The State of Innovation System Research: What Happens Beneath The Surface?

– A Bibliometric Network Analysis –

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Abstract: Since its emergence in the 1980s, the concept of "Innovation Systems" (IS) has inspired research and shaped discussions in academia and policy alike, leading to a cascading development of approaches and extensions at various analytical levels. IS research since has expanded far beyond its initial focus by generating new knowledge within but also attracting increased attention from adjacent fields. As a result, the broad understanding of IS and its diversity in applications has resulted in blurry boundaries of the field, making its contemporary delineation, synthesis, and assessment of its progress challenging. Using a combination of data-driven techniques from bibliometrics, natural language processing, and network analysis, this paper maps and analyzes the structure of knowledge production and the process of knowledge integration in current research. We find an overall growing tendency toward increasing diversity in the knowledge bases from which the field draws, accompanied by a decreasing coherence of collective research efforts. We point to the crucial role of institutions and academic entrepreneurs in shaping these developments in interdisciplinary and diverse fields, illustrating this in terms of the role of the Organisation for Economic Co-operation and Development (OECD).

Keywords: Innovation Systems; Bibliometrics; Knowledge base; Networks; Diversity; Coherence

JEL codes: O30, B40

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1 Introduction

The late 1980*s* saw the emergence of a new and more systemic understanding of innovation and diffusion processes. The resulting "National Innovation System" (NIS) framework[1] (Freeman, 1987; Lundvall, 1992; Nelson, 1993) has attracted significant attention among both researchers and policymakers since its emergence, resulting in the increased importance of the larger field of Innovation Systems (IS) research.

Subsequent research generated a cascade of further IS frameworks differing in their analytical and conceptual focus, highlighted elements and dimensions, system boundaries, and units of analysis, such as regional (Cooke, 2001; Malmberg and Maskell, 2002), sectoral (Breschi and Malerba, 1997; Malerba, 2002, 2005), technological (Bergek et al., 2008; Carlsson and Jacobsson, 1997; Hekkert et al., 2007), business (Whitley, 2000), and social systems of innovation and production (Amable, 2000), as well as national systems of entrepreneurship (Acs et al., 2014). Consequently, a substantial body of literature on IS has accumulated. Along the same lines, its community of users has expanded as researchers from adjacent fields have become interested in a systemic approach to studying innovation. The resulting blurred boundaries of the field in its current state call for efforts to delineate both what it currently consists of and the theoretical foundations it draws from.

Previous research has provided insights on the historical origin and context from which the approach emerged (Edquist, 2005; Godin, 2009; Lundvall, 2007; Sharif, 2006; Soete et al., 2010), its users and role in the world of science (Fagerberg and Sapprasert, 2011; Teixeira, 2013; Uriona-Maldonado et al., 2012), the unifying elements that bind these contributions together, and their role in a more narrow context of innovation studies (Fagerberg et al., 2012). Most studies have taken the field's historical core contributions as a point of departure and identified their users, thereby providing an account of its influence on the broader social science discipline. Such an approach comes with the implicit assumption that what is considered as the field's historical core literature remains stable over time, but this involves the risk of overlooking potential diverging characteristics in terms of the core contributions in the field.

In this article, we take a more contemporary perspective, starting from the highly cited journal publications on IS and the works cited therein. The assumption is that the field has become more mature and many contributions tend to be published in journal articles rather than books. Applying an inclusive, data-driven methodology, we aim at providing a comprehensive overview of the current state of IS research,

[1] While the terms "National Innovation System" (NIS) and "National Systems of Innovation" (NSI) are used interchangeably in the literature , we consistently use the term NIS for research on national innovation systems.

its internal structure of specializations, and the knowledge bases it draws from. To accomplish this, we identify in an iterative process in IS-related publications from Thompson Reuter's "Web of Science" (WoS) database (6,370) and their cited references (162,600) for the 1980–2018 period. In a bibliographic network analysis, we map the literature's current research and knowledge base, and we deploy clustering techniques to partition them into consistent areas. We augment this mapping by employing techniques from the field of natural language processing (NLP) to discover common topics in the publication abstracts. Finally, we provide insights into the unfolding process of knowledge integration in the field's research areas and the accompanying dynamics of coherence and diversity.

Overall, we find a growing tendency of increasing diversity of knowledge bases from which the field draws, accompanied by a decreasing coherence of collective research efforts. We highlight the heterogeneity of how this process takes place and identify distinct patterns of knowledge integration. For IS-related research, we argue that the pursuit of further knowledge integration requires effort toward obtaining both higher diversity and internal coherence. In fields that are interdisciplinary and diverse by nature, we point to the role of external forces in shaping these developments, which we exemplify with the role of the Organisation for Economic Co-operation and Development (OECD).

The remainder of the paper is structured as follows: Section 2 presents an overview of the literature and introduces important theoretical building blocks. Section 3 describes the data and introduces the methods used in our analysis. Following this, Section 4 presents the field's identified knowledge bases and research areas and illustrates trends in their relationship. Finally, Section 5 concludes, discusses the implications of the analysis, and provides avenues for future research.

2 Theoretical Considerations

2.1 Variations and nuances in the initial conceptualization of IS as a field of research

While the intellectual foundations for the IS literature go further back in history and are broader in scope (Carlsson et al., 2002), the contributions associated with the initial conceptualizations of the NIS framework propelled the field to prominence(Soete et al., 2010). These initial conceptualizations are commonly attributed to three founding researchers, namely Christopher Freeman, Richard Nelson, and Bengt-Åke Lundvall (e.g., Fagerberg and Sapprasert, 2011). Below, we point out the distinctiveness and commonalities between the approaches, complemented by a condensed overview in Table 1.

Table 1: Comparison Between the Original Versions of the NIS Concept

	Freeman, C. (1987)	Nelson, R. R. (1993)	Lundvall, B. Å. (1992)
Concept definition	*"The network of institutions in the public and private sectors which activities and interactions initiate, import, modify and diffuse new technologies may be described as 'the national system of innovation'."* (p. 1)	*"[...] a set of institutions whose interactions determine the innovative performance, in the sense above, of national firms."* (p. 4)	*"[...] all parts and aspects of the economic structure and the institutional set up affecting learning as well as searching and exploring - the production system, the marketing system and the system of finance present themselves as sub-systems in which learning takes place."* (p. 13)
Term "System"	Not explicitly defined	*"[...] a set of institutional actors that, together, plays the major role in influencing innovative performance."* (p. 4-5)	*"[...] a system of innovation is constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful, knowledge and that a national system encompasses elements and relationships, either located within or rooted inside the boarders of a nation state."* (p. 2)
Term "Innovation"	*"[...] continuing process of technical change, involving the introduction of new and improved products and novel ways of organizing production, distribution and marketing."* (p. 1)	*"[...] the processes by which firms master and get into practice product designs and manufacturing processes that are new to them, if not to the universe or even to the nation."* (p. 4)	*"[...] on-going process of learning, searching and exploring, which result in new products, new techniques, new forms of organization and new markets."* (p. 8)
Analytical framework	• Relationship between technology, socio-economic structures, and institutions	• Linking institutional arrangements to technological and economic performances.	• Interactive learning anchored in the production structure (including "demand conditions" and "supporting industries") • Institutional set-up including "firm strategy" • Modes of cooperation and competition
Type of the analysis	• Single case study (Japan)	• Comparative case study (15 countries divided into large high-income, small high-income, and low income countries)	• Conceptual/Theoretical

The NIS concept introduced by Freeman (1987) refers to the network of public and private institutions with activities and interactions intended to initiate, import, modify, and diffuse new technologies. The main focus of the qualitative analysis is on the ways in which the resources are organized and managed at the enterprise, industry, and country level, including the organization of research and development (R&D) and production in firms, relationships among firms, and the government's role. The concept is seen as having the greatest importance in explaining both the emergence and the rate at which the "technological gaps" between countries are closed.

Nelson (1993) defines the system as a set of institutional actors whose interactions determine the innovative performance of national firms. The main orientation of this work involves describing the mechanisms and institutions that support technological advances and how they came to be, as well as relating this to the differences in countries' economic performances in such dimensions as productivity, income, income growth, export, and import performances.

The distinctiveness of the approach developed by Lundvall (1992) includes a broader understanding of the concept, including all organizations and institutions that affect the production, diffusion, and exploitation of economically useful knowledge. Furthermore, the distinctiveness of Lundvall's approach is the focus on user–producer linkages and interactive learning as a basis of innovation. The concept is viewed as

an analytical and policy tool or framework to link innovation to economic performance at the national level.

In sum, the differences between the approaches can be attributed to narrower or broader definitions of the concept, a main focus of the analysis, and elements of the system included in studying NIS. What is regarded as common to all three approaches is the focus on the relationships between the institutions, organizations and the interactions between them on the one hand and learning, innovation, and economic performances at the national level on the other.

2.2 Meta-survey on the development of IS studies

Attempts to review the field and developments of the NIS literature adopting a qualitative approach based on literature review include Balzat and Hanusch (2004), Sharif (2006), Carlsson (2006, 2007), Lundvall (2007), Godin (2009), and Soete et al. (2010). A critical assessment of the weaknesses and strengths of the approach, and the implications and suggestions for its further development are discussed in Hart (2009). Critical assessments of IS concepts more broadly are found in Carlsson et al. (2002) and Edquist (2005).

A few contributions adopt a mix of qualitative and quantitative approaches. Fagerberg and Sapprasert (2011) investigate the emergence and role of NIS in IS, based on a combination of expert assessment to identify the most important contributions and the users of the literature. Similar approaches are found in mapping the field of IS (Fagerberg et al., 2012), entrepreneurship (Landström et al., 2012), and science and technology studies (STS) (Martin et al., 2012). Teixeira (2013) proposes a taxonomy of the main topics and methods, roots, and influence of the NIS literature based on a combination of qualitative assessment and bibliometric evidence. However, the main focus in these studies is more on the origins and less on the recent research contributions.

Recent accounts of the state of the IS field rely primarily on a quantitative bibliometric approach, and they study the institutionalization of IS literature. Uriona-Maldonado et al. (2012) provides a descriptive account of a chronological distribution, author relevance, articles and cited references, journals, institutions, and countries of relevance based on the citation count. Liu et al. (2015) identify and visualize the intellectual structure, turning points, and dynamics of IS research based on co-word and co-citation analysis.

2.3 Conceptual framework: Diversity and coherence

To understand the development of a research field, it is useful to map changes in its *structure of knowledge production* and output in terms of novel knowledge generation.

In an interdisciplinary field of research like IS,[2] we conceptualize this development mainly as a "process of knowledge integration," in which distinct and previously disconnected bodies of knowledge become related over time. To analyze this process, we conceptually distinguish between the field's current "knowledge frontier", where new knowledge is produced (which we label "research areas"), and thus, the bodies of knowledge to be utilized (which we label "knowledge bases"). This enables us to explicitly analyze the process of knowledge integration at the research frontier, which we envision as a dynamic process that can be expressed by changes in patterns of how the field's knowledge bases are (re-)assembled, (re-)used, and (re-)combined. The capacity for and extent and success of knowledge integration in a field of research can be described by the joint development of two central indicators-coherence and diversity (Porter et al., 2006).

Coherence: Coherence captures the extent to which a system's elements are consistently articulated and form a meaningful constellation. Hence, it can be viewed as a general system property capturing its functionality. Systems with low coherence are characterized by loosely connected or isolated elements that are unlikely to produce meaningful collective output. Within a bibliographic analysis of a field of research, coherence can be understood as the degree to which the publications under study exhibit common citation patterns, thereby indicating higher or lesser consensus on the content of research, developed and applied theories, and methods.

Diversity: The diversity of a research field can be expressed by the number, balance, and similarity of the bodies of knowledge from the categories it comprises (Stirling, 2007). In our bibliometric analysis, we conceptualize diversity by the pattern the field's research areas draw from the knowledge bases (cf. section 3 for details).

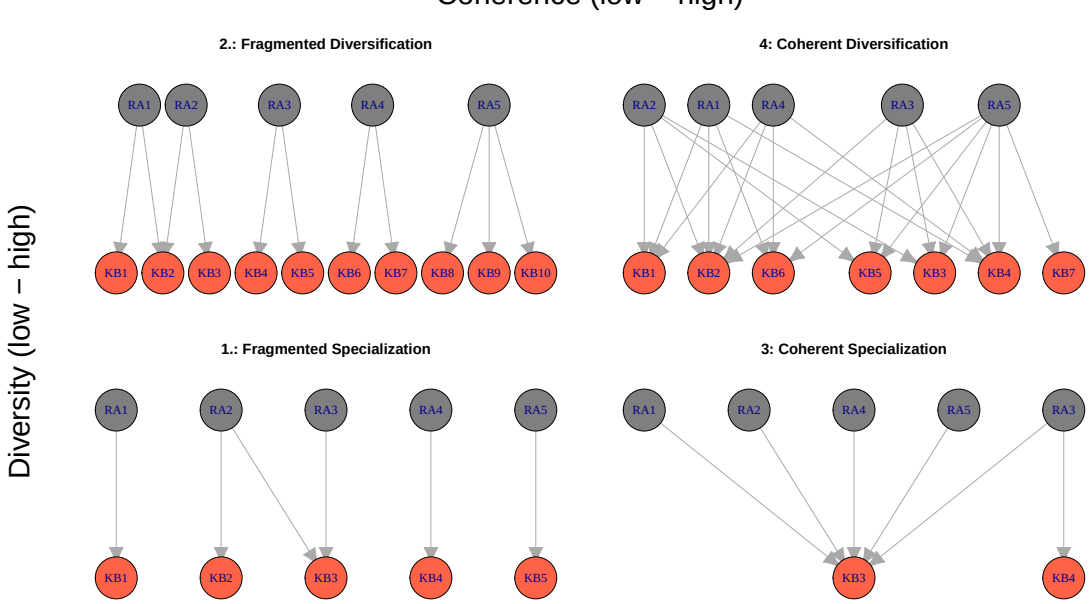
The combination of the two dimensions leads to four position characteristics of research, as illustrated in figure 1. It can be used to describe the static structure of knowledge production, as well as the dynamic process of knowledge integration in a field or narrow research area, as follows:

1. **Fragmented Specialization (Low diversity–Low coherence):** This includes specialized research areas that draw from a small number of knowledge bases without overlapping. It is an indicator of a field's immaturity or a temporal state in the process of internal reconfiguration and knowledge integration;

2. **Fragmented Diversification (High diversity–Low coherence):** Here, the research areas in a field are diversified and draw from a larger number of knowl-

[2]We follow Porter et al. (2006) in defining interdisciplinarity as a mode of research that integrates concepts, theories, methods, techniques, or data from different bodies of knowledge.

Figure 1: Knowledge base diversity and network coherence.



edge bases, yet without overlap. It is an indicator of fragmentation or lacking consensus on theoretical foundations;

3. **Coherent Specialization (Low diversity–High coherence):** The research areas within a field are specialized and draw from a small number of knowledge bases, which are the same across areas. It is an indicator of a strong consensus on dominant theories or a temporal state of refocusing; and

4. **Coherent Diversification (High diversity–High coherence):** In this category, the research areas in a field are diversified and draw from a large number of knowledge bases, which are used coherently across research areas. It is an indicator of a successful process of knowledge integration and cross-fertilization.

The relationship between coherence and diversity describes the dynamic process of knowledge integration in the normal progress of science; thus, it should be assessed not as a static state, but rather, in terms of a temporal derivative, that is, a change in coherence and diversity (Rafols and Meyer, 2010). Here, it is argued that diversity and coherence should develop in the same direction, since the increasing focus on "exploiting" a narrow knowledge base may lead to decreasing creativity and novelty generated in a field of research, while excessive but not coherent "exploration" may lead to a fragmentation of the research field and limit its ability to produce deep and meaningful insights and results (March, 2005). Generally, for

research areas of fields aiming at interdisciplinary knowledge integration, moving toward higher levels of diversity while maintaining the level of coherence suggests successful achievement of this integrative mission (Rafols and Meyer, 2010).

Applying a network perspective, further useful analogies can be drawn from insights on how individual and collective learning processes are affected by the underlying (social) structure. The literature on social capital has featured a long-lasting debate on the benefits of open or closed local network structures, where it is argued that open network structures provide their actors information advantages in terms of access to a diverse set of novel information (Burt, 1992, 2001), as well as that closed structures facilitate the exchange of in-depth information through frequent, trust-based interaction (Uzzi, 1996, 1997). Learning effects are also attributed to the composition of networks (e.g., homogeneous vs. heterogeneous) (Fleming et al., 2007; Reagans and McEvily, 2003), and more recently, the interaction of structure and composition (e.g., TerWal et al., 2016). Consequently, the methodological choice of applying a network analysis and theoretical choice of accentuating the aspects of structure and composition appear complementary to the concepts of diversity and coherence, promising new insights into the process of collective learning and knowledge integration.

3 Methods, Data, and Empirical Strategy

This section presents the methods used and our rationales for applying them given the aim of this study. First, we delimit IS research in an iterative "bottom-up" process. Second, we carry out a thematic mapping of the field by employing techniques from the field of NLP for discovering common topics in the publication abstracts. Third, based on a co-citation analysis, we identify the most prominent knowledge bases IS literature has drawn from during its development. Fourth, we carry out a bibliographic coupling analysis for identifying the current research frontier in IS. Finally, we explore the development of IS in terms of diversity and coherence of research efforts by analyzing how heterogeneous bodies of knowledge are utilized and integrated over time.

3.1 Delimiting the IS field: Initial corpus creation

The common challenge of delineation is especially prevalent in an interdisciplinary field like IS, which draws from a variety of academic disciplines, such as economics, organizational studies, sociology, and psychology. In attempts to delineate the somewhat blurry boundaries of IS or related (sub-)fields, different methodologies have been applied.

To start with, one can apply a string-search-based approach to identify publications in an academic database where the title, abstract, or keywords include certain terms, for example, "System(-s) of Innovation" (e.g., Teixeira, 2013; Uriona-Maldonado et al., 2012). Assuming all the relevant publications clearly state their association to a field of research by including some related keywords in the publication's description, this approach is likely to deliver a low rate of *false positives*. However, in the case of fields with blurry boundaries and without fully coherent terminology, a high rate of *false negatives* will also be evident.

Another possibility is following an authority-based approach, where the research field is delimited by the author's (e.g., Godin, 2009; Lundvall et al., 2002) perception of the field and relevant contributions, surveyed experts (e.g., Sharif, 2006), or authoritative surveys like handbooks (e.g., Fagerberg et al., 2012). Assuming the selected authorities' ability to delineate what is part of the field and what is not based on a small number of identified core contributions, this approach is less dependent on the use of consistent terminology.

If there is a wide consensus on a field's origins and core literature, an origin-based approach can be applied. Here, one starts with a predefined set of core contributions and then expands the corpus with the publications citing them (e.g., Meyer et al., 2004). This is helpful for assessing the influence of the core contributions independently of disciplinary associations of publications and authors, but it may miss later developments in the field that diverge from the original core.

Finally, more inductive "snowballing" approaches have been used, combining the identification of certain "seed" publications from previous studies and authorities in the field and further related publications based on various methodologies (e.g., Jurowetzki et al., 2018; Martin, 2012a).

To leverage the main advantages of the delineated approaches , we combine several of their features in a multistep process. We first apply a string-based strategy, searching WoS for publications including the terms "Innovation System(-s)" or "System(-s) of Innovation" in their titles, abstracts, or keywords (2,885).[3] First, we reduce the list to the top 1% of publications, both in terms of total citations average annual citations received (the overlap is >90%). This leads to a total of 38 *seed* publications[4] (cf. Table A.1 in the appendix), representing the most cited (journal) articles directly associated with IS. However, a sole focus on highly cited publications may exclude research that has contributed to the field in a more incremental way (Macroberts and Macroberts, 1987), as well as strongly related research that does not use

[3]Clearly, Technological IS (TIS), National IS (NIS), Sectoral IS (SIS), and Regional IS (RIS) with the additional prefix are also included.

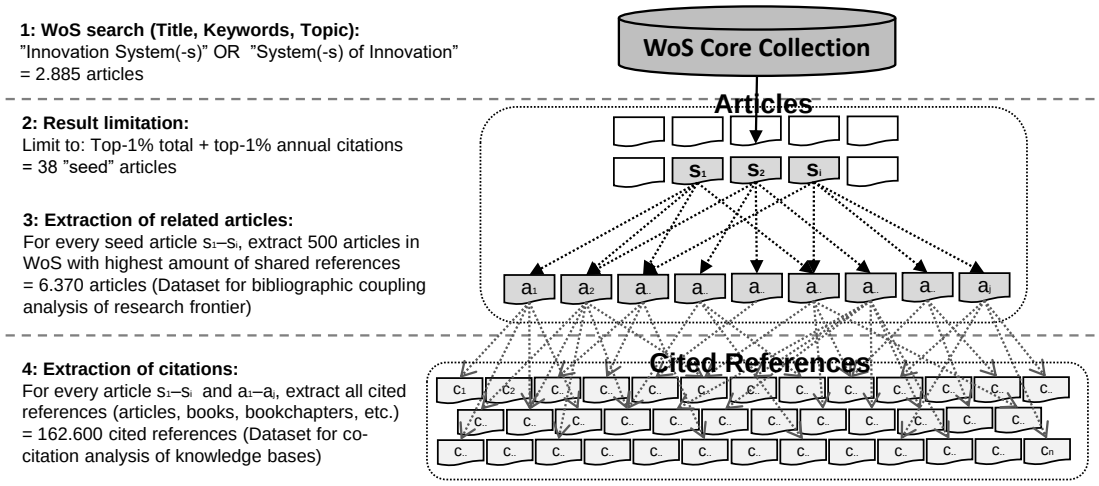
[4]We use the term "seed" in a technical manner, indicating the starting points in our data-driven approach of iterative corpus expansion. Hence, it should not be understood metaphorically, indicating the seminal contributions that gave rise to the "growth" of the field.

a certain terminology. Therefore, we take this selection of publication as the initial point of departure for an iterative process. To create our final corpus, for every initial "seed", we extract the 500 publications for the 1980–2017 period with the highest bibliographical overlap (i.e., highest number of shared references cited by both publications). The intuition behind this step is that a bibliographic overlap between two publications indicates similarities in the theoretical frameworks, applied methods, or context of the study (Boyack and Klavans, 2010).

When excluding duplicates and publications that were not cited at least once, our final corpus contains a total of 6,370 publications. In a last step, we extract the complete list of references (162,600 unique cited references) for each of these publications, to be analyzed separately. This process is illustrated in Figure 2.

The benefit of our multistep approach is that it considers both the use of an exact terminology and strong bibliographic overlap as a sufficient but not a necessary condition to be associated with a research field, and that it allows for a dynamic expansion of what can be considered a field's core. As a result of this inclusiveness, it will not provide a sharp boundary of the field under study, but rather a blurry one that tends to include related publications from adjacent fields that also substantially relate to the literature relevant to IS. Yet, it will not provide an overview of all systemic approaches to innovation (which is also not our aim). Centered around IS, by design, it will miss systemic approaches without any literature and terminology overlap, such as "Innovation Ecosystems" (Moore, 1993).

Figure 2: Illustration: Mltistep literature identification and selection process.



Our choice of utilizing the WoS database has certain implications, especially that it does not provide bibliographic data for books. We are unable to treat significant contributions in the form of books equally to journal articles, since the latter are

used as "seeds" for assembling our final corpus and mapping the research frontier, while the former can only be used to map the field's knowledge base. In addition, we can characterize journal articles by their composition of cited references, but for books, we can only use information regarding *received* citations from our corpus. To be confident regarding the use of the present methodology on a corpus solely based on journal articles, one has to assume that they represent a major part of a field's literature in terms of volume and significance and characterize the knowledge frontier sufficiently. In case of doubt, potential bias has to be approximated to assess the method's limitations.

Analyzing the references cited by the journal articles in our corpus can provide an indirect approximation regarding the relevance of books compared with journal articles. We find that, during the emergence of the field in the 1980*s*, books account for 59% of all the cited references in our corpus, which is indeed substantial. However, this share steadily decreases to 25% in the post-2010 period. Likewise, while books in the 1980*s* received about the same average amount of annual citations, this shifted in favor of journal publications since 2000, which nowadays receive 1.5 times more citations than books.[5] Previous studies point in a similar direction, highlighting that books represent an important part of the field's body of knowledge and many of its seminal contributions, especially during its formative stage (Martin, 2012a). However, this is much less the case in more recent periods, where the relevance of books as a publication outlet and citations to the field's defining books steadily declined Fagerberg and Sapprasert (2011).

In conclusion, it cannot be ruled out that the omission of books in our selection of "seed" publications, as well as our final corpus, will result in an incomplete map of the IS field. This potential bias should be especially prevalent in the pre-2000 formative stage, where many significant contributions are to be found in books. Accordingly, our pre-2000 results have to be interpreted with a healthy degree of skepticism. While recognizing the problem, we expect it to be less worrisome for our main analysis of interest regarding the more recent years of IS research (post-2000). It is our impression that a more inclusive bibliometric study covering journal and book publications alike would result in a broader and more detailed overview of the field, especially in its formative stage, without significantly altering our main results. Yet, in the absence of empirical evidence, this claim remains speculative. Even so, such an inclusive approach would not entirely solve the problem of delineating the blurry boundaries of the field.

[5] This indicator is only meaningful when assuming there is no systematic bias of journal articles against citing books. While we cannot directly prove this assumption, the fact that many of the most cited references are books (cf. Table 2) gives no strong indication that this should be the case.

3.2 Topical mapping: NLP

The way science progresses is largely extent reflected in the use of language, which can indicate general research trends and the emergence of a consensus or dispute (Kuhn, 1971). To provide a first intuition about general themes and topics in the IS literature, we facilitate our bibliometric analysis by deploying exploratory methods from the fields of NLP on the publication abstracts. We create a *topic model* via latent Dirichlet allocation (LDA) (Blei, 2012), a graphical Bayesian probability model for discovering latent thematic structures in text document collections. Such models identify `topics`[6] by the way words and word combinations are used in text documents. The basic idea is that documents are represented as mixtures over latent topics, where each topic is represented as a probability distribution over words in the corpus. An iterative process then generates a set of topics that describes the documents in the corpus and assesses the strength with which each document exhibits those topics. An inspection of the words with the highest assigned probability to each topic tends to provide an interpretable qualitative description of the topic's meaning and content.

3.3 Mapping the structure of research activity: Bibliometric methods

While the commonly used analysis of direct citations is helpful for identifying and summarizing the most important publications in a scientific corpus, the dichotomous nature of this measure limits its usefulness to expressing the relationship between publications, and thus, a structural mapping of research fields (Üsdiken and Pasadeos, 1995). Here, more nuanced methods leveraging the information found in a publication's bibliography can be utilized, such as co-citation and bibliographic coupling analysis (Boyack and Klavans, 2010).

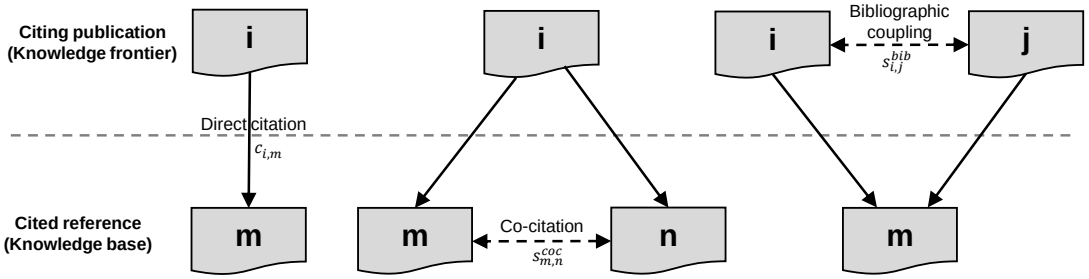
Technically, both measures exploit the bipartite nature of the publication→references data structure, which is common to bibliographic data,[7] and are equivalent to the projection of a two-mode network (publication → reference) to a one-mode network (publication ↔ publication or reference ↔ reference). For bibliographic coupling analysis, the projection is done on the level of publications, and for co-citation analysis on the level of references. The logic behind each approach is illustrated in Figure 3.[8]

[6] In this paper, we indicate the reference to a topic with a `typewriter` font.

[7] In bibliographic analysis, publications and their cited references are commonly treated as separate entities, and consequently, they are analyzed separately.

[8] We refer to the publication ↔ publication mode as the RESEARCH AREA network (formatted in SMALL CAPS) and the reference ↔ reference mode as the *knowledge base* network (formatted in *italics*).

Figure 3: Illustration: Direct citation, co-citation, and bibliographic coupling measures in a bipartite publication↔reference network.



3.3.1 Identifying the structure of the IS field's *knowledge base*: Co-citation analysis

Our first step in mapping the structure of the *knowledge base* in the IS literature is performing a co-citation analysis, where the cited references and not the original publications are the unit of analysis. Here, the strength of the relationship between a reference pair m and n ($s^{coc}_{m,n}$) is expressed by the number of publications C that jointly cite references m and n, as illustrated in equation 1. The intuition here is that references that are frequently cited together are likely to share commonalities in theory, topic, methodology, or context. This can be interpreted as a measure of similarity as evaluated by other researchers deciding to cite both references. Because the publication process is time consuming and citations accumulate over time, co-citation is a backward-looking measure, which is appropriate for mapping the relationships in the core literature of a field (Boyack and Klavans, 2010):

$$s^{coc}_{m,n} = \sum_i c_{i,m} c_{i,n}. \tag{1}$$

Since co-citations between two publications tend to correlate with their total number of citations, we avoid a general clustering of highly cited publications by normalizing the co-citation strength with the Jaccard similarity coefficient (cf. e.g., Hamers et al., 1989; Leydesdorff, 2008), where we weight the intercept of two publications' co-citations by their union. The resulting weight (cf. equation 2) is bounded between zero and one, where one indicates that two references are exclusively cited together and zero that they are never cited together:

$$S^{jac\ cocit}_{m,n} = \frac{C(m \cap n)}{C(m \cup n)} = \frac{s^{cocit}_{m,n}}{c_m + c_n - s^{cocit}_{m,n}}. \tag{2}$$

3.3.2 Identifying the structure of the IS field's knowledge frontier: Bibliographic coupling analysis

We identify the IS literature's current knowledge frontier by carrying out a bibliographic coupling analysis of the publications in our corpus. This measure uses bibliographical information of publications to establish a similarity relationship between them (Kessler, 1963). This "coupling strength" between publications is determined by the number of cited references they share, assuming a common pool of references to indicate similarity in context, methods, or theory. More recent articles have a higher pool of possible references to co-cite to; hence, they are more likely to be coupled. Consequently, bibliographic coupling represents a forward looking measure and the method of choice for identifying the current "knowledge frontier". In contrast to co-citations, bibliographic coupling is not influenced by a publication's number of citations. Hence, a publication's coupling strength is a measure of academic relevance (as indicated by the author's choice of references and the implied association with certain bodies of literature) rather than significance. Publications with a high degree of coupling strength should be interpreted as typical examples of work in a certain field rather than its core contributions.

Formally, the strength of the relationship between a publication pair i and j ($s_{i,j}^{bib}$) is expressed by the number of jointly cited references, as illustrated in equation 3. Since our corpus contains publications that differ strongly in terms of the number of cited references, we again normalize the coupling strength using the Jaccard similarity coefficient. It is again bounded between zero and one, where one indicates that the two publications have an identical bibliography and zero that they do not share any cited reference. Thus, we prevent publications from having high coupling strength due to a large bibliography (e.g., literature surveys):

$$s_{i,j}^{bib} = \sum_{m} c_{i,m} c_{j,m} \;\Rightarrow\; S_{i,j}^{jac\ bib} = \frac{C(i \cap j)}{C(i \cup j)} = \frac{s_{i,j}^{bib}}{c_i + c_j - s_{i,j}^{bib}}. \tag{3}$$

The choice of representing our corpus as a similarity network of publications based on a citation pattern comes with some implications and additional requirements in terms of data quality compared with a traditional bibliometric analysis of citation frequencies. Especially, the resulting network structure is sensitive to both false positives and false negatives. This becomes problematic when working with WoS data, since they provide information on cited references as free-text entries prone to inconsistent annotation (e.g., misspellings, full first name, only initials, with or without special characters). Consequently, we strove to homogenize the notation of references, where we first manually inspected all the most cited journals, publications,

and authors and corrected inconsistent spelling patterns, and further, we developed rule-based algorithms to correct commonly made mistakes in the references.[9]

3.4 Categorizing *knowledge bases* and research areas: Clustering techniques

To summarize the knowledge structure of scientific fields, most previous research (e.g., Fagerberg et al., 2012) has clustered publications according to similarity in characteristics like scientific discipline, publication outlet, and author affiliation. In contrast, we utilize the information of the corresponding bibliographic coupling or co-citation network and cluster publications according to their pattern of connectivity with other publications or cited references.[10] To partition networks into components or clusters, we deploy a "community detection" technique based on the *Lovain Algorithm* (Blondel et al., 2008) on our publication network to identify RESEARCH AREAS, and on the network of cited references to identify *knowledge bases*.[11]

3.5 Analyzing the development of the field: Diversity and coherence

As a final step, we analyze the development of the IS field and its research areas, focusing on the *coherence* of the structure of knowledge production and diversity of knowledge integration. The coherence of the IS field is operationalized as the aggregated coupling strength *between* its research areas, indicating a higher or lesser consensus on important and useful bodies of knowledge. A similar approach can be applied for measuring the coherence in a research area by looking at the density of the bibliographic coupling network of publications belonging to the same area.

In our context, diversity refers to how the corresponding research area draws from the identified IS knowledge bases. Generally, it can be measured by the variety (V), balance (B), and distance (D) of knowledge bases drawn from by the whole field or a specific research area (Stirling, 2007). We operationalize this concept using the diversity measure proposed by Leydesdorff (forthcoming):

[9] Here, we follow the advice of Raffo and Lhuillery (2009) on how to play the "name game". We also ran a fuzzy string matching algorithm on our list of references to match it with the most common spellings of core articles and the official journal abbreviation scheme used in WoS.

[10] In the jargon of network science, which we will adopt throughout our analysis, a network's elements are called *nodes* and the connections between them *edges*.

[11] The Lovain Algorithm is a heuristic method attempting to optimize the modularity of communities in a network by maximizing within- and minimizing between-community connectivity. Due to its proven high computational efficiency, accuracy in identification, and ability to handle weighted networks, this algorithm appears to be an appropriate choice for our task. In Table A.5, we benchmark the results with other popular community detection algorithms for undirected weighted large-scale networks, where for both networks, we identify the highest modularity and overall most desirable characteristics.

$$Div_c = V * B * D = \frac{n_c}{N} * (1 - Gini_c) * \sum_{i=1,j=1,i\neq j}^{i=n_c,j=n_c} \frac{d_{ij}}{n_c * (n_c - 1)}. \quad (4)$$

Here, N denotes the number of existing knowledge bases, n_c is the number of knowledge bases the field or area is citing, $Gini_c$ represents the Gini coefficient of the distribution of knowledge bases, and d_{ij} the distance between the corresponding knowledge bases as (measured as 1 - [sum of co-citation strength between the publications in knowledge bases i, j weighted by all possible connections between i, j]).

Similar approaches have been used for describing and analyzing the state and development of interdisciplinarity in research fields (e.g., Rafols et al., 2012; Rafols and Meyer, 2010). In contrast, our aim is not to analyze the integration of cross-disciplinary knowledge in a research field, but more broadly, the integration of distinct bodies of knowledge (*knowledge bases*), which may have their origin in different or the same scientific disciplines. Thus, we emphasize the pervasive heterogeneity of knowledge *within* a scientific discipline and develop a delineation approach that does not dependent on predefined disciplinary categories.

4 Results and Discussion

4.1 Basic characteristics of initial "seed" and final corpus of publications

The process of selecting our initial "seed" publications, as described in the previous section, resulted in 38 articles (listed in Table A.1 in the appendix). Here, the largest group (16) is associated with conceptual/theoretical frameworks and their empirical application, namely the following: i) the "Triple Helix" model of university, industry, and government relations (Etzkowitz and Leydesdorff, 2000); ii) "multilevel perspective on transitions" (Geels, 2004); iii) "sectoral system of innovation and production" (Malerba, 2002); iv) "regional systems of innovation" (Cooke et al., 1997); v) "technological IS" (TIS) (Carlsson and Stankiewicz, 1991; Hekkert et al., 2007; Jacobsson and Johnson, 2000); vi) a synthesis of a "TIS" and "multilevel framework" (Markard and Truffer, 2008); vii) "national innovation capacity" (Furman et al., 2002); viii) functional approach to a "national innovation system" (Liu and White, 2001); and ix) a "national system of entrepreneurship" (Acs et al., 2014). The empirical applications include papers dealing with the typologies of the following: x) regional systems (Asheim and Coenen, 2005), xi) the national modes of learning (Jensen et al., 2007); xii) the modes of university–industry interactions (Meyer-Krahmer and Schmoch, 1998); xiii) the role of knowledge-intensive business services (Muller and Zenker, 2001); and xiv) regulation in regional IS (Cooke, 1992).

Another group of articles (6) is associated with a historical account of NIS (Freeman, 1995) and a synthesis of research on networks of innovators (Freeman, 1991b) or survey of a single or various systems concepts (Carlsson et al., 2002; Lundvall et al., 2002; Markard et al., 2012; Morgan, 2004). Three articles focus on policy contributions (Acs et al., 2014; Asheim et al., 2011; Bergek et al., 2008), and one is concerned with the data used for measuring innovation (Acs et al., 2002a).

Overall, the list of seed publications appears to be relevant and capture the variety of research in the IS field and does not indicate systematic biases against certain frameworks or methodologies. It must still be noted that most of our "seeds" were published after 2000, demonstrating that indeed, most seminal contributions to the IS literature pre-2000 are to be found not in journal articles but in books.

Table 2: Final Corpus Characteristics

Institutional Affiliation			Most Occurring Journals			Internally Cited References	
Institution	N	%	Journals	N	%	Reference Name	Cit
Utrecht	104	2	Res. Policy	655	10	Cohen W, 1990	1014
Sussex	91	1	Eur. Plan. Stud.	224	4	Nelson R, 1982	869
Lund	85	1	Reg. Stud.	221	4	Lundvall B, 1992	654
Manchester	73	1	Tech. Forecast. Soc. Ch.	195	3	Audretsch D, 1996	530
Toronto	56	1	J. Int. Bus. Stud.	135	2	Nelson R, 1993	491
Eindhoven	52	1	Technovation	121	2	Jaffe A, 1993	445
Erasmus	51	1	Tech. Anal. Strg. Mng.	120	2	Porter M, 1990	440
Amsterdam	46	1	Strateg. Manage. J.	118	2	Barney J, 1991	413
Cambridge	45	1	Small Bus. Econ. Group	116	2	Edquist C, 1997	409
Uppsala	41	1	Ind. Corp. Change	110	2	Cohen W, 1989	393
Wageningen	40	1	Scientometrics	109	2	Granovetter M, 1985	382
Cardiff	38	1	J. Econ. Geogr.	104	2	Powell W, 1996	376
Harvard	37	1	Int. Bus. Rev.	89	1	Bathelt H, 2004	368
LSE	36	1	J. Evol. Econ.	83	1	Burt R, 1992	361
PennState	35	0	J. Technol. Transf.	82	1	Dosi G, 1982	359
Delft	34	0	Int. J. Technol. Manage.	66	1	Boschma R, 2005	355
Leuven	34	0	Ind. Innov.	65	1	Schumpeter J, 1934	345
Bocconi	32	0	Organ Sci.	64	1	Saxenian A, 1994	340
Singapore	32	0	Energy Policy	62	1	North D, 1990	320
Valencia	31	0	Entrep. Reg. Dev.	62	1	Etzkowitz H, 2000	310

Note. This table reports some basic information on the articles in the WoS corpus, such as the most often appearing institutions, journals, and the most (corpus internally) cited references. Overall, the corpus contains 6,368 articles, published between 1980 and 2018 (August).

In Table 2, we report some basic characteristics of our final corpus of 6,370 publications. Our corpus overlaps with the results of previous studies in terms of high-impact works in the field of science policy and innovation studies (Fagerberg et al., 2012; Martin, 2012a), illustrating the reproducibility of stylized facts across different corpora and methodologies. As for the publication outlet, the biggest shares of articles in our final corpus were published in *Research Policy* (10%), *European Planning Studies* (4%), *Regional Studies* (4%), and *Technological Forecasting and Social Change* (3%). The most cited references in our corpus include foundational books, book

chapters, and journal articles on many of the fields core topics, among others, the seminal book by (Nelson and Winter, 1982), the initial formulations of the NIS concept (Edquist, 1997; Lundvall, 1992; Nelson, 1993), and the concept of absorptive capacity (Cohen and Levinthal, 1990).

4.2 Results of the topic modeling and identification of themes

Table 3: Topics and Associated Terms

Topic	Top-10 Associated Terms
`Firms, Capabilities & Strategic Alliances`	Firms, Capability, Strategic Alliances, Competitive Advantage, Resources, Dynamic Capabilities, Strategy, Partner, Organization, Resource-based-View
`Learning, Organizations & Interaction`	Learning, Model, Process, Design, Organization, Interaction, Integration, Complexity, Mechanism, Transfer
`Globalization, Processes & Global Economy`	Production, Global, Business, ICT, Communication, Relation, Service, Globalization, World Economy, Trade
`R&D, Patents & Productivity`	R&D, Patents, Data, Productivity, Analysis, Growth, Indicator, Trade, Efficiency, Invention
`Localization, Clusters & Spillovers`	Local, Clusters, Spatial Proximity, Industry, City, Agglomeration, Geography, Location, Knowledge Spillovers, District
`University, Industry & Technology Transfer`	University, Science, Collaboration, Academic, Technology, Interaction, Researchers, Intellectual Property, Collaborative, Technology Transfer
`Firm-Level Innovation Determinants`	Firms, Industry, Manufacturing, SME, Sector, Size, Survey, Characteristics, Market, Determinant
`Innovation Policy, Evaluation`	Policy, Government, Support, Innovation Policy, Sector, Evaluation, Barriers, Challenges, Incentives, Implication
`HR Mamagement, Practices & Outcomes`	Institution, Organization, Management, Work Practices, Outcomes, Adoption, Formal, Informal, Quality, Employees
`Open Innovation, External Sources & Users`	Process Innovation, Product Innovation, Open Innovation, Strategy, External Sources, Radical, Innovation Activity, Innovation Process,
`Technological Change & Industrial Dynamics`	Technological Change, Industry, Evolution, Diffusion, Dynamics, Development, Patterns, Competition, Trajectory, Emergence
`Innovation Systems`	Innovation System, National, Function, Actor, Sectoral, Framework, Systemic, Approach, Regional, Foresight
`Networks, Embeddedness & Social Capital`	Networks, Social Capital, Relationships, Structure, Embeddedness, Community, Position, Exchange, Innovation Networks, Information
`Literature, Framework, Theoretical & Conceptual`	Literature, Theory, Framework, Concept, Approach, Understanding, Implication, Contribution, Issues, Review
`International Entrepreneurship & Cultural Distance`	Entrepreneurship, Cultural Distance, Opportunity, Entry Mode, Culture, International, Uncertainty, Joint Venture, Acquisition, Differences
`Transitions, Sustainability & Environment`	Transition, Energy, Governance, Sustainability, Niche Management, MLP, Socio-Technical, Transformation, Climate, Regime, Political
`Internationalization, MNE's & Entry Modes`	Foreign, International, Emerging, Strategy, Subsidiary, Institution, MNE, Host, FDI, Internationalization
`Knowledge Transfer, Absorptive Capacity`	Knowledge Creation, Capacity, Knowledge Transfer, Knowledge Flows, Absorptive Capacity, Tacit Knowledge, Knowledge Base, R&D, Knowledge Production, External Sources
`Regional Performance, RIS & Higher Education`	Region, Economic Growth, Economic Development, Regional Innovation, Related Variety, RIS, Europe, Competitiveness, Economic Ceography, Higher Education
`Empirical Evaluation, Econometrics, Performance`	Performance, Effect, Impact, Relationship, Results, Firm Performance, Data, Findings, Influence, Factor

Note. This table lists the topics identified with the LDA analysis of the abstracts of our main corpus, and their 10 most associated terms. The topic name reflects the authors' own description.

Table 3 reports the identified topics and associated terms based on the LDA. They can be interpreted as themes in the corpus, as expressed by the authors' description of the publications' theory, applied frameworks, context, and method. The topics have to be interpreted broadly, since some of them indicate an association with a certain theoretical framework (e.g., the topic of `IS`, which appears to be strongly associated with the IS framework), the study of a certain phenomenon (e.g., the topic o `University-Industry Relations & Technology Transfer`), or the application of particular methods (e.g., the topic of `Empirical Evaluation & Econometrics`, broadly in terms of empirical research). Overall, the identified topics appear to appropriately capture different academic and policy themes discussed in the IS literature. They will subsequently be used to capture the context of research effort in the research areas and derive specialization measures of those areas.

4.3 Results of the community detection analysis

4.3.1 Knowledge bases: Co-citation network

Table 4 provides a condensed summary of the identified knowledge bases, which are the result of a clustering exercise on the co-citation network of cited references. These knowledge bases can be interpreted as the distinct bodies of knowledge the IS field at its current state draws from or has been drawing from during its development. Below, we provide a brief qualitative summary of their content and context.

Territorial Innovation: This largest among the identified knowledge bases includes seminal contributions on NIS (Lundvall, 1992), the competitive advantage of nations (Porter, 1990), and regional clusters (Saxenian, 1994), as well as prominent theories on externalities and the economics of agglomeration (Glaeser et al., 1992; Jacobs, 1969; Marshall, 1920), which are also identified as core literature in IS from former researcher (e.g., Fagerberg et al., 2012; Martin, 2012a). The remainder consists of early work by economic geographers interested in spatial dimensions of innovation activity, such as R&D spillovers (Jaffe et al., 1993) and the geography of innovation and production (Audretsch and Feldman, 1996). More recent references discuss the competitiveness of clusters (Bathelt et al., 2004) and the influence of proximity on interactive learning and innovation (Boschma, 2005). The most central journals are *Regional Studies*, *Research Policy*, and the *Journal of Economic Geography*.

Organizational Learning: Mainly originating from strategic management and organizational studies, the most central references include seminal contributions on defining central concepts of intra-organizational learning, such as the resource-based view and the firm's sustained competitive advantage (Barney, 1991), "absorptive ca-

Table 4: Knowledge Bases Summary

Central References		*Central Authors*		*Central Journals*		*Central Concepts*
Reference	C_{int}	Author	C_{int}	Source	C_{int}	
Knowledge Base 1: Territorial Innovation, N: 8396 (25%)						
Lundvall B, 1992	0.32	Cooke P	1.00	Reg. Stud.	0.80	–Competitive advantage of nations
Bathelt H, 2004	0.30	Boschma R	0.55	Res. Policy	0.53	–Geography of innovation production
Boschma R, 2005	0.29	Asheim B	0.39	J. Econ. Geogr.	0.27	–Localization of knowledge spillovers
Jaffe A, 1993	0.28	Amin A	0.36	Am. Econ. Rev.	0.18	–Proximity & interactive learning
Audretsch D, 1996	0.27	Storper M	0.24	Eur. Plan. Stud.	0.15	–MAR & Jacob's externalities
Knowledge Base 2: Organizational Learning, N: 6259 (19%)						
Cohen W, 1990	0.37	Gulati R	0.61	Strg. Mng. J.	1.00	–Absorptive capacity
Powell W, 1996	0.29	Burt R	0.38	Adm. Sci. Q.	0.31	–Organizational learning
Nelson R, 1982	0.27	Cohen W	0.27	Organ. Sci.	0.26	–Collaboration networks
Burt R, 1992	0.22	Hagedoorn J	0.23	Acad. Mng. J.	0.17	–Firm resources & strategy
Ahuja G, 2000	0.20	Baum J	0.23	Res. Policy	0.17	
Knowledge Base 3: Internationalization, Institutions & MNEs, N: 5137 (15%)						
Kogut B, 1988	0.63	Dunning J	0.80	Int. Bus. S.	1.00	–Cultural distance & foreign entry mode
Johanson J, 1977	0.56	Cantwell J	0.51	Strg. Mng. J.	0.16	–Cultural distance & FDI
Hofstede G, 1980	0.51	Luo Y	0.49	Acad. Mng. J.	0.06	–MNE/TNE activities & performances
Kostova T, 1999	0.46	Rugman A	0.47	Acad. Mng. Rev.	0.03	
Shenkar O, 2001,	0.37	Peng M	0.43	Int. Bus. Rev.	0.03	
Knowledge Base 4: Transitions & Sustainability, N: 4309 (13%)						
Kemp R, 1998	0.31	Geels F	1.00	Res. Policy	0.65	–Multi-level perspective
Geels F, 2002	0.31	Kemp R	0.24	Energ. Policy	0.33	–Strategic niche management
Geels F, 2007	0.31	Smith A	0.16	Tech. For. Soc.	0.20	–Transition management
Rip A, 1998	0.21	Garud R	0.11	Tech. Anal. SMng.	0.12	–Technological innovation systems
Hekkert M, 2007	0.21	Bergek A	0.10	J. Evol. Econ.	0.04	
Knowledge Base 5: Knowledge Production, N: 3514 (10%)						
Etzkowitz H, 2000	0.44	Leydesdorff L	0.63	Res. Policy	1.00	–Modes of knowledge production
Cohen W, 2002	0.39	Etzkowitz H	0.32	J. Tech. Transfer	0.12	–University-industry interaction
Gibbons M, 1994	0.25	Mowery D	0.04	Scientometrics	0.11	–University-industry collaboration
D'Este P, 2007	0.25	Bozeman B	0.04	Technovation	0.02	–Economics of science
Meyer-Krahmer F, 1998	0.24	Nelson R	0.03	Sci. Publ. Policy	0.01	
Knowledge Base 6: Entrepreneurship, N: 3218 (10%)						
Shane S, 2000	0.56	Audretsch D	0.97	J. Bus. Vent.	0.99	–Entrepreneurial opportunity discovery
Baumol W, 1990	0.38	Acs Z	0.86	Small Bus. Econ.	0.98	–Entrepreneurship & competition
Davidsson P, 2003	0.36	Shane S	0.38	Entrep. Theo. Pract.	0.65	–Entrepreneurship effect on the economy
Reynolds P, 2005	0.36	Davidsson P	0.26	Acad. Manage. Rev.	0.08	–Entrepreneurial traits
Shane S, 2000	0.31	Aldrich H	0.23	Strg. Entrep. J.	0.04	
Knowledge Base 7: HR Management & Performance, N: 1821 (5%)						
Huselid M, 1995	0.75	Osterman P	0.76	Int. J. HRM.	0.55	–HRM practices & firm performance
Ichniowski C, 1997	0.61	Hofstede G	0.74	Acad. Manage. J.	0.51	–Strategic HRM
Macduffie J, 1995	0.58	Schwartz S	0.67	Ind. Labor Rel. Rev.	0.33	–High performance work practices
Appelbaum E, 2000	0.58	Guest D	0.63	Ind. Relat.	0.21	
Osterman P, 1994	0.55	Godard J	0.51	Int. Bus. Stud.	0.16	
Knowledge Base 8: Institutional Entrepreneurship, N: 1088 (3%)						
Seo M, 2002	0.30	Lawrence T	0.80	Acad. Manage. J.	0.76	–Institutional entrepreneurship
DiMaggio P, 1988	0.30	Greenwood R	0.51	Organ. Stud.	0.66	–Institutional change & innovation
Greenwood R, 2006	0.30	Suddaby R	0.36	Acad. Manage. Rev.	0.43	–Organizations & institutional environments
Maguire S, 2004	0.27	Battilana J	0.30	Admin. Sci. Quart.	0.28	
Battilana J, 2009	0.26	March J	0.29	Organ. Sci.	0.18	

Note. This table reports the most central references, authors, and journals within the identified knowledge bases in the co-citation network. All calculated centralities are Jaccard-weighted. It also summarizes the main central concepts (author's interpretation).

pacity" (Cohen and Levinthal, 1990), "combinative capabilities" (Kogut and Zander, 1992), and exploration and exploitation (March, 1991). Furthermore, the initial formulations of central concepts in interorganizational learning such as "structural holes" Burt (1992) and "structural embeddedness" (Uzzi, 1997), and broadly, the role of collaboration networks for innovation (Ahuja, 2000; Powell et al., 1996), are to be found here. It also includes the field's defining book by Nelson and Winter (1982), *An Evolutionary Theory of Economic Change*. The most central journals are associated with management or organizational fields of study, such as the *Strategic Management*

Journal, *Administrative Science Quarterly*, *Organizational Science Journal*, and *Research Policy*.

Internationalization, Institutions, and Multinational Enterprises: This knowledge base mainly includes contributions in international business and management studies. Central references are concerned with the role of multinational enterprises (MNEs) (Buckley and Casson, 1976) and transnational organizations (Bartlett and Ghoshal, 1989), as well as the internationalization process (Johanson and Vahlne, 1977) more generally. Another group of references relates to the role of work-related cultural dimensions (Hofstede and Bond, 1984) and foreign entry mode choices (Kogut and Singh, 1988), which are also critically reflected on (Shenkar, 2001). Some contributions are grounded in institutional theory and include work on "new institutionalism" (North, 1990) and the concept of "institutional isomorphism" (DiMaggio and Powell, 1983), while others apply an evolutionary perspective on firm growth (Kogut and Zander, 1993; Kostova and Zaheer, 1999). The most central journals are the *Journal of International Business Studies*, *Strategic Management Journal*, and *Academy of Management Journal*.

Transitions and Sustainability: In terms of transitions and sustainability, most of the central references are in the relatively young field of sustainability transition research, including central concepts like technological systems, technological regimes, niches, and the multilevel perspective (MLP) (Geels, 2004, 2002; Geels and Schot, 2007a; Rip and Kemp, 1998). Representative examples of topics are the development of a strategic niche management perspective on how to transition into a new regime (Kemp et al., 1998), the governance of sociotechnical transitions (Smith et al., 2005), and transition management in public policy (Rotmans et al., 2001). Another body of work in this group focuses on a functional approach to studying TIS (Bergek et al., 2008; Hekkert et al., 2007). The most central journals are *Research Policy, Energy Policy*, and *Technological Forecasting and Social Change*.[12]

Knowledge Production: Research in this knowledge base is centered around the role of universities in innovation in "knowledge-based" economies. It includes seminal work on the "Triple Helix" concept of university, industry, and government relations Etzkowitz (1998); Etzkowitz and Leydesdorff (2000), as well as work on new modes of knowledge production in contemporary societies (Gibbons et al., 1994). Other central references deal with different aspects of university-industry interactions, such as on the influence of public research on industrial R&D (Cohen et al.,

[12]The results are highly in line with the results obtained in the study by Markard et al. (2012) on identifying the intellectual contours of the emerging field of sustainability transition research.

2002), the different channels (D'Este and Patel, 2007) and patterns of university-industry interaction and co-operation (Meyer-Krahmer and Schmoch, 1998). Other contributions propose a "new economics of science" framework (Partha and David, 1994), discuss the role of patents as knowledge transfer indicator (Agrawal and Henderson, 2002) and the impact of regulation on university patenting (Henderson et al., 1998; Mowery et al., 2001). The most central publication outlets are concerned with different aspects of science (*Scientometrics*), technological innovation (*Technovation*), and the practice of technology transfer (*Journal of Technological Transfers*).

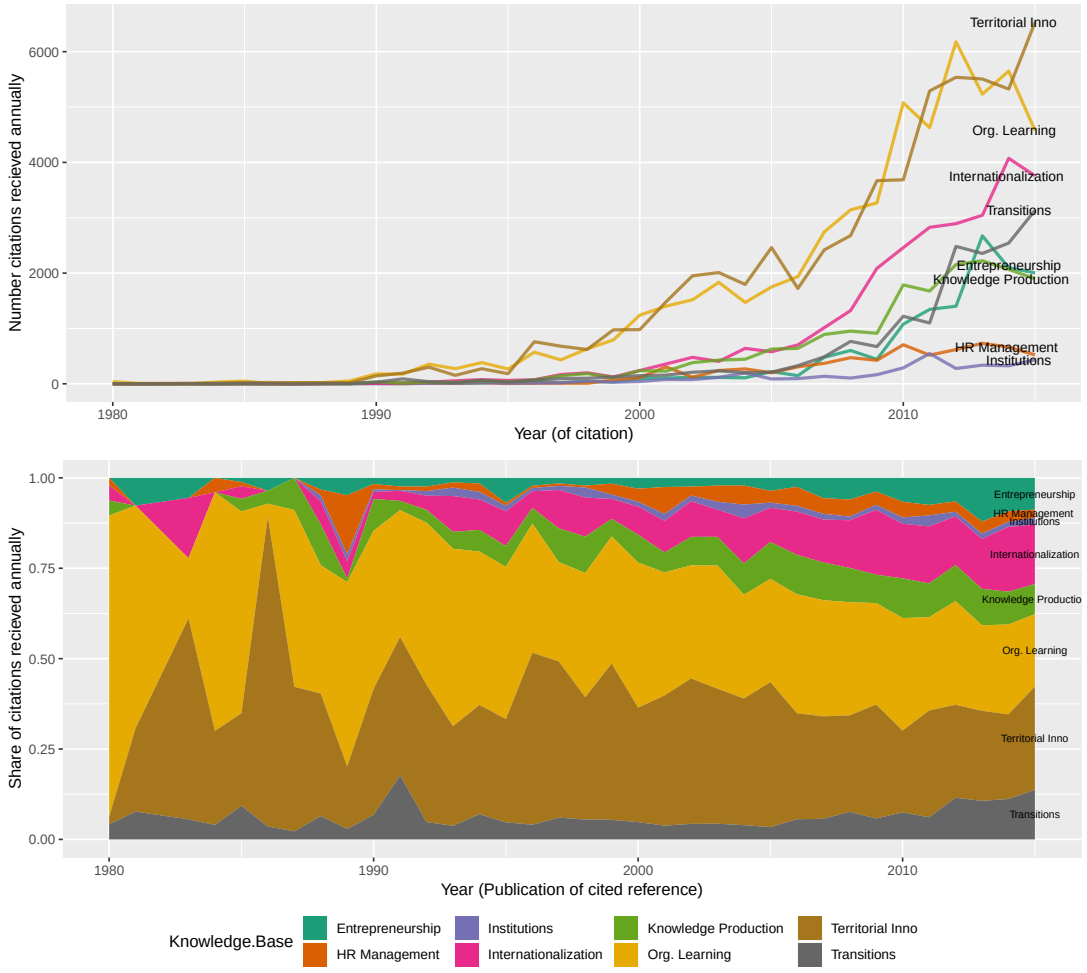
Entrepreneurship: This knowledge base includes mainly contributions concerned with different aspects of entrepreneurship, most notably classical works on entrepreneurship and competition (Kirzner, 1973, 1997). Other central references analyze productive, unproductive, or destructive contributions of the society's entrepreneurial activities (Baumol, 1990). More recent references address the promise of entrepreneurship as a field of research (Shane and Venkataraman, 2000), a general theory of entrepreneurship (Shane, 2003), and the limitations of the existing theories in entrepreneurship (McMullen and Shepherd, 2006). Further central references deal with the role of the entrepreneurs' knowledge, social and human capital in the discovery and utilization of opportunities (Davidsson and Honig, 2003; Shane, 2000). The most central journals are *Journal of Business Venturing*, *Small Business Economics* and *Entrepreneurship Theory and Practice*.

Human Resource Management (HRM) and Performance: This is the smallest of all identified knowledge bases, where the most central references include contributions dealing with human resource management (HRM) practices more generally, and with "high-performance" work practices or systems for organizing work and managing employees mainly in the manufacturing sector, more particularly. Most of the studies in this knowledge base are empirical studies dealing with different aspects of the relationship between the HRM practices or systems and the performances of firms (Appelbaum et al., 2000; Arthur, 1994; Becker and Gerhart, 1996; Cappelli and Neumark, 2001; Huselid, 1995; Ichniowski et al., 1997; MacDuffie, 1995; Osterman, 1994, 2000). However, it also includes a contribution on modes of theorizing in strategic HRM (Delery and Doty, 1996). The most central journals are *International Journal of Human Resource Management*, *Academic Management Journal*, *Industrial and Labor Relations Review*, and *Industrial Relations*, but also include journals from the field of psychology.

Institutional Entrepreneurship: The knowledge base consists mainly of central references sharing an institutional approach to organization theory and the role of

agency in institutional change. It includes work on a sensemaking perspective on organisations (Weick, 1995), and the conception of human agency (Emirbayer and Mische, 1998). Different aspects of "institutional entrepreneurship" (Battilana et al., 2009; DiMaggio, 1988; Garud et al., 2007; Greenwood and Suddaby, 2006; Maguire et al., 2004; Seo and Creed, 2002), the concept of "cultural entrepreneurship" (Lounsbury and Glynn, 2001), and the relationship between innovations and established institutional fields (Hargadon and Douglas, 2001) are also addressed. Most central publication outlets are journals in the field of strategy, management, and organization theory, but journals covering the field of sociology more broadly are also used.

Figure 4: Development of citations to the corresponding knowledge bases



Note. These figures illustrate the knowledge bases' absolute (upper) and relative (lower) amount of annual citations received. Only citations originating from our corpus are taken into account. Absolute citations are associated with the year of the citing publication, relative citations by the year of the corresponding reference.

In Figure 4, we depict the development of citations received by the corresponding knowledge bases, which serves as an indicator of popularity in a certain pe-

riod. For most knowledge bases, the annual number of citations received constantly grows (upper figure). Particularly *Organizational Learning* and *Territorial Innovation* over time become the by far dominant knowledge bases when measured in absolute terms.

In relative terms (lower figure), the field's main initial knowledge base in the 1980s was *Organizational learning*, a time when many of its core contributions were written (eg., Granovetter, 1985; Nelson and Winter, 1982; Teece, 1986). Soon after, *Territorial Innovation* started to increase in influence, and punctuating the dominance of *Organizational Learning* in years of its seminal contributions (eg., Freeman, 1987; Freeman and Soete, 1982; Pavitt, 1984). *Organizational Learning* (eg., Cohen and Levinthal, 1990) and *Territorial Innovation* (eg., Lundvall, 1992; Nelson, 1993; Porter, 1990), with a range of seminal publications remained relevant in the 1990s, yet we also witness new knowledge bases to emerge, particularly *Internationalization* (mainly its foundation in institutional as well as evolutionary economics, such as North (1990), and Kogut and Zander (1993)), and to some extent *Knowledge Production* (eg., Etzkowitz and Leydesdorff, 2000; Gibbons et al., 1994; Zucker et al., 1994)). In the late 2000*s* and afterwards, further knowledge bases gain prominence, particularly *Entrepreneurship* (eg., Acs et al., 2013, 2014; Bruton et al., 2010) and *Tranistions* (eg., Bergek et al., 2008; Geels and Schot, 2007b; Markard et al., 2012).

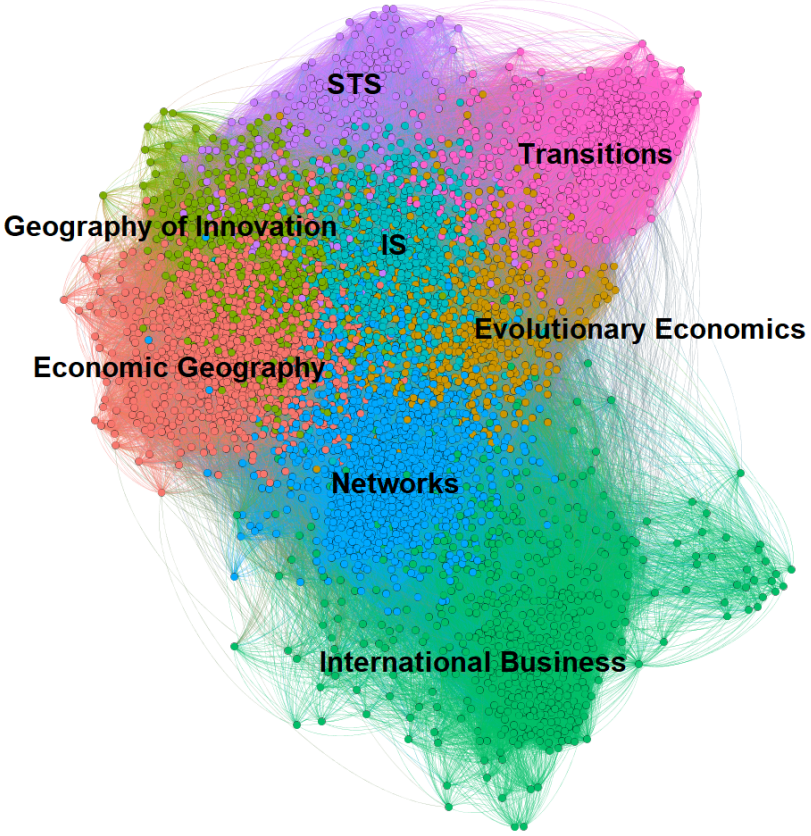
In summary, we see that the IS field during its development has stretched far beyond its original knowledge bases *Organizational learning* and *Territorial Innovation*, by borrowing, adapting, integrating, or developing new bodies of knowledge, and thereby undergone a considerable reconfiguration of its theoretical foundation.

4.3.2 Research areas: Bibliographic-coupling network

We proceed with the main part of our analysis, the community detection analysis on a bibliographic-coupling network of articles, We interpret the here identified communities as RESEARCH AREAS, which capture common trends at the field's research frontier. Again, bibliographic coupling analysis tends to favor current over older publications, therefore deemed as suitable to depict the state of more recent research. Since bibliographic coupling strength is not influenced by a publications number of received citations or other measures of popularity, the most central publications within a research area are the most thematically relevant (as signalled by the authors selection of references), and not the most academically significant ones, and can be seen as "typical" examples of research in terms of content, methods and theories applied. Consequently, the combined results of such an analysis provide insights and intuition of a research area's main content in general, rather than pin-

point seminal contributions in particular.[13] A graphical illustration of this network of publications is provided in figure 5, and a condensed summary of the identified research areas in Table 5, accompanied by a qualitative description.

Figure 5: Bibliographic coupling network of the IS literature



Note. Nodes represent the identified publications within the IS field of research, edges the bibliographic-coupling strength between them. Nodes are colored according to their association with identified research areas.

Economic Geography: This research area focuses on the role of geography for knowledge spillovers (Audretsch, 2003), and innovation activity (Audretsch, 2002), mostly in form of empirical and policy contributions. Commonly, the concept of the "knowledge production function" is applied. Further topics discussed are inter-regional (Greunz, 2003), inter-state (Smith, 1999) and university-industry knowledge spillovers (Acs et al., 2002b), the economic effect of the spatial decentralization (Andersson et al., 2004), specialization and diversification (Feldman and Audretsch, 1999), urban economics (Andersson et al., 2005) and the innovation advantages of

[13] Therefore we, for the sake of brevity, do not report them here and limit ourselves to a general overview, while providing a list of the most central publications and internally cited references per research area in Table A.2.

Table 5: Summary of Research Areas

Research Area	N	Central Journals	Relevant Topics	Related Knowledge Bases
Economic Geography: Externalities, Growth, Urban Economics	1.146 (18%)	Reg. Stud. (1.00) Res. Policy (0.90) Ann. Reg. Sci. (0.76) J. Econ. Geogr. (0.59) Small Bus. Econ. (0.56)	R&D, Productivity (0.09) Localization, Spillovers (0.09) Reg. Performance, RIS (0.07) Empirical (0.06) University-Industry (0.06)	Territorial Innov. Models (0.22) Knowledge Production (0.07) Entrepreneurship (0.04) Organizational Learning (0.04) Internationalization (0.02)
Networks: Strategic Alliances, Interfirm Relations, Open Innovation	1.103 (17%)	Strateg. Manage. J. (1.00) Res. Policy (0.67) Organ. Sci. (0.58) Acad. Manage. J. (0.42) Technovation (0.34)	Capab., Strateg. Allian. (0.11) Networks (0.08) Empirical (0.06) Knowledge Transfer (0.06) Open Innovation (0.06)	Organizational Learning (0.32) Internationalization (0.06) Territorial Innov. Models (0.05) Knowledge Production (0.04) Entrepreneurship (0.03)
International Business: Distance Studies, Institutions	1.041 (16%)	J. Int. Bus. Stud. (1.00) Int. Bus. Rev. (0.64) Manage. Int. Rev. (0.47) J. World Bus. (0.42) J. Int. Manage. (0.38)	Int., Entrep., Distance (0.12) Internationalization (0.11) HR Management (0.08) Empirical (0.07) Literature (0.06)	Internationalization (0.29) Entrepreneurship (0.15) HR Management (0.1) Organizational Learning (0.05) Institutional Entrep. (0.03)
Innovation Systems: National, Regional & Sectoral Approaches	783 (12%)	Res. Policy (1.00) Tech. Forecast. Soc. Ch. (0.61) Eur. Plan. Stud. (0.56) Scientometrics (0.45) Technovation (0.42)	Innovation Systems (0.09) Innovation Policy (0.06) Tech. Change, Industry (0.06) Reg. Performance, RIS (0.06) Open Innovation (0.06)	Territorial Innov. Models (0.14) Knowledge Production (0.07) Transitions (0.05) Organizational Learning (0.04) Internationalization (0.02)
Geography of Innovation: Knowledge Sourcing, Flows, & Bases	669 (11%)	Eur. Plan. Stud. (1.00) Reg. Stud. (0.76) J. Econ. Geogr. (0.41) Eur. Urban Reg. Stud. (0.34) Environ. Plan. A (0.33)	Localization, Spillovers (0.09) Reg. Performance, RIS (0.09) Knowledge Transfer (0.06) Globalization (0.06) Networks (0.05)	Territorial Innov. Models (0.18) Organizational Learning (0.02) Knowledge Production (0.02) Transitions (0.01) Entrepreneurship (0.01)
Technological Change & Evolutionary Economics	635 (10%)	Res. Policy (1.00) J. Evol. Econ. (0.84) Ind. Corp. Change (0.7) Tech. Anal. Strg. Mng. (0.48) Small Bus. Econ. (0.47)	Technol. Change, Industry (0.1) Open Innovation (0.06) Learning Processes (0.06) Firm Innov. Determinants (0.06) Literature (0.06)	Organizational Learning (0.08) Territorial Innov. Models (0.06) Transitions (0.05) Knowledge Production (0.04) Entrepreneurship (0.03)
Transitions: TIS, MLP, Regimes, Niches, Sustainability	605 (10%)	J. Clean Prod. (1.00) Environ. Innov. Soc. Tr. (0.92) Tech. Forecast. Soc. Ch. (0.91) Energy Policy (0.78) Tech. Anal. Strg. Mng. (0.67)	Transitions, Sustainability (0.19) Innovation Systems (0.08) Innovation Policy (0.07) Literature (0.06) Tech. Change, Industry (0.06)	Transitions (0.36) Territorial Innov. Models (0.02) Institutional Entrep. (0.02) Knowledge Production (0.01) Organizational Learning (0.01)
Science Technology Studies: Modes of Knowledge Production	386 (6%)	High. Educ. (1) Scientometrics (0.95) Minerva (0.86) J. Technol. Transf. (0.8) Sci. Public Policy (0.72)	University-Industry (0.14) Globalization (0.06) Literature (0.06) Innovation Policy (0.06) Learning Processes (0.06)	Knowledge Production (0.24) Institutional Entrep. (0.03) Transitions (0.03) Organizational Learning (0.01) Territorial Innov. Models (0.01)

Note. Summary includes most central journals; the most relevant topics; and the most related knowledge bases. All calculated centralities are Jaccard-weighted.

cities (Audretsch, 2002), as well as the international comparative advantage (Audretsch, 1998).

The most cited references are almost exclusively to be found in the knowledge base Territorial Innovation, include defining works on externalities in general (Jacobs, 1969; Marshall, 1920; Romer, 1990), spatially bounded knowledge spillovers (Griliches, 1979, 1990; Jaffe, 1989; Jaffe et al., 1993), and urban economics (Glaeser et al., 1992). Two most prominent journals are *Regional Studies* and *Research Policy*. Publication outlets generally reflect the main focus of the research area being on economic geography of innovation and regional science, the exception being *Small Business Economics* and *Journal of Technology Transfer*.

Networks and Inter-Organizational Learning: This mainly empirical research area includes publications thematically focused on firms' capabilities, strategic technology alliances, and inter and intra-organizational networks as means of knowledge creation, diffusion, absorption and use. It includes work on different aspects of the

firms' alliance networks and their influence on firms' learning and innovation (Gilsing et al., 2008; Karamanos, 2012; Paruchuri, 2010; Phelps, 2010; Schoenmakers and Duysters, 2006; Soh, 2003; Vanhaverbeke et al., 2015), and models of alliance partner selection (Baum et al., 2010). Theoretical contributions mainly aim at augmenting the resource-based view with a network perspective (Lavie, 2006).

The most cited references include Cohen and Levinthal (1990) on the concept of "absorptive capacity", Barney (1991) on the link between firm resources and sustained competitive advantage, Kogut and Zander (1992) on the knowledge-based-view of the firm, Powell et al. (1996) on the inter-organizational networks of learning in biotechnology, Burt (1992) on the concept of "structural holes", Nelson and Winter (1982) on evolutionary theory of economic change, and Ahuja (2000) on collaboration networks, structural holes and innovation. Other highly influential references include work by Granovetter (1985) on the concept of "embeddedness" of economic behaviour in social relations, and March (1991) on exploitation and exploration in organizational learning. The most central publication outlets are *Strategic Management Journal* and *Research Policy*.

International Business (IB): This is a relatively homogeneous research area mainly consists of work on various dimensions of cross-national, cultural, and institutional differences, and the internationalization process of firms in the context of international business, management, and strategy studies. Central publications address the role of the host country's local demand on the relationship between cross-national distance and foreign direct investment (FDI) (Bailey and Li, 2015), cross-cultural distance on the establishment mode choice of the MNEs (Slangen and Hennart, 2008), the role of host country's "governance quality" on the relationship between cross-cultural distance and MNEs' entry mode (Chang et al., 2012), the impact of added cultural distance and diversity on MNEs' expansion patterns (Hutzschenreuter et al., 2011), the level of local isomorphism adopted by firms from different home countries (Salomon and Wu, 2012), the institutional determinants of the foreign subsidiary staffing policies (Ando, 2011), and the interaction effect of institutional differences on foreign market entry mode (Ang et al., 2015). Other central publications discuss the operationalization and measurement of the concepts of distance and international experience (Dow and Larimo, 2009), the impact of entry mode choice on foreign affiliate performances (Kim and Gray, 2008), and the relationship between cultural distance, international entry mode choice and performances (Wang and Schaan, 2008).

The highly cited references in this research area address dimensions of cultural differences among nations (Hofstede and Bond, 1984), the effect of national culture on the choice of firms' entry mode (Kogut and Singh, 1988), the institutional isomorphism and collective rationality (DiMaggio and Powell, 1983), an analytic framework

for explaining how institutions and institutional changes affect economic performances of countries (North, 1990), a model of the internationalization of the firm with the main focus being on the knowledge of foreign markets and operations in explaining the extension of the firm's operations in individual countries (Johanson and Vahlne, 1977), the relationship between the institutional theory and the study of organisations (Scott, 2014), and the organizational legitimacy in the context of the MNEs (Kostova and Zaheer, 1999). The most central publication outlets are *Journal of International Business Studies* and *International Business Review*.

Innovation Systems (IS): This research area can be identified as the one most related to the original core concepts, context, and literature of the IS field. Its thematic orientation includes the systemic, evolutionary and spatial approaches for innovation analysis as well as theoretical and innovation policy contributions and focus on external sources of knowledge. The most central publications are concerned with the characteristics of RIS from the view of the Triple Helix model (Danell and Persson, 2003) or NIS (Chung, 2002), the characteristics of collaboration in the RIS (Edquist et al., 2002), a policy framework for IS-based strategies (Woolthuis et al., 2005), the regional strengths and weaknesses in the specific research domains (Islam and Miyazaki, 2010), the styles of innovation diffusion dynamics across countries (Weber and Hoogma, 1998), the role of firm's social capital formed in the context of NIS (Baba and Walsh, 2010). Other contributions discuss usefulness of the NIS approach and the concept of "style of innovation" (Lundvall, 1998), the relevance of NIS from policy and managerial perspectives (de la Mothe and Paquet, 1998), and usefulness of the IS approach for spatial innovation analysis (Fischer, 2001).

The most cited references are four books explicitly dealing with the NIS: Lundvall (1992), Nelson (1993), Freeman (1987), and Edquist (1997). Other highly influential references include Nelson and Winter (1982) on evolutionary theory of economic change, and Porter (1990) on the patterns of competitive success of nations. They further include contributions on the relevance of national and regional systems of innovation as a domain of economic analysis (Freeman, 1995), a chapter on innovation as an interactive process in the seminal book on *Technical Change and Economic Theory* (Dosi et al., 1988), the concept of RIS (Cooke et al., 1997) and "absorptive capacity" (Cohen and Levinthal, 1990). *Research Policy* is by far the most prominent journal in this research area.

Geography of Innovation: The thematic orientation of this research area includes regional development, the role of localization, clusters, knowledge spillovers, patterns of knowledge sourcing and innovation activity, as well as globalization and non-localized interaction pattern. Central publications are concerned with the geog-

raphy of innovation, and collaboration in emerging industries (Blažek and Žížalová, 2010), the relationship between innovation and wider spatial structure (Doloreux and Shearmur, 2011), the sources of firms' product and process innovation (Fitjar and Rodríguez-Pose, 2013), the variety in knowledge sourcing and the relevance of geography for firms' innovativeness (Grillitsch et al., 2015), the design and progress of regional innovation strategies (Blažek et al., 2013), the geography of linkages at the industry level (Chaminade, 2011), and the role of proximity for knowledge collaboration (Moodysson and Jonsson, 2007). The remainder of the most central contributions deal with the knowledge bases of a region (Martin, 2012b), the dangers associated with the use of RIS as a normative concept (Uyarra and Flanagan, 2010), and the impact of various dimensions of proximity and entrepreneurial dimension on the functioning of an RIS (Sternberg, 2007).

The research area's most cited references include studies on local buzz, global pipelines, and the process of knowledge creation (Bathelt et al., 2004), the impact of proximity on innovation (Boschma, 2005), the RIS (Asheim and Coenen, 2005; Asheim and Gertler, 2005; Asheim and Isaksen, 2002; Cooke et al., 1998), and tacit knowledge and the economic geography of context (Gertler, 2003). Other most cited references include the seminal works on the concept of "absorptive capacity" (Cohen and Levinthal, 1990), knowledge formation and management (Amin and Cohendet, 2004), and the process of regional development (Cooke et al., 1998). *European Planning Studies*, *Regional Studies*, and *Journal of Economic Geography* appear as the most central publication outlets.

Technological Change and Evolutionary Economics: This research areas focuses on various aspects of the process of technological change and the application of an evolutionary perspective in economics, management and organization studies. Central publications include work on the sources and obstacles to entrepreneurial behavior across technological regimes (Marsili, 2002), the relationship between the technological regimes and Schumpeterian patterns of innovation (Breschi et al., 2000), the economics of the technological systems and the environmentally sustainable economic development (Kemp and Soete, 1992), the concept of "architectural innovation" and its competitive consequences for the established firms (Henderson and Clark, 1990), the competitive consequences of the incumbent business' patterns of introducing incremental innovations (Banbury and Mitchell, 1995), the effects of the introduction of the new technology on the innovative firms' survival (Levitas et al., 2006), and the effect of the demand heterogeneity on the development and evolution of technology (Adner and Levinthal, 2001). Other most central publications discuss the nature of the selection environment for innovations and the concept "techno-economic

paradigms" (Freeman, 1991a), and the opportunities, incentives and collective patterns of technological change (Dosi, 1997).

The work by Schumpeter (1942), Nelson and Winter (1982), Dosi (1982); Dosi et al. (1988); Dosi and Orsenigo (1988), and Freeman and Soete (1982) are the most cited references. Other highly influential references include work by Abernathy and Utterback (1978) on patterns of industrial change, and Pavitt (1984) on sectoral patterns of technological change, as well as Rosenberg (1994) collection of essays on technological change. *Research Policy* and *Journal of Evolutionary Economics* are the most central publication outlets.

Sustainability Transitions: This research area is thematically focused on transitions towards sustainability from a systems as well as evolutionary economic perspective, and includes conceptual, literature review and policy contributions. Central publications are studies concerned with a framework for analyzing sustainable innovation policy (Meelen and Farla, 2013), the multi-level perspective (MLP) framework for assessing policy to stimulate socio-technical transitions (Kern, 2012), an integrated framework of TIS and MLP approaches on technological change (Markard and Truffer, 2008), a system dynamic model that crosses over the TIS and MLP frameworks (Walrave and Raven, 2016), a review of the current transition research and on the limitations of the MLP approach (Genus and Coles, 2008), the socio-technical regimes (Fuenfschilling and Truffer, 2014), and a comparison of empirical approaches and results of two "path creation" frameworks (Lovio and Kivimaa, 2012). Empirical contributions include studies on the interactions between niche and regime (Ingram, 2015), the actor strategies and resources in transition processes (Farla et al., 2012), and the translation mechanisms in socio-technical niches (Raven et al., 2011).

The most cited references in this line of research include a multilevel perspective on technological transitions (Geels, 2004, 2002; Geels and Schot, 2007a), a strategic niche management perspective on transitions (Kemp et al., 1998; Rip and Kemp, 1998; Schot and Geels, 2008; Smith et al., 2005), and a functional approach to studying TIS(Bergek et al., 2008; Hekkert et al., 2007). Here, the *Journal of Cleaner Production* and *Environmental Innovation and Societal Transitions* are the most central publication outlets.

Science and Technology Studies (STS): In STS, we find a strong thematic focus on different aspects of modes of knowledge production, such as university–industry interactions, and the role of university in the context of the global knowledge economy, as well as literature review and policy contributions. The most central articles address the paths of commercial knowledge occurring in scientist-sponsored firms (Shinn and Lamy, 2006), different approaches to measuring the relationships

among university, industry, and other sectors in the NIS (Sun and Negishi, 2010), the management of the multiple criteria for knowledge production in the context of collaborative research projects (Wehrens et al., 2014), the role of novel organizational forms on framing science-industry activities (Merz and Biniok, 2010), the limits of entrepreneurialism in the traditional public university (Tuunainen, 2005), the multiple forms of university–industry linkages (Ramos-Vielba and Fernández-Esquinas, 2012), the role of higher education in various knowledge society discourses (Välimaa and Hoffman, 2008), and the place of the university in the knowledge production system (Godin and Gingras, 2000). It also includes a systematic reflection on the Gibbons–Nowotny notion of "Mode 2" knowledge production (Hessels and Van Lente, 2008), and a critical assessment of the main approaches in the sociology of science and technology (Shinn, 2002).

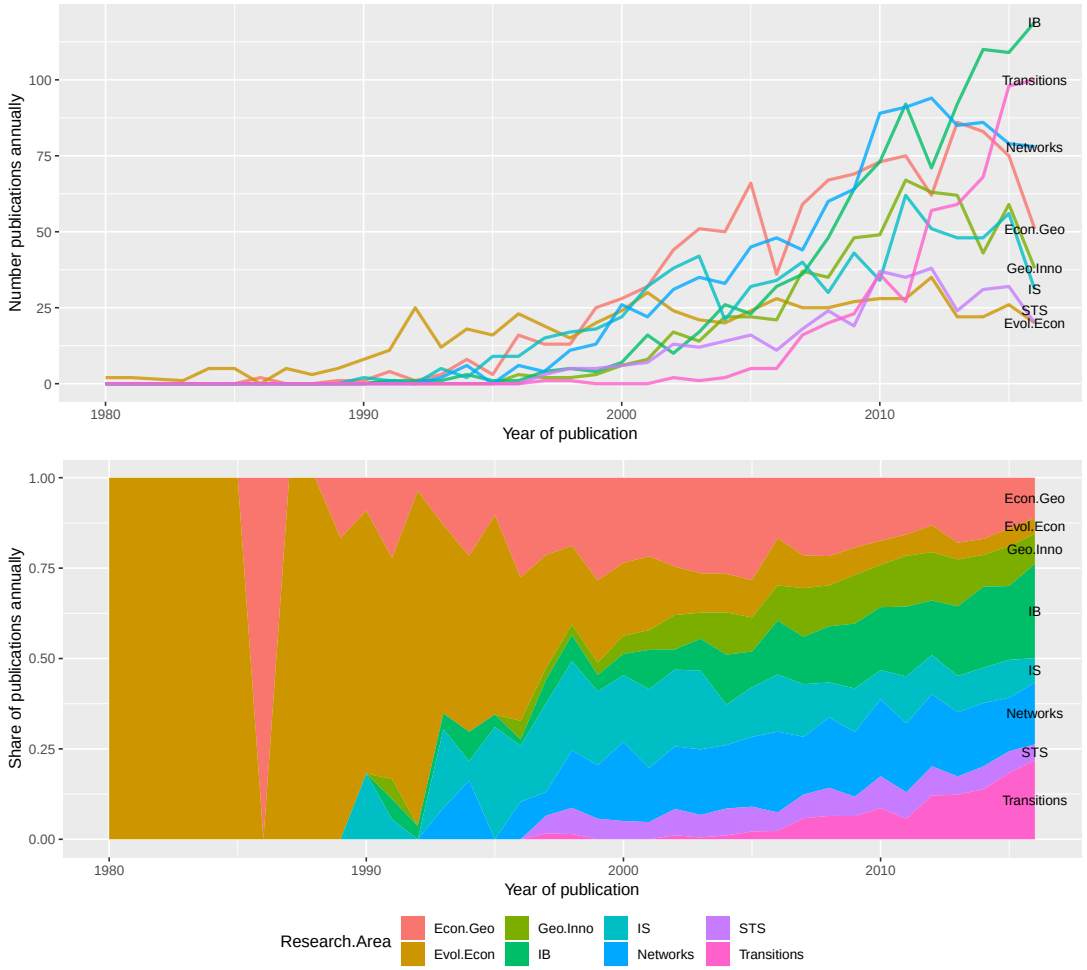
The most cited references consist of several contributions on the role of university in the knowledge economy and contemporary society (Clark, 1998; Etzkowitz, 1998, 2003; Etzkowitz and Leydesdorff, 2000; Gibbons et al., 1994; Nowotny et al., 2001). Other sources discuss the influence of public research on industrial R&D (Cohen et al., 2002), a "new economics of science" (Partha and David, 1994), patenting as a measure of the influence of university research (Agrawal and Henderson, 2002), and the different channels through which academic researchers interact with industry (D'Este and Patel, 2007). *Higher Education* and *Scientometrics* appear as the central journals.

4.4 Development of coherence in IS as a field of research

Delineating the field of IS research and identifying distinct areas of research within, while informative, is by nature a descriptive exercise. Yet, after setting the boundaries, further insights on the development of IS can be gained by analyzing its internal dynamics.

Figure 6 depicts the developments in terms of annual publications in the field's research areas. While we observe a somewhat steady increase in the annual number of publications across all the research areas (upper figure), after 2010, a stagnation or even decline is evident for all except International Business and Transitions. In relative terms (lower figure), the composition reveals the evolving research agenda originating from Evolutionary Economics, the only research area present in the early 1980*s*. Around the mid-1980*s*, the emergence of Economic Geography suggests an interest in the territorial aspects of technological change and economic growth. The field splits further in the early 1990*s*, into IS, with a focus on the link between the technological dynamics and social, institutional, and political factors on the one hand, and Geography of Innovation, with an interest in combining ter-

Figure 6: Developments in annual publications in the research areas.



Note. Absolute (upper) and relative (lower) numbers of publications per year in the research areas.

ritorial and institutional aspects with systemic aspects of innovation and regional development on the other. In the late 1990*s*, the field specialized further into Networks, International Business, STS, and Transitions. While the two research areas most associated with the field's initial topics and theoretical foundations, namely Evolutionary Economics and IS, represented the most popular research areas in the late 1990*s*, they recently became the ones with the lowest share of annual contributions. Among the field's early knowledge bases, only Economic Geography has maintained a certain level of relevance. In contrast, Transitions and International Business now occupy the top positions, reflecting that topics of transition toward sustainability and globalization have lately enjoyed increased attention from academics, policymakers, and practitioners.

In summary, the field's internal dynamics, which could already be observed in our previous analysis of the development of its knowledge bases, also manifests when observing its active research areas, leading to a much broader and more diverse field at present. The growing number of distinct research areas may either have developed from within or entered IS as a result of broadening research agendas from outside the field. How has this growing diversity influenced the field's coherence? While research areas can be expected to specialize somewhat in terms of methods, topics, and theories, is there enough common ground left to collectively pursue a larger research agenda, or has fragmentation and isolation in knowledge silos taken place? In a first attempt to provide answers to these questions, it is helpful to apply a network perspective and inspect the development of bibliographic coupling strength between the research areas in Figure 7 (consider Table A.3 for numerical values), measuring the extent to which they draw from a common pool of references and knowledge.

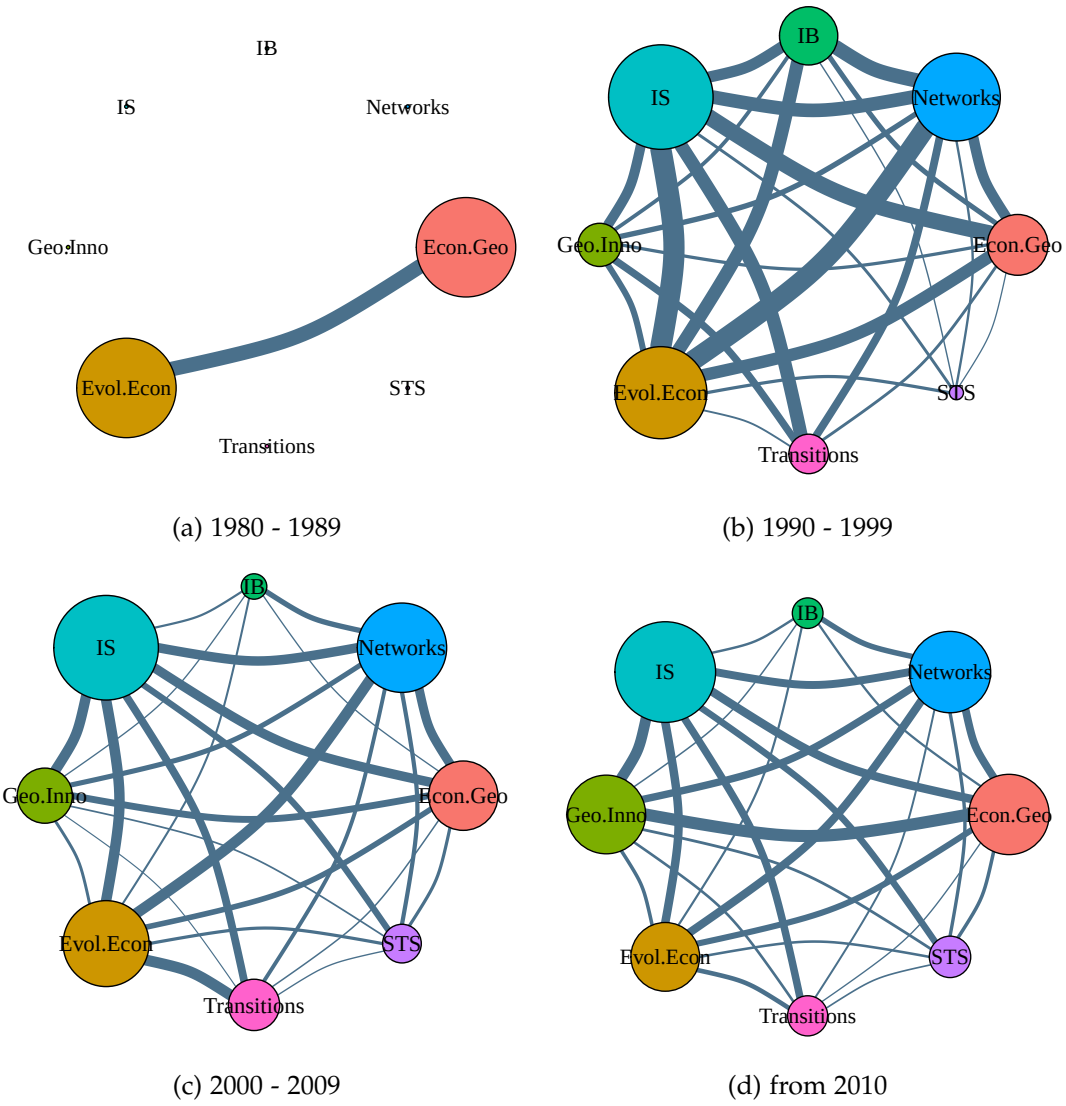
Figure 7a depicts the IS field's research areas in the 1980*s*, up to now only Evolutionary Economics and Economic Geography. The two areas are connected during this period, possibly due to the increasing popularity of research on the relationship between R&D, innovation, and productivity growth among economic geography scholars and their shared body of references to the early contributions in the economics of technical change. This is associated with knowledge spillover and the extent to which they are geographically localized (Breschi and Lissoni, 2001).

In the 1990*s* (Figure 7b), all research areas display an overall high level of coupling strength, indicating a high consensus in the core literature and dominant theories. This is unsurprising, since a major share of the field's seminal contributions now forming its core literature (e.g. Cohen and Levinthal, 1990; Edquist, 1997; Lundvall, 1992; Nelson, 1993) were published at this time. This demonstrates the influence of core contributions (in this case, mostly in the form of books) to inspire diverse work streams and form a coherent higher level field of research. Evolutionary Economics and IS stand in the center of this development.

In the 2000*s*, we observe a similar pattern, but with decreased strength. Interestingly, the coupling of Evolutionary Economics decreases with all research areas except Transitions, hinting at the challenges to further advance the field's overall theoretical evolutionary foundations. Likewise, International Business moves further toward the most peripheral position, hinting at an up to now unsuccessful integration. This configuration remains somewhat stable in the post-2010 period.

Overall, after a formative stage of "groundwork" in the 1980*s* and 1990*s*, we see the field evolve in a diverse and coherent manner. While the initial pattern established in this period remains somewhat stable, the field's overall coherence decreases and settles below its initial level (cf. Table A.3 for numerical values). This develop-

Figure 7: Development of coherence between research areas



(a) 1980 - 1989

(b) 1990 - 1999

(c) 2000 - 2009

(d) from 2010

Note. Bibliographic coupling network between research areas by time periods. Node-size reflects the research area's degree. Edge-width reflects the (Jaccard-weighted) coupling strength.

ment may be explained by the diminishing interest in—and reference to—the field's original core contributions (Fagerberg and Sapprasert, 2011). From a different point of view, it could also be interpreted as the unsuccessful integration of emerging areas, such as International Business and Transitions, into the field's theoretical foundations.

4.5 Development of coherence and diversity in research areas

Considering the one-mode bibliographic-coupling network between research areas gives us a good general overview on the field's development in terms of overall coherence, yet many questions remain unanswered in this type of analysis. What are the field's unifying theoretical building blocks? How did these foundations develop over time? Were they strengthened and developed further, neglected, or even substituted, and are these patterns homogeneous across the research areas?

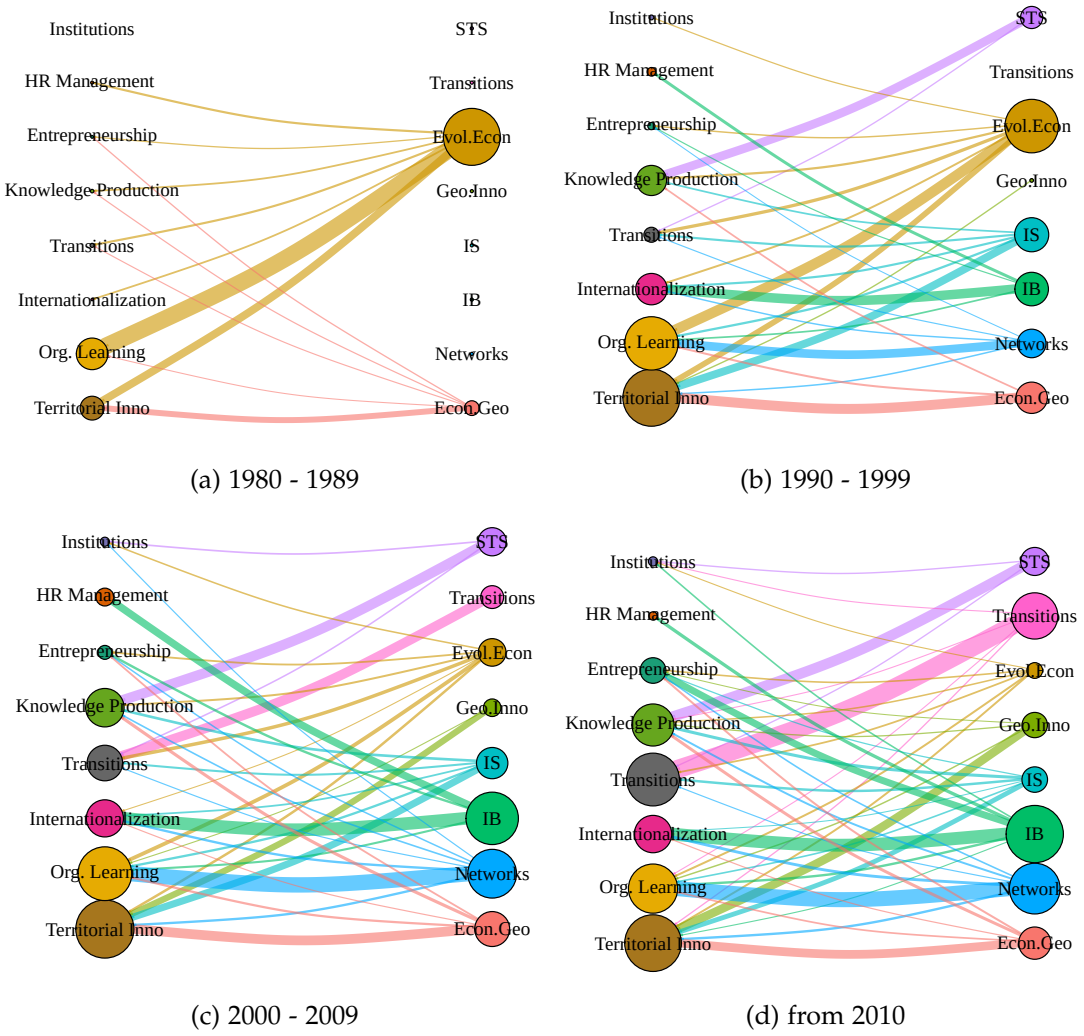
In an attempt to provide first answers, considering the full information contained in the multimodal bibliographic structure appears to be a promising way forward (Newman, 2001, 2004b; Opsahl, 2013). Thus, in Figure 8, we present the two-mode network (research area → knowledge base), providing insight into the pattern of how the field's research areas draw from (as measured by citations) and integrate the knowledge bases over time.

Figure 8a depicts the field in the 1980*s*, when we see that Evolutionary Economics first mainly drew from the literature associated with the knowledge bases *Organizational Learning* and *Territorial Innovation*, and to a lesser extent, almost all knowledge bases. This pattern is in line with the early attempts of the creators of an evolutionary program in economics and management research to develop and integrate a coherent theory of firm into analysis of the large systems (Winter, 2017). Initially, Economic Geography mainly drew from *Territorial Innovation*, and to a lesser extent, from several other knowledge bases. This connection of Economic Geography corresponds with the beginnings of the regional endogenous development approach (Moulaert and Sekia, 2003).

Evolutionary Economics in the 1990*s* (Figure 8b) maintains the strong connection to its original knowledge bases while additionally integrating *Institutions* to further increase the richness of its theoretical foundation. IS developed in a similar fashion, broadening its knowledge bases over time while decreasing the focus on its original foundation. In contrast, Economic Geography maintained and even strengthened its association with *Territorial Innovation* over time while integrating a relatively large number of knowledge bases. Similarly, Networks shows an overall tendency of increasing diversity of knowledge bases while growing a strong connection to its main knowledge base *Organizational Learning*. Both Geography of Innovation and Transitions mainly draw from literature associated with *Territorial Innovation* and *Transitions*, respectively. While continuously strengthening these connections over time, both become increasingly connected to diverse knowledge bases, such as *Organizational Learning* and *Knowledge Production*, after 2010.

A somewhat different tendency is observed for International Business, which mainly drew from literature associated with *Internationalization* in the 1990*s*, and only

Figure 8: Network of knowledge bases and research areas over time



(a) 1980 - 1989

(b) 1990 - 1999

(c) 2000 - 2009

(d) from 2010

Note. Node-size reflects the degree of the research area/knowledge base. Edge-weight corresponds to the (Jaccard weighted) number of citations a knowledge base receives from a research area. The corresponding numerical values can be found in table A.4 in the Appendix.

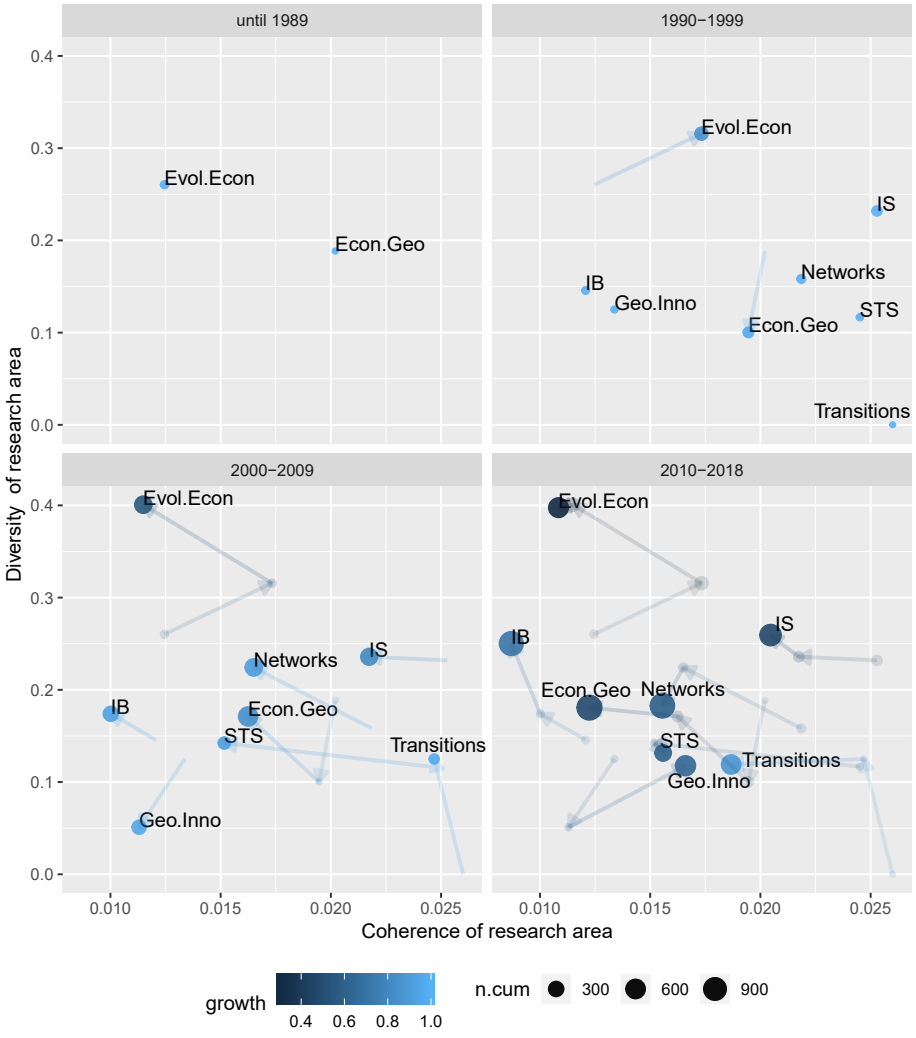
to some extent from *HR Management*, *Entrepreneurship*, and *Organizational Learning*. The later periods (Figure 8c and 8d) show a growing connection to several knowledge bases, such as *Institutions* and *Territorial Innovation*. Interestingly, we also observe a shift from the focus on *HR Management* in the 2000*s* to *Entrepreneurship*, reflecting a refocusing away from global MNE activity to global entrepreneurship.

In summary, over time, we observe heterogeneous processes of knowledge integration across the research. Most research areas were initially relatively focused but expanded their sources of knowledge while maintaining their initial specialty (namely Economic Geography, Geography of Innovation, STS, or Networks). In contrast, IS and Evolutionary Economics were always rather diverse, and this

diversity even increased but at the cost of losing their initial focus. International Business is the only research area that shows changes in the importance given to distinct knowledge bases over time, indicating their ability to pivot toward timely strands of research.

As discussed in section 2, to assess the process of knowledge integration within the research field, it is useful to trace the research areas' diversity and coherence trajectories (cf. Figure 1) over time, thereby illustrating heterogeneous processes of knowledge integration. Figure 9 depicts the joint developments of coherence–diversity dynamics at the research area level (consider Table A.4 for numerical values).

Figure 9: Developments in the research areas' coherence and diversity.



Note: (Internal) *Diversity* represents the (Leydesdorff, 2018) diversity measure of the corresponding research area for the cited knowledge bases ($Div = V * B * D$). *Coherence* is measured by the (internal) density of the (Jaccard-weighted) bibliographic-coupling network among publications in the research area. *Growth* represents the research area's growth rate in terms of the number of publications. Node size reflects the area's cumulative number of publications.

In the 1980*s*, Evolutionary Economics emerged around the seminal contribution of Nelson and Winter (1982) in a comparably incoherent way, while Economic Geography started advancing a less diverse and more coherent line of inquiry related to the issues around "localized knowledge spillovers". While Economic Geography first maintained its level of coherence while decreasing in diversity during the 1990*s*, it then started to decrease in coherence and increase in diversity, which may be a sign of theoretical expansion (mid-left in Figure 9). Evolutionary Economics first exhibits joint increases in diversity and coherence in the 1990*s*, and over time, further decreases in coherence while maintaining the high level of diversity (upper left in Figure 9). As suggested by Hodgson and Lamberg (2018), our results for Evolutionary Economics point to the combination of growth, diversification, and deepening theoretical fragmentation, leading to a situation where this research area draws from diverse knowledge bases, yet makes relatively few common references to its core theoretical works (with the exception of its foundation by Nelson and Winter (1982)). In contrast, the results for Economic Geography display tendencies toward not only specialization but also diversification and reintegration, in line with the attitudes expressed by Bathelt and Glückler (2018). Especially, the trend toward diversification and reintegration may be due to the launch of the *Journal of Economic Geography* in 2000, with the specific purpose of stimulating debate across research traditions converging around the common research interest (Bathelt and Glückler, 2018).

International Business changed its position in the process of knowledge integration from fragmented specialization in the 1990*s* and 2000*s* to the position of fragmented diversification after 2010. A possible explanation for this finding may be a lack of substantial integration of the diverse theoretical perspectives applied in the context of international business, as suggested by Buckley et al. (2017). Starting in the 1990*s*, the research area Networks draws from somewhat distinct knowledge bases; in the 2000*s*, it shows a further increase in diversity while slightly decreasing in coherence, indicating the successful integration of new knowledge bases. The change in position after 2010 points to some integration around the core literature. These results suggest the continuing tradition of this research area to engage with the concepts across a spectrum of knowledge bases, and reconfigure its knowledge bases in response to current practical challenges.

IS and STS emerged in the 1990*s* as theoretically cohesive research areas while exhibiting different levels of diversification. IS's starting position confirms earlier studies that claim that this strand of literature emerged at the intercept of disciplines and schools of thoughts. Although IS remains connected to diverse knowledge bases over time, its decrease in coherence suggests a lack of advancements in its theoretical core. In contrast, STS is an example of a trajectory moving from the position of more

to less coherent diversification. One possible interpretation is the progression from the influential "Mode 2" concept of 1990*s* to successive interest in the alternative approaches for studying changes in the science system, such as "Triple Helix" and "strategic science" through the 2000*s* and to a post-2010s refocus on university–industry linkages and academic entrepreneurship. Yet, no successful integrative development can be observed. Geography of Innovation displays a rather different trajectory. The starting point in the 1990*s* signals a rather specialized research area but loosely integrated theoretical basis. Interestingly, in the 2000*s*, it shows further specialization and fragmentation, while the post-2010s witness a process of coherent diversification, where diversity and coherence increase.

While starting from the position of a highly coherent and specialized research area in the 1990*s*, Transitions in the 2000*s* displays a sharp increase in diversity and slight decrease in coherence, which may be attributed to a reliance on insights from new knowledge bases while focusing on a narrow research interest. This trend changes after 2010, where research becomes more fragmented, probably as a result of an increasing interest in sustainability issues from researchers in other research areas, as indicated by Markard et al. (2012).

4.6 Some reflections: How did the field develop—and why?

So far, our analysis has illustrated the current state and evolving nature of the IS field, overlapping with the results of previous studies on the whole field (e.g., Fagerberg et al., 2013; Martin, 2012a), as well as its distinct research areas (e.g., Bathelt and Glückler, 2018; Buckley et al., 2017; Hodgson and Lamberg, 2018; Markard et al., 2012), thereby validating our methodology and corpus selection techniques. However, while attempting to exploit the full richness of bibliographic data, ultimately, we face limitations in terms of what the data at hand can explain in relation to why the field developed in this manner. For this—arguably more interesting—question, in the following, we provide some tentative answers to extend the inferences based on our analysis.

To start, what provided the initial spark for IS as a field of research on its own right? While systemic approaches to the economy, and specifically innovation, can be traced throughout the history of economic thought (e.g., List, 1909), there exists a consensus that the research on IS was launched in reference to the seminal book by Nelson and Winter (1982), *An Evolutionary Theory of Economic Change*, aiming at establishing a more realistic evolutionary foundation in economics that is useful for policy and management alike.

Along these lines, IS can be seen as one of the specializations of the broadly defined evolutionary agenda, yet more focused on informing science and technology

policy. Since, at that point, such policy was largely formulated at the national level, it is not surprising that the development of the "National Innovation System" concept around the seminal contributions by Freeman (1987); Lundvall (1992); Nelson (1993) was the initial focus. It should be noted that the seminal contributions so far have in common that they attempted to theoretically bridge several disciplines while being practically relevant. Consequently, it is unsurprising that all the contributions listed so far come in the form of books, a format that enables the formulation of complex and interdisciplinary concepts in sufficient detail while being shielded from the selection environment of established journals. We also observe that the publication of these books was associated with a sharp increase of coherence in the overall IS field and the formation of a stable pattern that persisted over time. According to their share of citations, the research areas where books appear the most relevant part of the knowledge base are IS (45%) and Evolutionary Economics (45%). This indicates the strong role that books, book chapters, and similar publications had on the central research areas in IS. Furthermore, in both research areas, the contributions to be found in books have an especially high within-area, as well as between-area, centrality, again demonstrating the crucial importance of these seminal contributions to unifying this field of research and stratifying its future development.

Notably, many seminal and formative contributions to the field of IS research—and research on innovation, R&D and technological change generally—was enabled and driven by the public policy needs of the time. Well-known examples are Christopher Freeman and Dick Nelson's early involvements with public policy institutions, such as the OECD and RAND. Therefore, it is also reasonable to assume that forces external to the academic community shape its development as much as interactions within academia do. Indeed, many historical accounts of IS as a research field pronounce that external engagements with governmental and intergovernmental organizations were instrumental for the formation of the field of IS and continue to shape its development (Fagerberg et al., 2013). A notable example is the concept of NIS. As explained by Sharif (2006), this concept emerged simultaneously in academic and policy arenas, while its development has been facilitated by the intercept of academics working at the OECD. Taking a closer look at whether traces of such engagements between policy and academia can also be found in our bibliometric data, we do not see this manifested in academic publications by actors from the policy space.[14] However, we do see intergovernmental organizations appearing among the cited references, suggesting they are less involved in academic knowledge production but nevertheless present as a source of knowledge. The most cited organization by far is the OECD (597 citations, making it the $43th$ most cited author, immediately

[14] We only find two publications with a first author directly affiliated with the OECD and one for the European Commission (EC).

behind Michael Storper), followed by the European Commission (EC) (149 citations, rank 266). Especially, the number of citations of OECD references steadily increased over time, with a sharp increase after 2008 (18 citations) to 2016 (58 citations). Most of the cited references of OECD documents (50%) are located in the knowledge base *Territorial Innovation*, followed by *Knowledge Production* (19%), and they receive the highest numbers of citations from the research areas IS (31%) and Geography of Innovation (22%). Both research areas aspire—at least by internal claims—to inform policy.

While a wide range of OECD reports receive few citations in our corpus, two stand out, namely the "Oslo Manual" (OECD, 1997, 65 citations) and "OECD Main Science and Technology Indicators" (OECD, 1988, 63 citations across different volumes). When considering the topic distribution (result of the LDA analysis) in the publications citing OECD documents, we see that especially the topic `R&D, Patents & Productivity` is strongly overrepresented, followed by `Regional Performance & RIS` and `Empirical Evaluations`, suggesting that the OECD mainly serves as a provider of data—and guidance on how to gather and compose such data—for empirical work. However, the third most cited OECD publication in our corpus is the project white paper on "National Innovation Systems" (OECD, 1999, 46 combined citations), a compilation of work on *NIS* geared toward explaining and promoting the concept to policymakers. It appears plausible that the importance given to the concept of IS by the OECD, as evident by the volume of policy-related documents, had and continues to have an effect on boosting research on IS by providing it with greater legitimacy. Others (Godin, 2009) have even claimed that most of the main building blocks of the NIS framework can be traced back to—and are built on—previous efforts at the OECD. While the jury is still out on this claim, it appears evident that the systemic approach to innovation fell on fertile ground at the OECD, which undertook substantial efforts to promote and diffuse it among policymakers across the globe. Likewise, many innovation scholars collaborated in various OECD studies, using concepts and indicators in their academic research; this suggests a mutual legitimization between academics and the OECD (Albert and Laberge, 2007). Moreover, the close cooperation between the OECD and EC on the design of innovation survey instruments and the commitment of resources for collecting firm-level innovation survey data in Europe and elsewhere, made this type of data more widely available and used by researchers. It is the new evidence stemming from these surveys that significantly influenced the evolution of the research agenda, including the emergence of new research frameworks and the importance given to specific issues like *dynamic capabilities* (Fagerberg et al., 2013, 2006). At the same time, the conceptual foundations of science, technology, and innovation indicators reflect the ideas, more or less informed by the innovation research, that have been taken up by data

gatherers and indicator developers. Consequently, one would expect the field not only to continue to be shaped by the demands but also, to some extent, driven by the work of policymakers and intergovernmental organizations. This type of analysis, while limited in our approach, would certainly provide a valuable insights on the societal role of different research areas. In summary, it can be speculated that the OECD and other intergovernmental organizations influenced the field as "producers of knowledge" from the supply (of data) side, as well as "user of knowledge" from the demand (of policy) side.

5 Conclusion

In this article, we delineated and mapped the field of recent IS research. We identified consistent research areas and knowledge bases, thereby enhancing our understanding of the diversity of research efforts that contributing to the field's collective advances. Further, we established a conceptual and analytical link between the research areas and knowledge bases. By doing this, we further developed and demonstrated a sound methodology for delineating an interdisciplinary academic field with blurry boundaries within a bibliometric corpus. We provided an inductive "bottom up" approach to identifying meaningful clusters of publications without relying on predefined classifications. We demonstrate the usefulness of this approach, especially for capturing the variety of research areas and knowledge bases of a research field that has undergone expansion and reconfiguration in terms of the issues it addresses, its users, and its theoretical foundations.

In an analysis of the resulting co-citation and bibliographic coupling network, we illustrated how the multidimensional structure of bibliometric data can be exploited for identifying and disentangling the structure of knowledge production, as well as the underlying knowledge bases utilized. By deploying methods from NLP, we added a further qualitative layer of information, thereby exploiting the full richness of bibliometric data to create insightful summaries of distinct research areas and their content. This is useful for verifying such a data-driven analysis, as well as giving the identified research areas meaning and context. In addition to the ability to provide an accurate and informative snapshot of a given research field, our method enabled us to unveil a persistent heterogeneity of knowledge integration across research areas and over time; this cannot be captured by commonly used methods for literature summary solely based on aggregated citation numbers. It also proved useful to derive temporal metrics and visualizations that provide insights into the process of knowledge integration, as well as some guidance and implications for its future

development. We think the presented methodology will prove useful for mapping and understanding other academic fields with similar characteristics.[15]

We provided what is, to the best of our knowledge, the most comprehensive bibliographic overview of the current state of IS research, its intellectual contours, and its heterogeneous internal dynamics of coherence and diversity at present. Thus, we contribute to the discussion on what constitutes the IS field now and how it evolved over time. We find the field in the 1980*s* centered on seminal works in Evolutionary Economics, and slightly later, IS, which served as the main unifying area of research. After the initial dominance of IS (1990*s* and 2000*s*) we witness a growing importance of other streams of research, especially International Business and Sustainability Transitions. The composition and changes in the field's research areas reveal the evolving research agenda, originating from the influential works in the 1980*s* and 1990*s* and inspiring subsequent development of research specialties. We illustrated how literature on IS has expanded its audience and contributors and the resulting diversity of issues addressed by the growing number of research areas. Despite the initial success of diverse streams of literature to form a coherent higher level field of research, IS has become less coherent, where diverse but fragmented research areas pursue narrower lines of inquiry.

Furthermore, the field's knowledge bases have changed over time, as has the way the research areas use them. Across research areas, we identified distinct development patterns that include starting from a narrow knowledge base and including new ones over time while maintaining the strong connection to a single source (e.g., Economic Geography, Geography of Innovation, and Transitions), as well as starting from a diverse knowledge base with subsequent movement to even higher levels of diversity (e.g., IS and Evolutionary Economics) while decreasing connections to its theoretical core. From the joint perspective of developments in coherence and diversity, we again illustrate how identified research areas follow different trajectories in the knowledge integration process. Evolutionary Economics appears to follow a trajectory of fragmented diversification, while Economic Geography suggests a disposition toward both diversified specialization and continuous reintegration. In turn, Geography of Innovation and Transitions research areas move from the position of coherent and specialized lines of inquiry and only lately started to broaden its knowledge bases.

Our analysis of coherence-diversity dynamics provides insights beyond the context of IS, especially on how research fields develop and what the promising development

[15]The present analysis also inspired the development of a bibliometrics package for the statistical programming environment R, which aims at easing its reconstruction and application in different settings. The current version of this package can be found at `https://github.com/ANONYMOUS` (anonymized for review). We hope other researchers will apply it to further enhance our knowledge on the development of research fields.

paths may be. We showed that research areas commonly associated with IS follow rather different trajectories in terms of coherence and diversity in their knowledge integration process. Thus, as the field grows larger in size as well as more diverse in thematic orientation, there is a danger of fragmented specialization to take place, where different specialties of IS pursue a narrow line of research interest without further enhancement of the common research agenda. There is a general consensus that a diversity of knowledge bases is integral for addressing complex phenomena and responding to the changing "grand challenges" posed by policy and society. Yet, we illustrated that the thriving toward higher diversity can also harm the collective alignment of research efforts if not accompanied by a maintenance of internal coherence. How can such a coherence be maintained? While not being able to make a strong empirical case, anecdotal evidence hints at the key role of institutions. These can take the form of intergovernmental organizations, such as the OECD in our case, which supports the research and data-gathering infrastructure, compiling a diverse set of results and simplifying them for—and promoting them to—the relevant audience, such as policymakers. Our results also hint at the role joint interdisciplinary journal outlets play in shaping a joint research agenda, in our case mainly *Research Policy*, as the only journal significant in almost all the research areas (and scoring highest on our measure of diversity at the journal level). However, we also illustrate that such integration attempts are not always successful, as in the case for International Business, which remains peripheral despite the evolutionary overlap in intellectual origins and the growing importance of analyzing IS on a global scale.

While we consider that we have done some substantial groundwork for a more nuanced discussion on the state of IS research, we are far from providing conclusive answers. To eventually do this, we suggest the following avenues for future research, which seem promising and fruitful. First, we suggest the importance of books as an outlet for establishing the basis of a interdisciplinary and diverse theoretical foundation and research agenda, yet fall short of thoroughly analyzing this process. The reasons for this are the limitations in the available data, since up to now, there is no comprehensive collection of bibliographic meta-data for books reaching far enough back in time. However, such shortcomings may be overcome by utilizing modern document-processing tools for efficiently creating such data for books; we consider the books central to our identified knowledge bases a natural point to start such an effort. This would also address one of our main limitations in providing a comprehensive overview over the development of a research field and enable a less biased analysis throughout the whole life-cycle of a research field, where the importance of certain types of publication outlets varies over time. Likewise, a similar exercise could be done for policy reports to shed light on the pattern whereby intergovernmental organizations collect, compile, and promote a field's bodies of research, and

the effect thereof. In the IS field or elsewhere, another promising issue to address relates to the different mechanisms of diversification and knowledge integration at the author level. Until now, we have only observed the effect of diversification in terms of knowledge production embodied in publications, but not if these publications originate from authors historically associated with the focal or adjacent fields. Consequently, integrating author level publication histories in such a bibliometric exercise would show us if a diversification process is internally or externally driven. Finally, we demonstrate the usefulness of techniques from NLP to "make sense" of text corpora that are too large for human comprehension, but the potentials of such methods are strongly underutilized. More thorough applications could, for instance, shed light on the unanswered question of directionality, meaning whether new directions of research are emerging from the academic community (and if so, where), policymakers, or intergovernmental "transfer institutions". Here, the application of semantic lead-lag models (e.g., Ramage et al., 2010) appears especially promising.

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Woolthuis, R. K., Lankhuizen, M., and Gilsing, V. (2005). A system failure framework for innovation policy design. *Technovation*, 25(6):609–619.

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A Appendix

Table A.1: List of Seed Articles

Publications	TC	TC_{year}
Etzkowitz & Leydesdorff, 2000, "The Dynamics of Innovation: From National Systems and Mode 2 to...", *Res. Policy*	1.788	94
Geels, 2004, "From Sectoral Systems of Innovation to Socio-Technical Systems...", *Res. Policy*	828	55
Malerba, 2002, "Sectoral Systems of Innovation and Production", *Res. Policy*	764	45
Freeman, 1995, "The National System of Innovation in Historical-Perspective", *Cambr. J. Econ.*	763	32
Cooke et al., 1997, "Regional Innovation Systems: Institutional and Organisational Dimensions", *Res. Policy*	741	34
Furman et al., 2002, "The Determinants of National Innovative Capacity", *Res. Policy*	636	37
Hekkert et al., 2007, "Functions of Innovation Systems: A New Approach for Anal. Tech. Ch.", *Tech. Forecast. Soc. Ch.*	622	52
Carlsson & Stankiewicz, 1991, "On the Nature, Function and Composition of TS", *J. Evol. Econ.*	574	20
Freeman, 1991, "Networks of Innovators - A Synthesis of Research Issues", *Res. Policy*	556	20
Acs et al., 2002, "Patents and Innovation Counts as Measures of Regional Production of New Knowledge ...", *Res. Policy*	518	30
Bergek et al., 2008, "Analyzing the Functional Dynamics of Tech. Inn. Systems: A Scheme of Analysis", *Res. Policy*	514	47
Markard et al., 2012, "Sustainability Transitions: An Emerging Field of Research...", *Res. Policy*	508	73
Jensen et al., 2007, "Forms of Knowledge and Modes of Innovation", *Res. Policy*	505	42
Asheim & Coenen, 2005, "Knowledge Bases and Regional Innovation Systems: Comparing...", *Res. Policy*	494	35
Lundvall et al., 2002, "National Systems of Production, Innovation and Competence Building", *Res. Policy*	445	26
Carlsson et al., 2002, "Innovation Systems: Analytical and Methodological Issues", *Res. Policy*	374	22
Jacobsson & Johnson, 2000, "The Diffusion of Renewable Energy Technology: An Analytical Frwk...", *Energy Policy*	370	19
Meyer-Krahmer & Meyer-Krahmer, 1998, "Science-Based Technologies: University-Industry Interactions ...", *Res. Policy*	360	17
Markard & Truffer, 2008, "Technological Innovation Systems and the Multi-Level Perspective...", *Res. Policy*	357	32
Smith & Raven, 2012, "What Is Protective Space? Reconsidering Niches in Transitions to Sustainability", *Res. Policy*	337	48
Muller & Zenker, 2001, "Business Services as Actors of Knowledge Transformation: the Role of KIBS ...", *Res. Policy*	337	19
Morgan, 2004, "The Exaggerated Death of Geography: Learning, Proximity and Territorial IS", *J. Econ. Geogr.*	334	22
Cooke P, 1992, "Regional Innovation Systems - Competitive Regulation in the New Europe", *Geoforum*	301	11
Asheim et al., 2011, "Constructing Regional Advantage: Platform Policies Based on Related Variety and ...", *Reg. Stud.*	286	36
Liu & White, 2001, "Comparing Innovation Systems: A Framework and Application to China's Trans. Cntxt", *Res. Policy*	276	15
Berry et al., 2010, "An Institutional Approach to Cross-National Distance", *J. Int. Bus. Stud.*	274	30
Gilsing et al., 2008, "Network Embeddedness and the Exploration of Novel Technologies...", *Res. Policy*	264	24
Coenen et al., 2012, "Toward a Spatial Perspective on Sustainability Transitions", *Res. Policy*	258	37
Boschma & Iammarino, 2009, "Related Variety, Trade Linkages, and Regional Growth in Italy", *Econ. Geogr.*	248	25
Hessels & Van Lente, 2008, "Re-Thinking New Knowledge Production: A Lit. Review and a Res. Agenda", *Res. Policy*	245	22
Wolfe & Gertler, 2004, "Clusters From the Inside and Out: Local Dynamics and Global Linkages", *Urban Stud.*	241	16
Christensen et al., 2005, "The Industrial Dynamics of Open Innovation - Evidence From...", *Res. Policy*	239	17
Schartinger et al., 2002, "Knowledge Interactions Between Universities and Industry in Austria: Sectoral...", *Res. Policy*	233	14
Owen-Smith et al., 2002, "A Comparison of US and European University-Industry Relations in the Life Sci.", *Mng. Sci.*	228	13
Phene et al., 2006, "Breakthrough Innovations in the US Biotechnology Industry: The Effects of...", *Strg. Mng. J.*	227	17
Rodriguez-Pose & Crescenzi, 2008, "Research and Development, Spillovers, Innovation Systems, and...", *Reg. Stud.*	223	20
Cantwell et al., 2010, "An Evolutionary Approach to Understanding International Business Activity...", *J. Int. Bus. Stud.*	222	25
Acs et al., 2014, "National Systems of Entrepreneurship: Measurement Issues and Policy Implications", *Res. Policy*	126	25

Note. This table reports the 38 initial seed articles. They represent the top 1% publications in terms of total plus top 1% in terms of average annual citations received in the WoS corpus which contain the terms "Innovation System(-s)" or "System(-s) of Innovation" in title, abstract, or keywords (total 2.885).

Table A.2: Clusters of Research Areas, Summary

Publications		*References*	
Publication	C_{int}	Reference	Cit
Research Area 1: Economic Geography: Externalities, Growth, Urban Economics, N: 1146 (18%)			
Audretsch D (2003) "Innovation and Spatial Externalities", *Int. Reg. Sci. Rev.*	1.000	Audretsch D, 1996	426
Andersson et al. (2004) "University Decentralization as Regional Policy: the Swedish Experiment", *J. Econ. Geogr.*	0.987	Jaffe A, 1993	279
Greunz (2003) "Geographically and Technologically Mediated Knowledge Spillovers Between European Regions", *Ann. Reg. Sci.*	0.949	Jaffe A, 1989	243
Andersson et al. (2005) "Agglomeration and the Spatial Distribution of Creativity", *Pap. Reg. Sci.*	0.925	Anselin L, 1997	239
Smith P (1999) "Do Knowledge Spillovers Contribute to US State Output and Growth", *J. Urban Econ.*	0.923	Glaeser E, 1992	175
Feldman & Audretsch (1999) "Innovation in Cities: Science-based Diversity, Specialization and Localized Competition", *Eur. Econ. Rev.*	0.888	Marshall A, 1920	161
Acs et al. (2002) "Hightechnology Employment and R&D in Cities: Heterogeneity vs Specialization", *Ann. Reg. Sci.*	0.836	Griliches Z, 1979	153
Del Rey (2001) "Teaching Versus Research: A Model of State University Competition", *J. Urban Econ.*	0.830	Griliches Z 1990	150
Audretsch D (2002) "The Innovative Advantage of US Cities", *Eur. Plan. Stud.*	0.828	Jacobs J, 1969	150
Audretsch D (1998) "Agglomeration and the Location of Innovative Activity", *Oxf. Rev. Econ. Policy*	0.818	Romer P, 1990	149
Research Area 2: Networks: Strategic Alliances, Inter-firm Relations, Open Innovation, N: 1103 (17%)			
Gilsing et al. (2008) "Network Embeddedness and the Exploration of Novel Technologies: Technological Distance, Betweenness Centrality and Density", *Res. Policy*	1.000	Cohen W, 1990	608
Karamanos A (2012) "Leveraging Micro and Macrostructures of Embeddedness in Alliance Networks for Exploratory Innovation in Biotechnology", *R&D Manage.*	0.934	Powell W, 1996	306
Tzabbar et al. (2013) "When Does Tapping External Sources of Knowledge Result in Knowledge Integration", *Res. Policy*	0.922	Burt R, 1992	286
Phelps C (2010) "A Longitudinal Study of the Influence of Alliance Network Structure and Composition on Firm Exploratory Innovation", *Acad. Manage. J.*	0.909	Ahuja G, 2000	262
Paruchuri (2010) "Intraorganizational Networks, Interorganizational Networks, and the Impact of Central Inventors: A Longitudinal Study...", *Organ. Sci.*	0.904	Nelson R, 1982	248
Vanhaverbeke et al. (2015) "Technological Performance and Alliances Over the Industry Life Cycle: Evidence From the ASIC Industry", *J. Prod. Innov. Manage.*	0.904	Barney J, 1991	225
Schoenmakers & Duysters (2006) "Learning in Strategic Technology Alliances", *Technol. Anal. Strateg. Manage.*	0.904	Kogut B, 1992	225
Baum et al. (2010) "Networkindependent Partner Selection and the Evolution of Innovation Networks", *Manage. Sci.*	0.897	March J, 1991	224
Lavie (2006) "The Competitive Advantage of Interconnected Firms: An Extension of the Resource-Based View", *Acad. Manage. Rev.*	0.896	Granovetter M, 1985	192
Soh P (2003) "The Role of Networking Alliances in Information Acquisition and Its Implications for New Product Performance", *J. Bus. Ventur.*	0.890	Baum J, 2000	190
Research Area 3: International Business: Distance Studies, Institutions, N: 1041 (16%)			
Bailey & Li (2015) "Crossnational Distance and FDI: the Moderating Role of Host Country Local Demand", *J. Int. Manag.*	1.000	Hofstede G, 1980	280
Dow & Larimo (2009) "Challenging the Conceptualization and Measurement of Distance and International Experience in Entry Mode...", *J. Int. Market.*	0.992	Kogut B, 1988	242
Slangen & Hennart (2008) "Do Multinationals Really Prefer to Enter Culturally Distant Countries Through Greenfields...", *J. Int. Bus. Stud.*	0.991	DiMaggio P, 1983	186
Salomon & Wu (2012) "Institutional Distance and Local Isomorphism Strategy", *J. Int. Bus. Stud.*	0.976	North D, 1990	184
Chang et al. (2012) "How Cultural Distance Influences Entry Mode Choice: The Contingent Role of Host Countrys Governance Quality", *J. Bus. Res.*	0.951	Johanson J, 1977	176
Ang et al. (2015) "The Interactions of Institutions on Foreign Market Entry Mode", *Strateg. Manage. J.*	0.919	Kostova T, 1999	157
Hutzschenreuter et al. (2011) "The Impact of Added Cultural Distance and Cultural Diversity on International Expansion Patterns...", *J. Manage. Stud.*	0.917	Shenkar O, 2001	129
Ando (2011) "Isomorphism and Foreign Subsidiary Staffing Policies", *Cross Cult. Manage.*	0.912	Barkema H, 1996	117
Kim & Gray (2008) "The Impact of Entry Mode Choice on Foreign Affiliate Performance: the Case of Foreign MNEs in South Korea", *Manag. Int. Rev.*	0.907	Scott W, 1995	113
Wang & Schaan(2008) "How Much Distance Do We Need Revisiting the National Cultural Distance Paradox", *Manage. Int. Rev.*	0.898	Barney J, 1991	107
Research Area 4: Innovation Systems: National, Regional & Sectoral Approaches, N: 783 (12%)			
Danell & Persson (2003) "Regional R&D Activities and Interactions in the Swedish Triple Helix", *Scientometrics*	1.000	Lundvall B, 1992	499
Edquist et al. (2002) "Characteristics of Collaboration in Product Innovation in the Regional System of Innovation of East Gothia", *Eur. Plan. Stud.*	0.998	Nelson R, 1993	365
Woolthuis et al. (2005) "A System Failure Framework for Innovation Policy Design", *Technovation*	0.945	Edquist C, 1997	320
Islam & Miyazaki (2010) "an Empirical Analysis of Nanotechnology Research Domains", *Technovation*	0.920	Freeman C, 1987	208
Weber & Hoogma (1998) "Beyond National and Technological Styles of Innovation Diffusion: A Dynamic Perspective...", *Technol. Anal. Strateg. Manage.*	0.871	Nelson R, 1982	144
Baba & Walsh (2010) "Embeddedness, Social Epistemology and Breakthrough Innovation: The Case of the Development of Statins", *Res. Policy*	0.868	Freeman C, 1995	104
Chung (2002) "Building a National Innovation System Through Regional Innovation Systems", *Technovation*	0.855	Lundvall B, 1988	95
De La Mothe & Paquet (1998) "National Innovation Systems, 'Real Economies' and Instituted Processes", *Small Bus. Econ. Group*	0.841	Porter M, 1990	94
Lundvall B (1998) "Why Study National Systems and National Styles of Innovation", *Technol. Anal. Strateg. Manage.*	0.827	Cooke P, 1997	93
Fischer M (2001) "Innovation, Knowledge Creation and Systems of Innovation", *Ann. Reg. Sci.*	0.818	Cohen W, 1990	90
Research Area 5: Geography of Innovation: Knowledge Sourcing, Flows, & Bases, N: 669 (11%)			
Blazek & Zizalova (2010) "The Biotechnology Industry in the... Region: A Cluster Within a Fragmented Innovation System", *Environ. Plan. C-Gov. Policy*	1.000	Bathelt H, 2004	283
Doloreux & Shearmur (2012) "Collaboration, Information and the Geography of Innovation in Knowledge Intensive Business Services", *J. Econ. Geogr.*	0.999	Boschma R, 2005	181
Uyarra & Flanagan (2010) "From Regional Systems of Innovation to Regions as Innovation Policy Spaces", *Environ. Plan. C-Gov. Policy*	0.975	Asheim B, 2005	140
Fitjar & Rodriguez-Pose (2013) "Firm Collaboration and Modes of Innovation in Norway", *Res. Policy*	0.963	Cooke P, 2004	102
Sternberg (2007) "Entrepreneurship, Proximity and Regional Innovation Systems", *Tijdschr. Econ. Soc. Geogr.*	0.962	Asheim B, 2002	87
Grillitsch et al. (2015) "Variety in Knowledge Sourcing, Geography and Innovation: Evidence From the Ict Sector in Austria", *Pap. Reg. Sci.*	0.957	Amin A, 2004	85
Blazek et al. (2013) "Emerging Regional Innovation Strategies in...: Institutions and Regional Leadership in Generating Strategic Outcomes", *Eur. Urban Reg. Stud.*	0.904	Asheim B 2005	85
Martin (2012) "Measuring Knowledge Bases in Swedish Regions", *Eur. Plan. Stud.*	0.898	Cohen W, 1990	82
Chaminade (2011) "Are Knowledge Bases Enough? A Comparative Study of the Geography of Knowledge Sources in China...", *Eur. Plan. Stud.*	0.869	Gertler M, 2003	82
Moodysson & Jonsson (2007) "Knowledge Collaboration and Proximity the Spatial Organization of Biotech Innovation Projects", *Eur. Urban Reg. Stud.*	0.844	Cooke P, 1998	75
Research Area 6: Technological Change & Evolutionary Economics, N: 635 (10%)			
Wonglimpiyarat (2005) "The Nano-revolution of Schumpeters Kondratieff Cycle", *Technovation*	1.000	Nelson R, 1982	275
Breschi et al. (2000) "Technological Regimes and Schumpeterian Patterns of Innovation", *Econ. J.*	0.961	Dosi G, 1982	140
Kemp & Soete (1992) "The Greening of Technological Progress: An Evolutionary Perspective", *Futures*	0.950	Freeman C, 1982	103
Marsili (2002) "Technological Regimes and Sources of Entrepreneurship", *Small Bus. Econ. Group*	0.944	Dosi G 1988	97
Henderson & Clark (1990) "Architectural Innovation the Reconfiguration of Existing Product Technologies and the Failure of Established Firms", *Adm. Sci. Q.*	0.919	Abernathy W, 1978	95
Levitas et al. (2006) "Survival and the Introduction of New Technology: A Patent Analysis in the Integrated Circuit Industry", *J. Eng. Technol. Manage.*	0.876	Schumpeter J, 1942	89
Freeman (1991) "Innovation, Changes of Techno-Economic Paradigm and Biological Analogies in Economics", *Rev. Econ.*	0.818	Pavitt K, 1984	88
Adner & Levinthal (2001) "Demand Heterogeneity and Technology Evolution: Implications for Product and Process Innovation", *Manage. Sci.*	0.811	Dosi G, 1988	85
Banbury & Mitchell (1995) "The Effect of Introducing Important Incremental Innovations on Market Share and Business Survival", *Strateg. Manage. J.*	0.809	Rosenberg N, 1982	78
Dosi (1997) "Opportunities, Incentives and the Collective Patterns of Technological Change", *Econ. J.*	0.798	Arthur W, 1989	72
Research Area 7: Sustainability Transitions: TIS, MLP, Regimes, Niches & Systainability, N: 605 (10%)			
Meelen & Farla (2013) "Towards an Integrated Framework for Analysing Sustainable Innovation Policy", *Tech. Anal. Strateg. Mng.*	1.000	Geels F, 2002	239
Markard & Truffer (2008) "Technological Innovation Systems and the Multilevel Perspective: Towards an Integrated Framework", *Res. Policy*	0.994	Geels F, 2007	191
Ingram (2015) "Framing Niche-Regime Linkage as Adaptation: An Analysis of Learning and Innovation Networks...", *J. Rural Stud.*	0.939	Kemp R 1998	185
Walrave & Raven (2016) "Modelling the Dynamics of Technological Innovation Systems", *Res. Policy*	0.929	Bergek A, 2008	131
Fuenfschilling & Truffer (2014) "The Structuration of Socio-Technical Regimes-Conceptual Foundations From Institutional Theory", *Res. Policy*	0.928	Geels F, 2004	129
Lovio & Kivimaa (2012) "Comparing Alternative Path Creation Frameworks in the Context of Emerging Biofuel Fields in the Netherlands...", *Eur. Plan. Stud.*	0.881	Hekkert M, 2007	125
Farla et al. (2012) "Sustainability Transitions in the Making: A Closer Look at Actors, Strategies and Resources", *Tech. Forecast. Soc. Ch.*	0.849	Rip A, 1998	122
Genus & Coles (2008) "Rethinking the Multilevel Perspective of Technological Transitions", *Res. Policy*	0.847	Smith A, 2005	110
Kern (2012) "Using the Multi-Level Perspective on Socio-Technical Transitions to Assess Innovation Policy", *Tech. Forecast. Soc. Ch.*	0.841	Schot J 2008	92
Raven et al. (2011) "Translation Mechanisms in Socio-Technical Niches: A Case Study of Dutch River Management", *Tech. Anal. Strg. Mng.*	0.834	Markard J, 2008	91
Research Area 8: Science Technology Studies: Modes of Knowledge Production, N: 386 (6%)			
Shinn & Lamy (2006) "Paths of Commercial Knowledge: Forms and Consequences of University-Enterprise Synergy in Scientist-Sponsored Firms", *Res. Policy*	1.000	Gibbons M, 1994	171
Sun & Negishi (2010) "Measuring the Relationships Among University, Industry and Other Sectors in Japans National Innovation System:...", *Scientometrics*	0.880	Etzkowitz H, 2000	142
Wehrens et al. (2014) "Hybrid Management Configurations in Joint Research", *Sci. Technol. Hum. Values*	0.837	Etzkowitz H, 1998	61
Shinn (2002) "The Triple Helix and New Production of Knowledge: Prepackaged Thinking on Science and Technology", *Soc. Stud. Sci.*	0.792	Nowotny H, 2001	59
Merz & Biniok (2010) "How Technological Platforms Reconfigure Science-Industry Relations: the Case of Micro- and Nanotechnology", *Minerva*	0.772	Agrawal A, 2002	46
Hessels & Van Lente (2008) "Rethinking New Knowledge Production: A Literature Review and a Research Agenda", *Res. Policy*	0.763	Cohen W, 2002	46
Tuunainen (2005) "Contesting a Hybrid Firm at a Traditional University", *Soc. Stud. Sci.*	0.708	Clark B, 1998	44
Ramosvielba & Fernandezesquinas (2012) "Beneath the Tip of the Iceberg: Exploring the Multiple Forms of University-Industry Linkages", *High. Educ.*	0.695	Dasgupta P, 1994	43
Valimaa & Hoffman (2008) "Knowledge Society Discourse and Higher Education", *High. Educ.*	0.687	Etzkowitz H, 2003	41
Godin & Gingras (2000) "The Place of Universities in the System of Knowledge Production", *Res. Policy*	0.683	Slaughter S, 1997	40

Note. This table reports the most central publications and the most cited references for the identified research areas in the bibliographic coupling network. All calculated centralities are Jaccard-weighted.

Table A.3: Research Area Network (1-Mode, external): Density and Diversity

	1980-1989		1990-1999		2000-2009		from 2010		All Periods	
Research Area	$Dens^{1m}_{ext}$	Div^{1m}_{ext}	$Dens^{1m}_{ext}$	Div^{1m}_{ext}	$Dens^{1m}_{ext}$	Div^{1m}_{ext}	$Dens^{1m}_{ext}$	Div^{1m}_{ext}	$Dens^{1m}_{ext}$	Div^{1m}_{ext}
Econ.Geo	0.365	0.000	0.043	0.218	0.031	0.223	0.036	0.229	0.065	0.172
Networks	–	–	0.063	0.179	0.040	0.146	0.037	0.139	0.073	0.121
IB	–	–	0.042	0.150	0.012	0.236	0.014	0.197	0.035	0.170
IS	–	–	0.075	0.141	0.047	0.125	0.046	0.115	0.087	0.093
Geo.Inno	–	–	0.031	0.161	0.025	0.267	0.036	0.251	0.048	0.144
Evol.Econ	0.365	0.000	0.066	0.221	0.039	0.213	0.031	0.175	0.078	0.150
Transitions	–	–	0.028	0.092	0.023	0.317	0.018	0.237	0.036	0.181
STS	–	–	0.010	0.095	0.017	0.216	0.019	0.183	0.023	0.117
all	0.729	0.000	0.357	0.404	0.235	0.395	0.237	0.360	0.446	0.372

Note. This table reports the development of the research area's external degree density ($Dens^{1m}_{ext}$, based on the bibliographic coupling network between research areas), and their diversity (Div^{1m}_{ext}, Leydesdorff diversity of edge-weights to other research areas).

Table A.4: Research Area - Knowledge Base (2-mode) Network: Coherence and Diversity

	1980-1989		1990-1999		2000-2009		from 2010		All Periods	
Research Area	Coh^{2m}_{int}	Div^{2m}_{int}	Coh^{2m}_{int}	Div^{2m}_{int}	Coh^{2m}_{int}	Div^{2m}_{int}	Coh^{2m}_{int}	Div^{2m}_{int}	Coh^{2-m}_{int}	Div^{2m}_{int}
Econ.Geo	0.020	0.188	0.019	0.100	0.016	0.171	0.012	0.181	0.013	0.190
Networks	–	–	0.022	0.158	0.017	0.224	0.016	0.183	0.015	0.211
IB	–	–	0.012	0.146	0.010	0.174	0.009	0.250	0.008	0.238
IS	–	–	0.025	0.232	0.022	0.236	0.020	0.259	0.020	0.242
Geo.Inno	–	–	0.013	0.125	0.011	0.051	0.017	0.118	0.013	0.101
Evol.Econ	0.012	0.260	0.017	0.316	0.011	0.401	0.011	0.398	0.011	0.300
Transitions	–	–	0.111	0.000	0.025	0.125	0.019	0.119	0.018	0.108
STS	–	–	0.025	0.117	0.015	0.142	0.016	0.132	0.014	0.134
all	0.010	0.181	0.005	0.197	0.002	0.225	0.002	0.215	0.002	0.211

Note. This table reports the development of the research area's internal coherence (Coh^{2m}_{int}, based on internal bibliographic coupling network) measured by internal degree density, and their diversity (Div^{2m}_{int}, measured by their Leydesdorff diversity of cited knowledge bases).

Table A.5: Community Detection Algorithm Benchmark

	Bibliographic			Co-citation		
Algorithm	M	N_{com}	G_{size}	M	N_{com}	G_{size}
Louvain (Blondel et al., 2008)	0.36	8.00	0.24	0.42	8.00	0.22
Infomap (Rosvall and Bergstrom, 2007)	0.21	23.00	0.85	0.40	114.00	0.83
Fast Greedy (Newman, 2004a)	0.27	6.00	0.62	0.35	4.00	0.28
Label Propagation (Raghavan et al., 2007)	0.00	2.00	0.50	0.00	1.00	0.00
Walktrap (Pons and Latapy, 2005)	0.27	21.00	0.79	0.37	35.00	0.77

Note. This table compares the achieved modularity (M), number of detected communities (N_{com}), and GINI coefficient (G_{size}) of community size between popular algorithms to detect communities in weighted networks.