2010. The beginning of the period ensures that patenting activities in all sectors reached normal levels again, as the ‘dot-com crisis’ (1999 to 2002) and its associated impacts should have been overcome by then. I chose 2010 as the end of the period because of drastically decreasing patent numbers as of 2011. This is due to the circumstance that the registration of patent applications that are filed at the EPO or that go through the internationalisation phase of the PCT is delayed by up to two years in the OECD REGPAT Database (SCHMOCH 1990, 1998). The actual number of the most recent applications, i.e. for the years 2011 and 2012, will thus be visible in later versions of the database. However, in total, the selected time period ensures a relatively stable picture of regional spatial patterns of innovation activities and processes, since the time duration implicitly covers annual patent application fluctuations as well as cyclical fluctuations influencing patenting activities.

Secondly, the *geographical assignment* of patent applications is of relevance. In this context it has to be decided whether the applicants or the inventors should be included in the analysis. In general, applicants are firms or research entities with the property rights to exploit the patent in case that it becomes an innovation. The inventors in turn generally carried out the R&D leading to the patent application. One possibility would be to use the addresses of the firms or research entities where the R&D was conducted. Unfortunately, unbiased information is not available, because patent applications are often made on behalf of the headquarters (HQ) instead of the subsidiary where the R&D was actually conducted – especially in case of patent applications from LMNEs. Therefore, the only available geographical information related to the applicants is considered to be strongly biased through the so-called ‘headquarter effect’ (BRESCHI 1999:80). For this reason, the *inventors approach* offers the only alternative to portray innovation processes at the regional level, because inventor names and

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[9] TL3 is a micro-region definition from the OECD. It is equivalent to the German county level (= Landkreiseebene) or the European NUTS3 level, respectively.

[10] Brazil, the Russian Federation, India, China, and South Africa.

[11] The priority year is the year in which the patent has been first registered in the domestic country (SCHMOCH 1990:17f).

addresses are also listed in the data base.

The third and final step involves problems caused by *different and incorrect spellings* of inventor names but also *falsely included blanks and punctuation* in the name cells. This has been addressed with the help of the tool ‘Google Refine’ using the fingerprint- and ngram-fingerprint-method (ngram size 2)[12]. In addition, academic titles (e.g. Dr. or Prof., etc.) and degrees (e.g. Dipl.-Ing., etc.) were removed from the inventor names. Taken together, these name and name-cell cleaning measures prevent multiple counting of per se equal inventors and therefore a distortion of the data.

Database for the Governance Innovation Dimension

Now the basis for depicting regional competences related to innovation process controlling and management will be discussed, as it has been decided to focus on the property dimension ‘Innovation Process Coordination’ in order to deduce a region´s GID type (see Section 2.3.1). Thereon based indicators should enable to assess whether a region´s GID can be defined as grassroots, network or dirigiste. Because of that, data is needed to provide information on the question whether and to what extent innovation process coordination in a region´s R&D sub-system (see Section 2.2.1) is made by a ROR itself or is controlled from the outside. However, such data is not available in a processed form, so that my own indicator calculations are necessary.

A promising source of raw data in this context is the Seventh European Framework Programme (FP7) database. The FP7 database really stands out from other existing databases which provide data about subsidised R&D in Germany (e.g. ‘Förderkatalog’[13]), as it also includes information about those actors involved in R&D and innovation-related projects who are the leading actors and thus responsible for the organisation of the project implementation and coordination. This information is particularly valuable because the *distinction between project coordinators and participants* allows perceiving how many actors are actually involved in original innovation process controlling and management in the regions. Based thereon it becomes possible to shed light on innovation governance structures.

The FP7 was a cornerstone among the European Union´s (EU) research and innovation policy instruments in the funding period 2007-2013. By addressing a variety of themes, sectors and actors, and the consideration of applied and basic research, the programme aims on

[12] A detailed description and background information about the applied fingerprint- and ngram-fingerprint-method can be found on the Google Refine website https://github.com/OpenRefine/OpenRefine/wiki/Clustering-In-Depth (checked: 16.09.2014).

[13] The ‘Förderkatalog” summarises more than 110,000 funded research activities of several federal ministries of Germany. Further information is available at http://foerderportal.bund.de/foekat/jsp/StartAction.do (checked: 16.09.2014).

strengthening the European Research Area (ERA) by supporting the production and exchange of R&D-related (non-)technological knowledge and the free circulation of researchers (EC 2006)[14]. Since all of these FP7-funded projects undergo a formalised and standardised application and granting procedure, the FP7 database contains extensive, consistent, and complete information on all projects and their actors (including geographical information).

I gained access to this database (issue dated December 2012) by participating in a project called 'Advanced Monitoring and Coordination of EU R&D Policies at Regional Level' (AMCER), funded by the 'European Spatial Planning Observation Network' (ESPON)[15].

Even though the above described features support the application of the FP7 data and its project coordinator information for indicator calculations, it also has limitations: A first aspect is that the FP7 covers only subsidised innovation projects and therefore only a small proportion of all innovation projects conducted. Thus, project coordinators from non-subsidised innovation projects are excluded. In addition, the database only provides information about operational actors, i.e. those who are directly involved in the innovation process. This focus, however, indicates that the role and influences of political actors are inadequately represented (also on the different spatial/administrative levels). In view of the actors it also must be noted that enterprises in general and SMEs in particular are rather underrepresented in the FP7 database, whereas HEIs and research institutes tend to be overrepresented. Thus, it is conceivable that this also affects project coordinators information. A final central aspect which might cause biased project coordinators information is that the FP7 is likely to be subject to political influences, as the programme is politically induced. Despite the risks associated with the circumstance that the programme is politically induced, it could also be possible that this aspect compensates a little for the above determined lack of consideration of political actors.

Despite these limitations, I finally decide to make use of the project coordinator information provided by the FP7 in order to approximate regional competences related to innovation process controlling and management (see ***Table 4***). It is clear that the constructed indicator draws only a rough picture about real-world innovation governance in regions. Accordingly, the results must be carefully considered. The problem is, however, that there is currently no viable alternative available that is able to depict innovation governance structures at the regional, national and international level in a quantitative, comparable manner. Against this backdrop, this approach may therefore be seen as an attempt to contribute to discussions

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[14] Detailed background information regarding the FP7 can be found on the Community Research and Development Information Service (CORDIS) website http://cordis.europa.eu/fp7/home_en.html (checked: 16.09.2014).

[15] Information regarding the ESPON AMCER project is available at http://www.espon.eu/main/Menu_Projects/Menu_TargetedAnalyses/amcer.html (checked: 16.09.2014).

about the quantitative assessment of governance.

However, since it is clear now which data will be used, two remaining methodological issues have to be addressed which are directly related to the FP7 database. The considered *time period* covers the years 2007 to 2012, and is thus bound to the available excerpt from the FP7 database. Accordingly, the calculation of the indicators both in the BID and the GID considers time periods that have the same scope and are almost identical.

Another aspect that must addressed relates to the *spatial assignment* of the coordinators. In this context, attention must be paid to the fact that often the data lists both the HQ and a branch as beneficiary in one row. However, in this case the HQ only appears, because the project application was processed through it. Consequently, the coordinators are appointed with the geographic information of the branches (i.e. implementing actor). If the geographical information of the HQ would be used in this case, the coordinator´s information could be HQ-biased (i.e. 'headquarter effect'), resulting in wrong spatial assignments of the coordinators.

Indicator Calculation for the BID and the GID

As the data selections and related specifications have been discussed, in the following the calculation of the indicators is presented. The indicators are ultimately used to depict the contents of the selected BID and GID property dimensions.

In terms of the BID, the indicator calculation involves all inventors from both regional single patents and inter-regional co-patents[16], thereby taking into account not only purely intra-regional innovation activities and processes but also those which are to varying extents coined by extra-regional actors. In the first step, the number of inventors located within each ROR i is determined (absolute figures). In the second step, the absolute number of extra-regional inventors is counted for each ROR i (either in a region k within the same country (here: Germany) or in a foreign region j). In the third and final step, for each ROR i the number of intra-regional inventors and the number of inventors from the respective extra-regional level over the total number of inventors from patent projects of the respective ROR i is calculated. Finally, the resulting indicators illustrate at which spatial levels and to which extent each ROR i and its actors (i.e. innovators) are involved in innovation processes:

1. *Regional level (indicator 1)*: Share of patent inventors from the respective ROR i (in % of total considered patent inventors);

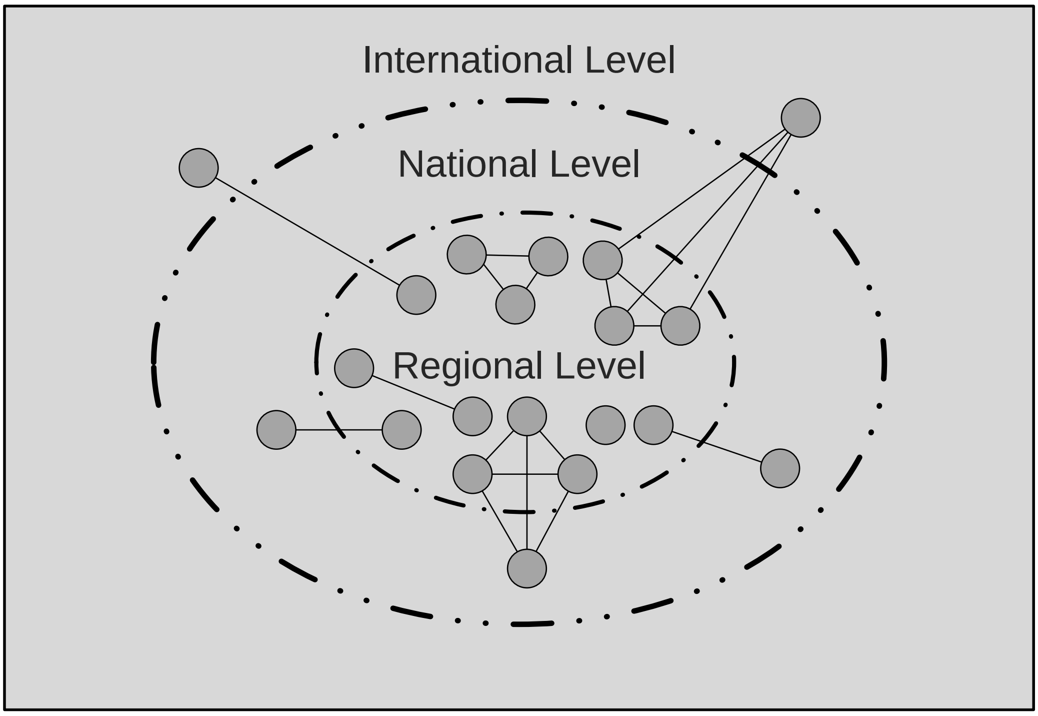
[16] The consideration of individual inventors and their patents in the RORs appears justifiable if one assumes that individual inventors – although they patent alone – are always somehow integrated into the RIS they are living in and that the patents they produce are thus always to some extent the result of this embeddedness.

2. *National level (indicator 2)*: Share of patent inventors from region k within the same country which are involved in the patent projects of the respective ROR i (in % of total considered patent inventors);

3. *International level (indicator 3)*: Share of patent inventors from region j in a foreign country which are involved in the patent projects of the respective ROR i (in % of total considered patent inventors).

Figure 3 visualises exemplarily the idea behind the just described calculations and the meaning of the BID indicators. The small circles represent innovating actors. The connections between the actors (i.e. thin solid lines) show that the actors work together in an innovation project (i.e. patent project). In this *fictive example*, the 'regional level indicator' would have the highest value since single regional patenting actors and regional actors involved in co-patents form the largest group. The second and third largest group is formed through extra-regional co-patenting by actors from other regions located in the same country and those from regions located abroad. Therefore, the 'national level indicator' and the 'international level indicator' would have the second and third highest value, respectively.

<u>Figure 3:</u> Exemplarily Illustration of Region´s Spatial Patterns of Innovation Activities and Processes Based on Single and Co-Patents



Author´s illustration; circles = innovating (i.e. patenting) actors

In terms of the GID, the indicator calculation is based on single and co-projects[17] and shows a similar procedure as in the case of the BID indicator calculation: In the first step, the absolute number of coordinators located within each ROR i is counted (absolute figures). In the next step, the absolute number of coordinators that are located outside the region is counted for each ROR i (either in a region k within the same country (here: Germany) or in a foreign region j). The final step includes the calculation of the relative shares, where for each ROR i the number of the regional coordinators and the number of coordinators from the respective extra-regional level over the total number of coordinators from projects of the respective ROR i is calculated. As a result, the following indicators show the extent of innovation process coordination that is made by a ROR itself or is controlled from the outside:

1. *Regional level (indicator 1)*: Share of project coordinators located in the respective ROR i (in % of total considered coordinators);

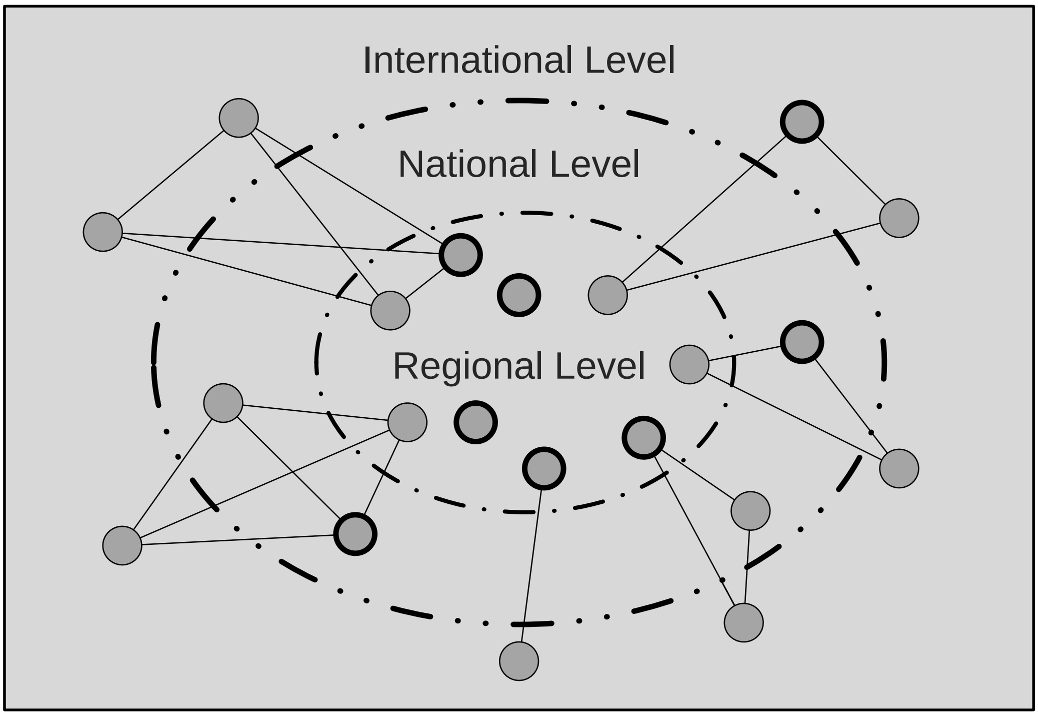
2. *National level (indicator 2)*: Share of project coordinators from region k within the same country which are leaders of projects of the respective ROR i (in % of total considered coordinators);

3. *International level (indicator 3)*: Share of projects coordinators from region j in a foreign country which are leaders of projects of the respective ROR i (in % of total considered coordinators).

Similar to Figure 3, ***Figure 4*** illustrates exemplarily in a *fictive example* the idea behind the GID indicator calculation for each ROR and the meaning of the indicators. The bolded circles stand for projects coordinators of R&D and innovation-related projects, whereas the other small circles represent ‘ordinary’ participating actors. The connections between these actors show that the actors work together in a FP7 project. In this example, the ‘regional level indicator’ would have the largest share, because in proportion to all considered coordinators those located within the ROR form the largest group. The second and third largest share is held by extra-regional coordinators. Therefore, the ‘national level indicator’ and the ‘international level indicator’ would show the second and third highest value, respectively.

[17] The consideration of single projects, i.e. projects which are coordinated and executed by only one actor, appears justifiable if one assumes that these actors are always somehow embedded in the region an its innovation system and therefore also contribute to the reflection of regions´ innovation governance.

<u>Figure 4:</u> Exemplarily Illustration of Region´s Competences Related to Innovation Process Controlling and Management Based on Single and Co-Projects from the FP7



Author´s illustration; circles = actors from FP7 projects; bolded circles = FP7 project coordinators

2.3.4 Implementation of the Theory-led RIS Assignment Approach

While having discussed the databases, the indicators, and the methodology behind the indicator calculations, it still remains open how to use the indicators in order to implement the theory-led BID and GID type deduction approach introduced in Section 2.3.1. In other words, the second half of the second research question[18] remains unanswered so far. Therefore, in the following I will clarify how to assign RORs to different BID and GID types according to the shaping of the calculated indicators. Finally, by merging these results, regions can be assigned to different RIS types.

The above described fictive examples (***Figure 3*** and ***Figure 4***) show that the innovation processes of this exemplary ROR are largely located within the region and that both national and international relations play a comparably minor role. Moreover, competences related to innovation process controlling and management are particularly located within the ROR and extra-regional influences play a comparatively minor role. However, what remains open are the striking questions how to interpret these results, and how to methodologically decide which specific BID or GID type is appropriate.

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[18] RQ2: Which databases and indicators are appropriate to cover the selected characteristics of the BID and the GID and **which method can be applied in order to operationalise them to uncover regions´ RIS types**? (see also Section 2.2)

To approach that for both the BID and the GID I introduce a '*relative grouping method*'. In the first step, each ROR´s values for the three indicators are compared with the corresponding German regional average. Thereafter, in the next step, each value is checked whether it corresponds to/is above the respective reference value or whether it is below-average. The former leads to the fact that the region is assessed to have an above-average shaping of an indicator. The latter is leading to the opposite conclusion. By using this method and taking the theory-led BID and GID type deduction approaches into account (see ***Table 3*** and ***Table 4***), it is now possible to assign RORs to different BID and GID types on the basis of their relative spatial patterns of innovation activities and processes or their regional competences related to innovation process controlling and management, respectively. ***Table 5*** and ***Table 6*** illustrate this. However, apart from the mere assigning issue, the use of this 'relative grouping method' also makes sense against the background that both (EPO/WIPO) patents and FP7 coordinator information are likely to overestimate extra-regional aspects of innovation processes and innovation process coordination due to their international orientation.

Regarding the BID, this method effectively means that RORs that have an above-average shaping of patenting activities and/or participations of intra-regional inventors are assessed to have a localist set-up in the property dimension 'Research Reach and Collaboration'. If such activities and/or participations are above-averagely shaped by extra-regional inventors RORs are assessed to have a globalised setting of the property dimension 'Research Reach and Collaboration'. In the case that patenting activities and/or participations are shaped above-averagely by both intra- and extra-regional (either national or international) inventors, RORs are assessed to have an interactive set-up of the property dimension 'Research Reach and Collaboration' (see ***Table 5***).

Table 5: Implementation Method of the Theory-led BID Type Deduction Approach

Localist BID Type	Interactive BID Type	Globalised BID Type
- is present in regions where the share of intra-regional patent inventors in regions´ innovation processes is above-average (indicator 1 ≥ Ø) (pronounced integration regional innovation processes)	- is present in regions where the share of intra-regional patent inventors in regions´ innovation processes is above-average (indicator 1 ≥ Ø) AND - where simultaneously the share of patent inventors either from another region within the same country (here: Germany) OR from abroad is above-average (indicator 2 ≥ Ø or indicator 3 ≥ Ø) (spatially mixed integration of regions´ innovation processes)	- is present in regions where the share of patent inventors either from another region within the same country (here: Germany) OR from abroad is above-average (indicator 2 and/or indicator 3 ≥ Ø) (pronounced integration in extra-regional innovation processes)

Table provided by author

With respect to the GID, the application of the assignment method entails that RORs are assessed to be a grassroots type region if their property dimension ‘Innovation Process Coordination’ (see Section 2.3.1) is above-averagely shaped by FP7 project coordinators who are located in the respective ROR. A dirigiste setting of the property dimension ‘Innovation Process Coordination’ is in turn evident in RORs where project coordinations are above-averagely organised by extra-regional coordinators. However, in cases where the property dimension ‘Innovation Process Coordination’ is coined by projects coordinations which are above-averagely organised by both intra- and extra-regional (either national or international) coordinators, RORs are assessed to have a network set-up (see ***Table 6***).

Table 6: Implementation Method of the Theory-led BID Type Deduction Approach

Grassroots GID Type	Network GID Type	Dirigiste GID Type
- is present in regions where the relative share of regional FP7 project coordinators is above-average (indicator 1 ≥ Ø)	- is present in regions where the relative share of regional FP7 project coordinators is above-average (indicator 1 ≥ Ø) AND - where simultaneously the relative share of FP7 project coordinators either from another region within the same country (here: Germany) OR from abroad is above-average (indicator 2 ≥ Ø or indicator 3 ≥ Ø)	- is present in regions where the relative share of FP7 project coordinators either from another region within the same country (here: Germany) OR from abroad is above-average (indicator 2 ≥ Ø or indicator 3 ≥ Ø)
(pronounced intra-regional control and management of innovation processes)	(spatially mixed control and management of innovation processes)	(pronounced extra-regional control and management of innovation processes)

Table provided by author

2.4 EMPIRICAL EXAMINATION

In light of the previous sections the empirical application is now performed. It addresses the issue of the third research question[19] with the aim to present and discuss the RIS assignment results gained through the application of the theory-led BID and GID deduction approach.

2.4.1 Presentation of Results

In the calculations for the BID all 96 RORs have been assigned to a BID type[20]. In eleven cases, the regions have a localist, in 31 cases an interactive and in 54 cases a globalised BID type (see ***Appendix B***). Regarding the GID[21], a typification was only possible for 95 regions due to missing values for the ROR 'Altmark' (Code 1501). Among them, nine RORs have been identified with as grassroots GID type, 20 as network GID type, and 66 as dirigiste GID type (see ***Appendix C***). By merging the just described typification results of the BID and the GID – as shown in ***Figure 2*** in Section 2.3.1 – ***Table 7*** shows the assignment results of different RIS types in Germany. This is illustrated in ***Figure 7*** in cartographic form.

Table 7: Metrix of Assigned RISs Based on Results of Regions´ BID and GID Types

Governance Innovation Dimension (columns) / Business Innovation Dimension (rows)

Type	Grassroots	Network	Dirigiste
Localist	0	4	7
Interactive	5	8	18
Globalised	4	8	41

Table provided by author; based on results from ***Appendix B*** and ***Appendix C***; no data for one region´s RIS type

The outlined and illustrated regional assignment results of the BID and GID or the resulting RIS types, respectively, illustrate that regions having localist BIDs or grassroots GIDs rarely exist in Germany. The majority of regions has globalised and interactive BID or dirgiste and network GID types. With regard to the theoretical contents related with the BID and GID

[19] RQ3: What are the results from the designed RIS type assignment approach, and how can the results be assessed? (see also Section 2.2)

[20] As stated in Section 2.2.1 and 2.3.3, the investigations regarding the BID are limited to the R&D subsystem of regions´ RIS.

[21] As stated in Section 2.2.1 and 2.3.3, the investigations regarding the BID are limited to the R&D subsystem of regions´ RIS.

types summarised in ***Table 3*** and ***Table 4*** (see Section 2.3.1), this is interpreted as follows:

Regarding their BID, German RISs are likely to be particularly coined either by innovating large enterprises/research entities and the corresponding pronounced integration in extra-regional innovation processes or by a rather balanced actor profile and the associated spatially mixed integration of regional innovation processes. Regarding their GID, the German RISs are likely to be shaped either by pronounced extra-regional or by spatially mixed innovation process control and management decisions. The figures nonetheless show that – even though the balanced BID and GID types are much more prominent than those which are particularly coined by regional activities – in both cases, however, the rather 'hierarchical' globalised BID or dirigiste GID type prevails.

Accordingly, the apparent skewed distribution is found also in the spatial pattern, so that an overall dominance of hierarchical BID and GID types is evident (see ***Figure 5*** and ***Figure 6***). In order to check whether this distribution is random and not systematically distorted by influences of the settlement size or structure, statistical tests seem necessary. ***Appendix D*** and ***Appendix E*** show, however, that a significant influence of population density on the typification results of the BID and GID cannot be found. This means neither urban nor rural regions automatically show specific RIS features.

However, it can be observed that particularly among the RISs with localist BID and grassroots GID characteristics a west-east divide exists. Regarding the localist type, nine out of eleven are located in the Western German States and only two are located in the so-called 'new', Eastern German States [22]. However, an even more pronounced west-east divide can be found with respect to the grassroots type, as all nine regions with grassroots characteristics are located in the Western German States. In both cases, the west-east divide is likely to be due to different economic and political preconditions and changes in the course of the German reunification. In this respect the absence of (innovative) SMEs in East German States, the decline of many formative large-sized technology-oriented East German enterprises during the reunification, and the comparatively strong support of the federal government in the new States certainly influenced subsequent developments of East German RISs and their BID and GID (PFÄHLER/HOPPE 1997; KOSCHATZKY 2000; HASSINK 2002; KOCH/STAHLECKER 2006).

Despite the observed differences between the regions in the old and new German States, it can be noted that in general the geographical distribution of the less hierarchical types is relatively dispersed across Germany. At this point no highly pronounced or clear spatial concentration can be identified (see ***Figure 5***, ***Figure 6***, and ***Figure 7***).

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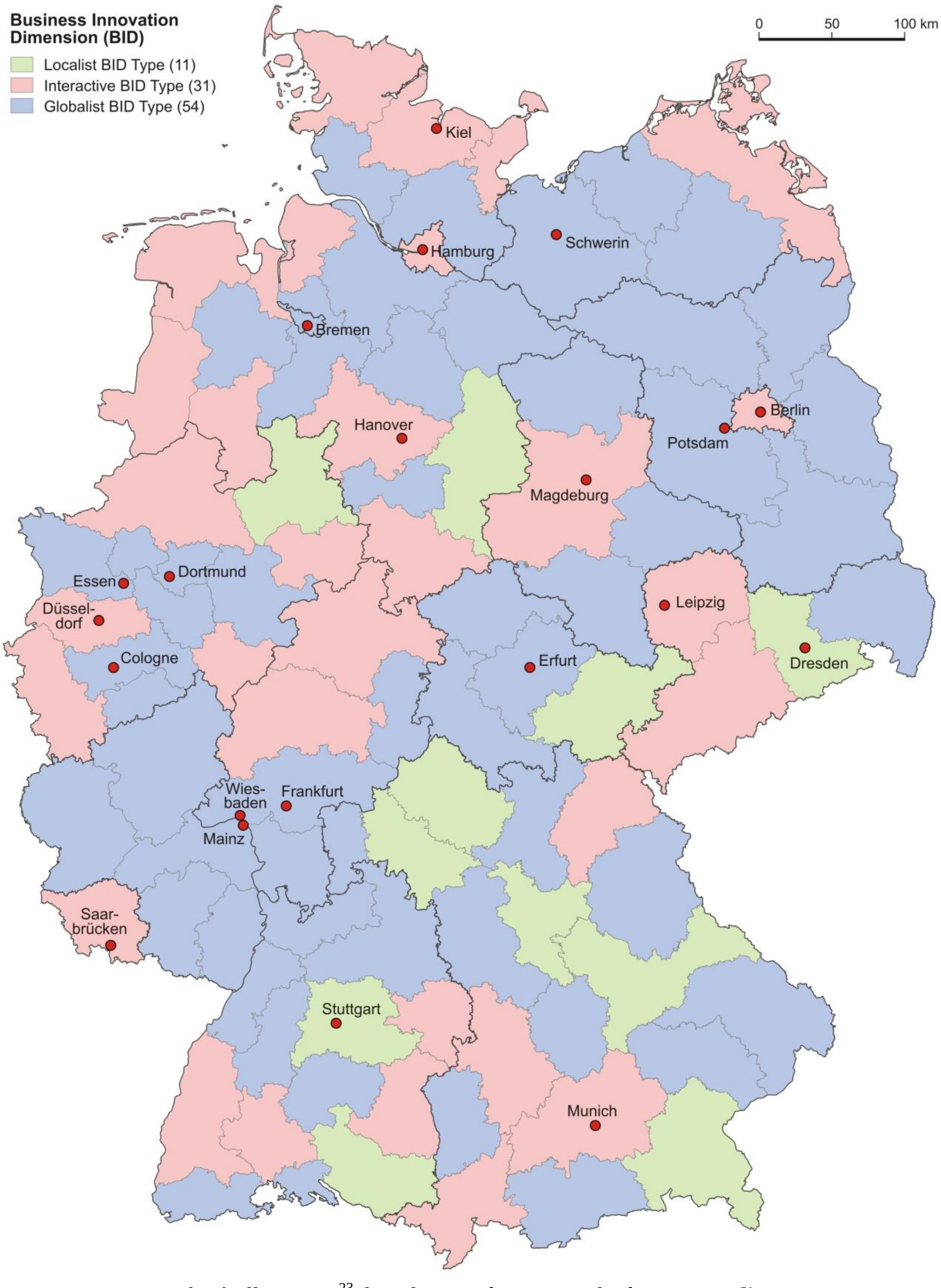
[22] A cartographic overview which States belonged to former West and East Germany can be found in ***Appendix A***.

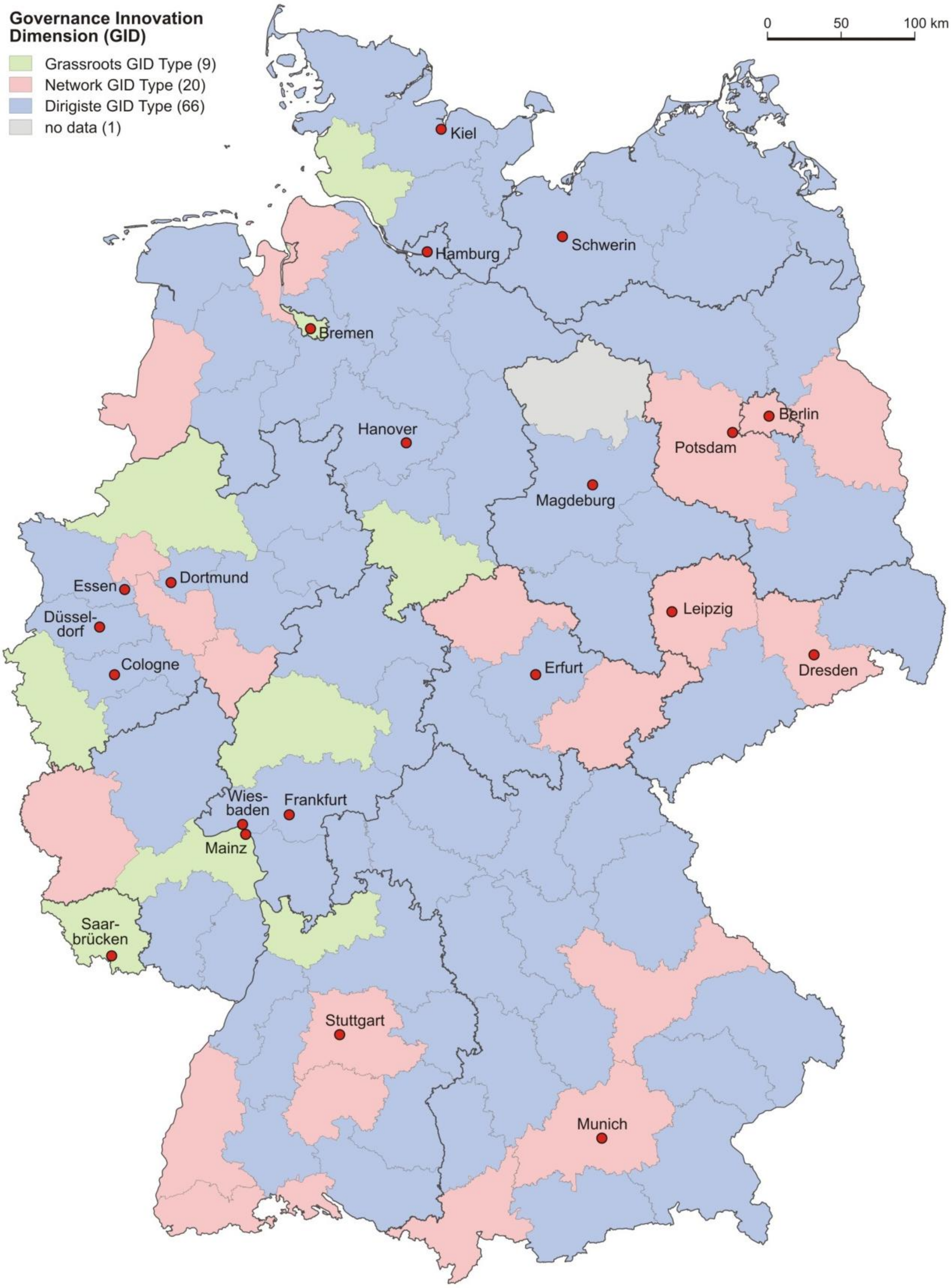
<u>Figure 5:</u> Cartographic Illustration of the BID Types in German Regions



Author´s illustration[23]; based on typification results from ***Appendix B***

[23] In order to ease the orientation, the capital cities of the Federal States *and* cities with more than 500,000 inhabitants are depicted in the map. Furthermore, the names of the ROR units can be concluded by using ***Appendix A*** and ***Appendix B***.

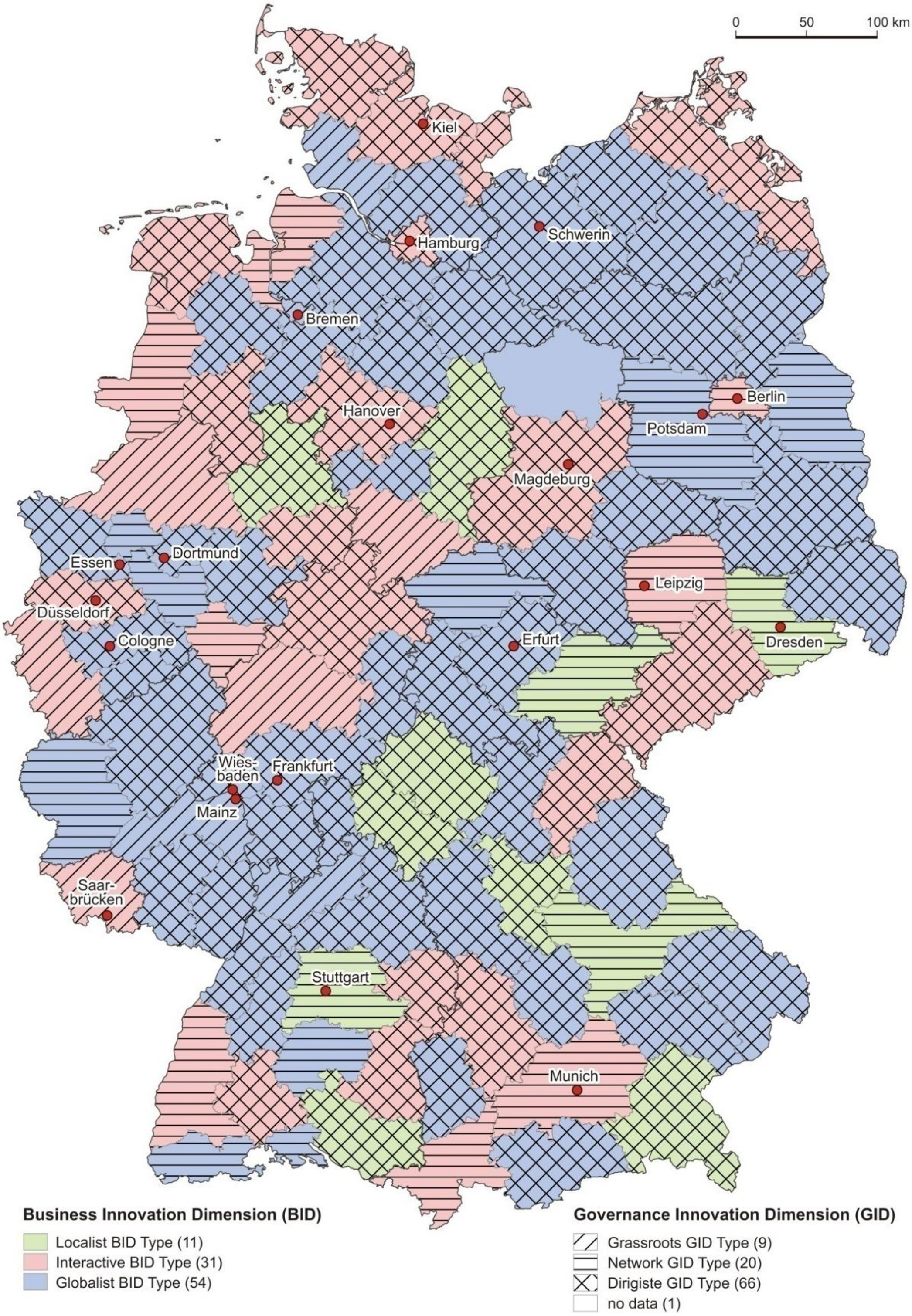
<u>Figure 6:</u> Cartographic Illustration of the GID Types in German Regions



Author´s illustration[24]; based on typification results from ***Appendix C***

[24] In order to ease the orientation, the capital cities of the Federal States *and* cities with more than 500,000 inhabitants are depicted in the map. Furthermore, the names of the ROR units can be concluded by using ***Appendix A*** and ***Appendix C***.

<u>Figure 7:</u> Cartographic Illustration of the RIS Types in German Regions



Author´s illustration[25]; based on typification results from ***Appendix B*** and ***Appendix C***

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[25] In order to ease the orientation, the capital cities of the Federal States *and* cities with more than 500,000 inhabitants are depicted in the map. Furthermore, the names of the ROR units can be concluded by using ***Appendix A*** in combination with either ***Appendix B*** or ***Appendix C***.

2.4.2 Discussion of Results

Finally, in this section the RIS assignment results (see ***Table 7*** or ***Figure 7***) of the designed theory-led BID and GID deduction approach will be discussed. The focus is on the question whether the characteristics of the identified BID and GID types differ significantly, and whether and to what extent the values of the applied and specially developed indicators reflect the major contents of each BID or GID type from theory.

Table 8: Spatial Patterns of Innovation Processes in Different BID-Types

BID Type	Regional Level (in %)	National Level (in %)	International Level (in %)
Localist	49	42	9
Interactive	43	45	14
Globalised	34	56	15

Author´s illustration; note: numbers are *weighted* regional mean averages

Table 8 summarises the average characteristics of the indicators of various BID-types. It can be seen that *localist BID types* – as expected from theory (see Section 2.3.1) – are on average particularly strongly embedded in regional and comparatively weakly embedded in national and international innovation processes. The summarised results of the significance tests in ***Appendix F*** largely confirm these results, although the differences of the international embedding are only significant compared to the interactive but not to the globalised type. According to the results of the table, RISs with a *globalised BID type* are particularly strongly involved in innovation processes at the national and international level, while regional integration is comparatively less pronounced. Thus, in this case again the presented results seem to reflect the expectations formulated in the theory. However, it must be pointed out that despite the apparently clear expression of the international integration in innovation processes of the BID type, the difference is only weakly significant compared to the interactive type and not significant compared to the localist type. Similar to the findings gained from the two preceding cases, also in the case of the *interactive BID type* the average results in the table fit very well with the theoretical assumptions. In terms of their expression all values of the indicators are between the values of both the localist and the globalised BID type. Moreover, in case of the regional and national level indicators the differences compared to the other BID types are highly significant, and in case of the international level indicator the differences are nevertheless still weakly significant.

Table 9: Location of Competences Related to Innovation Process Controlling and Management in Different GID-Types

GID Type	Regional Level (in %)	National Level (in %)	International Level (in %)
Grassroots	27	15	59
Network	23	17	63
Dirigiste	16	23	67

Author´s illustration; note: numbers are *weighted* regional mean averages

Table 9 shows the average characteristics of the indicators for the GID types. As assumed in theory (see Section 2.3.1), the values of the indicators of the *grassroots GID type* show that in such regions, innovation controlling and managerial competences are comparatively strongly located in the region itself, whereas the extra-regional influences are relatively less pronounced. The significance tests for the GID from ***Appendix G*** largely confirm this. The only exception is that the difference of the international level indicator between the grassroots type and network type is not significant. For the *dirigiste GID type* the values show a relatively strong pooling of innovation governance outside the region, whereby they coincide with the theory. The finding is supported by the fact that only in case of the national level indicator no significant difference could be identified between the globalised and the network type. Regarding the *network GID type*, the values are always between those of the two extreme cases. This type of shaping of the innovation governance thus reflects the theoretically assumed relative balance of influences coming from the different spatial levels. These results can be largely confirmed by the significance tests. They show that only the national level indicator in comparison with the grassroots type and the international level indicator in comparison with the dirigiste type have no significant differences.

As shown, despite a few insignificances and against the backdrop that all major theoretical contents of the selected property dimensions of the BID and GID are confirmed, in total it can be noted that both the designed indicators and the applied ‘relative grouping method’ seem to work well for differentiating the BID and GID types based on their core contents.

Despite this first general positive result, however, it cannot yet be finally and unequivocally assessed whether these RIS type assignments based on the theory-led BID and GID type deduction approach provide valid and reliable results. This requires further research with respect to the strong simplification of the GID and BID deduction approach (see Section 2.3.1), the methodological limitations associated with the selection of the spatial level of analysis (see Section 2.3.2), the choice of the indicators (see Section 2.3.3), and the implementation of the theory-led RIS assignment approach (see Section 2.3.4). Nevertheless, it must always be kept in mind that the approach presented here was specifically designed for simplified RIS type assignments of a large number of regions. Accordingly, adjustments to increase the security of the approach should not be disproportionate to the disadvantage of its applicability and practicability. A certain trade-off is probably unavoidable in this context. In addition, it must be considered that highly simplistic depictions of complex phenomena as presented here are not unusual despite criticism and problems (see for instance discussions of the Gross Domestic Product (GDP) as a social welfare indicator or unit labour costs as a competitiveness indicator). Furthermore, to some extent such approximate approaches may even help to cope with data availability and methodological constraints, thus preventing empirical stagnation.

In addition to these methodological discussions, it seems furthermore necessary to conduct a comparison of the assignment results achieved by using this new approach with already existing ones that applied the comprehensive approach. However, this appears to be rather difficult, as existing RIS studies for Germany are usually located at the Federal State level. Therefore, the results are hardly comparable. Accordingly, further RIS studies at the ROR level are necessary to allow for a final, needed comparison.

Nonetheless, this new approach promises spatially far more detailed results compared to those conducted at the Federal State level. For instance, in existing RIS studies (e.g. STRAMBACH/DI'LORIO 1999; HEIDENREICH/KRAUSS 2004) the State Baden-Wurttemberg in southwest Germany (see map in ***Appendix A***) is treated as one RIS (the same occurs to other German States in the course of RIS analyses, e.g. HILBERT et al. 2004, STUCK/REVILLA DIEZ 2013 or EC 2014b). Usually, this region is assigned to have an interactive network RIS. A look at ***Figure 7***, however, suggests a more heterogeneous picture when using RORs. A reason might be that Federal States are large territorial units (except the city states) which are intra-regionally coined by high socio-economic heterogeneity (e.g. population size, demography, economic power, sectoral shaping, etc.). This, however, is likely to distort RIS typification results. Accordingly, if this new approach works well at the ROR level, spatially more precise results can be expected.

Ultimately, both methodological aspects and content issues illustrate the need for further research and discussions associated with this work.

2.5 CONCLUSION

A look at the existing RIS literature shows that RIS type assignments are usually performed for one or very few regions (e.g. BRACZYK et al. 1998; COOKE et al. 2004; ASHEIM/COENEN 2005; STUCK/REVILLA DIEZ 2013). This is mainly due to the approach´s comprehensiveness and the high requirements for data availability regarding both qualitative and quantitative information. However, I argue that there is a crucial need to enable RIS type assignments for a large number of regions. For instance, scientists and practitioners could carry out initial and quick comparisons between potentially large numbers of regions with different RIS types. In addition, new empirical insights from studies involving a large number of regions may even support new or additional generalisations with respect to RIS theory.

In this light, the aim of the second chapter was to discuss how simplified RIS type assignments for a large number of regions may be achieved. In order to do so, I first decided that investigations addressing RISs (and their dimensions) are always limited to the R&D subsystem of a RIS. Thereafter, I performed a conceptual and methodological modification of COOKE´s existing two-dimensional RIS analysis and classification framework. This finally led to the development of an approach for *theory-driven, approximate assignments* of regions to different RIS types. This means, the approach utilises two quantifiable core contents of the BID and the GID, and makes it thus possible to depict major coining innovation process features of different RIS types. Based on these results, the remaining features of the BID and GID are derived based on what is known from RIS theory. Of course, both the results and the thereon based assignments of regions to different RIS types are rather ideal-typical and hypothetical. But, as the content of both dimensions and their types is based on extensive empirical research (CARLSSON 2007:860), it is plausible to argue that the actual regional conditions should have at least essential similarities with the theoretical predictions (COOKE 1998, 2004).

I tested the developed simplified theory-led RIS assignment approach on the basis of 'German Planning Regions' (= Raumordnungsregionen; (ROR)). The results can be found in ***Table 7***, ***Appendix B***, and ***Appendix C*** as well as in ***Figure 5***, ***Figure 6***, and ***Figure 7***. In the presentation and discussion of these results I showed that in total the approach and the therein applied indicators seem to work well to differentiate the various RIS types. Overall, this gives a promising indication that the discussed conceptual and the methodological modifications allow to perform sufficiently precise, simplified RIS type assignments for a large number of regions on the basis of core characteristics of regional innovation processes.

Given this result, the approach has the potential to stimulate the demanded discussion about RISs and their characteristics (MARKUSEN 1999; MOULAERT/SEKIA 2003;

DOLOREUX/PARTO 2005; TER WAL/BOSCHMA 2009). Insufficiently explored are, for instance, questions regarding the most innovative RIS type, the most important actors in different RISs, RIS type-specific institutional framework conditions, or the intra- and inter-regional collaboration patterns in different types of RIS. Moreover, it would be conceivable to use such an approach to find out if already attributed RIS type characteristics from the RIS literature are correct or have to be modified, because former findings forming the RIS framework largely result from successful regions analysed in the context of case studies (DOLOREUX/PARTO 2004).

Moreover, additional knowledge about RIS type-specific innovation or intra- and inter-regional collaborations resulting from the analyses of a large number of regions might even contribute to policy-related discussions about a better management and optimisation of RISs. In this context, on the one hand, it would be conceivable to promote innovation-related infrastructures or institutions according to a region´s BID or GID. On the other hand, measures addressing intra- and inter-regional collaborations between innovating actors in a region's RIS could be refined.

However, it is important to note that the simplified approach does not principally question COOKE´s comprehensive RIS analysis concept. Both approaches pursue different targets and have different advantages: The simplified one involves comparatively little data and uses a rather approximate RIS type deduction based on core contents, thus enabling researchers to carry out RIS type assignments for a potentially large number of regions on the basis of which they can make initial RIS type specific comparisons and further analyses. COOKE´s original analysis concept, in turn, involves numerous qualitative and quantitative characteristics and applies a comprehensive RIS analysis and typification scheme for in-depth analyses and assessments of only few selected regions. Therefore, the simplified and the comprehensive approach have the potential of complementing instead of substituting each other.

Although I believe that the work contributes to the existing literature, I have also identified a number of limitations in the course of the study. The most important ones are set out in the following. Firstly, the assignment approach is conceptually and with respect to the applied data very much limited to the R&D subsystem – both with regard to the BID and the GID. Actors creating innovations not as a results of (formalised) R&D as well as political actors were not or only inadequately taken into consideration. Moreover, there is a remaining risk of incorrect assignments due to discussed limitations associated with the conceptual simplification of the theory-led BID and GID deduction approach, the choice of the indicators, and the implementation of the theory-led RIS assignment approach (see discussions in Section 2.3.1, 2.3.3, and 2.3.4). To comply with these issues, further discussions in the context of future works are necessary. Nonetheless it is essential to keep in mind that the presented approach was expressly designed to aim at *simplified depictions of RISs*, similar to the GDP being used to depict wealth and other social phenomena. Ultimately, as it is the case in terms of the GDP, my RIS assignment approach should be seen as an instrument to partially overcome problems with data availability and applications for a large number of regions. In the case of applications for a small number of regions or those aimed at very detailed regional analyses and assessments, however, it is recommendable to use the more established, comprehensive RIS analysis and classification frameworks. Therefore, both the simplified and the comprehensive approaches have the potential of complementing rather than substituting each other.

Moreover, it should be noted that so far only the static view was analysed in the context of the application of the theory-led RIS assignment approach. In the light of the debate about lock-ins and path-dependency of RISs (e.g. GRABHER 1993; BATHELT et al. 2004; VISSER/BOSCHMA 2004; ASHEIM/GERTLER 2005; TÖDTLING/TRIPPL 2005) it may, however, be revealing to broaden the analytical focus by also taking the dynamic perspective in account. This could then give additional insights into the developments of RIS type specific actor settings, institutions, collaboration patterns, knowledge bases or industry structures (COOKE et al. 1998; ASHEIM et al. 2007; FU 2011).

Last but not least, further limitations may be associated with the chosen geographical level of analysis, as it remains unclear so far which regional level of analysis is appropriate when talking about the regional level in the context of RISs, and if all or only particular regions actually have a RIS (e.g. COOKE et al. 1997, 1998; HOWELLS 1999; KOSCHATZKY 2001; COOKE 2001a; 2002a; CARLSSON et al. 2002; DOLOREUX/PARTO 2005). Future research should therefore clarify these issues. Until then, however, the applied approach promises spatially more detailed results compared to those conducted at the Federal State level, because by applying the RIS approach to RORs – which depict functionally defined spatial units (i.e. economic centres and their related surroundings) – socio-economic distortions related to the size of the Federal States can be avoided.

Chapter 3

NETWORK STRUCTURES
IN
REGIONAL INNOVATION SYSTEMS

Abstract[26]

The Regional Innovation System (RIS) framework is one of the most prominent approaches for the analysis of regional innovation processes. While interactive learning and inter-organisational relations are fundamental building blocks in RIS theory, the approach is rarely applied to analyse knowledge network structures of regional innovation processes, because in RIS literature relational structures and interaction networks are discussed in a rather fuzzy and generic manner with the ‘network term’ often being used rather metaphorically.

This chapter sheds light on this issue by discussing theoretical arguments about interactions and knowledge exchange relations in the RIS literature from the perspective of social network analysis (SNA).

3.1 INTRODUCTION

The RIS framework is one of the most common and scientifically accepted approaches for the analysis of regional innovation processes (e.g. CHARLES et al. 2000; DOLOREUX/PARTO 2005; OECD 2009a, b; STUCK/REVILLA DIEZ 2013). At its core, it is argued that regional actors do not innovate in isolation but that they are embedded in interrelated and interactive regional innovation processes. This interrelatedness and interactivity calls for the perception of regions as ‘innovation systems’ and implies that their innovation success depends on the innovative capabilities of the actors and on the structure of their interaction (DOLOREUX 2002:243).

Hence, interactive learning and inter-organisational relations are fundamental building blocks of the RIS theory (COOKE/MORGAN 1993; COOKE 1996). However, discussions and analyses of interaction structures among RIS organisations are still rare and usually limited to direct linkages between major actors (KOSCHATZKY/STERNBERG 2000; REVILLA DIEZ 2000, 2001, 2002a, b) or focus on the overall embeddedness of the actors (DICKEN et al. 2001). In addition, research on RISs generally lacks theoretically precise and quantitatively measurable statements about structures and characteristics of inter-organisational interactions and knowledge exchange relations. For this reason, studies in this field frequently discuss relational structures and interaction networks in a fuzzy and generic manner (GRABHER 2006; TER WAL/BOSCHMA 2009). In many instances, these notions are used in a rather metaphorical manner in order to refer to relevant but by and large unspecified properties of the systems (e.g. FISCHER et al. 2001; ASHEIM/ISAKSEN 2002; COOKE 2004; ASHEIM/COENEN 2005). Ultimately, this ambiguity prevents RIS Research from developing clear-cut scientific hypothe-

[26] An earlier version of this chapter has been presented at the research colloquium of the Institute of Economic and Cultural Geography of the Leibniz Universität Hannover (2013), and the 2nd Geography of Innovation Conference in Utrecht (2014).

ses and policy recommendations with respect to one of its central building blocks.

I argue in this chapter that the RIS literature can be enriched by insights from graph theory and social network research, which are still ignored largely in the RIS literature (GRABHER 2006; TER WAL/BOSCHMA 2009). *The objective* is to highlight how existing arguments about interactions and knowledge exchange relations from the RIS literature can be rendered more precisely by evaluating the arguments from a network-theoretical perspective. Ultimately, this work may sharpen the RIS framework and form a basis to integrate an explicit 'Network Dimension' into the RIS approach.

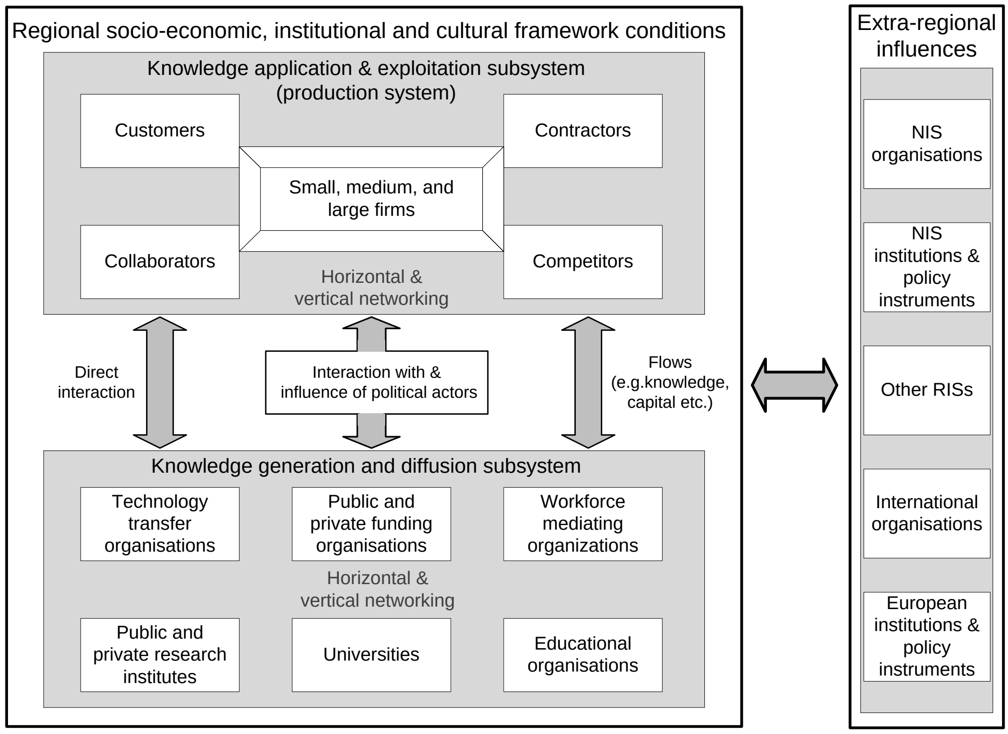
The chapter is structured as follows: Section 3.2 introduces and briefly discusses the RIS approach. In Section 3.3, the research focus is described, concepts from social network analysis (SNA) that help to translate terms frequently put forward in the RIS literature are introduced, and limits of the discussion are outlined. In Section 3.4, network-relevant statements made in the RIS literature are assessed against insights on interaction- and network-related aspects from network research. As a result, arguments about relational structures in the RIS literature are expressed in SNA terminology and key features of network-structures in RIS are derived. Section 3.5 concludes the chapter and puts the findings into perspective.

3.2 THE REGIONAL INNOVATION SYSTEM APPROACH AND ITS VIEW ON NETWORKS

The RIS framework is rooted in discussions about National Innovation Systems (NIS) (FREEMAN 1982, 1987, 1988) and developments linked to Post-Fordism (AMIN 1994). According to DOLOREUX (2002:244), its theoretical basis is influenced by heterogeneous research fields such as evolutionary economics (e.g. NELSON/WINTER 1982), institutional economics (e.g. NELSON 1993), (industrial) clusters (PORTER 1998), new regional economics (e.g. PIORE/SABEL 1984; AYDALOT/KEEBLE 1988; STORPER 1995, 1997a; FLORIDA 1995), economics of learning (e.g. FORAY/LUNDVALL 1996), economics of innovation (e.g. DOSI et al. 1998), and network theory (e.g. HAKANSSON 1987).

As shown in ***Figure 8***, a RIS constitutes a system of interacting actors (bright boxes) and subsystems (dark boxes). Usually, such actors are understood as organisations. From a heuristic and theoretically idealised point of view, organisations within a RIS belong either to the knowledge application and exploitation (i.e. firms and customers) or to the knowledge generation and diffusion subsystem. Actors from the former sub-system are the major drivers of commercial innovation activities in a RIS and thus of vital importance. Actors from the latter subsystem conduct business sector supporting activities and engage in the production and dissemination of both codified and tacit knowledge, and skills (AUTIO 1998:134). The approach also imputes that public and especially political actors may have a substantial influence on the RIS by generating incentives, upgrading infrastructures, developing technological alternatives, promoting emerging technological systems, and supporting collaboration activities (LUNDVALL/BORRÁS 1997:56; FORNAHL/BRENNER 2003:4).

<u>Figure 8:</u> Schematic Illustration of a Regional Innovation System



Author´s illustration; based on AUTIO (1998:134) and COOKE (2002a:137)

According to this description, RISs are generally known as „interacting knowledge generation and exploitation subsystems linked to global, national and other regional systems“ (COOKE 2004:3) „in which firms and other organisations are systematically engaged in interactive learning through an institutional milieu characterised by embeddedness“ (COOKE et al. 1998:1581). RISs thus constitute the supporting institutional, organisational and technological infrastructure within a regional production system.

Interdependent linkages – resulting from diverse types of interactions – within and between the actors and subsystems as well as between the region and the outside world form the system-creating fundament (UYARRA 2011). On the one side, the fundamental relevance of interactions results from the natural need to learn and exchange information and knowledge in the process of invention and innovation. On the other, in a rapidly evolving environment, with shorter and shorter innovation and product life cycles, increasing complexity and specialisation, interactive learning and cooperations ensure external expertise, potential for cost reductions, efficiency gains and reduction of uncertainties (DODGSON 1994).

The way interdependent linkages between the actors and subsystems work highly depends on the institutional milieu consisting of e.g. regional rules, attitudes, standards or values (NORTH 1990; COOKE et al. 1997). Such institutional and cultural framework conditions shape social interactions and make economic and knowledge processes region- and context-specific (SAXENIAN 1994, 2006; GERTLER 2010; STRAMBACH 2010; ZUKAUSKAITE 2013). This in turn makes regional innovation processes difficult to duplicate (DOLOREUX 2002:246).

The RIS approach especially highlights the regional dimension of innovation processes and emphasises how innovative and economic competitive advantages of regions arise from geographical proximity, how actors and institutions are spatially interconnected, and the way RISs are constituted with respect to organisational and socio-institutional framework conditions. Such advantages promote access to local and extra-regional knowledge and allow for region-specific learning processes that ease the coordination of joint projects and facilitate face-to-face contacts. This in turn stimulates inter-organisational knowledge spillovers[27] and promotes capabilities of organisations to collaborate and/or cross-fertilise in networks. This supports the generation and diffusion of (tacit) knowledge, innovations, and technological progress among regional actors, which ultimately increases the innovation performance of the region (CAMAGNI 1991; BATHELT et al. 2004; COOKE 2004; FRITSCH/FRANKE 2004).

Ever since the pioneering works of COOKE (1992) and COOKE & MORGAN (1994), one of the major fields of RIS Research is to elaborate on how RISs are structured and how they function. The prime foci are thereby their institutional and organisational dimensions (e.g. COOKE et al. 1997, 1998), their evolutionary character (e.g. COOKE et al. 1998; UYARRA 2010; FU 2011), governance and policy aspects (e.g. COOKE et al. 2000; ANTONELLI/QUÉRÉ 2002; COOKE 2007), the importance of firms, higher education institutions (HEIs)[28], and research institutes for RISs development (e.g. REVILLA DIEZ 2000; MULLER/ZENKER 2001; TÖDTLING/KAUFMANN 2002; AGRAWAL/COCKBURN 2003; REVILLA DIEZ/BERGER 2005; CANIËLS/VAN DEN BOSCH 2011), and to what extent RISs exist in different types of regions (i.e. metropolitan areas, old-industrial regions, regions in transition, etc.) (e.g. ASHEIM/ISAKSEN 1997; KAUFMANN/TÖDTLING 2000; REVILLA DIEZ 2002b; DOLOREUX 2003;

[27] Based on the theoretical assumption that face-to-face contacts are important to transfer tacit knowledge, a number of empirical findings have found out that knowledge spillovers are to a significant extent a regional/local phenomenon (JAFFE 1989; JAFFE et al. 1993; ACS et al. 1992, 1994; AUDRETSCH/FELDMAN 1996; ANSELIN et al. 1997). Regarding this, FRITSCH & FRANKE (2004:245) state that "[t]herefore, it can be assumed, that knowledge spillovers constitute an important factor in shaping regional conditions for innovation activities".
[28] HEIs are universities, applied universities, polytechnical universities or the like.

DOLOREUX/DIONNE 2008).

The vast majority of empirical studies thus describe how innovation processes are organised and realised in different regions with different organisational, institutional, and political set-ups. Much less attention has been paid to the actual role and structure of RIS internal and external interactions in the cause of the innovation process. Theoretical contributions that discuss the relevance of interactive behaviour and networking for RISs are especially those by COOKE & MORGAN (1993), COOKE (1996), and FORNAHL & BRENNER (2003). They discuss the general importance of regional networks and interactions as well as the relevance of relations between specific types of innovating actors such as HEIs and firms. These insights are rendered more precisely by empirical studies, which usually employ methodologies targeted principally at the investigation of selectively chosen, direct interactions of and/or between firms, research institutes, HEIs, i.e. the knowledge generation and diffusion, and the knowledge application and exploitation subsystem. For instance, studies by FRITSCH & SCHWIRTEN (1999), REVILLA DIEZ (2000, 2002a), KOSCHATZKY & STERNBERG (2000), and STERNBERG (2000a, b) explicitly focus on actually realised inter-organisational interactions that take place within or across regional boundaries.

However, the existing theoretical and empirical studies so far neglect two inherent features of RISs as a representation of a complex system of interrelated and interdependent organisations: indirect relations and structural characteristics of the complete system of (*direct and indirect*) relations. Indirect relations refer to the idea that two organisations are related if they have at least one interaction partner in common[29]. Given the relevance of such indirect relations, structural characteristics of the complete system of relations (i.e. the network) become relevant as well. These two aspects are essential in network research, and their relevance for understanding interactive systems is underlined in almost all studies, which have been conducted in different fields of economic geography (e.g. GRABHER 2006; GLÜCKLER 2007; TER WAL 2011; SCHERNGELL/BARBER 2011). In fact, many of the central concepts in network research rely on the relevance of indirect linkages (for an overview see e.g. WASSERMAN/FAUST 1994). However, without considering indirect relations and structural characteristics of the complete set of relations within a RIS (RIS internal network), significant portions of the system-character of RIS are ignored. In other words, without applying a true system-oriented perspective that includes indirect relations and network structures, RIS as 'systems of interactive elements' cannot be fully understood.

The question is therefore why these features have not played a more prominent role in RIS

[29] In network research indirect relations are explained by the concept of 'transitivity'. It assumes that if there is a link between A and B, and also between B and C, then there is also a link between A and C (WASSERMAN/FAUST 1994:243).

Research? While it would take a chapter on its own to dwell on this question, it appears feasible to conclude that it is primarily the insufficient network-theoretic foundation of the RIS concept that has prevented an explicit analysis of regional network structures within this framework. More precisely, and this will be shown in more detail later in this chapter, most theoretical statements about interactions and networks in the RIS approach are vaguely formulated and do not allow for precise conclusions on regional structures of interactions (GRABHER 2006; TER WAL/BOSCHMA 2009). This may be related to the 'fuzziness' that has been attributed to the RIS approach in general (MARKUSEN 1999). In addition, the RIS approach has been developed by geographers, which were not familiar with network concepts and methodologies developed in sociology and mathematics. It may even be the case that the rather quantitative nature of SNA did not appear to be very attractive for many geographers in the 1990s and early 2000s, who rather applied qualitative research strategies in their empirical studies. As a result, few RIS studies exist that explicitly focus on interactive behaviour in innovation processes and those that do appear to be outdated (TER WAL/BOSCHMA 2009; UYARRA 2011).

In the light of this, the aim of the present chapter is the integration of relevant theories and concepts of network research into the RIS approach. This will enrich the RIS approach with an explicitly, i.e. theoretically derived 'Network Dimension', which has been called for by TER WAL & BOSCHMA (2009). Prospectively, this theoretical contribution will then allow for the development of empirically testable hypotheses regarding network structures in regional innovation processes of RISs.

It is, however, also important to point out that the integration of the network perspective into the RIS approach yields future possibilities for network research as well, since it benefits from the RIS approach´s views on institutional and governance factors. In particular, the debate about regional institutions (MACKINNON et al. 2008; BOSCHMA/FRENKEN 2008) and their influence on network structures (TER WAL/BOSCHMA 2009) may receive stimulating input from such a conjunction.

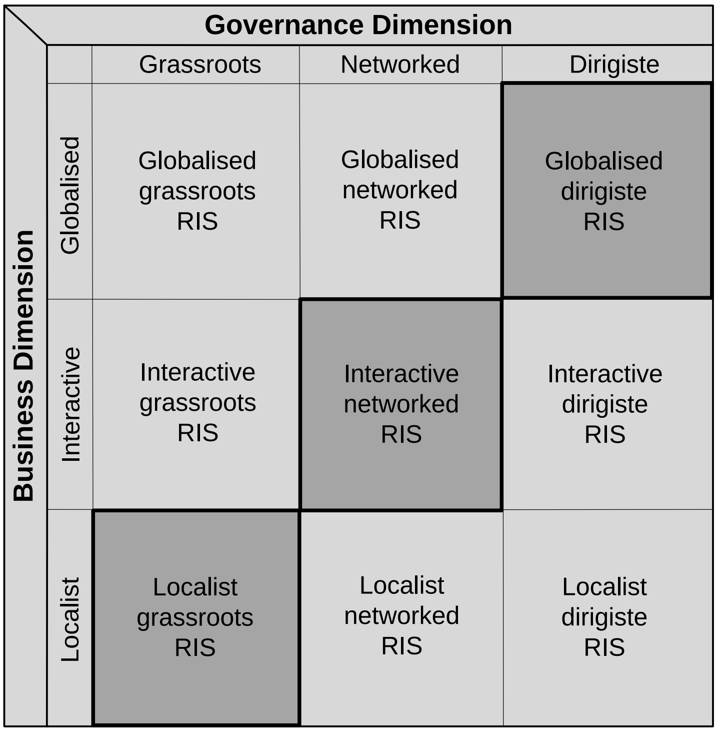
3.3 SCOPE OF DISCUSSION

3.3.1 Defining the Object of Analysis – COOKE's RIS Concept

Given the broad nature and scope of the RIS approach, it has attracted a lot of attention from different scholars and disciplines (e.g. OECD 2009a, b; STUCK/REVILLA DIEZ 2013; EC 2014b) resulting in a very large and diverse literature in the last two decades. To keep the literature clear and manageable, the work has to be limited to a particular stream within the

RIS literature (for an overview see Thomi/Werner 2001; Doloreux 2002). The discussion is therefore conceptually concentrated on the RIS concept proposed by Cooke (1998, 2004). Most arguments about relational and interaction structures as well as networks concerning RIS arise from this or related literature streams. Given that Cooke´s concept is probably the most widespread and has been extensively applied in empirical studies (e.g. Braczyk et al. 1998; Cooke et al. 2004; Stuck/Revilla Diez 2013), I am convinced that this reduction is acceptable. I leave it to future research to expand this discussion to other RIS designs.

Figure 9: Types of Regional Innovation Systems



Author´s illustration; based on Cooke 2004:15

Cooke's RIS concept differentiates between two analytical dimensions – the '*Governance Innovation Dimension*' (GID) and the *'Business Innovation Dimension'* (BID). According to Thomi & Werner (2001:212), the BID especially depicts major characteristics and structures of the innovating actors as well as their spatial patterns in innovation processes, while the GID particularly aims to reveal how innovation processes are managed and controlled by innovating and political actors.

The concept distinguishes three categories within each of these dimensions (see ***Figure 9***). In the BID, these are the interactive, the localist, and the globalised model. In the GID the classification contains a grassroots, a network, and a dirigiste model. By combining both dimensions Cooke identifies nine theoretical RIS types. Those RISs located on the diagonal of the matrix (darker boxes) can be seen as most *’ideal types’* of cases, as their characteristics are most clearly distinguishable. They are therefore chosen to form the basis for the following discussion, implying the identification of arguments, empirical facts, and hypotheses put forward in this literature for each of these three cases about formal and informal regional knowledge interactions and collaborations. The discussion will moreover focus on inter-organisational knowledge exchange relations of the most important research and development (R&D) performing actors, i.e. firms, public research institutes, and HEIs (NELSON/WINTER 1982; ROTHWELL/ZEGVELD 1982; FRITSCH/SCHWIRTEN 1999). These correspond most to what is usually investigated in the network-related literature in the field of Economic Geography (e.g. BOSCHMA/TER WAL 2007)[30]. Again, I leave it to future research to expand this discussion to the other RIS types and modes of interaction.

3.3.2 Relevant Concepts of Network Research

As for the RIS approach, the number of concepts from network research also has to be reduced in order to keep the discussion clear and manageable. The concepts which are applied are those which are most common and suitable to ‘translate’ interaction- and network-related terms frequently used in the RIS literature into SNA terminology. Of course, given the scope of the chapter, the list of presented concepts is far from being complete. I leave it to future research to expand the list.

Network Size and Density

Networks are based on nodes that are connected by links. The two most fundamental characteristics of networks are their size and density. The number of nodes (i.e. actors) commonly defines *network size*. The density of a network is estimated as the ratio of the number of observed and the number of theoretically possible links given the number of nodes n. In a directed network, the latter is equal to $n * (n - 1)$. It is half that number in an undirected network[31]. In the context of this chapter, size corresponds to the number of organisations within a region that may potentially establish knowledge exchange relations. Accordingly, the density can be used as a general indicator of how quickly information, knowledge, and innovation can be disseminated within a network (JANSEN 2003:94, 108-112). It may also give a first indication of the intensity of social relationships (AVENARIUS 2010).

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[30] This particularly concerns formal and informal collaboration in R&D. However, also labour mobility, joint R&D work, and unintended knowledge spillover may be included.
[31] In a directed network links can have a direction, i.e. node A may have a relation to node B while B might not have a relation with A. In undirected networks, node A has the same relation with node B as node B has with A.

The *network density* is closely related to its size, as the probability that all theoretically possible combinations are realised usually decreases when the number of nodes grow (JANSEN 2003:94). This can be explained by the limitations in an individual node's capacity to initiate and maintain links to other nodes, which is particularly the case when links imply some kind of social relation.

Centrality and Centralisation

Centrality is a fundamental concept in network research. It captures which "[...] actors are those that are extensively involved in relationships with other actors" (WASSERMAN/FAUST 1994:173). Based on centrality, it is possible, for instance, to investigate positions of the nodes within a network as well as their role with respect to their influence and relevance. A number of different centrality measures have been developed in recent decades (for an overview see e.g. BORGATTI/EVERETT 2006). Among the most important measures are the basic concepts of centrality summarised by FREEMAN (1979): degree and betweenness centrality.

Degree centrality is simply a node's number of direct links to other nodes. It is a measure for its local centrality and embeddedness into the network. The other measures are more complex and also consider indirect links. Many of them are based on the concept of the *shortest path* (also known as geodesic distance), which is the minimum number of 'steps' along the network to reach another node. A 'step' corresponds to a direct link between two nodes (see for more details WASSERMAN/FAUST 1994). Based on this idea, the measure of *betweenness centrality* describes a node as being central when it holds a 'broker position' within a network. It reflects the number of shortest paths between nodes in the network that include the focal node. Since information and knowledge are most likely to diffuse along these shortest paths through the networks, it can be argued that an organisation characterised by large betweenness centrality owns the potential to control the diffusion of information and knowledge (or other flows) in the network (GRAF 2011).

These two measures describe the centrality of a particular node within a network. On this basis it is also possible to derive measures of the *overall centralisation* of a complete network. Centralisation allows for conclusions regarding the macro-structure of a network. For instance, the most centralised network is a star-shaped network in which all connections are focused on one node, which implies that the degree and betweenness centrality of the dominant node is at its maximum. In practice, the centralisation of networks is mostly evaluated by comparisons with this theoretically maximal centralised network structure, i.e. by comparing the centralisation of the empirical network with that of the equally sized star-type network.

Networks with a low centralisation are usually seen to be non-hierarchical while the opposite holds for highly centralised networks (for more details see e.g. WASSERMAN/FAUST 1994).

Centralisation of a network and the distribution of centrality among its nodes may be seen as a rough measure of a network's *robustness*. The robustness of a network describes the resilience of a network's structure to the event of node disappearance (COWAN/JONARD 2007). The more a network is centralised around one or few nodes the higher the likelihood that its structure will change when the most central nodes fail and disappear. Centralised networks are hence more prone to structural change, i.e. they are less robust in their structure.

Related to the centralisation of a network is its *fragmentation*. In network research fragmentation may refer to the number of components in a network. A component refers to a structure of at least two nodes that are at least indirectly connected. A highly fragmented network consists of multiple components. That is, a number of sub-networks (components) exist, of which each node is at least indirectly linked to all other nodes in the component, while none are linked to a node in another component. Networks with multiple components are more robust to node disappearance, as each node's relations matter only for the component it is part of. In addition, such networks may show a considerable number of *isolates*, that is, actors that do not collaborate at all.

Hierarchy and Network Structure

In addition to the above outlined star-type network, network research has identified further network structures with specific implications for knowledge diffusion and power structures among the members of a network. While there are different types of structures, the focus is set on two of the most prominent: the small-world type and the core-periphery type network.

While the idea of small-world type network structures dates back to MILGRAM (1967), WATTS & STROGATZ (1998) and WATTS (1999a, b) were the first to formalise a model representing the basic principle of '*small-worldness*'. Their model has been further developed by BARABÁSI & ALBERT (1999, 2002) in their so-called 'scale-free small-world network model'.

A small-world network can be characterised by a high degree of 'clustering', i.e. the frequent presence of cliques (at least three nodes that are completely linked) in the network. Moreover, these cliques are connected by few 'far-reaching' links. As a result, even large networks with low density may obtain low node-to-node distances implying that the average shortest path length in the network is relatively low. The last characteristic of small-world networks is a distribution of degree (centrality) values similar to that of power-law function: few nodes are characterised by high centrality and many by low centralities. Small-world structures generally support an efficient diffusion of knowledge in the network. Moreover, as nodes that link the different cliques hold prominent broker positions (high betweenness centrality), the network is characterised by a strong power hierarchy (RAVASZ/BARABÁSI 2003).

The most popular definition of *core-periphery structures*[32] can be found in BORGATTI & EVERETT (1999)[33]. Accordingly, a network has a core-periphery structure if its nodes can be partitioned into two sets: the core and the periphery. Nodes in the core are strongly linked among themselves. In contrast, nodes in the periphery are sparsely interlinked. Frequently, they are either isolates (no links at all) or weakly linked to the core nodes. If networks qualify as core-periphery their nodes are obviously in a hierarchical order with those belonging to the core being more powerful and influential than nodes in the periphery. In contrast to the small-world type network, the speed of knowledge diffusion is likely to be lower.

Regional (Inter-)Connectivity

In addition to the intra-regional network structures that have been described above, the degree of the *connectedness of regional actors to extra-regional actors* regarding knowledge and innovation generating processes is also crucial for regional innovation activities (e.g. OWEN-SMITH/POWELL 2004; BATHELT et al. 2004; MALMBERG/MASKELL 2006; BRESCHI/LENZI 2013). Thus, at the aggregated regional level, for instance, the shares of regional, national, and international connections may show which spatial level (i.e. intra-regional, national, international) contains the most important knowledge sources for regional actors. Related to the discussion of regional inter-connectivity is the discussion about regional '*gatekeepers*' (for an overview see e.g. PROVAN et al. 2007 or BARZILAI-NAHON 2008).

Gatekeepers are central actors within a regional network that additionally link the regional to extra-regional networks. On the one hand, such gatekeepers ensure that 'up-to-date-knowledge' flows into a region and diffuses within it. On the other, they are able to 'broker' these knowledge flows to some extent, giving them a crucial position in regional knowledge networks (GRAF 2011).

3.4 REGIONAL INNOVATION SYSTEM TYPES FROM A NETWORK RESEARCH PERSPECTIVE

RIS-related literature often suggests that all organisations within a RIS (and independently of a specific type of RIS) benefit equally from regional knowledge spillovers (ASHEIM 1994;

[32] The here elaborated core-periphery structure should not be confused with the core-periphery model developed and discussed in fields of Economic Geography by researchers like e.g. PREBISCH (1959) and FRIEDMAN (1973).
[33] Other and somewhat stricter definitions can be found e.g. in BRAMOULLÉ (2007).

SAXENIAN 1994; AUDRETSCH/FELDMAN 1996; COOKE 2001a). This in turn is based on the assumption that due to regional and socio-institutional proximity all actors are part of extensive regional networks (BOSCHMA/TER WAL 2007). However, this implies that all regional actors are similarly embedded in regional networks and that network structures hardly vary between regions and RIS types. This clearly contradicts insights from network research that suggest significant heterogeneity in the embeddedness of organisations into regional networks (GIULIANI/BELL 2005; GIULIANI 2007; BOSCHMA/TER WAL 2007; BROEKEL/BOSCHMA 2011) as well as heterogeneous regional network structures (FLEMING et al. 2007).

In the following, the previously presented network-theoretical measures (see Section 3.3.2) will be employed to evaluate and render more precisely the arguments made in the RIS literature, thus applying a network perspective. As pointed out in Section 3.3.1, thereby the focus is set on three different 'ideal-typical' RIS types put forward by COOKE (1998, 2004).

3.4.1 Interactive Network RIS

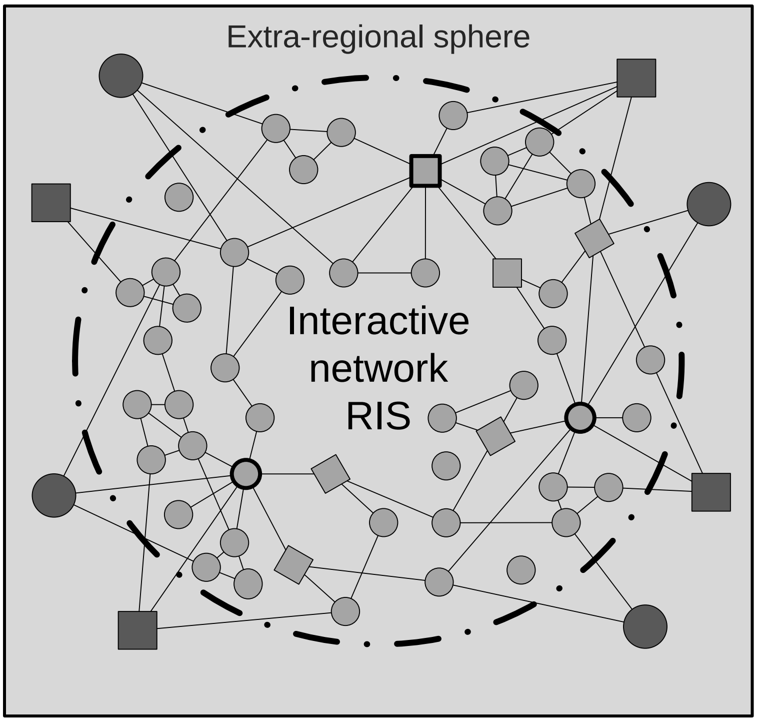
From a normative perspective an interactive network system is universally regarded as the most ideal RIS type. The GID of such a RIS has a 'network' modality, which implies a multi-level approach with regard to both policy and business governance. Policy governance is located at all territorial levels (regional, national, and supranational) and its measures are well-designed and soundly applied. With respect to business governance, innovation management and coordination are similarly distributed, thus showing a mix of local, regional, and inter-regional influences (COOKE 1998, 2004).

The 'interactive' modality of the BID of this RIS shows a relative balance between small and medium-sized enterprises (SMEs), as well as large firms (domestic or foreign-owned), with the majority of firms being engaged in R&D. The R&D activities are predominantly focused on advanced or high-tech sectors. Usually, numerous research entities (i.e. HEIs and/or research institutes) exist in such regions, supporting firm R&D activities. Nevertheless, the profit-oriented private sector is the clear driving force in the system with the research sector particularly playing a supportive role (BEISE/STAHL 1999; CANIËLS/VAN DEN BOSCH 2011). In general, the propensity for collaboration between regional actors is argued to be very high, as technological sophistication of organisations is associated with strong efforts to participate in knowledge networks. Moreover, these regional innovation activities are embedded in well-developed regional institutional infrastructures (BRACZYK et al. 1998; COOKE et al. 2004).

In addition to the intense regional collaboration characterising this RIS, many regional actors (public and private) are well connected to extra-regional actors, as they "[…] cannot rely only on localized learning, but must also have access to more universal [(i.e. extra-regional)], codified knowledge […]" (ASHEIM/ISAKSEN 2002:84). Hence, an interactive network RIS corresponds to a significantly sized agglomeration of public and private organisations that interactively engage in R&D on the regional as well as on the national or international level.

Translating this description into network terminology, it becomes obvious that interactive network RISs can be expected to show a large regional network (i.e. large number of nodes) with an above-average number of linkages. Moreover, due to their interactive set-up it seems probable that − compared with other RIS types − the regional nodes are likely to be more extensively embedded in intra-regional knowledge networks and that many of them are additionally engaged in extra-regional (i.e. national or international) relations. ***Figure 10*** summarises these arguments in a schematic illustration.

<u>Figure 10:</u> Schematic Illustration of Knowledge Networks in an Interactive Network RIS



Author´s illustration; circles=firms, squares=HEIs and/or research institutes, bolded circles/square=most central actors, dot-dashed circle=RIS

The first insight that can be gained from applying the network perspective to this RIS type is that it does not take into account the previously outlined negative relationship between network size and density; accordingly, relatively low densities characterise large networks. Density is likely to decrease as the number of organisations in the RIS exceeds the average capacities of actors to initiate and maintain links. The RIS's balanced mix of SMEs and large firms yields a rather average link maintenance and initiation capacity, which in turn suggests that the network will be of lower density than in other regions.

Moreover, the RIS description refers to a generally high collaboration propensity, which in network terminology is likely to result in the existence of few isolates, i.e. actors that do not engage in regional collaboration at all. Another feature of this type of RIS is that its actors differ in terms of reputation and absorptive capacities due to size differences (COHEN/LEVINTHAL 1990; GIULIANI/BELL 2005; GIULIANI 2007; BOSCHMA/TER WAL 2007), with large innovative firms likely to lead the field, followed by research entities and SMEs. Moreover, this type of RIS is dominated by firms, since the business sector is argued to play the most important role for knowledge generating activities (SCHUMPETER 1911; NELSON/WINTER 1982). Accordingly, owing to the advantages of firms regarding reputation and absorptive capacities as well as their importance with respect to knowledge creation, it can be expected that they also hold most of the central positions, i.e. they are most central in terms of degree and betweenness centrality (see ***Figure 10***). However, this likely applies particularly to larger firms, as they have the necessary levels of reputation and absorptive capacities to take central positions. Given that there are large numbers of highly central actors in this type of RIS, network centralisation is expected to be rather low.

The importance of preferential attachment processes[34] in network formation processes ensures that their position will remain stable over time. Moreover, they link otherwise unconnected parts of the network, which primarily include SMEs and research entities that play supportive roles to their R&D activities. In this sense, they are integrative nodes and impose a hierarchical network structure, as their centrality is larger than that of supportive actors. This is, however, not to say that the (public) research sector is irrelevant (CANIËLS/VAN DEN BOSCH 2011; KROLL et al. 2012). This sector is argued to be significant and actively contributes to knowledge production and diffusion (FRITSCH/SCHWIRTEN 1999; COOKE 1998, 2004). This somewhat but still significant importance of the research entities implies that its organisations are characterised by (regionally) average degree and betweenness centralities.

All the major features – the unequal distribution of network centralities, the large size of the network paired with a generally low density have important implications for the capacity of a RIS to diffuse knowledge among its organisations. Knowledge diffusion generally becomes easier with increasing network density (COWAN/JONARD 2004). Given the outlined characteristics, one might therefore not expect an interactive network RIS to be characterised

[34] "In the case of degree distributions, it is conjectured that, for a variety of reasons, vertices [(i.e. actors)] accumulate new edges [(i.e. links)] in proportion to the number they have already, leading to a multiplicative process which is known to give power-law distributions. This process is often called 'preferential attachment' " (NEWMAN 2001a:64).

by easy and fast knowledge diffusion. The contradiction between RIS characteristics and network mechanics can only be dissolved by a network structure that combines low density, unequal node centralities, and (still) high diffusion properties. As pointed out above (see Section 3.3.2), a network structure with such features is a small-world type network (ibidem). Hence, the high number of highly interrelated actors with a distinct hierarchy in the R&D processes, and the easy and fast knowledge diffusion lead to the hypothesis that a knowledge network within an interactive network RIS is characterised by small-world properties. Besides the leading firms being most central, this structure requires that the (public and private) support organisations form groups of strongly interlinked actors, which corresponds to clustering processes in network terminology (WATTS/STROGATZ 1998). In light of the above RIS description this seems to be very feasible.

The existence of a small-world type structure also requires that interaction between the densely linked groups of support actors is rare and most of the between group interaction is provided by the leading firms, which thereby integrate the otherwise unconnected parts of the network. Initial empirical evidence points in this direction, thereby supporting this hypothesis (NAKANO/WHITE 2006).

Despite the relatively small number of actors holding central positions in the network, the small-world network structure is relatively robust (COWAN/JONARD 2007). Even in case a single central actor fails or vanishes for whatever reason, the greatest part of the network will remain intact (WATTS 1999a; ALBERT/BARABÁSI 2002). The reason is the strongly clustered network structure in the vicinity of this organisation, which is likely to remain and continue to connect other parts of the network. In this sense, network structures in interactive network RIS are well suited to absorb failures of central nodes, which contributes to the temporal stability of this type of RIS.

Despite the outlined advantages of small-world networks, so far it is not yet clear whether such structures in regional internal knowledge networks actually explain a region's innovation performances (FLEMING et al. 2007; BRESCHI/LENZI 2011). Clearly, more research on this issue is needed in the future.

3.4.2 Localist Grassroots RIS

The 'grassroots' modality of the GID of a localist grassroots RIS implies that policy and business governance are predominantly organised at the regional level. Innovation activities are thus above-averagely controlled and managed by regional/local actors (COOKE 1998, 2004).

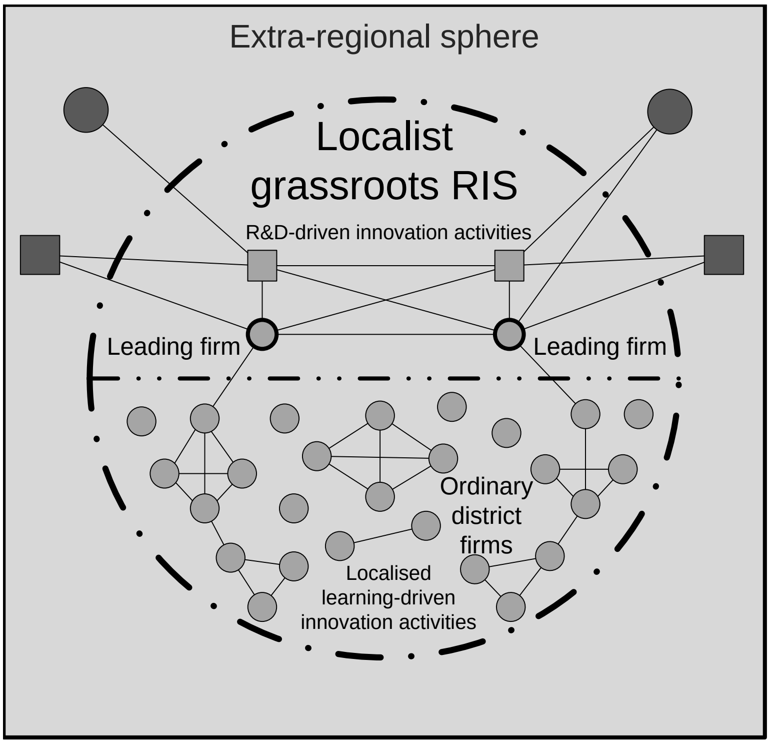
The 'localist' modality of the BID of this type of RIS usually comes into existence because of one or more small-scaled industrial districts being located in the region. The districts are usually characterised by regional inter-firm learning processes in a neo-Marshallian sense (BRUSCO 1986; PIORE/SABEL 1984; BEST 1990). The firm population is dominated by SMEs (so-called 'ordinary district firms'). The SMEs are hardly involved in R&D. Consequently, R&D related knowledge relations are generally rare, as most district firms are, if at all, interested in spontaneous, industry-specific, and practical support (ASHEIM/COENEN 2005). Lacking R&D, the SMEs remain competitive through flexible production, specialisation, strong division of labour, and innovation processes based on tacit knowledge. Hence, compared to other RIS types, the localist grassroots RIS hosts a relatively small number of R&D performing actors (COOKE 1998, 2004). However, a few 'leading firms' active in R&D and/or few research entities are usually present in this type of RIS (MORRISON/RABELLOTTI 2009; MUNARI et al. 2012). These show highly developed potentials for advanced or even high-tech R&D (COLETTI 2007). Naturally, these actors dominate regional R&D activities in terms of capacities and knowledge exchange.

In order to access external knowledge, the R&D conducting actors frequently rely on cross-regional knowledge exchange (COLETTI 2007; MORRISON/RABELLOTTI 2009; MUNARI et al. 2012). In addition, these actors are intensively connected, whereby in particular research entities tend to be strongly interlinked with each other (STOKMAN/DOCTER 1987; RABELLOTTI 1995; CURZIO/FORTIS 2002; COLETTI 2007). In contrast to the vast majority of research entities, which rarely interact with local SMEs (STOKMAN/DOCTER 1987), leading firms also maintain some relations to regional SMEs with limited R&D activities. Due to these relations and their embeddedness into cross-regional knowledge links, they play a crucial role in this type of RIS. Recent studies unveil their function as a sort of 'knowledge translators' for the rest of the district or cluster (MORISSON 2008; OWEN-SMITH/POWELL 2004; GIULIANI/BELL 2005). This is achieved by absorbing, decoding, and diffusing knowledge from within and outside the district. These actors thereby make technological knowledge accessible for most of the regional SMEs (BECATTINI/RULLANI 1996) and integrate various groups of organisations and subsystems of the RIS (ASHEIM/COENEN 2005). Due to this, MORISSON (2008:817) refers to them as "gatekeepers of knowledge". In network research, such positions are referred to as gatekeeper/broker positions. It implements a hierarchical structure into the set of regional knowledge relations, which together with the segregation between SMEs and research entities makes a fragmentation of the knowledge networks of district firms very likely. Many SMEs even remain isolated from the regional knowledge networks due to the lack of R&D and knowledge capacity constraints (e.g. BOSCHMA/TER WAL 2007; GIULIANI 2007; MORIS-

SON/RABELLOTTI 2009). This adds further to the fragmentation of the system.

Figure 11 summarises these arguments and represents a schematical visualisation of regional knowledge networks in localist grassroots RISs. Applying the network perspective and its terminology in accordance to the above descriptions, the following can be derived: The described fragmentation of the network, which is by and large caused by the institutional divide between R&D and non-R&D performing actors is partly overcome by gatekeeper organisations that link otherwise unconnected components (BRITTON 2002:999). The knowledge diffusion from the outside into the region and among regional actors therefore strongly depends on these organisations.

<u>Figure 11:</u> Schematic Illustration of Knowledge Networks in a Localist Grassroots RIS



Author´s illustration; circles=firms, squares=HEIs and/or research institutes, bolded circles=most central actors, dot-dashed circle=RIS

Moreover, knowledge networks in an ideal-typical localist grassroots system are likely to be small in terms of the number of nodes (i.e. organisations). Due to the system´s localist BID set-up and the predominantly regionally oriented R&D and interaction activities it is most probable that − compared to other RIS types − the regional nodes show an above-average share of regional knowledge links. Simultaneously, the distinct multi-component structure of the regional network tends to show similarities to the previously discussed core-periphery model (see Section 3.3.2). The core-periphery network structure mirrors the RIS's distinct hierarchical structure because the periphery (SMEs) is dependent on 'translation activities' of the core (leading firms and research entities). The separation of the core and periphery is indicated in ***Figure 11*** by the 'dash-point-point-dash' line in the middle of the large circle.

A core-periphery structure has severe consequences for the application of other network related measures. For instance, the average density of the network is almost meaningless as there are two parts to the network. The core consisting of private and public organisations active in R&D is very densely interconnected. Hence, its nodes are clearly superior in terms of degree centrality. A localist grassroots RIS will therefore show a bimodal degree distribution with few actors (core actors) having large degree centralities and many actors (SMEs) with low to medium centrality values. In addition, nodes in the core with connections to actors in the periphery will be dominant in terms of betweenness centrality. In contrast, the periphery with SMEs lacking R&D activities has low centralities and consequently a low network density. This is not to say that actors in the periphery do not cooperate in R&D. While they are weakly interconnected, they may still form some small network components (GIULIANI/BELL 2005; GIULIANI 2007; MORISSON/RABELLOTTI 2009).

Due to the core-periphery structure it is difficult to make predictions also about the centralisation of the system. It can nevertheless be expected that the overall centralisation of the localist grassroots RIS is between of that of the interactive network and the (ideal-typical, one hub-led) globalised dirigiste RIS (the latter is described in Section 3.4.3). This follows the following reasoning: On the one hand, R&D-related knowledge exchange relations in a localist grassroots RIS are comparatively more concentrated on a few central actors than in an interactive network RIS. In total, this leads to a higher overall network centralisation in a localist grassroots RIS than in an interactive network RIS. On the other hand, interactions in a localist grassroots RIS are comparatively less concentrated than in a globalised dirigiste system, since in a localist grassroots RIS, R&D-related knowledge exchange relations are neither focused on one hub-actor nor are the knowledge network or the system in general oriented towards the needs of a dominating actor.

Despite the higher centralisation, the robustness of this network structure in general and of the core in particular can be expected to be relatively high, since both are extensively connected. This means that in case a node drops out the other nodes will remain strongly interconnected. The 'weak spots' of the structure are the few organisations connecting the core and the periphery. If one of these drops out for whatever reason, the integration of the complete knowledge diffusion system between the core and the periphery will be significantly disturbed (CALLAWAY et al. 2000).

3.4.3 Globalised Dirigiste RIS

The 'dirigiste' modality of this type of GID is characterised by a strong influence and control of actors located outside the RIS. Decisions on regional matters are made top-down. In other words, decisions are made and enforced by region-external actors (e.g. central governments) (COOKE 1998, 2004).

The system´s BID is shaped by the existence of one or more (industrial) districts, such as high-tech clusters, science parks, etc. These usually centre on an organisation's headquarters (HQ) or a subsidiary of a large multinational enterprise (MNE), which is very active in R&D (ibidem). In some cases, large or important governmental research organisations and their institutes may play a similar role as well (ASHEIM/ISAKSEN 2002). The overwhelming importance and economic weight of such large actors (so-called 'focal actors') induces a 'globalised' modality, with other actors in the districts primarily playing supportive roles. Usually, these actors are either supporting SMEs or other small local research entities (COOKE 1998, 2004). Joint innovation activities within the region are highly concentrated in the districts. The focal actor in the district leads regional knowledge exchange network. This implies that the network is strongly oriented towards the needs of the focal actor (COOKE et al. 2004; LORENZEN/MAHNKE 2002; ZHOU/XING 2003; ALMEIDA/PHENE 2004). That is, for instance, this actor defines the directions of research and frequently also chooses the collaboration partners. When the focal actor is a subsidiary of a region external organisation, such decisions are frequently made outside the region.

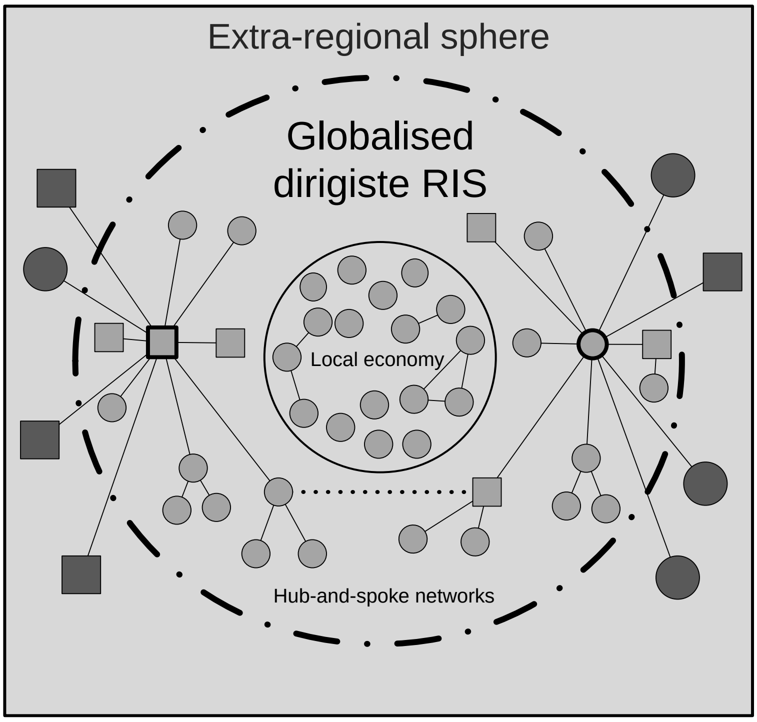
Moreover, in addition to regional links with dependent SMEs and smaller local public research entities, particularly extra-regional links play a prominent role for the major R&D facility (COOKE 1998, 2004). This is because "[…] parts of industry and the institutional infrastructure are more functionally integrated in national or international innovation systems […]" (ASHEIM/ISAKSEN 2002:84).

In addition to the strong outward focus of the focal actor, it is the lack of other district members participating in regional knowledge networks that makes the districts´ networks relatively isolated from the regional economy outside the district (HENRY et al. 1995). There are many regions-specific reasons for the lack of connectedness to the regional economy. In many cases, it is however a mismatch between industrial, organisational, and institutional conditions. Such mismatches typically arise when the focal actor is (too) strongly oriented towards region-external networks or when the entire RIS is subject to strong top-down interventions by national or supranational policies (MARKUSEN 1996; COOKE 2001b).

Figure 12 illustrates schematically the networks of an ideal-typical globalised dirigiste

RIS. The small circle in the middle represents the regional economy that is not organised in or connected with the district. The two star-type structures on the left and right visualise the industrial districts with its core member being strongly embedded in region-external networks (lines crossing the thick dot-dashed circle[35]).

Figure 12: Schematic Illustration of Knowledge Networks in a Globalised Dirigiste RIS



Author´s illustration; circles=firms, squares=HEIs and/or research institutes, bolded circle/square=most central actors, dot-dashed circle=RIS

With its central (or focal) actor and the surrounding smaller support organisations, a globalised dirigiste RIS is likely to entail hub-and-spoke structures as elaborated by MARKUSEN (1996). This structure translates to the networks with the hub being the central actor and the other actors (spokes) being organised similarly to a chariot wheel (see ***Figure 12***). The actors in the district headed by the central actor are likely subject to a distinctive 'depth' hierarchy of power and governance. The hub organisation is at the top of a 'pyramid' and numerous, subordinated suppliers are ordered at different levels below (NAKANO/WHITE 2006:12-19). This structural type is expected to occur to varying degrees where, firstly, supplier and industrial structures revolve around one or several large, vertically integrated companies in one or more industries and/or where, secondly, one or more major public or non-profit organisations (e.g. a government/public research institute, HEI, governmental office, military facility, etc.) an-

[35] This may also encompass the aforementioned HQ-subsidiary relations, where either the subsidiary or the HQ is located inside and the respective other part outside the region.

chor a district (MARKUSEN 1996: 302, 306). In any case, the hub coordinates and governs the regional network activities of their subordinate organisations. At the same time, they ensure necessary, non-regional knowledge flows into the district through their global embeddedness. If a region hosts more than one hub, local interactions between them are possible, even though interaction activities always depend on firm- and industry-specific characteristics and the willingness of the respective organisations to collaborate (ibidem).

When applying the network perspective to this RIS type consistency with the other cases is necessary. However, the case-wise strong integration of the hub into non-regional governance and knowledge exchange systems implies that it is a mere extension of these systems. This becomes particularly visible when the hub is a subsidiary of a MNE with its headquarters outside the focal region. For analytical reasons, I will ignore this particularity and exclusively focus on regional hub(s) and their intra-regional network(s).

What can be straightforwardly said, though, is that by nature this hub has a very large absolute number of cross-regional links, while the supportive organisations are characterised by low numbers. In addition, the following insights about this RIS type can be derived when applying the network perspective.

The size of the intra-regional network(s) can range from very small to large depending on the number of hub organisations (i.e. focal actors) and the size of the respective districts they are heading. The number of networks mirrors the number of hubs, which are, however, unlikely to exist in great numbers as the number of focal actors is usually small. In the case of two or more hub organisations, the network of the RIS has multiple fragments. In any case, due to the hierarchy, the hub network(s) will consist of weakly connected sub-networks (components) formed among organisations that are part of the hub's support network (see ***Figure 12***). Moreover, the network is most likely to consist of a small number of components as only very few regional R&D actors meet the needs in order to participate in these globalised knowledge networks (HENRY et al. 1995). If multiple hub organisations exist and are only weakly interlinked (which is very likely according to MARKUSEN (1996)), the overall density of the network will be relatively low due to the network's hierarchy and the existence of multiple components (see explanation above; NAKANO/WHITE 2006). If a single hub organisation exists, network density will be higher but not high.

According to their hub-and-spoke structure, hub networks usually show star-like structures (see Section 3.3.2). The length of the rays depends on the hierarchical structure of the hub's regional knowledge network and on the number of value-chain stages that district organisations contribute to. NAKANO & WHITE (2006) suggest that subcontracting in MNE networks fosters the emergence of complex supplier networks which may exhibit small-world features. However, this requires significant collaboration among the subcontracting SMEs, which are usually rare when hub-and-spoke type structures are ideal-typically developed.

The interpretation of the distribution of node centralities is also relatively clear. The hubs are characterised by superior degree centralities as they are intensively linked to their support organisations due to the above mentioned depth hierarchy patterns. The hubs qualify as gatekeepers for the rest of the region, as they are the only actors that link the region's (or district's) internal networks with actors outside the region. However, the hubs do not necessarily dominate in terms of betweenness centrality, as it might be the case that smaller regional actors are able to simultaneously link to multiple hub-headed-networks. Such smaller regional actors are not hubs themselves but most likely (public) research institutes or HEIs located in the region. They are able to offer services and knowledge to different industries and hence link different sub-networks (see ***Figure 12***, indicated through the dotted line in the middle) (FRITSCH/SCHWIRTEN 1999; BECKER/PETERS 2000; FRITSCH/KAUFFELD-MONZ 2010; KROLL et al. 2012). They thereby obtain the highest values in betweenness centrality, which if they do not exist, characterise the hub actors. The presence of such organisations that link otherwise unconnected parts of the network significantly increase knowledge diffusion in the RIS, which is otherwise severely hampered due to the existence of multiple hub networks.

When a globalised dirigiste RIS is formed around single or few hubs, its networks are highly centralised and exhibit the largest network centralisation of all RIS types. Centralisation, however, decreases with the number of hubs in the system. Isolates and strong fragmentation are not typical within a network characterised by hub-and-spoke structures. However, hub-and-spoke networks are particularly vulnerable in case a hub ceases to exist (e.g. closing or relocation), as the number of hubs is likely to be small. In case of such an event, the network or at least the respective network component (if more than one hub is present) will lose its integrative force and completely dissolve, which implies significant reductions in regional knowledge diffusion and access to inter-regional knowledge pipelines (BATHELT et al. 2004). If more than one hub exists, the other network components will remain intact; which indicates that the robustness of the total network structure depends on the number of hub organisations present in the region.

It is important, however, to point out that such RISs have at least one component that does not show the described hub-and-spoke characteristics. This component represents the network of the regional economy that is not part of any hub-headed district (in ***Figure 12***, small circle in the middle). Given the low relevance of these organisations for innovation activities in the region, it can be neglected at this point.

3.5 CONCLUSION

The aim of this chapter was to integrate the network perspective into the RIS approach, as the latter strongly relies on the conceptual basis of networks but so far lacks network theoretical components (GRABHER 2006; TER WAL/BOSCHMA 2009). By applying a network-theoretical perspective I evaluated arguments made in RIS Research on knowledge sharing and interaction structures of regional innovation processes. In the theoretical discussion I focused on three ideal-typical types of RIS put forward by COOKE (1998, 2004): the interactive network RIS, the localist grassroots RIS, and the globalised dirigiste RIS. The results of the discussion are summarised in ***Table 10***.

<u>Table 10:</u> Summary of Knowledge Network Characteristics in Different RIS Types

Knowledge network characteristics	Interactive networked RIS	Localist grassroots RIS	Globalised dirigiste RIS
Basics			
Size	- Large	- Small	- Medium (increases with number of hubs)
Density	- Low	- Overall: Medium - Core: High - Periphery: Low	- Medium (decreases with number of hubs)
Structural appearance			
Network governance	- Multi-level	- Regional	- Regional external
Dominant actors	- None	- Research organisations & larger firms	- Large firm or research organisation
Collaboration propensity	- Very high	- Between and among leading firms and research organisations:high - Between leading firms and SMEs: low - Between research organisations and SMEs: very low - Among SMEs: high	- Within network of the hub actor: high - Between the network of the hub actor and the local economy: low
Relevance of regional interaction	- High	- High	- Low
Relevance of cross-regional interaction	- High	- Low (depends on size of core)	- High
Isolates	- Few	- High	- Few
Fragmentation	- Low	- Overall: Medium - Core: Low - Periphery: High	- One hub-and-spoke network: Low - More than one network: Medium
Network structure	- Small-world	- Core-periphery	- (Multiple) hub-and spoke
Robustness to node failure	- Very robust	- Robust	- Highly vulnerable to hub(s) failure
Centrality and centralisation			
Distribution of degree centralities	- Power-law like	- Bimodal	- Bimodal
Highest betweenness centrality	- Organisations (mostly firms) connecting clusters	- Leading firms	- Public R&D actors or hub firms
Network centralisation (comparative view)	- Low	- Medium	- High (depends on number of hubs)

Table provided by author; based on discussion results from Section 3.4

The table shows distinct network-structural properties that have been derived for the three RIS types on the basis of existing literature. For instance, small-world type network structures are likely to characterise the interactive network RIS; core-periphery network structures can be expected in localist grassroots RIS, while the most pronounced characteristic of networks in globalised dirigiste RIS are multiple (largely) unconnected star-type network components. In addition, I elaborated on, for instance, the distribution of centralities, network size, density, and degree of network centralisation. I thereby add to the integration of the two (still) largely unrelated streams of literature on RIS and network research and provide inputs for empirically testable hypotheses in future research.

Given the significance of knowledge relations and R&D related interaction in RIS, the present work contributes to the addition of an explicit *Network Dimension* to the analysis and classification framework of RIS types. This further sharpens and enriches existing classifications and enhances the application of analytical and methodological concepts of network analysis within the framework of RIS. The benefits of integrating the network perspective into RIS Research are, however, not limited to scientific issues. For instance, network-related insights can be used as additional input for tailored policy designs that aim to stimulate (regional) collaborative R&D and knowledge exchange. Moreover, SNA may serve as a basis for a more targeted management of interactions and networks in RISs. In the design, execution, and evaluation, the Network Dimension will valuably complement the existing Business and Governance Innovation Dimensions.

It is, however, equally important to highlight the benefits of integration for research on inter-organisational networks in Economic Geography. For instance, the present work indicates a strong correspondence of RIS types and distinct network structures. Given that this (so far hypothetical) correspondence will be validated in future research, network-oriented research can be enriched with the substantial insights offered by the RIS literature with respect to organisational and institutional settings and relationships (MACKINNON et al. 2008; BOSCHMA/FRENKEN 2008; TER WAL/BOSCHMA 2009).

While I believe that the work presented in this chapter makes a valuable contribution to the existing literature, there are a number of limitations, of which the most important ones have to be addressed. Firstly, I applied the network perspective to the three most ideal-typical RISs of COOKE´s RIS concept. It has yet to be shown whether the network perspective will be as insightful when the remaining six RIS types and other RIS concepts (e.g. ASHEIM/ISAKSEN 2002) are considered. In addition, I focused on the most common and suitable SNA concepts. In a next step, it would thus be interesting to discuss additional, so far neglected network structural characteristics (e.g. actor type-specific closeness and eigenvector centralities). This provides the chance to further expand the network-theoretical basis of the RIS approach.

Furthermore, my elaboration on structures of knowledge networks and RISs uses a static perspective. I focused on ideal types of RIS and network structures observed at one particular stage of development. The debate about lock-ins, path-dependency, and the evolution of RISs in general and knowledge networks in particular (e.g. GRABHER 1993; COOKE et al. 1998; BATHELT et al. 2004; VISSER/BOSCHMA 2004; ASHEIM/GERTLER 2005; TÖDTLING/TRIPPL 2005; FU 2011; BALLAND 2012), however, requires a more dynamic perspective in future research. This research should strongly focus on the co-evolution of RIS and network structures. For instance, small-world properties are more likely to emerge when preferential attachment processes are at work. Hence, in light of this study, one may ask why these processes are particularly strong in the evolution of interactive networked RIS.

Last but not least, the present chapter exclusively puts forward theoretical and hypothetical considerations. This implies, however, that empirical validation is still missing. Thus, in addition to further theoretical elaborations, future research should also include a substantial empirical agenda.

Chapter 4

THE REGIONS OR THE SECTORS: WHAT DETERMINES SMALL-WORLD NETWORK STRUCTURES IN REGIONS?

Abstract[36]

The small-world network structure has increasingly moved to the front of the innovation-related research, because its advantageous knowledge diffusion properties and its very robust structure promise high inventive productivity. From an economic geographic point of view, it is particularly interesting that recently useful and enriching insights have been provided regarding the impact of the small-world network structure on regional innovation capabilities.

However, what is missing so far is a discussion about how the existence of this favourable network structure is determined in regions. Arguments that assume an influence can be found in the innovation literature from both Economic Geography and Industry Research. While the former stresses the importance of the regions in this respect, the latter highlights the relevance of sectors. In both cases, however, empirical evidence is rare. To shed light on this, this chapter empirically investigates whether variables depicting regional and sectoral characteristics relate to the probability of finding small-worldness in regional knowledge networks.

4.1 INTRODUCTION

Since it is accepted that innovations are major drivers of economic development and prosperity (OECD 2007), their formation is subject of incessant scientific debate (for an overview see e.g. KOSCHATZKY 2001). In this context, in the last two decades especially research on innovation processes at the regional scale moved to the fore (CAMAGNI 1991; MORGAN 1995; STORPER 1995, 1997a; COOKE et al. 2004). In addition, within (regional) innovation research, the field of network research has become established due to the increased interest in the networking of actors in (regional) innovation processes (for an overview see e.g. GRABHER 2006 and TER WAL/BOSCHMA 2009). Within this broad field, however, some researchers particularly highlight the network structural level, as it is supposed to influence regional innovation capabilities (FLEMING et al. 2007; BRESCHI/LENZI 2011). However, the small-world network structure is particular popular in this respect. This particular network structure is proven to be best in diffusing knowledge and considered to be very robust (COWAN/JONARD 2004, 2007).

Research has provided useful and enriching insights with regard to the impact of small-world network structures on innovation processes and capabilities. However, very little is known about how the existence of such a favourable network structure is determined in regions. I will show that both the RIS literature from Economic Geography and the literature from Industry Research provide arguments that allow to assume a connection. While the for-

[36] An earlier version of this chapter has been presented at the research colloquium of the Institute of Economic and Cultural Geography of the Leibniz Universität Hannover (2014).

mer stresses the importance of the region in this respect, the latter highlights the relevance of the sector. In both cases, however, empirical evidence is rarely provided.

In light of this, *the aim* of the present chapter is to gain empirical insights on the question whether regional and/or sectoral characteristics relate to small-world network structures in regional knowledge networks[37]. In order to address this issue, innovation networks are constructed in German Planning Regions based on patent data, and are categorised as being small-world or not. Subsequently, I test whether variables depicting regional and sectoral characteristics are associated with the probability of finding small-worldness in regions. In doing so, this combined examination has the potential to contribute to the discussion whether regional and/or sectoral characteristics influence network structures.

The chapter is structured as follows: Section 4.2 discusses theoretical issues from economic geographic RIS Research and Industry Research that indicate a relation to the existence of small-world network structures in regions. Moreover, research deficits are pointed out and expectations are formulated leading to the formulation of a research question and hypotheses. Section 4.3 addresses data and methodological issues that are necessary to perform the empirical examination. In Section 4.4, the model quality is tested and the empirical findings are presented. In Section 4.5, the results are discussed. Section 4.6 concludes with final remarks.

4.2 THEORETICAL BACKGROUND

It is generally accepted in academia and politics that innovations are a major driver of technological change and economic prosperity (ROMER 1986, 1990; MALECKI 1997; VERSPAGEN 2006) and it is widely known that innovation creation is often a process characterised by interactions and networking (NOOTEBOOM 2000; POWELL/GRODAL 2006; SORENSON et al. 2006). On the one hand, the fundamental relevance of interactions results from the need to learn and exchange information and knowledge. On the other hand, in a rapidly evolving environment of ever shortening innovation and product life cycles, increasing complexity and specialisation, interactive learning activities and cooperations also ensure external expertise, potential for cost reductions, efficiency gains and reduction of uncertainties (DODGSON 1994; HAGEDOORN 2002). Consequently, the success of innovation generation is closely related with the capability of innovating actors to cooperate and participate in networks[38] (POWELL et al. 1999; UZZI 1996; PITTAWAY et al. 2004; SINGH 2005; PIPPEL 2013). Politicians have recog-

[37] In order to improve the legibility of the text, in the following the term 'small-worldness in regions' is frequently applied instead of, for instance, 'small worldness in regional knowledge networks' or 'small worldness in knowledge networks of regional innovation processes'. However, the meaning is the same.

[38] Collaborations are not per se important or beneficial to innovation. They might also imply negative effects which could threaten the success of innovation projects (e.g. SHAPIRO/WILLING 1990; BLEEKE/ERNST 1993; KESTELOOT/VEUGELERS 1995).

nised this fact and have massively extended policy-driven supports of *joint* innovation projects since the mid 1980s (CZARNITZKI et al. 2003; BROEKEL forthcoming).

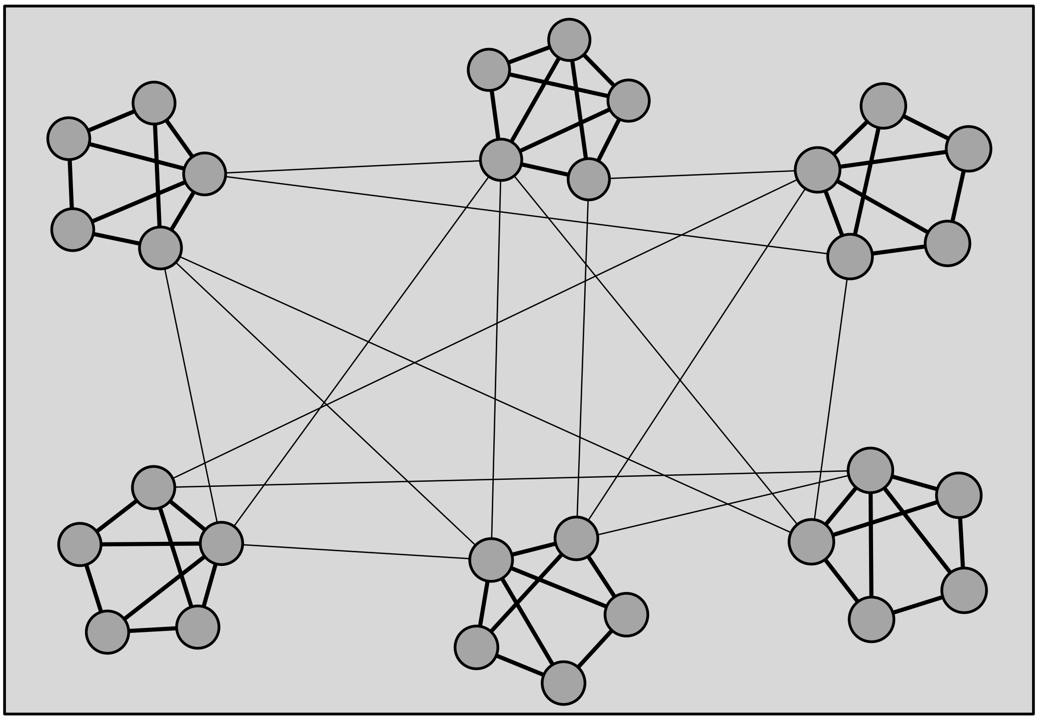
Both the generally accepted importance of networking for innovation and the interest from the political level have led to an increased popularity of network analyses in the last two decades (see e.g. BERGENHOLTZ/WALDSTRØM 2011). Within the wide range of innovation-related network research, however, a growing number of researchers are especially dealing with questions related to the structure of a network. They are particularly concerned with questions regarding the relevance of nodes (i.e. actors) and their relations for the network structure (CANTNER/GRAF 2006; BOSCHMA/FRENKEN 2010; BROEKEL 2012) as well as for the development of network structures over time (BALLAND 2012; BALLAND et al. 2013; TER WAL 2013).

Moreover, some studies focus increasingly on the impacts arising from network structures. Thereby, many authors especially focus on the small-world network structure, and analyse the influences of 'small-worldness' on the innovation capability of actors (SCHILLING/PHELPS 2007), regions (FLEMING et al. 2007; BRESCHI/LENZI 2011), and countries (CHEN/GUAN 2010). The focus on the small-world network structure can be particularly attributed to its advantageous features. COWAN & JONARD (2004) have for instance shown in their simulation-based test of network structures that the small-world network structure is best in diffusing knowledge, i.e. "that new information or ideas generated within the network may rapidly reach (or spill over to) all other nodes and be recombined with their own knowledge, thereby improving inventive productivity" (BRESCHI/LENZI 2011:2). In addition, small-world networks are characterised by a comparably high robustness to changes, meaning that in contrast to other types of network structure the failure of actors does not necessarily have significant implications for the integration of the complete network (KOGUT/WALKER 2001; COWAN/JONARD 2007).

Generally, the small-world network structure is probably one of the most studied network structures in science since MILGRAM (1967) published his landmark study. Examples of small-world properties in the real world are numerous. They are discussed, for instance, with respect to social or friendship networks (TRAVERS/MILGRAM 1969; DODDS et al. 2003), Hollywood networks of actors (WATTS 1999a), collaboration networks of scientists (NEWMAN 2001b; GUIMERA/AMARAL 2005), interfirm alliance networks (BAUM et al. 2003), the human brain (BASSETT/BULLMORE 2006), urban street networks (JIANG 2007), or large-scale networks of suppliers and buyers in industrial districts of Tokyo (NAKANO/WHITE 2006).

But what is small-worldness and what are its characteristics leading to the favourable features mentioned above? Small-world networks are characterised by a high degree of 'clustering', i.e. the frequent presence of cliques (at least three nodes (i.e. actors) that are completely linked) in a network (see ***Figure 13***). This implies that the average shortest path length in the network is relatively low, because as the cliques are connected by few 'far-reaching' links (brokers or gatekeepers), even large networks with low density may obtain low actor-to-actor distances. Therefore, the small-world network structure is a network structure "that is both highly locally clustered *and* has a short path length, two network characteristics that are normally divergent" (UZZI/SPIRO 2005:448). This structure is the result of a specific distribution of degree values (i.e. centrality) similar to that of power-law function. The actor population thus tends to have power hierarchy, as a few central actors act as brokers by establishing the links between the interlinked groups and cliques of actors. Finally, this means that few actors are characterised by high centralities and many by low centralities (RAVASZ/BARABÁSI 2003).

Figure 13: Schematic Illustration of a Small-World Network



Author´s illustration; circles = network actors; thin lines = inter-clique links; bolded lines = intra-clique links

Although small-worldness in knowledge networks can be discussed at different (territorial) levels, I focus on the regional (i.e. sub-national) level. Regions as geographical units are recognised as being central to the organisation of economic and innovative activities (OMAE 1995; STORPER 1997b; DUNNING 2002; SCOTT/STORPER 2007; OECD 2009b). This is because due to social aspects of learning and interacting (SAXENIAN 1994, 2006; SINGH 2005), innovation processes are particularly located at the regional level (LUNDVALL/BORRÁS 1997:39).

Unlike in existing works, however, the emphasis of my work is not put on the impact of small-worldness on the region (for instance its innovation capabilities), but deals with the largely insufficiently explored question of *what determines small-world network structures in regions*. In this context I examine whether characteristics of the regions or the sectors relate to the existence of small-world network structures in regional innovation networks[39]. The reason to do so is that innovation literature frequently cites characteristics of *regions* and/or *sectors* as the crux of networks and their underlying structures (e.g. CAMAGNI 1991; BROEKEL/GRAF 2012). Therefore, it is also likely that these 'levels' relate to small-worldness. In addition, so far both perspectives have always been discussed separately in the network context.

In the following, the arguments suggesting a relation between regional and/or sectoral characteristics and small-world network structures in regions are elaborated.

4.2.1 Regional Characteristics Supporting Perspective

The perspective that particularly stresses the importance of the region in relation with networks is largely rooted in the field of Economic Geography. It is traditionally assumed that the region, consisting of various actors, elements and characteristics, shapes most economic and innovative activities (e.g. CAMAGNI 1991; STORPER 1995).

So far, however, related approaches like the concept of industrial districts (e.g. PYKE et al. 1990), the concept of innovative regional milieus and networks (AYDALOT/KEEBLE 1988), the concept of learning regions (e.g. FLORIDA 1995, 1998), the cluster approach (e.g. PORTER 2000), and the Regional Innovation System (RIS) approach (COOKE et al. 2004) make rather vague statements about networks in general and on the influence of regional factors on regional innovation network structures in particular (TER WAL/BOSCHMA 2009). This theoretical imprecision is caused by the fact that empirical evidence on the relation between the region and networks is still rare (ibidem).

In principle, the above mentioned approaches follow the same theoretical argumentation: It is assumed that geographical and socio-institutional proximity lead to extensive, i.e. large and dense regional networks. This implies that all regional actors are similarly embedded in regional networks and that network structures hardly vary between regions (BOSCHMA/TER WAL 2007, 2009). However, this clearly contradicts insights from network research suggesting significant heterogeneity in the embeddedness of organisations into regional networks (e.g. GIULIANI/BELL 2005; GIULIANI 2007; BOSCHMA/TER WAL 2007; BROEKEL/BOSCHMA 2011) as well as heterogeneous regional network structures (FLEMING et al. 2007).

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[39] I use innovation networks to depict knowledge networks of innovation processes in regions. Both the construction of innovation networks as well as the limitations related to this approximation to reality is described in Section 4.3.1.

This research deficit has already been emphasised in Chapter 3. By discussing theoretical arguments about interactions and knowledge exchange relations in the RIS literature from the perspective of social network analysis, I elaborated to what extent regional characteristics are connected to the existence of *specific* regional network structures. As a result, I finally provide hypotheses on why and how RIS (or regional) characteristics may influence the type of network structures in regions. My discussion involves three types of regions (i.e. RIS types) with three distinct coining network structures – including also the small-world structure.

Referring to these discussions, it can be expected that small-worldness is associated with characteristics found in regions with an interactive network RIS[40]: From a normative perspective an interactive network system is universally regarded as the most ideal RIS type (COOKE 1998, 2004). It shows a relative balance between small and medium-sized enterprises (SMEs) as well as large firms, with the majority of firms being engaged in R&D. The R&D activities are predominantly focused on advanced or high-tech sectors. Usually, numerous research entities (i.e. HEIs[41] and/or research institutes) exist in such regions, which support the R&D activities of firms (ibidem). Nevertheless, the profit-oriented private sector is clearly the driving force in the system; the research sector particularly plays a supportive role (BEISE/STAHL 1999; CANIËLS/VAN DEN BOSCH 2011). In general, the propensity for collaboration between regional actors is argued to be very high, as the technological sophistication of organisations is associated with strong efforts to participate in knowledge networks. Moreover, these regional innovation activities are embedded in well-developed regional institutional infrastructures (BRACZYK et al. 1998 or COOKE et al. 2004). In addition to the intense regional collaboration characterising this type of RIS, many regional actors (public and private) are well connected to extra-regional actors, as they "[…] cannot rely only on localized learning, but must also have access to more universal [(i.e. extra-regional)], codified knowledge […]" (ASHEIM/ISAKSEN 2002:84). Hence, an interactive network RIS corresponds to a significantly sized agglomeration of public and private organisations that interactively engage in R&D on the regional as well as on the national and international level.

Translating this description into network terminology, according to the elaborations from the third chapter, it becomes obvious that interactive network RISs can be expected to show large regional networks (i.e. large number of nodes) with an above-average number of linkages. Moreover, due to their interactive set-up regional nodes are not only likely to be above-averagely embedded in intra-regional knowledge networks but also that many nodes have

[40] Parts of the description regarding the relation between the interactive network RIS type and small-worldness are taken directly from Chapter 3.
[41] HEIs are universities, applied universities, polytechnical universities or the like.

extra-regional (i.e. national or international) links.

However, taking into account the law that low densities characterise large networks, this is only plausible if the RIS's balanced mix of SMEs and large firms yields a rather average link maintenance and initiation capacity, which in turn suggests that the network will be of lower density than in other regions. This follows the reasoning that density is likely to decrease as the number of organisations in the RIS exceeds the average capacities of the actors to initiate and maintain links (see Chapter 3, Section 3.3.2).

Another feature of this type of RIS is that its actors differ in terms of reputation and absorptive capacities due to size differences (COHEN/LEVINTHAL 1990; GIULIANI/BELL 2005; GIULIANI 2007; BOSCHMA/TER WAL 2007), with large innovative firms likely to lead the field, followed by research entities and SMEs. Moreover, the interactive network RIS is dominated by firms, since the business sector is argued to play the most important role for knowledge generating activities (SCHUMPETER 1911; NELSON/WINTER 1982). Accordingly, owing to advantages of firms regarding reputation and absorptive capacities as well as their general importance with respect to knowledge creation, it can be expected that firms also hold the central positions. However, this is likely to apply particularly in terms of larger firms, as they have the necessary levels of reputation and absorptive capacities to take central positions. Given that there is a large number of highly central actors in this type of RIS, network centralisation can be expected to be relatively low.

The central actors link otherwise unconnected parts of the network, which primarily include SMEs and research entities that play supportive roles in R&D activities. In this sense, they act as integrative nodes and impose a hierarchical network structure, as their centrality is larger than that of supportive actors. This is, however, not to say that the (public) research sector is irrelevant (CANIËLS/VAN DEN BOSCH 2011; KROLL et al. 2012). In an interactive network RIS, public research is argued to be significant and to contribute actively to knowledge production and diffusion (FRITSCH/SCHWIRTEN 1999; COOKE 2004).

All the major features – the unequal distribution of network centralities, the large size of the network paired with a generally low density – have important implications for a RIS's capacity to diffuse knowledge among its organisations. Knowledge diffusion generally becomes easier with increasing network density (COWAN/JONARD 2004). Given the outlined characteristics, one might therefore not expect an interactive network RIS to be characterised by easy and fast knowledge diffusion. The contradiction between RIS characteristics and network mechanics can only be dissolved by a network structure combining low density, unequal node centralities, and (still) high diffusion properties. As known from former explanations, a network structure with such features is the small-world type. Hence, the high number of highly interrelated actors with a distinct hierarchy in the R&D processes, and the easy and fast knowledge diffusion lead to the hypothesis that a knowledge network within an interactive network RIS is characterised by small-world properties. Besides the leading firms being most central, this structure requires that the (public and private) support organisations form groups of strongly interlinked actors, which corresponds to clustering processes in network terminology (WATTS/STROGATZ 1998).

4.2.2 Sectoral Characteristics Supporting Perspective

In contrast to the field of economic geographic RIS Research, the very broad field of Industry Research particularly stresses the relevance of sectoral characteristics when discussing the differences of networks. This stream of literature generally claims that sector-specific considerations are of major importance. This assessment is based on various findings, e.g. pioneering contributions which discuss sectoral differences of technical change (PAVITT 1984), patenting behaviour (ARUNDEL/KABLA 1998), sectoral differences of technological regimes (BRESCHI et al. 2000), and sectoral difference of knowledge bases (ASHEIM et al. 2007).

The assumption about the existence of sector-specific impacts on innovation networks arises, however, particularly from works of BRESCHI & MALERBA (1997) and MALERBA (2002, 2004) about Sectoral Innovation Systems (SIS). As it is known from innovation system literature in general, also in SISs actor relations and networks are seen as key elements of innovation and production processes (EDQUIST 1997). However, in contrast to other related concepts such as National Innovation Systems (NIS) (e.g. FREEMAN 1987; LUNDVALL 1992; NELSON 1993), Regional/local Innovation Systems (RIS) (e.g. COOKE et al. 2004), or Technological Innovation Systems (TIS) (e.g. CARLSSON/STANKIEWICZ 1991) the SIS approach suggests that especially *sector-specific* superior conditions (e.g. knowledge base, technologies, inputs, demand, etc.), attributes of actors (e.g. learning processes, competencies, organisational structure, etc.), and institutional settings (e.g. routines, norms, behaviours, rules, etc.) are shaping innovation and production processes in general as well as therewith associated interactions and networks in particular (MALERBA 2002:248).

These expectations are backed up by related network research, as empirical evidence from this field shows that the degree of network embeddedness (centrality) of organisations, i.e. an individual node's capacity to initiate and maintain links to other nodes, is usually limited and depends on numerous factors such as size, market power, and knowledge capacities (GIULIANI/BELL 2005; GIULIANI 2007; BOSCHMA/TER WAL 2007; MORRISON 2008;

BROEKEL/BOSCHMA 2011). Taking into account, that according to Malerba (2002), such actor attributes vary across sectors (see above), and therefore also the abilities of actors from different sectors to initiate and maintain links to others, it is plausible to argue that sector-specific influences on network structures in regions also exist.

Another study from network research points into the same direction, but adds an evolutionary perspective. TER WAL & BOSCHMA (2011) have recently discussed how networks evolve along an industry´s life cycle. Thereby they distinguish four stages of an industry life cycle: (1) the introductory stage, (2) the growth stage, (3) the maturity stage, and, finally, (4) the stage of industry decline or start of a new cycle. Within each stage of this life cycle, due to changing conditions and needs associated with the stepping through of the phases, industries have changing features in terms of the above mentioned superior conditions, actor attributes, and institutions. This in turn will "[…] affect the evolution of variety across firms in the industry, the networks in which firms take part and the pattern of spatial clustering" (TER WAL/BOSCHMA 2011:924).

While having enough evidence to assume that sectoral characteristics correlate with network structures in general, it is necessary to discuss how sectors – that in principle follow a multidimensional rather than a space-specific view (MALERBA 2002) – can be thought to be related with networks and their structures in regions. From a theoretical perspective this works best when following PORTER´s notion of 'clusters' as geographically concentrated industrial sectors (PORTER 2000)[42]. In this sense, the vertical dimension of clusters (intersectoral) is to be understood as the regional manifestation of SISs (COOKE 2002b). Thus, by means of regional sectoral clusters, sectoral characteristics can be related to innovation networks in regions.

Based on this conceptual clarification, it can now be discussed how sectoral characteristics relate to small-worldness in regions. It is known that small-worldness requires a certain degree of power hierarchy, as it ensures that some central actors interlink groups. Finally, this characteristic leads to the shaping clique-structure (i.e. clustering) of small-worldness (see ***Figure 13***). But it is also known that the ability of an actor to take on such a central function highly depends on, for instance, its competencies, market power, or knowledge capacities, which is in turn strongly associated with the sector-specific size of an actor. Therefore, it can

[42] PORTER (2000:16) defines cluster as "geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions (e.g., universities, standards agencies, trade associations) in a particular field that compete but also cooperate." Such clusters may have a horizontal and/or a vertical dimension. The former describes cooperations between actors from different but related industries (inter-sectoral), the latter cooperations from the same industry (intra-sectoral). When talking about 'clusters as geographically concentrated industrial sectors' – with regard to the applied data – I focus on intra-sectoral clusters, as regional innovation networks are technology-specific within the regions (see Section 4.3.1).

be expected that innovation networks in regions, which are coined by collaborating actors from sectors with a medium to large actor-size structure will have a larger probability to show small-worldness than those which are coined by collaborating actors from sectors (and SISs) with relatively small actor-size structure.

Furthermore, by analysing the structure of innovation networks from ten different industries, BROEKEL & GRAF (2012) have found out that sectoral networks systematically differ in terms of structural characteristics. Reasons for this are particularly attributed to varying actor compositions within the industries. According to the authors, knowledge networks which are significantly coined by HEIs and research institutes are smaller, more centralised, and denser than those being firm-oriented (ibidem:367). They argue that this is due to advantages of research actors in knowledge fields with a high codification level, leading to the circumstance that firms are less represented and less influential. Hence, as it is known that small-worldness exhibits rather low overall centralisation as well as low density values, it can be expected from these findings, that sectors with significant research participations will have an adverse effect on the probability to find small-worldness in innovation networks in regions.

The theoretical discussion unveils that, in contrast to the former view, Industry Research rather follows a multidimensional, integrated and dynamic view of sectors, suggesting that innovation networks in space – i.e. also those in regions – are especially influenced by sectoral characteristics (e.g. MALERBA 2002). However, as it is the case with the field of Economic Geography, empirical evidence is also largely non-existent in this field.

4.2.3 Research Question and Hypotheses

The above discussion clarifies that from a theoretical perspective both regional and sectoral characteristics could explain regional innovation network structures in general and small-worldness in particular. Nonetheless, in both cases empirical evidence is rare, especially from a comparative point of view. This means, little is known so far whether regional or sectoral characteristics or if even both relate to small-worldness in regions. With the present chapter, I want to contribute to this debate. The leading research question thus is:

Are regional and/or sectoral characteristics associated with the probability to find small-world network structures in regions?

In order to answer the research question, hypotheses have to be tested which are based on the arguments and expectations from the above discussion (see Section 4.2.1 and 4.2.2). The following hypotheses are derived:

HYPOTHESIS 1 (**H1**): *Characteristics of regions with features of interactive network RISs relate to small-world network structures in regions, i.e.:*

a) *Small-worldness is more likely to occur in regions where the RISs have a large number of innovating actors.*

b) *Small-worldness is more likely to occur in regions where the RISs show high overall collaboration propensities.*

c) *Small-worldness is more likely to occur in regions where the business sector is the driving force in innovation processes in the RISs, and the public research sector plays an important supportive role.*

d) *Small-worldness is more likely to occur in regions where the RISs have intense intra-regional collaboration activities.*

HYPOTHESIS 2 (**H2**): *Characteristics of sectors relate to small-world network structures in regions, i.e.:*

a) *Small-worldness is more likely to occur in regions where the collaborating actors are from sectors with a medium to large actor-size structure.*

b) *Small-worldness is more likely to occur in regions where sectors are not coined by significant participation of research entities.*

4.3 METHODOLOGY AND DATA

4.3.1 Regional Innovation Networks

Database

I construct the innovation networks in regions by making use of patent application information from the OECD REGPAT Database[43], July 2013 edition. Patents provide information on the output and processes of inventive activities (OECD 2009c), and are therefore somewhere in between inventions and innovations. A patent protects new inventions and gives the owner the spatial and temporary privilege of exclusive use and exploitation of the invention. Simultaneously, the patent owner can prohibit unauthorised use of the patent and the knowledge contained therein. This monopolisation of the use and exploitation and the resulting possibility of exclusive economic exploitation is a major incentive to apply for a patent (DPMA 2014).

[43] Scientific access to this database can be gained by writing an email to sti.contact@oecd.org.

However, there are also a variety of limitations attached to them (PAVITT 1985; GRILICHES 1990). In the context of this chapter, the most relevant are the following: For instance, patents only include a part of the totally produced knowledge (FRIETSCH et al. 2008:1), namely explicit, codified knowledge (GRUPP 1997). [44] The implicit knowledge resulting from learning processes is not considered. In addition, patents usually result from R&D activities. But, more than half of all innovating firms in the European Union (EU) and about 40% of all innovating firms from Germany are non-research and development (R&D)-performers (ARUNDEL et al. 2008; RAMMER et al. 2011). Moreover, according to their nature, patents tend to indicate only technical or technological knowledge created by the industrial sector. Only 3-5% of all patents come from service companies (FRIETSCH/SCHMOCH 2006:94). As a result, innovations from the service sector and organisational innovations are almost not considered (MAIRESSE/MOHNEN 2003).

A strong technology-oriented understanding of innovation may in particular have a distorting influence when regions have no significant industrial firms and/or research entities (HEIs and/or research institutes), or when they are marked by a strong presence of SMEs. The latter has a distorting effect, because SMEs are often either involved in non-technological innovation processes or in technological innovation processes that are not patented (e.g. MASUREL 2002). In addition, patents list only those innovating actors who have been directly certified. This means, in case regional actors have been involved only indirectly in the invention or innovation process – e.g. in the form of informal consultations – they would not be registered.

Furthermore, the validity of a patent may be limited by sectoral differences regarding patenting propensities. This means that in practice R&D activities of some sectors may not necessarily lead to patents, although innovation activities might have taken place and R&D processes might have been completed (MANSFIELD 1986:177). In addition, patents can also be registered for strategic reasons and not for bringing new products on the market. BLIND et al. (2009) point out that patents can be used to prevent competitors from registering their own patents or even to foreclose entire technologies. Additionally, the possibility exists to use patents as a quasi ‘currency’ in the context of exchange contracts (cross-licensing) in order to get access to foreign technologies.

Despite these peculiarities, I finally decide to make use of patent data, as it is generally assumed that patents are predominantly registered with the goal of bringing new knowledge and new technologies to the market (OECD 2009c). Moreover, as all patent applications go through a formally prescribed procedure, patents have the advantage that the resulting data-

[44] Relative to the total knowledge, the proportion of explicit technical and technological knowledge produced within R&D activities is likely to be comparatively small.

bases are publicly accessible, consistent, and complete (GRAF 2011). In total, this makes patents one of the most widely used innovation activity and process indicators in innovation research (NAGAOKA et al. 2010).

The applied database represents patent applications to the European Patent Office (EPO; based on PATSTAT, April 2013) and Patent Cooperation Treaty (PCT) patents at international phase (based on the OECD patent database, including patents published up to May 2013) and includes the addresses of applicants and inventors at a very detailed regionalised level (Nomenclature of Territorial Units for Statistics (NUTS) 3, for European regions, and Territorial Level (TL) 3 [45] for regions of other countries) for most OECD and EU27 countries, plus the BRICS[46] countries (MARAUT et al. 2008; EPO FORUM 2013; OECD 2013).

Definition and Approximation

Innovation networks in regions form the observation set of this work. They depict only intra-regional relations in knowledge networks of innovation processes and are defined as technology-specific networks $G_{i,j}$, where j denotes the respective technology-field each of the different innovation networks are assigned to, and i denotes the respective region the innovation networks are located in [47].

Patents provide information about actor names (i.e. persons or organisations), their relations in co-patent projects, and their geographical information. Due to this, actor-by-project information can be extracted from the OECD REGPAT Database, finally allowing creating the so-called two-mode incidence matrix. By transforming this matrix, in turn, the unimodal actor-by-actor information results, the so-called adjacency matrix or neighbourhood matrix, respectively. This matrix unveils which actors are related to each other and thus are part of the same innovation network. As – according to the research aim – the present work is focused on the network structural level, innovation networks are unweighted and undirected, i.e. all edges m (links) between nodes or vertices n (actors) ignore weights (e.g. frequency of cooperations) and are bidirectional (WASSERMAN/FAUST 1994). However, before starting to work with the information from the OECD REGPAT Database the following methodological aspects have to be addressed:

Firstly, it is of interest which *time period* is used. I investigate patent applications which

[45] TL3 is a micro-region definition from the OECD. It is equivalent to the German county level (= Landkreiseebene) or the European NUTS3 level, respectively.
[46] Brazil, the Russian Federation, India, China, and South Africa.
[47] For the avoidance of doubt, hereinafter the term is also referred to as the 'innovation networks', 'innovation networks in regions' or 'regions´ innovation networks'.

were first filed (priority year[48]) between 2004 and 2008 (i.e. pooled data for five years). In total, the selected five year period ensures a relatively stable picture of innovation networks, since the time duration implicitly controls for annual patent application fluctuations as well as cyclical fluctuations influencing patenting activities.

Secondly, the *geographical assignment* of patent applications is of relevance. In this context it has to be decided whether the applicants or inventors form the issue for analysis. In general, applicants are firms or research entities, and they own the property rights to exploit the patent in case it becomes an innovation. Inventors are in turn generally the persons who carried out the R&D leading to the patent application. One way would be to use the addresses of the firms or research entities where the R&D was conducted. Unfortunately, unbiased information is not available, because patent applications often take place on behalf of the headquarters (HQ) instead of the subsidiaries where the R&D actually was performed – especially in case of patent applications from large or multinational enterprises (LMNE). Therefore, the only available geographical information related to the applicants is probably strongly biased through the so-called 'headquarter effect' (BRESCHI 1999:80). For this reason, the *inventor approach* offers the only alternative to draw networks at the regional level, because the names and addresses of the inventors are also listed in the database.

However, while the application of the inventor instead of the applicant approach prevents distortions caused by the headquarter effect, in return it implies distortions from organisation-internal network structures, as the inventor approach is based on individuals or persons, respectively. This, however, leads to the next limitation: strictly speaking, the networks derived on the basis of the inventor approach do not correspond with the theories discussed above, as they emphasise network relations between organisations but not individuals. It becomes obvious that both approaches have limitations with regard to network analyses at the regional level. Nevertheless, finally the inventor approach has become most common in patent based network investigations at the regional level. This can be traced back to the circumstance that it is commonly assumed that knowledge flows especially between people rather than between organisations, and that the negative effects arising from the headquarter effect would significantly outweigh the benefits of the applicant approach.

The third and final issue involves problems such as *different and incorrect spellings* of inventor names but also *falsely included blanks and punctuations* in the name cells. This has been addressed with the help of the tool 'Google Refine' using the fingerprint- and ngram-

[48] The priority year is the year in which the patent has been first registered in the domestic country (SCHMOCH 1990:17f).

fingerprint-method (ngram size 2)[49]. In addition, academic titles (e.g. Dr. or Prof., etc.) and degrees (e.g. Dipl.-Ing., etc.) were removed from the inventors´ names. Taken together, these name and name-cell cleaning measures prevent multiple counting of per se equal inventors and therefore a distortion of the networks.

Having discussed aspects related to the database so far, it is now necessary to elaborate a bit more on the actual construction of the innovation networks. Firstly, it has to be discussed *along which regional boundaries the innovation networks are constructed*. But what is actually meant when talking about a 'region'?

According to the theoretical basis set out in Section 4.2.1, regions are considered to be RISs. RISs always follow a cross-sector perspective, i.e. they are technology and/or sector-unspecific. Single region- and technology-specific innovation networks within a region represent sector-specific networks (see description above). They thus depict regional sectoral knowledge clusters (see Section 4.2.2). Each RIS thus consists of numerous knowledge clusters (ASHEIM/ISAKSEN 2000; COOKE 2001a).

Talking about RISs always raises the question as to which regional level RISs can be expected. Due to lacking theoretical and conceptual unity in the field of RIS Research, currently a general definition of the 'optimal' regional level to locate RISs still does not exist (see for instance discussions of COOKE 2001a, 2002a; KOSCHATZKY 2001, 2009; CARLSSON et al. 2002). Against this backdrop and since a continuation of this debate would go far beyond the scope of this work, I follow THOMI & WERNER (2001) and apply a rather flexible and pragmatic approach. I decide to make use of the 96 'German Planning Regions' (= Raumordnungsregionen; (ROR))[50]. The allocation of networks to RORs was possible because the patent database contains information about the county (= Landkreis) in which the inventor lives. This information, in turn, can be used to assign actors to RORs. By applying the RORs in the context of RISs, I follow studies conducted for instance by KOCH & STAHLECKER (2006) or FRITSCH & SLAVTCHEV (2011). Furthermore, linked to this is the fundamental assumption that "all regions have some kind of regional innovation system, including not only regions with strong preconditions to innovation but also old industrial regions, peripheral regions, rural regions and regions in transition" (DOLOREUX/PARTO 2005:141). This conceptualisation of RISs is inspired by works such as those of ASHEIM & ISAKSEN (1997), COOKE et al. (2000), BUNNEL & COE (2001), STUCK & REVILLA DIEZ (2013) or EC (2014b).

[49] A detailed description and background information about the applied fingerprint- and ngram-fingerprint-method can be found on the Google Refine website https://github.com/OpenRefine/OpenRefine/wiki/Clustering-In-Depth (checked: 16.09.2014).

[50] Locations and names of the ROR units can be concluded by using ***Appendix A*** in combination with either ***Appendix B*** or ***Appendix C***.

RORs are an important instrument of the German 'Federal Institute for Research on Building, Urban Affairs and Spatial Development' (= Bundesinstitut für Bau-, Stadt- und Raumforschung; (BBSR)) in order to perform large-scale spatial analyses of specific structures, effects, developments and disparities. The RORs depict large-scaled, functionally defined spatial units that represent economic centres and their related surroundings. Therefore, they are not too large and simultaneously socio-economically more homogeneous than for instance German Federal States (= Länder). RORs are defined on the basis of county-specific commuting relations of employees subject to social security deductions, and they largely coincide with the German States, i.e. they are also State-specific (except for ROR Bremerhaven) (see map in ***Appendix A***). According to the BBSR (2013), owing to the definition of the RORs, they are particularly suitable for inter-regional, nationwide comparisons.

Finally, it is worth discussing *the way the technological assignment of the innovation networks is performed in order to make them technology-specific*. The basis is provided by the International Patent Classification (IPC) codes stored for each patent in the OECD REGPAT Database. As these IPC codes can also be found in the concordance table developed by SCHMOCH et al. (2003:64-65), it is possible to relate the IPC codes from the patents to 44 technology fields (see the 44 technology fields in ***Appendix H***). By applying this assignment approach, I follow other studies, e.g. CANTNER et al. (2010), PONDS et al. (2010), and VON PROFF & BRENNER (2014).

Assuming to find networks in all regions (96) and technology fields (44) in the period 2004-2008, the total sample could be expected to consist of 4224 innovation networks. However, since in reality not all regions have networks in all fields of technology, initially a total sample size of 3010 innovation networks (with at least three participants) was obtained. However, this number has further decreased, since the calculation of network properties like small-worldness requires networks with a minimum number of actors. To ensure that structural properties like small-worldness can be calculated properly, only innovation networks that have at least 20 participations (i.e. nodes or actors) within the entire period 2004-2008 are taken for the calculations. Therefore, for the time being, the dataset constitutes 253 technology and region-specific innovation networks (see ***Appendix I***).

4.3.2 Variables

Dependent Variable

According to the aim of this study, it has to be tested whether characteristics of regions or sectors relate to the probability that innovation networks in regions show small-worldness.

Therefore, based on the 253 innovation networks from the regions (see Section 4.3.1), for each innovation network a dependent variable is calculated which shows whether it is a small-world network or not. The indicator is calculated on the basis of the largest connected component, the so-called giant or main component of an innovation network. The construction of the indicator is explained in the following:

As Section 4.2 shows, networks with small-world properties are characterised by two coining features: (1) high degree of clustering, and (2) small average shortest path length (WATTS/STROGATZ 1998).

The clustering coefficient measures the extent to which network´s actors are interconnected. In other word, it shows the extent to which clustering is present within the networks. However, as this investigation concentrates on the network structural level, the global clustering coefficient is applied for each of the 253 innovation networks. The global clustering coefficient is based on triplets of nodes. A triplet consists of three nodes which are tied, whereby a closed triplet is connected by three and an open triplet by two ties (WASSERMAN/FAUST 1994:243ff). Following the approach of OPSAHL & PANZARASA (2009), the global clustering coefficient is calculated as the ratio of the number of closed triplets (or 3 x triangles) and the total number of triplets in a network. This can formally be expressed as

$$CC = \frac{total\ number\ of\ closed\ triplets}{total\ number\ of\ triplets} = \frac{\sum \tau_{\Delta}}{\sum \tau} \qquad (1)$$

where $\sum \tau_{\Delta}$ represents the sum of closed triplets in the network, and $\sum \tau$ the sum of both opened and closed triplets in the network. The global clustering coefficient can range between 0 and 1, with a result of $CC = 0$ representing a network without any clustering, and with a result of $CC = 1$ representing a network of complete connectedness (OPSAHL/PANZARASA 2009:156).

The next step involves the calculation of the mean distance (or average shortest path length). It measures the average of all shortest path lengths in a network, thereby unveiling its efficiency for instance with respect to knowledge diffusion (COWAN/JONARD 2007). The shortest path length between networks´ actors can be calculated with the formula

$$L = \frac{1}{N(N-1)} \sum_{k,l} D_{k,l} \qquad (2)$$

where – in an undirected graph – $D_{k,l}$ denotes the shortest distance between the actors a_k and a_l, and N is the total number of connected actors (LATORA/MARCHIORI 2001:1).

Based on equation (1) and (2), it is now possible to identify small-worldness. To do so, the quantitative, continuous small-world determination approach proposed by HUMPHRIES & GURNEY (2008) is applied. According to the authors, an innovation network G_j in region i with n actors and m links can be considered as a small-world network when, on the one hand, the clustering coefficient $CC_{G_{i,j}}$ is higher, and, on the other hand, the average shortest path length $L_{G_{i,j}}$ is not higher than the respective counterparts CC_{random} and L_{random} of an equivalent random graph with the same number of actors (n) and links (m) as it is the case in $G_{i,j}$. To ensure, however, that each comparison provides significant and not only random results, I further developed HUMPHRIES & GURNEY´s approach by generating not only one equivalent random graph per empirical network $G_{i,j}$ for the comparison but 100. Thereafter, for each empirical network the respective 5th largest clustering coefficient $CC_{random.95_{G_{i,j}}}$ and the 95th largest average path length $L_{random.05_{G_{i,j}}}$ is used to compare the networks. By applying this extended approach, I go beyond the approaches of existing related literature (e.g. WATTS/STROGATZ 1998; FLEMING et al. 2007; CHEN/GUAN 2010). Finally, small-worldness in regions´ innovation networks can thus be expressed by

$$SW_{G_{i,j}} = \frac{\dfrac{CC_{G_{i,j}}}{CC_{random.95_{G_{i,j}}}}}{\dfrac{L_{CC_{G_{i,j}}}}{L_{random.05_{G_{i,j}}}}} \quad (3)$$

where an innovation network G_j in region i is a small-world network if $SW_{G_{i,j}} > 1$. Thus, the dichotomous dependent variable takes the value 1 if an innovation network is found in a region and the value 0 if not.

After applying the presented approach, 250 out of 253 innovation networks are categorised. In three cases, the calculation of the small-world indicator did not work, because calculations of random clustering coefficients failed due to too sparsely linked empirical networks. However, since this loss represents only about 1% of the total dataset, I am convinced that it is acceptable.

Explanatory Variables

As discussed in Section 4.3.1, I defined regions as RISs and as those they are geographically covered by RORs. Therefore, in order to approximate influences and to test whether RIS characteristics relate to innovation networks in regions, I also specify the explanatory regional variables along the boundaries of RORs. To depict *RIS characteristics*, I use information from the OECD REGPAT Database as well as data from the German Patent Atlas 2006 (= Patentatlas Deutschland 2006) published by the German Patent and Trade Mark Office (= Deutsches Patent- und Markenamt; DPMA). The explanatory variables described in the following serve as the basis to test hypothesis 1 and its respective sub-hypotheses 1a-d.

Hypothesis 1a contains the expectation that the number of actors in a RIS relates to the probability to find small-worldness in the regions´ innovation networks. In order to depict the number of innovating actors in a RIS and test this relation I use for each region the number of patenting actors in the period 2004-2008.

Hypothesis 1b implies a correlation between the actors´ collaboration propensity in a RIS and the probability to find small-worldness in the regions´ innovation networks. In order to measure this, I use the share of cooperative patents in region i (variable: collab.prop.reg) in the period 2004-2008. Cooperative patents are defined as patents with more than one involved actor.

Hypothesis 1c suggests that the actor composition in innovation processes in a RIS might relate to the probability to find small-worldness in the regions´ innovation networks. To test this, I use the share of patents from the science sector and the share of patents from the business sector in region i (variables: (1) share.pats.science.reg, and (2) share.pats.bus.reg) in the period 2000-2005. The third category – share of patents of individuals in region i – is not included in the model[51]. An inclusion would lead to multicollinearity, as the shares would sum up to 100%. However, taking into account only the science and business category, which are of most interest from a theoretical point of view, does not lead to any problematic multicollinearity (see ***Appendix K***).

Finally, I use the share of regional patent inventors from collaborative patents residing in region i (variable: share.reg.pats.reg) in the period 2004-2008 in my model, in order to depict the extent to what actors from a RIS are embedded in intra-regional innovation processes. In doing so, I want to test hypothesis 1d, implying that extensive collaborations within a RIS are positively correlated with the probability to find small-worldness in the regions´ innovation networks.

Sectoral influences that might relate to innovation networks in regions are approximated by applying PAVITT´s (1984) taxonomy. He suggests four superordinate sectors: (1) the supplier dominated sector, (2) the scale intensive sector, (3) the specialised suppliers sector, and (4) the science-based sector.

[51] The data and the differentiation in business sector, science sector, and individuals are taken from the German Patent Atlas 2006 (=Patentatlas Deutschland 2006).

The supplier dominated sector consists of traditional and service-related sectors with a relatively small-scale firm size structure, low technical appropriation, and low technological capabilities. The scale intensive sector and the specialised suppliers sector, on the contrary, encompass in the broadest sense manufacturing sectors with medium- to large-scaled firms, high technical appropriation, and developed technological capabilities. The science-based sector has the highest technical appropriation and technological capabilities, is coined by rather large firms, and consists particularly of research intensive sectors like chemical, electronics, and other sectors that rely on cutting-edge knowledge. In innovation processes of this sector, research entities (i.e. HEIs and research institutes) play a special and prominent role (PAVITT 1984).

However, in order to enable the application of this taxonomy, my data needs to be linked with PAVITT´s taxonomy. The basis for this is provided by the already conducted assignment of the regions´ innovation networks to the 44 technology fields (see Section 4.3.1). Based on this, it is possible to relate the 44 technology fields to the 22 industrial sub-sectors proposed by SCHMOCH et al. (2003). The latter in turn allows linking my data with the sectoral taxonomy designed by PAVITT (1984). Thereby, each of the regions´ innovation networks is assigned to one of the four sectors as the technology fields of all of them are known. This occurs in accordance with the sectoral technological trajectories described by PAVITT (1984). The resulting assignment table of technology fields and industrial sub-sectors to PAVITT´s sectors can be found in ***Appendix H***.

The gained information about the sectoral identity of the innovation networks in the regions allows constructing sector dummy variables. These dummies cover the effects related to the sectors, so that hypothesis 2 and its related sub-hypotheses 2a-b can be tested, respectively. Hypothesis 2a suggests that the firm size structure of a sector relates to the probability of finding small-worldness in the innovation network G_j in a region i. Hypothesis 2b implies a correlation of the actor composition of a sector and the probability to find small-worldness in the innovation network G_j in a region i. In the model, dummies are included for the supplier dominated sector (variable: DUMMY.suppl.dom.sec), the scale intensive sector (variable: DUMMY.scale.int.sec), and the science-based sector (variable: DUMMY.science.based.sec). The fourth dummy variable – specialised suppliers sector – acts as reference category and is thus not included in the model. This dummy setting is justified for two major reasons: Firstly, due to the elaborations regarding the connection between actor size and small-worldness in Section 4.2.2, I wanted to have a reference category which is coined by relatively small actors. The reason why I then chose the specialised supplier sector and not the supplier dominated sector leads to the second point: If I had chosen the supplier dominated instead of the specialised supplier dummy, problems with multicollinearity would have resulted, due to the small number of cases in case of the supplier dominated dummy.

Control Variables

In order to avoid biased results because of additional influences on the dependent variable, I moreover include control variables at the level of the networks (technology-*and* region-specific) as well as the region. The necessary data is either derived from the OECD REGPAT Database or taken from the INKAR 2012 dataset[52].

At the *network or individual case level*, two controls are introduced: (1) density (variable: density.netw), and (2) edges (variable: edges.netw). The former depicts the ratio of the number of realised edges and the number of all possible edges in each single innovation network. The latter simply shows the number of established links between actors (WASSERMAN/FAUST 1994). Keeping in line with the calculation of the small-worldness indicator, both indicators are calculated for the main component of regions´ innovation networks. They are of technical nature and represent important characteristics of small-worldness. Using those, I check whether small-worldness is more than just the result of the network itself.

At the *regional level*, population density (variable: pop.density.reg) for 2011 is included and is calculated as the ratio of the total regional population and the size of a region in square kilometres. Population density controls for regional size effects, on the one hand, and urbanisation economies, on the other hand. Especially against the backdrop that FISCHER et al. (2001) have discussed how the degree of urbanisation influences the shaping and the constitution of RISs, this control seems necessary.

In addition, I also control for regional specialisation (variable: specilization.reg) and concentration (variable: concentration.reg) patterns. The reason is because in both cases the probability to find small-worldness could be highly biased by the technology-field-specific tendency to form small-world structures. This means, if a region would be highly shaped by a technology that has innately the tendency to organise in small-worldness, the results might be biased. The specialisation control is calculated as the proportion of patents from the technology-specific innovation network G_j in region i and patents from the overall (i.e. technology-unspecific) network G in region i. It depicts to what extent a region is technologically specialised in certain innovation processes. The concentration control is calculated as ratio of the

[52] Background information about the INKAR dataset and how to purchase it can be found on the BBSR website http://www.bbsr.bund.de/BBSR/DE/Veroeffentlichungen/INKAR/inkar_node.html (checked: 16.09.2014).

patents from the technology-specific innovation network G_j in region i and patents from the technology-specific innovation network G_j from Germany (i.e. region-unspecific). It covers the extent to which innovation processes of a certain kind are concentrated within a region.

4.3.3 Estimation Approach

To measure small-world network structures in regions, the dichotomous small-worldness indicator constructed in Section 4.3.2 is used. Consequently, a binary logistic regression approach is used as the appropriate estimation method[53]. This approach is useful if a dependent dichotomous variable (e.g. $SW_{G_{i,j}}(0,1)$) represents the presence or absence of an event. The independent variables can have any scale level. In contrast to the linear regression approach, parameters are not estimated with the help of the least squares method but with the maximum likelihood (ML) method. Using the logistic function, the objective thereby is to maximise the probability that an event of the dependent dichotomous variable Y occurs. In total, this fits very well with the overall research design described in this chapter. For one exemplarily case k the probability P that an event takes place $(y = 1)$ is calculated as

$$p_k(y = 1) = \frac{1}{1 + e^{-z_k}}$$

with $e = 2{,}71828183$ (Euler´s number), and (4)

with $z_k = \beta_0 + \sum_{j=1}^{J} \beta_j * x_{jk} + u_k$

The z-scores are also referred to as 'logits'. In the equation of the z-scores β_0 is the constant, β_j is the estimated logit-coefficient and reflects the impact strength of the considered variable X_j on the level of the probability of occurrence $P(y = 1)$, x_{jk} are the values of the independent variables, and u_k is an error term (BACKHAUS et al. 2008:249).

Similar to other regression approaches, of course also the binary logistic regression approach has requirements that must be met in order to get robust results. The first requirement is concerned with the *sample size*. The quality of the estimation results increases with increasing sample size as the ML estimators are asymptotically consistent and efficient (MAYERL/URBAN 2010:26).

Another requirement is related to *linearity*. When applying a logistic regression, the logits

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[53] Although the data structure might suggest a multi-level approach in the first instance, this can be ruled out when going deeper, because, firstly, no clear and consistent hierarchical data structure exists (see description in Section 4.3.1), secondly, the sample size for each level (individual, regional, sectoral) is not sufficiently large to conduct powerful statistical analysis with multiple independent variables, and, last but not least, thirdly, the applied data are not clustered, i.e. at the regional and sectoral level the observations are independent (indicated by the Intraclass Correlation Coefficient (ICC) with a value of 3% at the regional as well as the sectoral level and further tests conducted in Section 4.3.4) (SNIJDERS/BOSKER 2011).

should be in a linear relationship with the metric, independent variables. If this is not the case, distorted estimates of the parameters may be a consequence (MAYERL/URBAN 2010:28).

The third requirement is concerned with the *value distribution of the dependent variable* Y. Each of its two values (0 or 1) should at least be represented by a small group in the sample. Too few observations of either the one or the other of the independent variable result in little variance which in turn might lead to the circumstance that the ML procedure cannot converge or will produce implausible estimates (MAYERL/URBAN 2010:26).

A further requirement is that of *complete information*. This means, that the values of combinations of the dependent and independent variables should always include at least one case. Even small numbers of cases where this assumption is not met, the ML procedure may not converge or will produce incorrect estimates (MAYERL/URBAN 2010:27).

It is moreover important to avoid *complete separation*. Complete separation exists if values of the dependent variable always occur in combination with specific values of the independent variables. In this case, the independent variables in question would be 'perfect predictors' for each Y event. This could lead to the circumstance that the ML procedure cannot find the ML values for the parameters to be estimated (MAYERL/URBAN 2010:27).

Furthermore, there should be *no multicollinearity* among the dependent variables in the model, and the *residuals should be independent*. In case of multicollinearity, strong linear relationships between the independent variables are present. This will inevitably lead to incorrect estimates, very high standard errors and sometimes inaccurate high regression coefficients. Residual independence means that the values of an independent variable are not correlated with each other across the observations, and thus no autocorrelation exists. Autocorrelation might lead to extremely small standard errors and thus produce misleading significances (MAYERL/URBAN 2010:28).

The final aspect that has to be considered when applying a binary logistic regression is that of *outliers*. Outliers are cases where observed and estimated values of independent variables are exceptionally different. A large number of outliers can therefore lead to a poor overall model fit as well as to biased estimates (MAYERL/URBAN 2010:29).

4.3.4 Test of Model Requirements

To ensure the robustness of the statistical model, the requirements listed briefly in the previous section are now tested prior to the actual results described in Section 4.4.

The first requirement which is checked is that of a sufficiently large sample size. Even though no exact limit value exists, one can find different rules that address this issue. I adhere to STOKES et al. (2009:58), who say that a sample size is sufficiently large if one guarantees to have at least five observations in the rarer of the two binary levels per independent variable. Thus, the sample size seems to be sufficiently large (see ***Table 11***).

The second requirement calls for a linear relationship between the logits and the metric, independent variables. To test this, MAYERL & URBAN (2010:28) propose to construct an additional interaction variable by multiplying the original independent variables with their respective natural logarithm. If then a regression of the original independent variable and the constructed interaction terms is performed on the dependent variable, significant interaction effects would signal non-linear relationships between the logits and the metric independent variables. The implementation of this test shows, however, that no significant differences at the 5% level are present (see ***Appendix J***). Thus, linearity between the logits and the metric independent variables is ensured.

The third requirement is concerned with the distribution of the dichotomous events of the dependent variable. A general rule is that the 0 or 1 values of the dichotomous, independent variable should comprise at least 10% of cases (MAYERL/URBAN 2010:26). Since this is the case for the model used, compliance can be ensured (see ***Table 11***).

The fourth requirement calls for complete information regarding the values of combinations of the dependent and independent variables. A good indicator to detect a violation of this requirement is an excessively large estimated standard error that is very much different from the estimate of the coefficients (MAYERL/URBAN 2010:27). Both parameters show, however, that the model used complies with the requirement (see ***Table 11***).

The fifth requirement is the avoidance of complete separation, i.e. events of the dichotomous dependent variable always occur in combination with certain values of the independent variables. The occurrence of perfect predictors is favoured by three major aspects: firstly, by small sample sizes, secondly, by a highly unequal distribution of values of the dependent variable, and finally by (too) large numbers of independent variables (MAYERL/URBAN 2010:27). Since these issues have already been discussed above, and it is therefore known that all of these aspects do not apply for the model, this requirement is fulfilled.

The sixth model requirement calls for a low level of multicollinearity, i.e. a strong linear relationships between the independent variables. To test for multicollinearity, the 'Variance Inflation Factor' (VIF) is calculated. The VIF simply measures how much of the inflation of the standard error could be caused by relationships between the independent variables. Low levels of multicollinearity are normal. However, although there is no exact limit for multicollinearity, a general rule for detecting problematic multicollinearity is to apply a threshold somewhere between 5 and 10 (BELSLEY 1991:28; KENNEDY 1998:190; STUDENMUND 2001:257). I decide to apply the conservative value of 5. The test results lie between 1.270 and 4.890 (see ***Appendix K***). Problematic multicollinearity can thus be ruled out.

The seventh requirement calls for independent residuals, i.e. the non-existence of problematic autocorrelation. Temporal autocorrelation is not a problem, since longitudinal data is not applied. Instead, it has to be tested whether the observations are clustered on the regional and sectoral dimension. With regard to the former, it is checked if the residuals of the innovation networks in a particular region are correlated. In case of the latter, it is in turn checked if the residuals of the innovation networks in a particular technology field are correlated. In both cases the null hypothesis assumes a random distribution of the residuals. In case of a rejection, clustered – i.e. dependent – residuals would be present, thus indicating an insufficiently specified model. This could, for instance, involve missing variables or a misspecification of regions and/or technology-fields. Furthermore, clustered residuals could indicate that the wrong statistical approach has been chosen (see ***Footnote 53***). Thus, clustered residuals on the regional and sectoral dimension would entail model improvements. However, as demonstrated in ***Appendix L*** for both dimensions no evidence could be found that indicate clustered error values. This suggests that the statistical approach is correct and the model is well specified.

Finally, the eights requirement considers the presence of outliers in the model. Outlier detection is usually conducted by examining the Pearson residuals. Again, no exact limits exist. However, values that considerably exceed the threshold of $\pm$ 3 indicate the existence of extreme cases or outliers, respectively (MATIGNON 2005:486). Applying this rule to the model, six cases have to be removed, thus further reducing the available cases to 244. Two of the remaining cases are still slightly outside the defined threshold of $\pm$ 3 (see ***Appendix M***). However, due to the fact that the deviations are quite small and also their exclusion causes no fundamental changes in the outcome of the model, I keep them in the observation set.

4.4 ESTIMATION RESULTS

Following the methodological part, the examination of the specified model is now addressed. ***Table 11*** shows the estimation results located in the upper half of the table, and some information regarding the model quality in order to evaluate the model located in the lower part. I begin with a discussion of the quality of the model and then briefly describe its results. The discussion of the results, however, follows in Section 4.5.

Table 11: Results of the Binary Logistic Regression Model

Level	Independent variable	Coefficient (B)	Standard error	Wald	Exp(B) (1/exp(B))
	(Intercept)	-33.264***	7,4504	-4,46	3.578E-15 (2.795E+14)
Region (RIS)					
	inno.actor.reg	-0.001***	0,0001	-3,82	1,000
	collab.prop.reg	0.221**	0,0769	2,88	1,247
	share.pats.science.reg	0.243**	0,0997	2,43	1,275
	share.pats.bus.reg	0,023	0,0498	0,45	1,023
	share.reg.pats.reg	0.160***	0,0459	3,48	1,174
Sector (SIS)					
	DUMMY.suppl.dom.sec	0,290	1,2026	0,24	1,336
	DUMMY.scale.int.sec	0,361	0,5526	0,65	1,435
	DUMMY.science.based.sec	0.890*	0,5207	1,71	2,435
Controls					
	density.netw	22.293***	4,3328	5,15	4,805,E+09
	edges.netw	0.037***	0,0055	6,76	1,038
	pop.density.reg	0,000	0,0003	-0,45	1,000
	specilization.reg	-0.375***	0,0853	-4,40	0.687 (1.455)
	concentration.reg	-0,010	0,0581	-0,17	0.990 (1.010)
Observations	244				
Y=1 Obs.	147				
Y=0 Obs.	97				
Model $\chi 2$	177.85***				
Nagelkerke´s R^2	0,700				
McFadden´s R^2	0,542				
Hosmer-Lemeshow test	p-value = 0.550				

*** highly significant ($p \leq 0.01$); ** significant ($0.05 \geq p > 0.01$); * slightly significant ($0.1 \geq p > 0.05$)

Table provided by author; based on own calculations

4.4.1 Model Quality

For the calculation of a binary logistic regression a stepwise approach is applied. At first, a model is calculated which contains only the intercept, the so-called null-model. By including independent variables in a next step, this null-model is expanded and adjusted. This results in a second, the so-called saturated model. Finally, both models are compared. It must be considered whether the saturated model provides a significant improvement over the null-model which consists only of the intercept. Only if this is the case further utilisation and interpretation are possible and also consequential (HOSMER/LEMESHOW 2013). In order to compare the models, a likelihood ratio test (also called model χ^2 test) is performed. The difference between both models is 177.85. By comparison with the reference value from the χ^2 table, the saturated model (see ***Table 11***) turns out to provide a highly significant improvement. Therefore, the model produces results which can be transferred to the total population (BACKHAUS et al. 2008:261-263).

The next step is to assess the predictive power of the model, i.e. its ability to predict the dependent variable based on the independent variables. To do so, two of the most popular pseudo-R^2 measures are applied: (1) Nagelkerke´s R^2, and (2) McFadden´s R^2 (see ***Table 11***). Even though pseudo-R^2 measures are not equivalent to the R^2 known from OLS regressions, both have the function to unveil the model´s predictive power. The applied measures have a scale ranging from 0 to 1. A higher value generally indicates a better fit. Following BACKHAUS et al. (2008:270) in their evaluation of these pseudo R^2 measures, the model can be assessed to have a good to very good predictive power.

Finally, it has to be addressed whether the model is consistent with the data. In other words, it has to be checked whether the model is correctly specified. In order to do so, the Hosmer-Lemeshow goodness-of-fit (GOF) test is applied (see ***Table 11***). The GOF test divides the sample into maximal 10 groups and checks the differences between the observed and expected values. The smaller the difference, the better the model fit (HOSMER/LEMESHOW 2013:157ff). In case of the specified model the p-value is 0.550, indicating no significant differences. Thus, the model seems to be correctly specified.

4.4.2 Significance and Nature of the Relationship of the Coefficients

At the network or individual case level, the variables *density.netw* and *edges.netw* are both highly significant with a positive coefficient. I also tried to introduce a control representing the number of actors (or nodes). Even though the variable´s coefficient would have been significant it was, however, not possible to integrate it due to multicollinearity. It was only possible to integrate either density or nodes since both have a strong negative relationship. Overall, these results thus reflect what was expected from (network) theory (WATTS/STROGATZ 1998). At the same time, moreover, this result substantiates the necessity and importance of this investigation, since network structures (i.e. small-worldness) do not seem to be merely the result of characteristics from the individual network level but additionally to be in relation with regional and sectoral characteristics.

Regarding the regional level controls, it can be asserted that neither the variable *pop.density.reg* nor the variable *concentration.reg* significantly relate to the probability to find small-worldness in regions. Regional size, urbanisation economies, and concentration patterns thus do not seem to influence the results. The only significant regional control variable is *specilization.reg*. The control variable thus intercepts specialisation effects and thereby prevents distortions of the overall results of the model.

When looking at the significances of the regional factors, the results of the regional variables show that, in general, characteristics of regions relate to the probability of finding small-worldness in regions´ innovation networks. Therefore, in general the superordinate hypothesis 1 can be confirmed.

For the variable *inno.actor.reg*, which reflects the overall number of innovating actors in a RIS, the coefficient is highly significant and has a negative value. This means, the probability of small-worldness in regions´ innovation networks tends to decrease with large numbers actors in a RIS. The negative relationship – even though it is very small – thus contradicts the formulated expectations, so that hypothesis 1a[54] has to be rejected.

The coefficient of the variable *collab.prop.reg*, which reflects the overall collaboration propensity in a RIS, is significant and has a positive value. This means, the probability to find small-worldness in regions´ innovation networks tends to increase a RIS features a high propensity to collaborate. The result thus supports hypothesis 1b[55].

The variables *share.pats.science.reg* and *share.pats.bus.reg* represent the role that the business and the science sector play in innovation processes in a RIS. The results show that the coefficient of the science-sector variable is significant and positive, whereas the coefficient of the business sector variable is insignificant and positive. This means, that the probability of finding small-worldness is higher if innovation processes in RISs are coined by purposes from the science sector. However, this contradicts the formulated expectation and leads to the refutation of hypothesis 1c[56].

The variable *share.reg.pats.reg*, which depicts the overall extent of intra-regional collaboration activities in RISs, is highly significant and positive. Thus, the probability to find small-worldness increases if the actors of a RIS are highly embedded in innovation activities within the region. The finding thus supports the expectation formulated in hypothesis 1d[57].

Concerning the sectoral factors, one can also find evidence that, at least in general, characteristics of sectors relate to the probability of finding small-worldness in regions´ innovation networks. This result thus generally supports the superordinate hypothesis 2.

Regarding the dummy variables, however, one can see that only the dummy representing science-based sectors (*DUMMY.science.based.sec*) is (slightly) significant with a positive coefficient. This means, compared with the reference category, the probability to find small-worldness is higher if innovation processes of a RIS are coined by research intensive sectors. But how can this result be assessed in the light of hypotheses 2a[58] and 2b[59]? On the one hand, the finding verifies the expectation formulated in hypothesis 2a that small-worldness in regions is more likely if the innovating and collaborating actors belong to sectors which are not coined by a small actor-size structure. This is because, according to the applied taxonomy of PAVITT (1984) (see Section 4.3.2), firms in research intensive sectors are supposed to be rather large, and the also important research actors (particularly HEIs) are also in most cases

[54] H1a: Small-worldness is more likely to occur in regions where the RISs have a large number of innovating actors.
[55] H1b: Small-worldness is more likely to occur in regions where the RISs show high overall collaboration propensities.
[56] H1c: Small-worldness is more likely to occur in regions where the business sector is the driving force in innovation processes in the RISs, and the public research sector play an important supportive role.
[57] H1d: Small-worldness is more likely to occur in regions where the RISs have intense intra-regional collaboration activities.
[58] H2a: Small-worldness is more likely to occur in regions where the collaborating actors are from sectors with a medium to large actor-size structure.
[59] H2b: Small-worldness is more likely to occur in regions where sectors are not coined by significant participation of research entities.

rather large (Polt et al. 2010). On the other hand, however, the result thus contradicts the expectation from hypothesis 2b that the probability of finding small-worldness in regions is higher if the innovative activities are coined by sectors in which innovative activities are not coined by significant participations of research entities.

4.4.3 Model-internal Comparison

This section evaluates the *'impact strength'* of independent variables. However, the value of the coefficients cannot be used directly in order to compare the coefficients. To cope with this, so-called odds ratios or effect coefficients are formed through exponentiation of the coefficients (see column 6 in ***Table 11***). Effect coefficients describe the change in the chance for the event $Y = 1$, if in the regression model an independent variable is increased by one empirical unit. Based on this, on the one hand, it is possible to determine the effect size of an independent variable compared to its respective reference category (in case of dummy variables), and, on the other hand, it allows that effect sizes can be compared among different independent variables (Mayerl/Urban 2010:17-21).

The value range of the effect coefficients lies above and below the value 1. A value of 1 indicates that the two events ($Y = 0$ and $Y = 1$) are equally probable, thus no effect exists. Values below 1 indicate a shift in the likelihood ratios in favour of $Y = 0$. Values above 1 express a shift of the likelihood ratios in favour of $Y = 1$. However, since the range of values below 1 (0 to 1) is smaller than the range of values above 1 (1 to ∞), for effect coefficients < 1 the reciprocal value has to be additionally formed (values in brackets in column 6 in ***Table 11***). Finally, this step makes the effect coefficients comparable (Mayerl/Urban 2010:17-21).

Regarding the regional level variables, the effect coefficients shows that the variable *share.pats.science.reg* has the highest impact on the probability to find small-worldness, (closely) followed by the variable *collab.prop.reg* and *share.reg.pats.reg*. The variable *inno.actor.reg* does not seem to have any measurable impact. Concerning the sectoral level variables, no inter-sector comparisons are possible, since only one dummy is significant. In addition, a comparison between regional and sectoral characteristics does not make sense, because at the regional level I applied multiple variables depicting single characteristics of one RIS type, whereas at the sectoral level I applied one dummy variable per sector.

4.5 DISCUSSION OF RESULTS

The statistical analysis in Section 4.4 has shown that both the regional and the sectoral characteristics have achieved significant results in the statistical model. Both strands of literature thus demonstrate their general relevance for network structures in regions in general and the existence of small-worldness in regions in particular. How the results are to be assessed will be discussed in more detail in the following.

No evidence is found in the model that the sole number of innovative actors in RISs increases the likelihood of small-worldness in a region. On the contrary, a small negative relationship is found. This is likely to be due to the applied inventor approach and the related distortions because of organisation-internal network structures. Such internal network structures can superimpose the inter-organisational network structure, so that no small-worldness can be found although it might actually be present. This also implies that this result does not rule out the basic relevance of numerous innovative actors for the existence of small-worldness in regions. Small-worldness needs a critical mass to occur and numerous connecting (i.e. central), innovative players are necessary in order to ensure that groups or cliques are connected by a few far-reaching links (WATTS/STROGATZ 1998). Rather, the result calls for further research based on reliable applicant data. Such future work, however, should not be limited to an indicator that exclusively depicts quantitative aspects. Retrospectively, it would additionally be important to control for qualitative actor features, for example whether and to what extent actors are able to establish high numbers of connections and occupy central positions in the network to ensure the emergence and maintenance of small-world network structures. GIULIANI (2007) and BOSCHMA & TER WAL (2007), for instance, suggest that actors especially can take central positions in a network if they have a certain size and thus also a sufficient level of knowledge and absorptive capacities (COHEN/LEVINTHAL 1990). Other authors support the role of experience, the number of already established contacts, and the importance of power and reputation (WATTS/STROGATZ 1998; AMARAL et al. 2000; NEWMAN 2001a, b; DAVIS et al. 2003). These features could not be taken into account in the present work, however, since the applied database does not provide such information.

Collaboration propensity shows the expected positive relationship. This reflects what is known from network theory. Small-worldness presupposes a high degree of interaction (WATTS 1999a). At the level of the central actors, relatively many linkages are created between cliques. Through this group interlinking function the central actors guarantee that knowledge and information can circulate between groups within the overall network, and thus be productively applied by other, distant actors (UZZI/SPIRO 2005:449). At the level of the ordinary actors (i.e. less central actors), although they establish comparatively few linkages, there has at least to be the willingness to link with rather close actors, thus establishing intra-clique links (see ***Figure 13***). In total, this reflects the positive relation between collaboration propensity and small-worldness. In case regional actors were not willing to cooperate and interlink and thus the region be shaped by low collaboration propensity, the formation and maintenance of small-worldness in a region would be difficult.

The model has also shown that small-worldness is more likely in regions in which the overall regional innovation processes of RISs are shaped by the science sector. Evidence for the assumed relevance of the business sector could not be determined. Furthermore, evidence exists that amongst the considered regional factors, the extent to which a RIS is characterised by scientific actors, has the largest influence on small-worldness in regions (see Section 4.4.3). I argue that this is likely to be associated with the circumstance that the science sector is dominated by rather large actors with appropriate capacities (FRITSCH/SCHWIRTEN 1999; POLT et al. 2010). Thus they are supposed to be able to occupy central positions and to connect comparably high numbers of actors (GIULIANI/BELL 2005; GIULIANI 2007). The business sector, in turn, is usually characterised by a much more heterogeneous actor-size structure, with SMEs playing a very prominent role (SCHMIEMANN 2008). Following the above argumentation, it is therefore likely that in a RIS´s business sector a lower proportion of actors bring the necessary conditions to establish small-world network structures. This fits with the circumstance why no evidence was found supporting the assumed relevance of the business sector in relation with small-worldness in regions. However, despite this, a final assessment does not appear to be possible before controls have been conducted on size effects and other qualitative aspects in this context. Further research is needed to address this issue.

With regard to the regional level, the gained results have moreover shown that the probability of finding small-worldness in regions is positively related to the overall regional embeddedness of actors in the RIS. I argue that this can ultimately be ascribed to two key causes: Firstly, small-worldness is characterised by dense social interactions. Such dense interactions (in innovation processes), however, make a high level of trust necessary, which is in turn often assured by geographical and therewith related social proximity (BOSCHMA 2005:67). The second explanation points to the capacity constraints of actors. From earlier explanations it is known that only a few actors show the ability to take up central positions and therefore have the potential to enable small-worldness. But, logically, even such actors do not have unlimited capabilities to interlink actors and groups. This means, if these actors enter into too many connections with extra-regional actors, the possibility of small-worldness in their host region is prevented. To avoid misunderstandings: connections to the outside world are of great importance, as they give regional actors access to new or additional knowledge and counteract lock-in processes (CAMAGNI 1991; BATHELT et al. 2004; MORRISON 2008; BRESCHI/LENZI 2013). Nevertheless, the result makes clear that the benefits of extra-regional connections may increase only up to a certain threshold after which point they hinder the formation of small-worldness in regions. In turn, this means that too many intra-regional connections may also bear the risk of regional lock-ins.

Regarding the sectoral level, only the dummy representing research intensive sectors turned out to be significant. On the one hand, according to PAVITT´s taxonomy (see Section 4.3.2), this result implies that small-world network structures in regions are more likely to occur if the innovating and collaborating actors belong to sectors which are coined by a rather large actor-size structure. This can be attributed, among other things, to the fact that actors´ knowledge and absorptive capacities are crucial to initiate and maintain links to other nodes and establish small-world structures (GIULIANI/BELL 2005; GIULIANI 2007; BOSCHMA/TER WAL 2007; MORRISON 2008; BROEKEL/BOSCHMA 2011).

On the other hand, the result also implies that small-world network structures in regions are more likely if the innovative activities are coined by sectors in which research actors are of significant importance. This result, however, contradicts the expectations derived from the work of BROEKEL & GRAF (2012). They found out that networks in which research entities play a significant role are rather small and shaped by high centralisation and density patterns; therefore showing characteristics speaking against small-worldness. Reasons for the opposing findings might be the different sector assignment approaches and databases being applied. While I make use of PAVITT´s taxonomy and patent data, BROEKEL & GRAF´s study is based on the German subsidies catalogue ('Förderkatalog'[60]) and a therein applied, internal sectoral classification. However, a final assessment of both findings is beyond the scope of this work and therefore calls for further research.

Until then, I argue that this finding may be explained by the high complexity of (technological) problems being addressed in sectors in which research plays a significant role (PAVITT 1984; KROLL et al. 2012). This involves high interaction intensities and makes necessary a relatively high number of capable innovating and collaborating actors, therefore favouring the formation of small-world network structures. Moreover, in such an environment research entities are predestined to take over central positions (e.g. gatekeeper or brokering positions) (GRAF 2011), as they have the needed cutting-edge knowledge and absorptive capacities to interconnect the network (BECKER/PETERS 2000; FRITSCH/KAUFFELD-MONZ 2010).

However, although the proven correlation of sectoral characteristics and small-worldness

[60] The 'Förderkatalog' summarises more than 110,000 funded research activities of several federal ministries of Germany. Further information is available at http://foerderportal.bund.de/foekat/jsp/StartAction.do (checked: 16.09.2014)

in regions is scientifically interesting, it must be kept in mind that it is difficult to discuss thereon based implications which might count for each region having such sectors. This is because it is not conclusive that each research intensive sector, which in general may enhance the probability to find small-worldness in regions, in practice has the necessary actor capacities (i.e. number of actors) to form small-world network structures in each region in which the sector is present. Supposing for instance that a region, which in principal hosts sectoral knowledge clusters with a high probability to form small-worldness, does not host the necessary medium to large firms and the research entities but rather the small firms. Small-worldness would thus be relatively unrealistic.

4.6 CONCLUSION

The aim of the chapter was to investigate whether regional and/or sectoral characteristics are associated with the probability of finding small-world network structures in regions[61]. Arguments supporting the role of the regional level were taken from the economic geographic field of RIS Research (e.g. BRACZYK et al. 1998; COOKE et al. 2004), whereas arguments supporting the role of the sectoral level were derived from different fields of Industry Research (e.g. PAVITT 1984; PORTER 2000; MALERBA 2002, 2004; TER WAL/BOSCHMA 2011; BROEKEL/GRAF 2012). While the former states that specific regional characteristics have an impact on the type of network structures in regional knowledge networks, the latter follows a multidimensional, integrated view of sectors, suggesting that innovation networks in space – i.e. also those in regions – do especially relate to the characteristics of sectors.

To approach this, at first, I constructed innovation networks reflecting knowledge networks in innovation processes of German Planning Regions (RORs) based on patent data. I then applied a further developed version of the quantitative, continuous small-world determination approach proposed by HUMPHRIES & GURNEY (2008) in order to categorise whether the innovation networks in the regions are small-world types or not. Subsequently, by applying a binary logistic regression approach, I tested whether independent variables depicting regional (i.e. RIS-related) or sectoral characteristics relate to the probability of finding small-worldness in regions.

Regarding the regional characteristics, evidence indicates that the probability to find small-worldness in regions increases (1) if a region´s RIS is characterised by a high propensity to collaborate, (2) if innovation processes in a region´s RIS are coined by innovation activities

[61] In order to improve the legibility of the text, the term ‘small-worldness in regions’ was frequently applied instead of, for instance, ‘small worldness in knowledge networks of innovation processes in regions’. However, the meaning is the same.

from the science sector, and (3) if a region´s RIS actors are strongly embedded in intra-regional innovation activities. No evidence could be found at the regional level to support that the probability to find small-worldness in regions correlates with large numbers of innovative actors or with the role of the business sector in regional innovation processes. Regarding the sectoral level, only research intensive sectors were found to be significantly related to the probability to find small-worldness in regions.

When comparing the effect strength of the regional factors, the highest impact on the probability to find small-worldness is recorded by the extent to which a RIS is shaped by scientific actors, followed by the propensity to collaborate and intra-regional embeddedness. A comparison between regional and sectoral variables was not conducted. This is because at the regional level I applied multiple variables depicting single characteristics of one RIS type, whereas at the sectoral level I applied one dummy variable per sector.

Given the results, I believe that this work makes a valuable contribution to the literature. From a scientific perspective this is the case because this work is the first to demonstrate in a single model that *regional and sectoral characteristics are associated with small-world network structures in regions*. In addition, through this work I have also provided (indirect) evidence for relation between a RIS type and its prevailing network structure, as theoretically discussed in Chapter 3. The empirical finding, however, not only gives inputs to theoretical discussions but also provides inputs for policy designing, as both levels have demonstrated to be related with network structures in regions.

The finding that the overall collaboration propensity in regions is positively correlated with the probability to find small-worldness, provides opportunities for political action, as it is considered that the collaboration propensity of actors in regions is shaped particularly by a region's institutional framework well as well as its industrial and technological sophistication (COOKE et al. 2004). This is emphasised by the (above explained) comparative relevance of the indicator. Thus, in regions which already have appropriate industrial and technological conditions but not yet a sufficient level of small-worldness, it would be conceivable to further improve the (regional) institutional conditions. However, in case the industrial and technological conditions do not exist yet, industrial political measures should be implemented, so that potentially resulting industrial and technological upgrades can lead to increased networking and small-world network structures. Especially in the latter case, however, a parallel improvement of both institutional framework conditions and industrial/technological conditions is likely to be needed.

With regard to the finding that small-worldness is more likely to occur in regions in which the overall regional innovation processes of RISs are shaped by the science sector, it might be advisable to strengthen the regional scientific actors and to encourage them to collaborate with other actors in the region. However, since it is necessary to check – in the context of future research – whether size effects or other qualitative aspects biased the results of the comparison between the role of the business and the science sector for the existence of small-worldness in regions, the derived policy recommendation is rather speculative and preliminary.

The finding that small-worldness in regions is positively correlated with the overall intra-regional embeddedness of actors in the RIS, however, has the potential to be particularly challenging for policy-makers. This is because it is also known that extra-regional embeddedness is important to prevent lock-ins (CAMAGNI 1991; BATHELT et al. 2004; MORRISON 2008; BRESCHI/LENZI 2013). Both the support of intra- and extra-regional connections thus appears to be legitimate. Ultimately, this calls for balanced policy intervention. This means, if policy-makers want to support inter-regional knowledge exchange *and* simultaneously foster the development of small-worldness in regions, they should not promote extra-regional connections to the disadvantage of intra-regional connections. Otherwise small-world network structures would be difficult to realise in regions. The same applies the other way around, with the consequence that the risk of regional lock-ins increases.

The findings from the sectoral level suggest that sector-based policy approaches to influence the existence of small-worldness in regions are only useful in case science-based sectors exist, i.e. those with a medium to large actor-size structure and a significant contribution by HEIs and research institutes. However, since it is not conclusive that in practice all research intensive sectors have the necessary actor capacities to form small-world network structures in all regions in which the sector is present, it is difficult to derive policy implications which might count for each region having such sectors.

However, generally, it must be considered that one-size-fits-all innovation policies are not promising (TÖDTLING/TRIPPL 2005). Therefore, the stated policy recommendations should only be considered as contributions to the discussion or as suggestions. Adjustments to region-specific contexts remain indispensible.

Although the present empirical study contributes to current research, certain limitations need to be considered, of which the most important ones are addressed in the following. Firstly, the analysis is only applied to one particular network structure, namely the small-world network structure. Even though it is argued that it is the most favourable one, it might nevertheless be insightful to expand future analyses to other prominent network structures such as the core-periphery or the hub-and-spoke network structure (MARKUSEN 1996; BORGATTI/EVERETT 1999; RANK et al. 2006; NAKANO/WHITE 2006). In this context, arguments from the third chapter may again provide the basis to derive expectations and hypotheses. Therefore, the findings could contribute to further verify the theoretically discussed relations between RIS types and specific network structures.

Future research might also apply a finer sectoral distinction than that of PAVITT (1984). This could lead to more detailed results on the relation between sectoral characteristics and regional knowledge network structures.

Furthermore, my study on the relation between regional and/or sectoral characteristics and the probability to find small worldness in regional innovation processes uses a static perspective. However, against the backdrop that both RISs and network structures evolve over time (COOKE et al. 1998; TER WAL/BOSCHMA 2011; FU 2011; BALLAND 2012; BALLAND et al. 2013), future research should try to apply a dynamic perspective to this analysis. This could make it possible to find out, for instance, at which stage of development which regional and/or sectoral characteristics are more or less associated with certain regional knowledge network structures.

Moreover, the use of patent data in order to construct innovation networks has its limitations. Even though patents are a common indicator offering a wide range of possibilities to depict and analyse innovations and innovation processes since they convey information on the output and processes of inventive activities (OECD 2009c), there are also a variety of limitations attached to them (PAVITT 1985; GRILICHES 1990). In this context, it is particularly necessary to stress that patents are coined by a strong technology-oriented understanding of innovation. Innovations in the service sector and organisational innovations are excluded. This exclusion, however, might lead to distortions when regions have no significant industrial companies and/or research entities. Future research should therefore include additional sources to depict innovation networks.

Another limitation related to the use of patent data is that the constructed innovation networks are based on the inventor approach. This may cause distortions by organisation-internal network structures, so that no small-worldness can be found although it might actually be present. In addition, the use of the inventor approach may lead to problems in the interpretation of the results. Under optimal conditions, the use of the applicant approach could solve both problems. However, since applicant-based data is highly biased by the headquarter effect (BRESCHI 1999), the applicant approach is currently not an alternative for investigations that are located at the regional level. Future research should therefore develop a method that is able to remove the headquarter effect from applicant data.

Finally, it is still largely unclear at which regional scale RISs are located, and if all or only special regions actually have a RIS (e.g. COOKE et al. 1997, 1998; HOWELLS 1999; KOSCHATZKY 2001; COOKE 2001a; 2002a; CARLSSON et al. 2002; DOLOREUX/PARTO 2005). Future research is thus also obliged to clarify these issues.

Chapter 5

SUMMARY AND CONCLUSIONS

This PhD thesis consists of a compilation of papers that address three selected topics that relate to the analysis of regional innovation processes in the context of the RIS approach: the application of a RIS type classification framework for a large number of regions (Chapter 2), the theoretical discussion of an explicit 'Network Dimension' in the RIS approach that shows which knowledge network structures are to be expected in different types of RISs (Chapter 3), and the analysis whether regional knowledge network structures are associated with regional/RIS-related or sectoral characteristics (Chapter 4). In doing so, this dissertation provides additional theoretical, methodological and empirical input to economic geographic RIS Research and contributes to a better understanding of regional innovation processes. In this final chapter, the main chapters are briefly summarised and the major contributions are outlined (Section 5.1), aspects of future research are discussed (Section 5.2), and policy implication are presented (Section 5.3).

5.1 CHAPTER SUMMARIES AND MAJOR RESULTS

The aim of Chapter 2 (***'Regional Innovation System Classification: An Approach to Assign a Large Number of Regions to RIS Types'***) was to develop an approach to perform approximate RIS type assignments for a large number of regions on the basis of a simplistic approach that utilises a few quantifiable core contents reflecting major innovation process structures in the R&D subsystem of regions´ RISs, and makes it thus possible to depict major coining innovation process features of different RIS types. The reason for this was that so far the conceptual comprehensiveness as well as the related high requirements for data availability of existing RIS type classification and analysis frameworks allowed only conducting regional innovation process analyses and RIS type assignments for small numbers of regions (see research gap and objective in Section 1.2 and 1.3).

I first decided to focus on the RIS concept designed by COOKE (1998, 2004). In his RIS analysis and classification framework, regions can be analysed along two dimensions. The 'Business Innovation Dimension' (BID) depicts characteristics and structures of the innovating actors as well as their spatial patterns in innovation processes. The 'Governance Innovation Dimension' (GID) aims to reveal how innovation processes are managed and controlled by innovating and political actors (THOMI/WERNER 2001:212). Along each of these two dimensions, three GID and BID types with distinct characteristics can be distinguished. By merging the results from the two analysis dimensions, COOKE´s concept offers the possibility to identify nine different RIS types. Which RIS type a region has, however, depends on the manifestation of various different qualitative and quantitative characteristics in both the BID and the GID.

In order to reduce the resulting comprehensiveness and to make the concept more applicable for the analyses of a large number of regions, I decided that investigations addressing RISs (and their dimensions) are always limited to the R&D subsystem of a RIS, and I discussed conceptual modifications to COOKE´s two analysis dimensions. The result is that from a theoretical and conceptual point of view, regions can be assigned to different RIS types by focussing only on one core characteristics of the BID and GID, instead of taking all characteristics in the two dimensions into account as proposed by COOKE´s original concept. The remaining characteristics of the BID and GID are derived based on assumptions known from RIS theory. This was possible due to identified theoretical and conceptual interdependencies between the selected and the other characteristics existing in the BID and GID analysis framework. Of course, both the results and the thereon based assignments of regions to different RIS types are rather ideal-typical and hypothetical. Nonetheless, it is plausible to argue that the actual regional conditions should have at least essential similarities with the theoretical predictions (COOKE 1998, 2004), as the content of both dimensions and their types is based on extensive empirical research (CARLSSON 2007:860).

Following the conceptual and methodological discussions, I tested the developed theory-led RIS assignment approach exemplarily for German regions. In this context, it was of particular interest to find out whether the characteristics of the BID and GID types, which I empirically derived on the basis of the theory-led RIS assignment approach and the developed indicators, differ significantly and whether and to what extent the empirical values are consistent with the respective major theoretical contents of each BID and GID type. The final result is that the developed approach and the applied indicators generally seem able to differentiate the RIS types. Therefore, overall, this gives a promising first indication that the conceptual and the methodological modifications made to COOKE´s RIS analysis and classification framework allow to perform approximate and highly simplistic RIS type assignments for a large number of regions on the basis of core characteristics of regional innovation processes.

Finally, it is important to note that the developed simplified approach does not question COOKE´s comprehensive RIS concept. Both approaches pursue different targets and have different advantages: The simplified one involves few data and applies a theory-led, approximate RIS type deduction. Resulting RIS type assignments for potentially large numbers of regions provide the opportunity for initial RIS type specific comparisons and further analyses. COOKE´s original analysis concept, in turn, involves numerous qualitative and quantitative characteristics and applies a comprehensive RIS analysis and typification scheme for in-depth analyses and assessments of only few selected regions. Therefore, both approaches have the potential of complementing instead of substituting each other.

In Chapter 3 ('***Network Structures in Regional Innovation Systems'***) the aim was to integrate the network research perspective into the RIS approach, because so far the RIS approach is barely applied in the context of regional knowledge network structure analyses (GRABHER 2006; TER WAL/BOSCHMA 2009). This is due to the circumstance that the RIS approach conceptually relies on networks in the course of innovation processes but lacks theoretically precise and quantitatively measurable statements about structures and characteristics of inter-organisational interactions and knowledge exchange relations (see research gap and objective in Section 1.2 and 1.3).

To approach this deficit, I rendered network-relevant statements put forward in the RIS literature more precisely by evaluating them from a network-theoretical perspective. However, in order to keep this purpose clear and manageable I had to focus the theoretical discussion. With regard to the RIS literature, I concentrated on statements on inter-organisational interactions and knowledge exchange relations of three most ideal-typical types of RIS put forward by COOKE (1998, 2004): the interactive network RIS, the localist grassroots RIS, and the globalised dirigiste RIS. With respect to the applied concepts and insights from social network analysis (SNA), I limited the theoretical discussion to those concepts from network research that were most common and suitable for 'translating' interaction- and network-related terms from the RIS literature into SNA terminology.

As a result, this integration of the two largely unrelated streams of literature on RISs and network research contributes to the foundation of an explicit 'Network Dimension' in the RIS approach that allows deriving empirically testable hypotheses in future research. In summary, I showed that the three different RIS types have distinct network structures of knowledge sharing and inter-organisational interactions: Interactive network RISs are likely to be characterised by small-world type network structures, localist grassroots RISs can be expected to be shaped by core-periphery network structures, and in case of globalised dirigiste RISs it can generally be assumed that star-type network structures are present. In addition, I devised clear statements on, for instance, the distribution of centralities, network size, density, and degree of network centralisation of the three RIS types. Thus, the sharpening of the theoretical body of the RIS approach enhances the applicability of analytical and methodological concepts of SNA within the framework of RIS Research.

The objective of Chapter 4 ('***The Regions or the Sectors: What Determines Small-World Network Structures in Regions?'***) was to analyse from a comparative perspective whether regional or sectoral characteristics are associated with network structures in regional innovation processes. Arguments supporting a relation between regional characteristics and knowledge network structures in regions were based on the discussions made on RISs and their prevailing network structures I have conducted in the third chapter ('Network Structures in Regional Innovation Systems'). Arguments that suggest a relation between sectoral characteristics and network structures in regions were based on findings from different fields of Industry Research (e.g. PAVITT 1984; PORTER 2000; MALERBA 2002, 2004; TER WAL/BOSCHMA 2011; BROEKEL/GRAF 2012). This topic is of particular importance because research repeatedly points out that knowledge network structures in regions can influence innovation capabilities of regions (FLEMING et al. 2007; BRESCHI/LENZI 2011) (see research gap and objective in Section 1.2 and 1.3).

For the investigation of this research issue, I focused on the small-world network structure. Based on patent data, I then constructed innovation networks reflecting knowledge networks of innovation processes in German regions. In order to categorise whether these innovation networks are small-world types or not, I applied my modified version of the quantitative, continuous small-world determination approach proposed by HUMPHRIES & GURNEY (2008). Finally, by using a binary logistic regression analysis, I exemplarily analysed for German regions whether variables that depict RIS characteristics and sectors relate to the probability of finding small-world structures in regional innovation networks.

Interesting results came out from this analysis. The first major result of this empirical examination is that RIS *and* sectoral characteristics are associated with (small-world) network structures in regions. The probability to find small-world network structures in regional innovation networks increases, firstly if a region´s RIS is characterised by a high propensity to collaborate, secondly if innovation processes in a region´s RIS are coined by innovation activities from the science sector, and, thirdly if a region´s RIS actors are strongly embedded in intra-regional innovation activities. No evidence could be found to support that the probability to find small-worldness in regions correlates with the number of innovative actors in a RIS or with the role the business sector plays in regional innovation processes. Among the tested sector dummies only the science-based sector dummy achieved significant results. Against the backdrop of the underlying arguments from the literature, it can therefore be suggested that major sectoral characteristics that are likely to influence the probability to find small-world network structures in regional innovation networks are a relatively high research intensity and a relatively large actor-size structure.

Both 'levels' – the regional and the sectoral – thus seem to have an influence on or are at least correlated with regional knowledge network structures. The second major result is that the assumptions discussed in the third chapter regarding the prevailing knowledge network structures in an interactive network RIS are partly confirmed. This is a promising result if one considers that research on concrete network structures in RISs has just started.

5.2 IMPLICATIONS FOR FUTURE RESEARCH

Although this dissertation achieved interesting and valuable results, it leaves some open questions which were pointed out in the above chapters. This section summarises the most important ones.

In the second chapter, I presented an approach to assign a large number of regions to different RIS types. This may serve as a tool to clarify insufficiently explored questions related to RISs, for instance which is the most innovative RIS type, who are the most important actors in different RISs, what kind of institutional framework conditions do different RIS types have in common, or which collaboration patterns shape different types of RISs. Moreover, considering that former findings constituting the current RIS framework were largely based on analyses of successful regions that have been examined in the context of case studies, future research could also discuss whether and to what extent the attributed RIS type characteristics from the RIS literature are adequate or require adaptations (MARKUSEN 1999; MOULAERT/SEKIA 2003; DOLOREUX/PARTO 2005; TER WAL/BOSCHMA 2009).

In the third chapter, I integrated the network research perspective into the RIS approach by applying SNA concepts to three selected ideal-typical RIS types drawn from COOKE´s RIS concept (1998, 2004). Therefore, it would be interesting to discuss in the future which network structures coin the innovation processes of the remaining six RIS types, and to apply such a theoretical discussion to other RIS concepts (e.g. ASHEIM/ISAKSEN 2000). Moreover, since I concentrated on selected SNA concepts, future research could also look at additional network structural characteristics that have yet not been taken into account. Particularly insightful could be discussions about further actor type-specific centralities (e.g. closeness or eigenvector), as those could give additional inputs for network-theoretical discussions in the context of the RIS approach. However, in spite of the need for further theoretical elaborations, future research should particularly stress empirical works, as this is the only way to find out if the (so far hypothetical) discussions are heading in the right direction or if adaptations and/or corrections are necessary. Both the assignment approach presented in the second and the analysis concept applied in the fourth chapter may contribute to this purpose.

In the fourth chapter, I analysed whether regional or sectoral characteristics relate to the probability of finding small-world network structures in regional innovation processes. However, as I concentrated the analysis only on one particular network structure, future research should expand the analyses to other prominent network structures such as the core-periphery or the hub-and-spoke (i.e. star-type) network structure (MARKUSEN 1996; BORGATTI/EVERETT 1999; RANK et al. 2006; NAKANO/WHITE 2006). Expectations and hypotheses to do so are provided in the third chapter. The results of future research could therefore further verify the theoretically discussed relations between RIS types and specific network structures and thus contribute to an empirical agenda. Furthermore, it may be insightful to apply a finer sectoral distinction than that of PAVITT (1984). This could open a path to gain more precise results on the relation between sectors and regional knowledge network structures. Moreover, considering that I focused on regional and sectoral characteristics, it would also be interesting to add national influences to the analysis. It remains unclear so far, for instance, which influence subsidised national joint research programmes have on networks in regional innovation processes, which role embeddedness in international innovation processes plays in regional network structures, or how regional innovation network structures can be assessed in the context of a wider, i.e. national innovation network.

In addition, the topics discussed in the course of this dissertation were based on a static view. However, (regional) innovation processes are dynamic in nature (ROTHWELL 1994; LUNDVALL/JOHNSON 1994). This is particularly important in view of lock-in and path-dependency processes as well as the evolution of RISs in general and knowledge networks in particular (GRABHER 1993; COOKE et al. 1998; BATHELT et al. 2004; VISSER/BOSCHMA 2004; ASHEIM/GERTLER 2005; TÖDTLING/TRIPPL 2005; FU 2011; BALLAND 2012). Therefore, with respect to the second chapter, it would be interesting to analyse developments of RIS type specific actor settings, institutions, collaboration characteristics, knowledge bases, or industry structures. With regard to the third chapter, future research should focus on the co-evolution of RIS types and network structures. For instance, small-world properties are more likely to emerge when actor relations are coined by preferential attachment processes (see ***Footnote 34***). Accordingly, future research could ask why preferential attachment is particularly strong in the evolution of interactive networked RIS. With regard to the fourth chapter, it would be interesting to investigate, for instance, at which stage of development which regional and/or sectoral characteristics are associated with certain regional knowledge network structures.

A further point concerns the fact that the applied indicators and data sources can only partly display complex phenomena like regional innovation processes as well as therewith related regional structures (see Section 2.3.3 and 4.3.1). Therefore, future research should further develop these or even try to find new and/or additional ones. Improvements that allow depicting (parts of) non-technological innovation processes as well as aspects of innovation process governance or management would be particularly important. Moreover, in order to approach the suggestions for a dynamic/evolutionary perspective outlined above, longitudinal data at a regional level is needed. However, at the regional level, data on innovation topics is often only available for short periods of time (for instance in case of the applied FP7 database or the INKAR dataset, but also in case of data from the European Statistic Office (Eurostat)). Therefore, future research should also ensure that data that is suitable for regional innovation process analyses is available for longer time periods.

Another issue concerns the fact that it has yet not been theoretically and conceptually answered at which regional scale RISs are located, and if all or only particular regions actually have a RIS (e.g. COOKE et al. 1997, 1998; HOWELLS 1999; KOSCHATZKY 2001, 2009; COOKE 2001a; 2002a; CARLSSON et al. 2002; DOLOREUX/PARTO 2005). Regarding both the former and the latter a conservative and a liberal perspective exists. However, as both approaches entail advantages and disadvantages, so far researchers usually apply the approach that fits best in the research framework. I applied the liberal approaches, thereby following the works of e.g. KOCH & STAHLECKER (2006) or FRITSCH & SLAVTCHEV (2011), on the one hand, and STUCK & REVILLA DIEZ (2013) or EC (2014b), on the other. Future research should therefore intensify theoretical and conceptual discussions addressing these topics and clarify at which regional scale and under which conditions RISs are to be expected.

Last but not least, it may be interesting to find out to what extend my elaborations can be generalised. Firstly, both the theoretical and conceptual basis of this dissertation as well as the thereon based discussions largely rest on research results that were derived from a few, selected successful regions in North-America and/or Europe (see critical debate e.g. in DOLOREUX/PARTO 2004, 2005). Secondly, I conducted the empirical examinations only for and on the basis of data from German regions. Therefore, it is not unequivocally clear if my discussions and results are valid for other contexts. It would thus be interesting and enriching to expand RIS Research in general and my elaborations in particular to further regions. In this context, it would be especially interesting to increase the focus on innovation process analyses in RISs of developing countries (for an overview see e.g. LUNDVALL et al. 2009).

5.3 POLICY IMPLICATIONS

This section summarises the policy implications from the chapters of this dissertation. However, the suggestions must be considered conditionally with regard to the implications for future research identified in the previous section.

As described in the introduction (see Section 1.1), innovations are of central significance for regional development. However, since many regions do not have sufficient innovation capabilities and successful regions are also exposed to increasing competition for new ideas, since the 1990s politicians from the European, national, and regional levels feel obliged to intervene, and introduce innovation policy measures in order to encourage the innovation capabilities of innovation systems in regions. In this respect, policy-makers could benefit from the elaborations of this dissertation: For instance, additional theoretical and empirical knowledge regarding RIS type-specific innovation capabilities, innovating actors, innovation infrastructures, institutions, or intra- and inter-regional collaborations arising from the RIS analyses of a large number of regions could contribute to a better management and optimisation of RISs. Moreover, the Network Dimension resulting from the integration of the network research perspective in the RIS approach could enable more precise analyses of network structures in regional innovation processes. The empirical results from this dissertation support this. Therefore, network-related insights could be used as additional input for tailored policy designs that aim particularly to stimulate (regional) collaborative R&D and knowledge exchange. Moreover, SNA could serve as a basis for a more targeted management of interactions and networks in RISs. In the design, execution, and evaluation of policy measures, the Network Dimension could thus valuably complement the RIS analysis framework.

In addition, there are policy implications which relate to the empirical analysis of whether regional/RIS-related or sectoral characteristics are associated with network structures in regional innovation processes. However, it should be noted that there is no such thing as 'one-size-fits-all' (innovation) policy (TÖDTLING/TRIPPL 2005). Any policy should be tailored according to the specific regional context for which it is implemented. Accordingly, the following recommendations are rather general in nature and should be understood as suggestions or contributions to the debate.

As my thesis indicates, regional and sectoral characteristics relate to small-world network structures in regional innovation networks. This is of particular interest, as recent studies conducted by e.g. FLEMING et al. (2007) and BRESCHI & LENZI (2011) suggest that small-world network structures in regions have a positive impact on a region´s innovative capabilities. Therefore, the first recommendation that can be derived is that policy-makers who want to influence network structures in regions should consider both 'levels' when designing policy measures.

For instance, at the regional 'level', the positive correlation between a region´s overall collaboration propensity and the probability to find small-worldness in this region provides opportunities for political action, since the collaboration propensity of actors in regions is argued to be shaped particularly by a region's institutional framework well as well as its technological sophistication (COOKE et al. 2004). For regions which already show appropriate industrial and technological conditions but not yet a sufficient level of small-worldness, it would thus be conceivable to further improve the (regional) institutional conditions. However, in regions where the industrial and technological conditions are relatively underdeveloped, industrial political measures should be implemented, so that potentially resulting industrial and technological upgrades can perspectively lead to increased networking and small-world network structures. However, in case a region´s technological sophistication is underdeveloped, it is advisable to improve both institutional *and* industrial and technological framework conditions, as both aspects are closely related.

The result that the probability to find small-worldness in a region is associated with the extent to which the overall regional innovation processes of a region´s RIS is shaped by the science sector, suggests that policy-makers should strengthen regional scientific actors and encourage them to collaborate with other actors in the region in order to accelerate small-world network structures in regional knowledge networks.

However, particularly challenging for policy-makers is the finding that small-world network structures in regional innovation networks are positively correlated with the overall intra-regional embeddedness of actors in a RIS. This is because the literature also states that extra-regional embeddedness is important to prevent lock-ins (CAMAGNI 1991; BATHELT et al. 2004; MORRISON 2008; BRESCHI/LENZI 2013). Both the support of intra- and extra-regional connections thus appears to be relevant. Therefore, balanced policy intervention is indispensible. This means, if policy-makers want to support inter-regional knowledge exchange *and* simultaneously foster the development of small-worldness in regions, they should not promote extra-regional connections to the disadvantage of intra-regional connections. Otherwise, small-world network structures would be difficult to realise. The same applies the other way around, with the consequence that the risk of regional lock-ins increases.

Last but not least, the results concerning the sectoral 'level' suggest that sector-based policy approaches to influence the existence of small-worldness in regions are only useful in case science-based sectors exist. Usually, these sectors show relatively large actor-size structures and have significant contributions made by research entities. However, policy-makers should take into account that not all research intensive sectors have the necessary actor capacities to form small-world network structures in all regions. This means, the sectoral approach to possibly influence small-world network structures in a region is not a tool that can easily be applied to a large number of regions.

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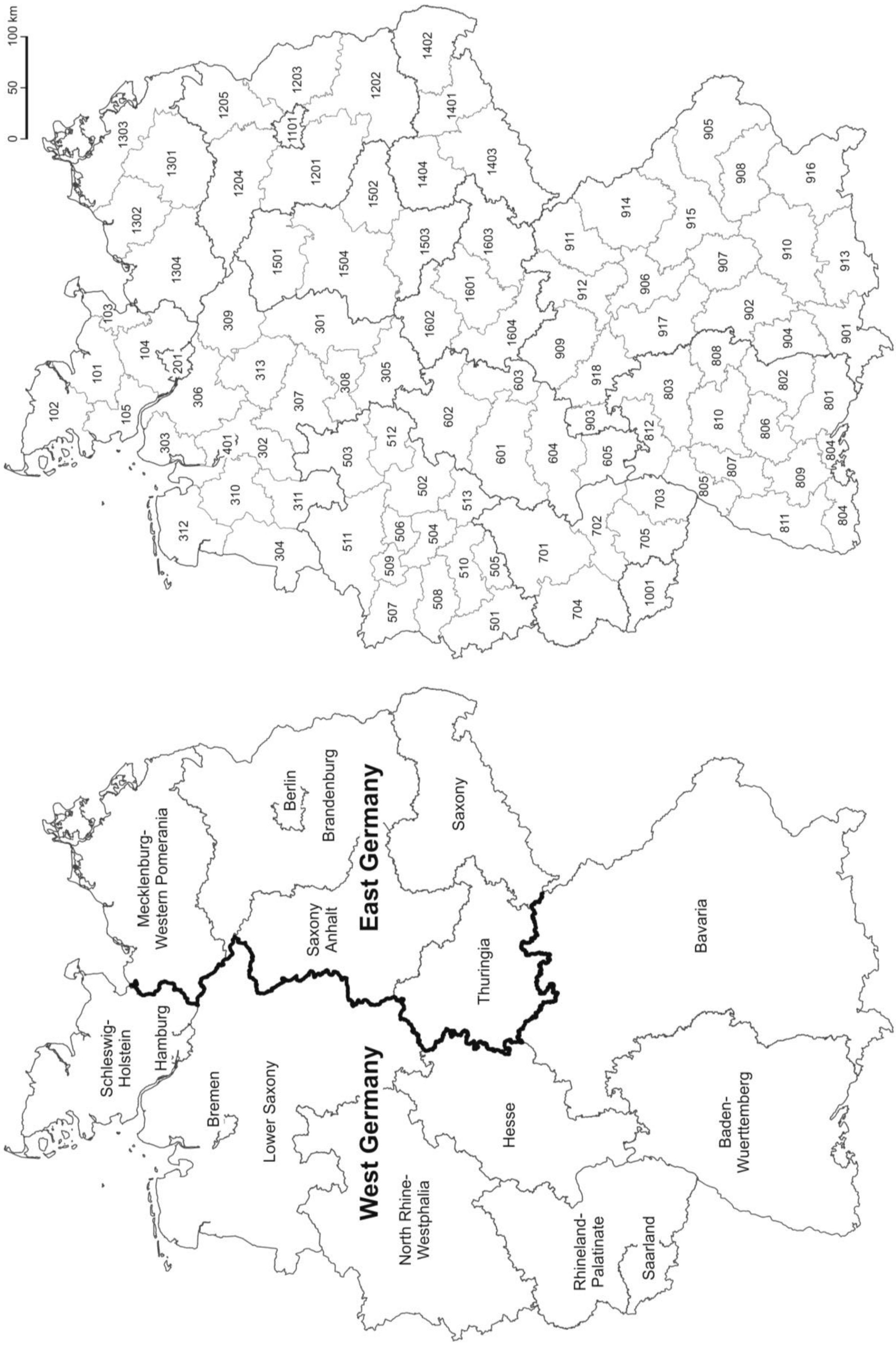
APPENDICES

<u>Appendix A:</u> Overview of the German Länder and the Planning Regions (RORs)



Author´s illustrations; left hand side: German Länder and former border between West and East Germany; right hand side: German Planning Regions (RORs)

<u>Appendix B:</u> Indicator and Typification Results for the BID

ROR-Name	ROR-Code	Regional Level (Indicator 1)	National Level (Indicator 2)	International Level (Indicator 3)	BID Type (1=localist, 2=interactive, 3=globalised)
Schleswig-Holstein Mitte	101	0.45	0.43	0.12	2
Schleswig-Holstein Nord	102	0.39	0.46	0.15	2
Schleswig-Holstein Ost	103	0.40	0.50	0.09	2
Schleswig-Holstein Süd	104	0.37	0.56	0.07	3
Schleswig-Holstein Süd-West	105	0.34	0.57	0.09	3
Hamburg	201	0.43	0.45	0.12	2
Braunschweig	301	0.46	0.45	0.09	1
Bremen-Umland	302	0.33	0.59	0.08	3
Bremerhaven	303	0.41	0.50	0.09	2
Emsland	304	0.40	0.43	0.17	2
Göttingen	305	0.42	0.46	0.12	2
Hamburg-Umland-Süd	306	0.30	0.62	0.08	3
Hannover	307	0.44	0.44	0.12	2
Hildesheim	308	0.34	0.58	0.08	3
Lüneburg	309	0.28	0.67	0.04	3
Oldenburg	310	0.37	0.56	0.07	3
Osnabrück	311	0.39	0.52	0.09	2
Ost-Friesland	312	0.41	0.53	0.06	2
Südheide	313	0.35	0.50	0.14	3
Bremen	401	0.38	0.51	0.11	3
Aachen	501	0.47	0.37	0.16	2
Arnsberg	502	0.38	0.54	0.08	3
Bielefeld	503	0.50	0.44	0.06	1
Bochum/Hagen	504	0.29	0.63	0.07	3
Bonn	505	0.34	0.56	0.10	3
Dortmund	506	0.31	0.62	0.07	3
Duisburg/Essen	507	0.35	0.56	0.09	3
Düsseldorf	508	0.39	0.47	0.14	2
Emscher-Lippe	509	0.27	0.65	0.08	3
Köln	510	0.35	0.52	0.13	3
Münster	511	0.39	0.51	0.10	2
Paderborn	512	0.39	0.56	0.05	2
Siegen	513	0.44	0.51	0.05	2
Mittelhessen	601	0.40	0.51	0.09	2
Nordhessen	602	0.44	0.50	0.07	2
Osthessen	603	0.33	0.58	0.09	3
Rhein-Main	604	0.38	0.45	0.17	3
Starkenburg	605	0.30	0.58	0.12	3
Mittelrhein-Westerwald	701	0.34	0.57	0.10	3
Rheinhessen-Nahe	702	0.31	0.57	0.13	3
Rheinpfalz	703	0.31	0.53	0.16	3
Trier	704	0.38	0.41	0.21	3
Westpfalz	705	0.32	0.58	0.10	3
Bodensee-Oberschwaben	801	0.46	0.45	0.09	1
Donau-Iller (BW)	802	0.39	0.51	0.10	2
Franken	803	0.35	0.59	0.06	3

Note: Continuation of this table follows on next page.

Continuation of ***Appendix B***

Hochrhein-Bodensee	804	0.32	0.29	0.38	3
Mittlerer Oberrhein	805	0.37	0.53	0.10	3
Neckar-Alb	806	0.37	0.55	0.08	3
Nordschwarzwald	807	0.29	0.66	0.06	3
Ostwürttemberg	808	0.41	0.49	0.09	2
Schwarzwald-Baar-Heuberg	809	0.48	0.39	0.13	2
Stuttgart	810	0.55	0.36	0.09	1
Südlicher Oberrhein	811	0.39	0.40	0.21	2
Unterer Neckar	812	0.35	0.49	0.16	3
Allgäu	901	0.40	0.48	0.12	2
Augsburg	902	0.41	0.50	0.09	2
Bayerischer Untermain	903	0.29	0.62	0.09	3
Donau-Iller (BY)	904	0.32	0.61	0.07	3
Donau-Wald	905	0.37	0.53	0.09	3
Industrieregion Mittelfranken	906	0.47	0.43	0.10	1
Ingolstadt	907	0.36	0.57	0.07	3
Landshut	908	0.32	0.60	0.08	3
Main-Rhön	909	0.48	0.46	0.06	1
München	910	0.48	0.36	0.16	2
Oberfranken-Ost	911	0.40	0.52	0.08	2
Oberfranken-West	912	0.33	0.60	0.07	3
Oberland	913	0.31	0.57	0.11	3
Oberpfalz-Nord	914	0.38	0.55	0.07	3
Regensburg	915	0.46	0.45	0.08	1
Südostoberbayern	916	0.43	0.46	0.11	1
Westmittelfranken	917	0.31	0.60	0.09	3
Würzburg	918	0.43	0.48	0.09	1
Saar	1001	0.40	0.47	0.13	2
Berlin	1101	0.46	0.40	0.14	2
Havelland-Fläming	1201	0.27	0.65	0.08	3
Lausitz-Spreewald	1202	0.28	0.66	0.06	3
Oderland-Spree	1203	0.38	0.55	0.07	3
Prignitz-Oberhavel	1204	0.22	0.70	0.08	3
Uckermark-Barnim	1205	0.21	0.70	0.09	3
Mecklenburgische Seenplatte	1301	0.38	0.59	0.03	3
Mittleres Mecklenburg/Rostock	1302	0.28	0.64	0.08	3
Vorpommern	1303	0.43	0.49	0.08	2
Westmecklenburg	1304	0.33	0.61	0.06	3
Oberes Elbtal/Osterzgebirge	1401	0.48	0.41	0.11	1
Oberlausitz-Niederschlesien	1402	0.30	0.64	0.06	3
Südsachsen	1403	0.43	0.50	0.06	2
Westsachsen	1404	0.39	0.52	0.09	2
Altmark	1501	0.29	0.66	0.05	3
Anhalt-Bitterfeld-Wittenberg	1502	0.33	0.59	0.08	3
Halle/S.	1503	0.37	0.49	0.13	3
Magdeburg	1504	0.40	0.52	0.08	2
Mittelthüringen	1601	0.35	0.59	0.06	3
Nordthüringen	1602	0.17	0.71	0.12	3
Ostthüringen	1603	0.44	0.47	0.10	1
Südthüringen	1604	0.34	0.60	0.06	3
German Average		0.39	0.49	0.12	

Table provided by author; highlighted cells correspond or are above the national reference value

<u>Appendix C:</u> Indicator and Typification Results for the GID

ROR-Name	ROR-Code	Regional Level (Indicator 1)	National Level (Indicator 2)	International Level (Indicator 3)	GID Type (1=grassroots, 2=network, 3=dirigiste)
Schleswig-Holstein Mitte	101	0.19	0.18	0.64	3
Schleswig-Holstein Nord	102	0.00	0.25	0.75	3
Schleswig-Holstein Ost	103	0.13	0.08	0.79	3
Schleswig-Holstein Süd	104	0.15	0.13	0.73	3
Schleswig-Holstein Süd-West	105	0.50	0.00	0.50	1
Hamburg	201	0.19	0.14	0.68	3
Braunschweig	301	0.14	0.21	0.65	3
Bremen-Umland	302	0.00	0.50	0.50	3
Bremerhaven	303	0.23	0.09	0.69	2
Emsland	304	0.22	0.11	0.67	2
Göttingen	305	0.31	0.14	0.55	1
Hamburg-Umland-Süd	306	0.00	0.33	0.67	3
Hannover	307	0.18	0.15	0.67	3
Hildesheim	308	0.10	0.50	0.40	3
Lüneburg	309	0.14	0.00	0.86	3
Oldenburg	310	0.16	0.20	0.65	3
Osnabrück	311	0.19	0.19	0.62	3
Ost-Friesland	312	0.00	0.57	0.43	3
Südheide	313	0.00	0.00	1.00	3
Bremen	401	0.24	0.13	0.63	1
Aachen	501	0.22	0.16	0.62	1
Arnsberg	502	0.00	0.40	0.60	3
Bielefeld	503	0.16	0.14	0.71	3
Bochum/Hagen	504	0.25	0.10	0.65	2
Bonn	505	0.16	0.18	0.65	3
Dortmund	506	0.16	0.28	0.56	3
Duisburg/Essen	507	0.14	0.14	0.71	3
Düsseldorf	508	0.16	0.26	0.58	3
Emscher-Lippe	509	0.21	0.21	0.57	2
Köln	510	0.18	0.19	0.62	3
Münster	511	0.24	0.16	0.60	1
Paderborn	512	0.18	0.18	0.64	3
Siegen	513	0.21	0.48	0.31	2
Mittelhessen	601	0.25	0.13	0.63	1
Nordhessen	602	0.12	0.14	0.74	3
Osthessen	603	0.00	0.00	1.00	3
Rhein-Main	604	0.15	0.26	0.60	3
Starkenburg	605	0.09	0.16	0.74	3
Mittelrhein-Westerwald	701	0.13	0.27	0.60	3
Rheinhessen-Nahe	702	0.28	0.14	0.58	1
Rheinpfalz	703	0.03	0.12	0.85	3
Trier	704	0.22	0.22	0.56	2
Westpfalz	705	0.19	0.13	0.68	3
Bodensee-Oberschwaben	801	0.11	0.25	0.64	3
Donau-Iller (BW)	802	0.11	0.20	0.69	3
Franken	803	0.04	0.22	0.74	3

Note: Continuation of this table follows on next page.

Continuation of ***Appendix C***

Hochrhein-Bodensee	804	0.21	0.23	0.55	2
Mittlerer Oberrhein	805	0.19	0.14	0.67	3
Neckar-Alb	806	0.30	0.17	0.53	2
Nordschwarzwald	807	0.00	0.44	0.56	3
Ostwürttemberg	808	0.13	0.19	0.69	3
Schwarzwald-Baar-Heuberg	809	0.00	0.54	0.46	3
Stuttgart	810	0.20	0.18	0.63	2
Südlicher Oberrhein	811	0.27	0.19	0.55	2
Unterer Neckar	812	0.30	0.15	0.55	1
Allgäu	901	0.23	0.54	0.23	2
Augsburg	902	0.17	0.33	0.50	3
Bayerischer Untermain	903	0.00	0.25	0.75	3
Donau-Iller (BY)	904	0.17	0.50	0.33	3
Donau-Wald	905	0.10	0.19	0.71	3
Industrieregion Mittelfranken	906	0.12	0.14	0.74	3
Ingolstadt	907	0.00	0.38	0.63	3
Landshut	908	0.00	0.50	0.50	3
Main-Rhön	909	0.00	0.75	0.25	3
München	910	0.22	0.13	0.66	2
Oberfranken-Ost	911	0.17	0.41	0.41	3
Oberfranken-West	912	0.17	0.33	0.50	3
Oberland	913	0.13	0.33	0.53	3
Oberpfalz-Nord	914	0.00	0.67	0.33	3
Regensburg	915	0.34	0.26	0.40	2
Südostoberbayern	916	0.08	0.25	0.67	3
Westmittelfranken	917	0.00	0.00	1.00	3
Würzburg	918	0.17	0.23	0.60	3
Saar	1001	0.26	0.16	0.58	1
Berlin	1101	0.22	0.14	0.64	2
Havelland-Fläming	1201	0.23	0.10	0.67	2
Lausitz-Spreewald	1202	0.00	0.20	0.80	3
Oderland-Spree	1203	0.26	0.18	0.56	2
Prignitz-Oberhavel	1204	0.00	0.00	1.00	3
Uckermark-Barnim	1205	0.00	0.67	0.33	3
Mecklenburgische Seenplatte	1301	0.00	0.25	0.75	3
Mittleres Mecklenburg/Rostock	1302	0.14	0.20	0.65	3
Vorpommern	1303	0.16	0.16	0.68	3
Westmecklenburg	1304	0.00	0.80	0.20	3
Oberes Elbtal/Osterzgebirge	1401	0.22	0.17	0.61	2
Oberlausitz-Niederschlesien	1402	0.00	0.18	0.82	3
Südsachsen	1403	0.06	0.21	0.73	3
Westsachsen	1404	0.34	0.17	0.50	2
Altmark	1501	no data	no data	no data	not specified
Anhalt-Bitterfeld-Wittenberg	1502	0.00	0.17	0.83	3
Halle/S.	1503	0.06	0.18	0.76	3
Magdeburg	1504	0.06	0.29	0.65	3
Mittelthüringen	1601	0.10	0.33	0.58	3
Nordthüringen	1602	0.20	0.40	0.40	2
Ostthüringen	1603	0.22	0.18	0.60	2
Südthüringen	1604	0.00	0.29	0.71	3
German Average		0.20	0.17	0.63	

Table provided by author; highlighted cells correspond or are above the national reference value

<u>Appendix D:</u> Relation between BID Types and Population Density (Kruskall-Wallis-Test[62])

Indicator	BID Typ	Number	Mean rank
Population Density	localist	11	53,45
	interactive	31	55,23
	globalised	54	43,63
	total	96	

	Population Density
Chi-square	3,806
df	2
Asymptotic significance	0,149

Note: $p \leq 0.01$ = highly significant; $0.05 \geq p > 0.01$ = significant; $0.1 \geq p > 0.05$ = slightly significant

Tables provided by author

<u>Appendix E:</u> Relation between GID Types and Population Density (Kruskall-Wallis-Test)

Indicator	GID Typ	Number	Mean rank
Population Density	grassroots	9	63,33
	network	20	52,25
	dirigiste	66	44,62
	total	95	

	Population Density
Chi-square	4,251
df	2
Asymptotic significance	0,119

Note: $p \leq 0.01$ = highly significant; $0.05 \geq p > 0.01$ = significant; $0.1 \geq p > 0.05$ = slightly significant

Tables provided by author

[62] The Kruskall-Wallis-Test is a nonparametric test procedure that examines whether the ranking of the values (here the values of the indicators 1 to 3) are different *for more than two independent samples* (here the three BID types).

Appendix F: Pairwise Differences of the Spatial Indicators between the BID Types (Kolmogorov-Smirnov-Z-Test[63])

Test 1: Localist vs. Interactive BID Type

		Regional level	National level	International level
Extreme Differences	Absolute	0,645	0,548	0,452
	Positive	0,645	0,070	0,065
	Negative	0,000	-0,548	-0,452
Kolmogorov-Smirnov-Z		1,838	1,563	1,287
Asymptotic significance		0,002	0,015	0,073

Note: $p \leq 0.01$ = highly significant; $0.05 \geq p > 0.01$ = significant; $0.1 \geq p > 0.05$ = slightly significant

Test 2: Localist vs. Globalised BID Type

		Regional level	National level	International level
Extreme Differences	Absolute	1,000	0,944	0,283
	Positive	1,000	0,019	0,283
	Negative	0,000	-0,944	-0,204
Kolmogorov-Smirnov-Z		3,023	2,855	0,855
Asymptotic significance		0,000	0,000	0,458

Note: $p \leq 0.01$ = highly significant; $0.05 \geq p > 0.01$ = significant; $0.1 \geq p > 0.05$ = slightly significant

Test 3: Interactive vs. Globalised BID Type

		Regional level	National level	International level
Extreme Differences	Absolute	1,000	0,787	0,297
	Positive	1,000	0,019	0,297
	Negative	0,000	-0,787	-0,019
Kolmogorov-Smirnov-Z		4,438	3,494	1,320
Asymptotic significance		0,000	0,000	0,061

Note: $p \leq 0.01$ = highly significant; $0.05 \geq p > 0.01$ = significant; $0.1 \geq p > 0.05$ = slightly significant

Tables provided by author

[63] The Kolmogorov-Smirnov-Z-Test is a non-parametric test method which analyses the distributions of the values (in this case the values of the indicators 1 to 3) of *exactly two independent samples* (here the different BID types).

Appendix G: Pairwise Differences of the Spatial Indicators between the GID Types (Kolmogorov-Smirnov-Z-Test)

Test 1: Grassroots vs. Network GID Type

		Regional level	National level	International level
Extreme Differences	Absolute	0,589	0,700	0,300
	Positive	0,589	0,089	0,217
	Negative	0,000	-0,700	-0,300
Kolmogorov-Smirnov-Z		1,467	1,744	0,747
Asymptotic significance		0,027	0,005	0,632

Note: $p \leq 0.01$ = highly significant; $0.05 \geq p > 0.01$ = significant; $0.1 \geq p > 0.05$ = slightly significant

Test 2: Grassroots vs. Dirigiste GID Type

		Regional level	National level	International level
Extreme Differences	Absolute	1,000	0,727	0,621
	Positive	1,000	0,000	0,136
	Negative	0,000	-0,727	-0,621
Kolmogorov-Smirnov-Z		2,814	2,047	1,748
Asymptotic significance		0,000	0,000	0,004

Note: $p \leq 0.01$ = highly significant; $0.05 \geq p > 0.01$ = significant; $0.1 \geq p > 0.05$ = slightly significant

Test 3: Network vs. Dirigiste GID Type

		Regional level	National level	International level
Extreme Differences	Absolute	1,000	0,255	0,389
	Positive	1,000	0,091	0,015
	Negative	0,000	-0,255	-0,389
Kolmogorov-Smirnov-Z		3,918	0,997	1,526
Asymptotic significance		0,000	0,273	0,019

Note: $p \leq 0.01$ = highly significant; $0.05 \geq p > 0.01$ = significant; $0.1 \geq p > 0.05$ = slightly significant

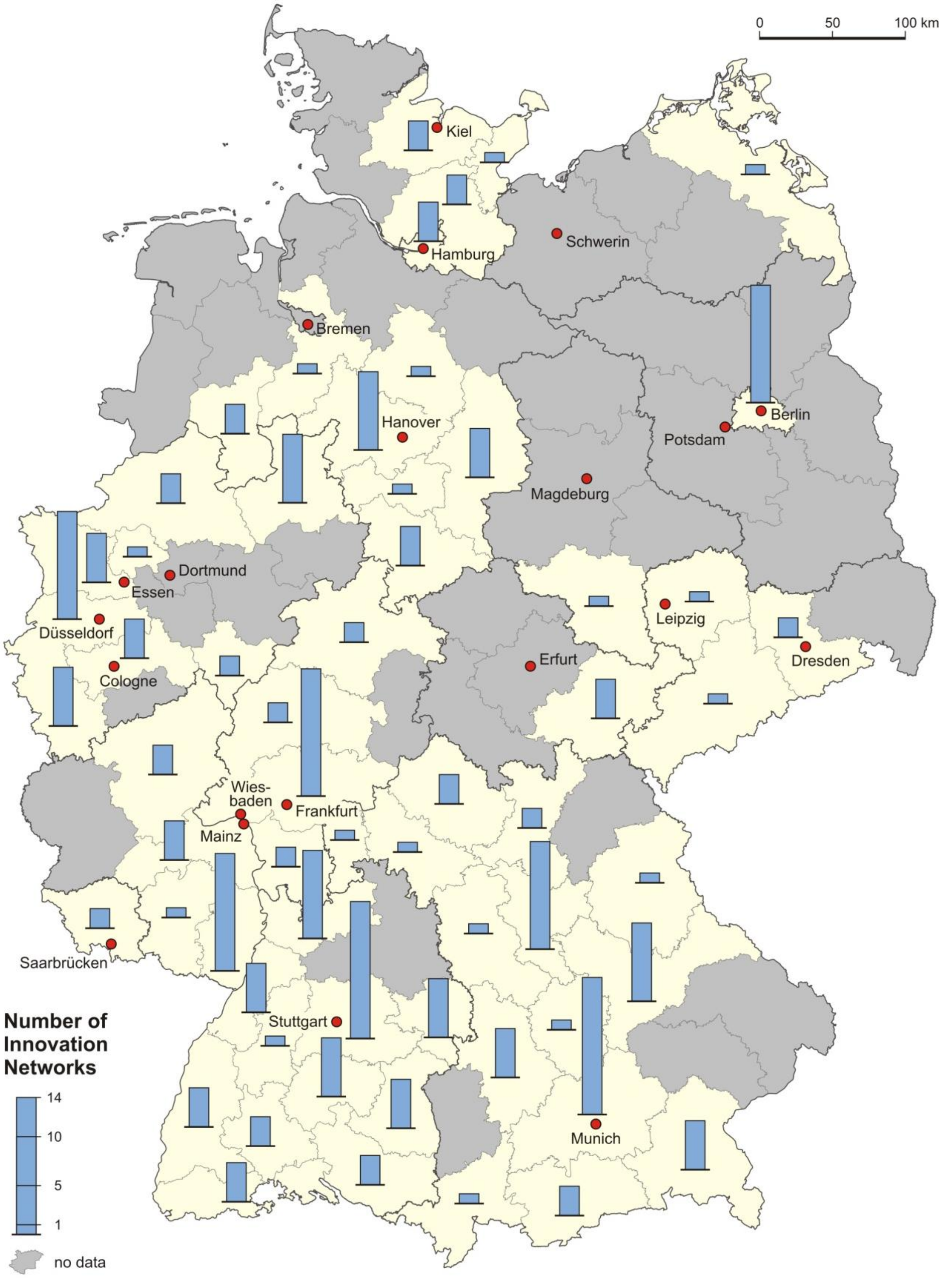
Tables provided by author

<u>Appendix H:</u> Industrial Sub-sectors, Technology Fields, and Pavitt´s Taxonomy

Industrial sub-sector	**Description**	**Technology field**	**Description**	**Pavitt´s Taxonomy**
I.1	Food, beverages	T.1	Food, beverages	Scale-intensive
I.2	Tobacco products	T.2	Tobacco products	Supplier dominated
I.3	Textiles	T.3	Textiles	Supplier dominated
I.4	Wearing apparel	T.4	Wearing apparel	Supplier dominated
I.5	Leather articles	T.5	Leather articles	Supplier dominated
I.6	Wood products	T.6	Wood products	Supplier dominated
I.7	Paper	T.7	Paper	Supplier dominated
I.8	Publishing, printing	T.8	Publishing, printing	Supplier dominated
I.9	Petroleum products, nuclear fuel	T.9	Petroleum products, nuclear fuel	Scale-intensive
I.10	Chemicals	T.10	Basic chemical	Science-based
I.10	Chemicals	T.11	Pesticides, agro-chemical	Science-based
I.10	Chemicals	T.12	Paints, varnishes	Science-based
I.10	Chemicals	T.13	Pharmaceuticals	Science-based
I.10	Chemicals	T.14	Soaps, detergents, toilet,	Science-based
I.10	Chemicals	T.15	Other chemicals	Science-based
I.10	Chemicals	T.16	Man-made fibres	Science-based
I.11	Rubber and plastics products	T.17	Rubber and plastics products	Scale-intensive
I.12	Non-metallic mineral products	T.18	Non-metallic mineral products	Scale-intensive
I.13	Basic metals	T.19	Basic metals	Scale-intensive
I.14	Fabricated metal products	T.20	Fabricated metal products	Scale-intensive
I.15	Energy machinery	T.21	Energy machinery	Specialised
I.15	Non-specific purpose machinery	T.22	Non-specific purpose machinery	Specialised
I.15	Agricultural and forestry	T.23	Agricultural and forestry	Specialised
I.15	Machine-tools	T.24	Machine-tools	Specialised
I.15	Special purpose machinery	T.25	Special purpose machinery	Specialised
I.15	Weapons and ammunition	T.26	Weapons and ammunition	Specialised
I.15	Domestic appliances	T.27	Domestic appliances	Specialised
I.16	Office machinery and computers	T.28	Office machinery and computers	Specialised
I.17	Electrics	T.29	Electric motors, generators,	Science-based
I.17	Electrics	T.30	Electric distribution, control, wire,	Science-based
I.17	Electrics	T.31	Accumulators, battery	Science-based
I.17	Electrics	T.32	Lightening equipment	Science-based
I.17	Electrics	T.33	Other electrical equipment	Science-based
I.18	Electronics	T.34	Electronic components	Science-based
I.18	Electronics	T.35	Signal transmission,	Science-based
I.18	Electronics	T.36	Television and radioreceivers,	Science-based
I.19	Optics and precision instruments	T.37	Medical equipment	Specialised
I.19	Optics and precision instruments	T.38	Measuring instruments	Specialised
I.19	Optics and precision instruments	T.39	Industrial process control	Specialised
I.19	Optics and precision instruments	T.40	Optical instruments	Specialised
I.19	Optics and precision instruments	T.41	Watches, clocks	Specialised
I.20	Motor vehicles	T.42	Motor vehicles	Scale-intensive
I.21	Other transport equipment	T.43	Other transport equipment	Scale-intensive
I.22	Furniture, consumer goods	T.44	Furniture, consumer goods	Scale-intensive

Table provided by author; based on PAVITT (1984) and SCHMOCH et al. (2003)

Appendix I: Distribution of Innovation Networks Across German Regions



Author´s illustration[64]

[64] For a better orientation, the capital cities of the Federal States *and* cities with more than 500,000 inhabitants are depicted in the map. Furthermore, the names of the ROR units can be concluded by using ***Appendix A*** in combination with either ***Appendix B*** or ***Appendix C***.

Appendix J: Test for Linearity

Interaction term	z value	p value
inno.actor.reg * log(inno.actor.reg)	-1,045	0,296
collab.prop.reg * log(collab.prop.reg)	-1,303	0,193
share.pats.science.reg * log(share.pats.science.reg)	1,390	0,164
share.pats.bus.reg * log(share.pats.bus.reg)	1,277	0,202
share.reg.pats.reg * log(share.reg.pats.reg)	-0,647	0,518
density.netw * log(density.netw)	0,642	0,521
edges.netw * log(edges.netw)	1,820	0,069
pop.density.reg * log(pop.density.reg)	-0,826	0,409
specilization.reg * log(specilization.reg)	0,340	0,734
concentration.reg * (concentration.reg)	-0,446	0,656

Notes: dependent variable = small worldness (0 / 1); $p \leq 0.01$ = highly significant; $0.05 \geq p > 0.01$ = significant

Table provided by author

Appendix K: Test for Multicollinearity

Independent variable	VIF value
inno.actor.reg	2.787
collab.prop.reg	2.205
share.pats.science.reg	3.508
share.pats.bus.reg	4.386
share.reg.pats.reg	2.087
DUMMY.suppl.dom.sec	1.271
DUMMY.scale.int.sec	1.270
DUMMY.science.based.sec	1.368
density.netw	2.365
edges.netw	4.890
pop.density.reg	1.857
specilization.reg	2.832
concentration.reg	1.738

Note: VIF value > 5 indicates problematic multicollinearity

Table provided by author

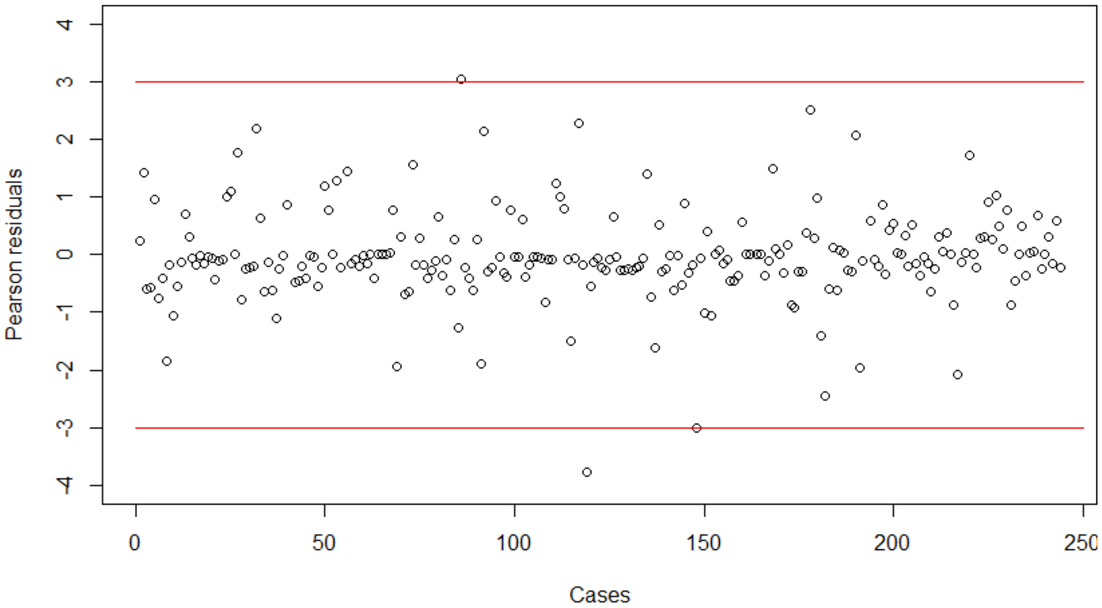
Appendix L: Test for Independent Residuals

Level	Moran I statistic	Expectation	Variance	Standard deviate	p value
Spatial	-0,017	-0,0045	0,0012	-0,347	0,636
Technological	0,014	-0,0042	0,0006	0,732	0,232

Note: $p \leq 0.01$ = highly significant; $0.05 \geq p > 0.01$ = significant

Table provided by author

Appendix M: Distribution of Pearson Residuals



Author´s illustration

Curriculum Vitae

Personal Details

Jérôme Jürgen Stuck

Born: 25th July 1984 in Berlin, Germany

Education, and Academic and Research Positions

08/2011 - 01/2015	**Dr. rer. nat. (Ph.D.), Institute of Economic and Cultural Geography** Leibniz Universität Hannover, Germany
08/2011 - 12/2014	**Freelance Scientific Consultant and Service Provider** Empirical Studies on Regional Economic and Business Issues
08/2011 - 09/2014	**Research Associate, Institute of Economic and Cultural Geography** Leibniz Universität Hannover, Germany
10/2006 - 07/2011	**Diploma (Master of Arts), Economic Geography, Economics & Business** Leibniz Universität Hannover, Germany
09/2009	**Study Project (Topic: Multinationals in China and Hong Kong)** PR China & Hong Kong SAR
09/2008 - 01/2009	**Participant of the ERASMUS Programme, Economic Geography** University of Utrecht, Netherlands
1997 - 2004	**Abitur (University-Entrance Diploma)** Gustav-Heinemann-Oberschule, Berlin (Germany)