



Paper to be presented at  
the DRUID16 20th Anniversary Conference  
Copenhagen, June 13-15, 2016

## **Varieties of the Concept of National Innovation Systems**

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### **Abstract**

The main idea of the paper is to map the development in the studies on National Systems of Innovation. The first aim of the paper is to come to a more comprehensive understanding of the initial versions of the NIS analytical framework as introduced in the three NIS books, that shaped the development of the field. The second aim of the paper is to provide an insight into its developments over time, in terms of whether (or not) it has over time led to a more comprehensive understanding, and a coherent framework suitable for conducting a systematic analysis of NIS. Therefore, we analyse the development of work within - and relationship between - dominant analytical focuses, which we explain this by the underlying academic community structure, and trends in the research themes. In order to map the structure and development within the branch of NSI research, we first carry out a bibliometric analysis, where we identify existing and emerging academic community structures within the NIS literature, as revealed in by a network-analysis of co-citation pattern. Further, we deploy methods from natural language processing to add in an unrestricted and data-driven way a qualitative layer of information on the context of work within the literature. Finally, we manually categorized the most relevant publications in this branch of literature according to its conceptual and analytical focus.

# Varieties of the Concept of National Innovation Systems\*

**Abstract:** The main idea of the paper is to map the development in the studies on National Systems of Innovation. A greater comprehensiveness in understanding and systematic operationalization of the NIS concept has a potential to contribute to the development of comparative studies of different NISs. The first aim of the paper is to come to a more comprehensive understanding of the initial versions of the NIS analytical framework as introduced in the three NIS books, that shaped the development of the field. The second aim of the paper is to provide an insight into its developments over time, in terms of whether (or not) it has over time led to a more comprehensive understanding, and a coherent framework suitable for conducting a systematic analysis of NIS. Therefore, we analyse the development of work within - and relationship between - dominant analytical focuses. We explain this by the underlying academic community structure, and trends in the research themes. In order to map the structure and development within the branch of NSI research, we first carry out a bibliometric analysis. Our main aim here is to identify existing and emerging academic community structures within the NIS literature, as revealed in by a network-analysis of co-citation pattern. Our assumption is that the way articles and other contributions refer to each other's carries information on their conceptual relatedness. Further, we deploy methods from natural language processing, namely LDA topic modeling, to add in an unrestricted and data-driven way a qualitative layer of information on the context and themes of work within the literature and its communities. Finally, we manually categorized the most relevant publications in this branch of literature according to its conceptual and analytical focus.

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\*Paper prepared for the 2016 DRUID Conference, Copenhagen

# 1 Introduction

The “National Innovation System” (NIS) conceptual framework has diffused rapidly since its emergence in the mid-1980<sup>s</sup> among both researchers and policy makers, promising an alternative theoretical perspective on economic development as well as powerful policy implications. However, it can be seen that the various adopters attach very different meanings to the NIS framework, leading also to differences in its operationalization and conclusions drawn, which may be in line with its originators’ understanding or not. In this paper, we analyze the development of NIS related research and the associated structure of knowledge production, in terms of whether (or not) it has contributed to a more comprehensive understanding, and a coherent framework suitable for conducting a systematic theoretical and empirical analysis.

Variations in focus and approach in studying and conceptualizing NIS trace back to the seminal contributions by originators of the concept, Lundvall (1992), Nelson (1993) and Freeman (1987). Subsequent research cascaded in the development of conceptual frameworks of “innovation systems” differing in analytical and conceptual focus, 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 Stankiewicz, 1991; Hekkert et al., 2007), business (Whitley, 2000) and social systems of innovation and production (Amable, 2000).

Despite the somewhat peaceful coexistence of the constructs in the literature there are still difficulties in understanding what each construct means, and how they are related to each other. The conceptual frameworks have been developed in different contexts, the theoretical underpinnings are not always explicitly stated or are drawing upon different disciplinary fields, and the encompassing concepts are not always well developed or are not defined in the same manner (Edquist and Hommen, 2008). Therefore, there seem to be no consensus in respect to conceptualization of the term. Related, it is not clear how the subsequent work in this tradition have shaped the

development of the NIS concept over time. While low consensus in respect to the conceptual framework elements does not necessarily represent a problem in formative stages, it might over time limit the systemic advances of knowledge (Pfeffer, 1993).

Such contributions can to some extent be made by studying different aspects on NISs in isolation. Yet, in the spirit of the originators, a comprehensive analysis of NIS optimally includes the joint effects of – and interaction between – organizations, institutions, and the structure in which they relate to each others. Consequently, a development towards more inclusive analysis in respect to its different building blocks within the NIS framework could reflect the growing sophistication of the research community towards its operationalization. The necessity for interdisciplinary work calls for diverse inputs from various disciplinary fields, where the increasing interaction between specialized research communities might manifest in an emerging common consensus on theoretical understanding, and an exchange methodological practice, enabling them to manage the increasing complexity of jointly operationalizing different theoretical and analytical perspectives (Jones et al., 2008; Singh, 2005; Wagner and Leydesdorff, 2005) In contrast, an ongoing trend to study different aspects in isolation might be attributed to a lacking interaction between isolated research communities. Yet, other reasons could also be found in the lacking availability of appropriate data, methodological tools, gaps in theoretical understandings given the complex and multidimensional nature of the phenomena under study, or more general flaws and incompatibilities in the original design of the framework and its underlying assumptions. Consequently, studying the structure and organization of knowledge production within an scientific field or branch provides valuable explanation for its development.

The main aim of the paper is to provide an insight to what extent the contributions in the NIS literature have over time led to a more coherent and comprehensive framework for conducting a coherent and systematic empirical analysis of NISs, provided empirical evidence for the theoretical claims made, and derive real-word

implications thereof. In this paper, we analyze the knowledge structure within the NIS literature and associated research community as revealed by related academic publications, and relate that to the development of academic contributions towards the theoretical advancements or practical operationalization of the NIS framework. We do so by first examining and comparing the initial versions of NIS concept as introduced in the three main contributions within the NIS literature (Freeman, 1987; Lundvall, 1992; Nelson, 1993) with respect to the concept definition, the main analytical focus, the elements of the system put forward, and the approach used for studying NISs.

In order to map the structure and development within the branch of NIs research, we first carry out a bibliometric analysis. Our main aim here is to identify existing and emerging academic community structures within the NIS literature, as revealed in by a network-analysis of citation pattern. Within these communities we analyze their development over time in terms of produced publications and received citations, and identify main contributions and most influential authors. To identify specialization pattern among these clusters of publications, we in a next step enhance the obtained structural publication information with first indicators on their content. Therefore, we manually label most strongly bibliographically coupled publications within the identified clusters according to their analytical focus, theoretical contribution, methodological features and level of aggregation of analysis. Thereby, we are able to investigate advances within the relatively coherent groups of publications in relation to their main research subject.

We complement our mapping of advances within the identified clusters of publications with an linguistic analysis of publication abstracts by deploying methods from the field of natural language processing. We apply LDA topic modeling, to add in an unrestricted and data-driven way a qualitative layer of information on the context and themes of work within the literature and its communities, where we identify common topics and trends across publications and communities. The way how science progresses is to a large extend reflected in the use of language, which

can indicate general research trends, but also the emergence of common consensus or dispute (Kuhn, 1970). Such topics provide us with additional insights on the context of NIS research within and across communities, and its development over time.

We are able to identify consistent communities and publication clusters of work related to the building blocks of the NIS framework from various academic fields. We also find that certain communities over time progressed towards more inclusive analysis and building bridges between academic disciplines. We attribute that to changes of the network structure between communities, where we see more progressive communities to over time move to more central positions.

The remainder of the paper is structured in the following manner. Section 2 introduces briefly the conceptual framework of NISs as developed by Freeman, Lundvall, and Nelson. We emphasize the main differences and similarities between these original approaches to studying NISs. This section also serves as a basis for the development of the classification scheme that will be used for characterizing the selected publications within the identified clusters in this branch of literature. More specifically, the first dimension of the scheme refers to analytical focus being either on organisations, institutions or relationships or some combination of these three categories. Section 3 describes data for mapping the advances in the NIS branch of literature, and introduces the methods used in our analysis, namely bibliographic coupling, and LDA topic modeling. Section 4 presents the analysis of the overall developments in the field and a more detailed analysis of some specific patterns that emerge. Section 5 draws some conclusions on the advances in the studies of NISs.

## **2 The Origins of NIS as a conceptual and analytical framework**

## 2.1 Comparison of the Original Versions of the NIS Concept

The initial conceptualizations of the term “National Systems of Innovation” or “National Innovation Systems” in the field of innovation studies is usually attributed to the three founding fathers that are Christopher Freeman, Bengt-Åke Lundvall, and Richard Nelson. Based on former bibliometric research on the development of NIS literature (Fagerberg and Sapprasert, 2011; Teixeira, 2013), and confirmed by the results of this study, the core contributions on the subject are “*Technology, policy and economic performance: lessons from Japan*” by Freeman (1987), “*National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*” edited by Lundvall (1992), and “*National Innovation Systems: A Comparative Analysis*” edited by Nelson (1993).

The common elements associated with this branch of literature include a holistic approach to studying innovation, a focus on the interdependencies between the actors, organizations and institutions that influence innovation, and a focus on policy (Fagerberg and Sapprasert, 2011). Beside the common elements, the original versions of the conceptual framework and approaches to studying NISs also differ. Even though, all three major contributions to the NIS literature are usually cited together by the users of this literature (Fagerberg and Sapprasert, 2011) it is not clear to what extent these differences are confronted in the research literature. Edquist and Hommen (2008) also argue that it is fair to say that the researchers tend to adopt Nelson’s, Lundvall’s version or some alternative variation without considering the alternative approaches when studying NISs. While early stages in the development of a novel concept tend to be associated with the frameworks that evolve as they are empirically applied, it is not evident how the NIS conceptual framework have been refined through its application. Even though the main aim of the paper is to understand whether the consequent work in the NIS tradition have contributed to a more coherent and comprehensive framework for conducting systemic empirical analysis, the useful starting point is to go back in history and compare the three

initial versions of the concept definition and approaches in studying NISs, followed by the discussion on different contexts in which each approach has been developed.

Drawing on the earliest versions of the concept as presented in the three NIS core contributions as well as on a book edited by Dosi et al. (1990) which included three chapters on NIS by Freeman, Lundvall and Nelson, the following section will try to point out the distinctiveness and commonalities between the approaches. In particular we contrast the approaches in relation to conceptual and definitional issues, the main analytical focus, the elements of the system put forward, the theoretical underpinnings, the orientation of studies, as well as particular approaches adopted in studying NISs (to be found in ??).

According to Lundvall (1992), the NIS concept introduced by Freeman refers to the nation-specific organization of sub-systems, and to the interaction between sub-systems. Yet, Freeman's main focus is the analysis of the organization of R&D and production in firms, the relationships among firms, and the role of the government. The analysis is mainly historical and draws upon innovation theory. On the other side, Nelson analysis focuses on the public-private character of technology and information, and the role of private firms, government and universities in the production of new technology. The distinctiveness of the approach developed by Lundvall in comparison with two other approaches includes the main focus of analysis being an interactive learning. Lundvall concludes that different theoretical approaches bring forward different aspects of the system and that one single approach to studying NIS should not be preferred (Lundvall, 1992).

In the preface of the section on National Systems of Innovation in the volume edited by (Dosi et al., 1988), where all three authors presented their theoretical and/or empirical research on NISs, Nelson emphasized that what is common for his preliminary report that focuses on the United States and Freeman's chapter on Japan is a complex institutional structure that characterize innovation system of the modern industrialized nations. Additionally, the definition of NIS involves the actors and activities of industrial R&D as well as institutions such as universities and gov-



Table 1: Comparison between the original versions of the NISs concept

	Freeman, C	Nelson, R. R.	Lundvall, B.Å.
<b>Concept definition</b>	<i>"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."</i>	<i>"[...] set of institutions whose interactions determine the innovative performance of national firms."</i>	<i>"[...] 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 a sub-systems in which learning takes place."</i>
<b>Term "National"</b>	Not explicitly defined	<i>"[...] national differences and boundaries define the NIS" (p.16)</i>	<i>"[...] national system encompasses elements and relationship, either located within or rooted inside the borders of the nation state. "</i>
<b>Term "System"</b>	Not explicitly defined	<i>"[...] the set of institutional actors that, together, plays the major role in influencing innovative performances."</i>	<i>"[...] a system of innovation is constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge."</i>
<b>Term "Innovation"</b>	<i>"[...] continuing process of technical change, involving the introduction of new and improved products and novel ways of organizing production, distribution and marketing."</i>	<i>"[...] the process by which firms master and get into practice product design and manufacturing process that are new to them."</i>	<i>"[...] on-going process of learning, searching and exploring, which result in new products, new techniques, new forms of organization and new markets." Lundvall (1992)</i>
<b>Analytical framework</b>	<ul style="list-style-type: none"> <li>Relationship between technology, socio-economic structures and institutions</li> </ul>	<ul style="list-style-type: none"> <li>Linking institutional arrangements to technological and economic performances.</li> </ul>	<ul style="list-style-type: none"> <li>Interactive learning anchored in the production structure (including "demand conditions" and "supporting industries")</li> <li>Institutional set-up including "firm strategy"</li> <li>Modes of cooperation and competition</li> </ul>
<b>Elements of the system put forward</b>	<p>Quantitative aspects:</p> <ul style="list-style-type: none"> <li>Long term-trends in the growth and distribution of the national levels of R&amp;D</li> <li>Comparison of the indicators of science and technology (output and input indicators) at disaggregated level</li> <li>The relationship between these indicators and measures of economic performances</li> </ul> <p>Qualitative aspects:</p> <ul style="list-style-type: none"> <li>The role of the Ministry of International Trade and Industry</li> <li>The role of company R&amp;D strategy in relation to imported technology and reverse engineering</li> <li>The role of education and training and related social innovations</li> <li>The conglomerate structure of industry</li> </ul>	<ul style="list-style-type: none"> <li>The allocation of R&amp;D activity and the sources of its funding</li> <li>The characteristics of firms (style of management and organization) and the important industries</li> <li>The role of Universities and government laboratories</li> <li>Government policies aimed at industrial innovation</li> </ul> <p>Key interactions or networks of actors (dependent on technology and industry):</p> <ul style="list-style-type: none"> <li>Component and system producers</li> <li>Upstream and downstream firms</li> <li>Universities and industry</li> <li>Government agencies, university and industry</li> </ul>	<ul style="list-style-type: none"> <li>The internal organization of firms</li> <li>Inter-firm relationships</li> <li>Role of the public sector</li> <li>Institutional set-up of the financial sector</li> <li>R&amp;D intensity and R&amp;D organization</li> </ul>
<b>Main orientation</b>	<ul style="list-style-type: none"> <li>To develop the idea of "National Systems of Innovation" associated with pervasive changes in technology affecting many or all branches of the economy as well as combinations of technical and organizational innovation.</li> </ul>	<ul style="list-style-type: none"> <li>To understand and describe differences and similarities between national systems and the extent that these differences explain variation in national economic performances</li> </ul>	<ul style="list-style-type: none"> <li>To provide a theoretical perspective that might be used in case studies and to discuss some important sub-systems</li> </ul>
<b>Type of the analysis</b>	<ul style="list-style-type: none"> <li>Single case study (Japan)</li> </ul>	<ul style="list-style-type: none"> <li>Comparative case study (15 countries divided into large high-income, small high-income and low income countries)</li> </ul>	<ul style="list-style-type: none"> <li>Conceptual/Theoretical</li> </ul>

ernment funds and programs. In contrast, the main focus of analysis in Lundvall's chapter is on user-producer interactions (patterns of interaction between upstream and downstream firms or university-industry interactions) while the NIS concept refers to the networks of technological interactions that tend to be enclosed within the national borders. Additionally, Nelson points that while his and Freeman chapter assume the existence of NISs, Lundvall presents a theory that try to explain this.

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 a main theoretical perspective used for studying the NISs. What is regarded as common to all three approaches is a focus on the constituents of systems of innovation, that is, institutions, organizations and interactions.

## **2.2 Deriving an Article Classification Scheme**

Based on the review of similarities and differences between the three original versions of the NIS concept and on the research question posed in this article, the labeling scheme has been defined including the three dimensions. The scheme will be used for manual labeling of a sample of the most centrally positioned articles in the identified clusters of NIS branch of literature. The aim of the manual labeling was to map the distinctive features of research being conducted within the clusters in relation to the main analytic focus, contribution to the theory, the type of research methods, and level of aggregation and spatial scale used by the researchers. While it is impossible to claim that the centrally positioned articles within the identified clusters represent the most relevant contributions, as well as that not all of the centrally positioned articles fit neatly within the NIS research program. However, all the centrally positioned papers within the clusters share at least one or all of the building blocks of the NIS conceptual framework.

The first dimension used for labeling the identified articles includes the main focus of the research paper being either institutions, organizations, key interactions or networks of actors, or some combination of the two or all the three categories. The

main rationale for labeling the papers based on their main focus was to explore the main approaches taken and elements of the system studied in the NIS literature. A scheme for labeling the articles based on their main focus was developed by authors based on the original version of the NIS conceptualization that put forward different aspects of NISs as their main focus. The three categories may also be regarded as the main building blocks of the NIS approach that include elements of the systems (organizations, institutions) and relationships between them.

The manual labeling of the papers under the previously introduced dimension was based on readings of the title, authors key words (when available) and abstract of the paper. The example of the research paper focusing mainly on the institutional aspect includes conceptual paper on the need of taking into account the role of society-wide institutions and local and informal institutions in order to explain economic growth robustly Farole et al. (2010). The number of papers that could be exclusively labeled as having a main focus on single dimension was rather limited. Most of the analyzed papers have as their main focus some combination of institutions and organizations, institutions and networks or include all three dimensions. An alternative approach that could be used to identify the main focus of the articles may include the existence and variation in NISs definition by researchers in a sample of selected articles instead of imposing the predefined categories.

The second dimension that has been used for labeling of the sample of articles includes theoretical contribution of the articles. The abstracts of the articles were analyzed to determine if the main theoretical contribution of the article belongs to activities of describing theory, theory building, theory testing and no theory. The main rationale for using these dimension was to gain insight into the main attributes and maturity of the most central papers in the different clusters of the NIS branch of literature. There is a general agreement that theory development is a requirement for the development of any field (Kuhn, 1970). Additionally, the maturity of the field may be evaluated based on the proportion of the activities associated with theory building versus theory testing. The early stages of the development of the field are

usually related to more extensive work on theory building, while later stages of the development of the field would include more activities connected to theory testing (Handfield and Melnyk, 1998). The abstract of the articles were analyzed to determine if the authors are explicitly stating contribution to theory. The abstracts that contained the explicit statement on the hypotheses testing were grouped together within the category validation, extension and/or refinement of theory. The abstracts that contained the statement on contribution to theory were grouped within the category theory building. If the theoretical contribution of the article was not explicitly stated, the abstract of the article were further assessed to determine the extent to which the article can be characterized as contributing to building new theory and the extent to which it can be regarded as theory testing. For example, the explorative research papers were classified under the category theory building. An additional category labeled descriptive contribution to theory was used for classifying the articles within the sample which synthesized or critically reviewed the theoretical and empirical contributions of the literature with no implicit statement on a novel theory contributions, while the same type of articles with the claim on theory contribution were labeled as theory building. The articles containing no reference to theoretical contribution (based on the review of the abstract) or only stating the practical implications were grouped within the separate category named no contribution to theory. It is though important to emphasize that there is no general agreement in relation to what constitute the significant theoretical contribution to our understanding of the phenomena under study (Sharif, 2006). Another difficulty in assessing the theoretical contributions relates to the interdisciplinary nature of the NIS concept that spans across different disciplines.

The next dimension that has been used for manual classification of the articles in the sample includes the type of research methodology used. More specifically, the abstracts of the articles were analyzed to determine if the articles fall into the two broadly defined categories named analytical or empirical research methods. Analytical research methods dimension were further categorized as conceptual and

formal modeling, while the empirical methods dimension were further categorized as quantitative and qualitative research methodology. The main rationale for using this dimension was to get an insight into the potential patterns in the literature in relation to the methodological and empirical advances within the identified clusters.

The last dimension includes labeling the articles dependent on the level of aggregation being micro (focusing on the individuals and firms), meso (focusing on technology, industry, sector, city, region), macro-scale (focusing on national level) or some combination of the two or all three levels. While the originators of the NIS concept have been mainly working on either macro (Freeman, 1987; Nelson, 1993) or micro level of aggregation (Lundvall, 1992), Castellaci et al. (2005) argued that the distinctive groups of scholars continued to carry out studies on either micro, meso or macro level of aggregation and that links between the theoretical and empirical findings on these different levels had not been explored. Moreover, it is argued that the field will greatly benefit from the studies working on all three levels of analysis. More recently, it is stated that Sharif (2006) challenged this simple dichotomy of traditions and argued that instead there is an overlapping spectrum of tradition within the Innovation System Program.

The breadth of the analysis covered by the label scheme based on the three dimensions can be extended by introducing additional dimensions or more fine-grained sub-categories within the each dimension in order to develop more comprehensive understanding of the analytic, theoretical, empirical and methodological contributions.

### **3 Method**

In order to map the structure of knowledge production and its development within the branch of NSI research, we use a set of different methods. The following section provides a brief overview over their characteristics and potentials, and our rationales to apply them given the aim of this study.

First, we carry out a bibliometric analysis, where we focus on mapping knowledge and community structure as revealed in by a network-analysis of citation pattern. Our underlying assumption is that the way articles and other contributions refer to each others carries information on their conceptual relatedness. Our main aim here is to identify existing and emerging community structures within the NIS literature. Within these communities we analyze their development over time in terms of produced publications and received citations, and identify main contributions and most influential authors.

To identify specialization pattern among these clusters of publications, we in a next step enhance the obtained structural publication information with first indicators on their content. Therefore, we manually label most strongly bibliographically coupled publications within the identified clusters according to their analytical focus, theoretical contribution, methodological features and level of aggregation of analysis.

We complement our mapping of advances within the identified clusters of publications with an linguistic analysis of publication abstracts by deploying methods from the field of natural language processing.

### **3.1 Data description**

For our bibliometric analysis of the NIS literature, we draw from the Thompson Reuter’s “Web of Science” (WoS) database. Since the branch of NIS literature can be seen as rather interdisciplinary and heterogeneous, finding an initial corpus of publications proves to be challenging. First intuitive possibility would be to search the database for articles including the terms “National Innovation Systems” or “National Systems of Innovation”. This would likely lead to an initial corpus containing very little unrelated studies (false positives), but due to inconsistency in the usage of vocabulary within the community exclude many relevant studies (false negatives). To solve this problem arising from the blurry boundaries of NIS literature, we apply an iterative search strategy. First, we select a set of three seed article with literature-

review characteristics, meaning that it is likely to contain references to a large part of the NIS core literature. In our case, we choose Fagerberg and Sapprasert (2011), Godin (2009), and Sharif (2006), three in the community recognized reviews of the emergence and development of NIS literature, published between 2006 and 2011. WoS offers the functionality to search for related articles, meaning such that share common references with the initial one.<sup>1</sup> We selected for every of the three original seed articles further 5,000 articles that share most common references with them, and excluded ones that did not receive any citation, leaving us with 8.154 articles that form our initial corpus. For further analysis, we extracted all citation information from this initial corpus, resulting in 270.882 unique references cited.

### **3.2 Organization of knowledge production: Bibliometric methods**

Bibliometric network analysis based on publication and citation data represents a powerful and established tool to map and investigate knowledge structures within academic disciplines and communities. Bibliometric and scientometric research has produced a number of different measures that can be applied to quantify the relationship between publications in different ways, such as direct citation, co-citation and bibliographic coupling analysis. When focusing on the conceptual relatedness of academic publications, we deploy bibliographic coupling, a measure that uses bibliographical information extracted from the publications to establish a similarity relationship between them. Two publications are bibliographically coupled if they both cite one or more ore in common, where the “coupling strength” increases with the number of citations to other articles they share. It follows the intuition that the relationship between articles is measured by their internal logic of how they relate to the rest of the community, and from where they draw the input for their research. It hence assumes, that two articles sharing a common pool of references are in some way related in terms of context, methods or theory they use, and to which academic community they relate to.

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<sup>1</sup>Which is, basically, the same intuition as behind bibliographic coupling, which is used and explained later.

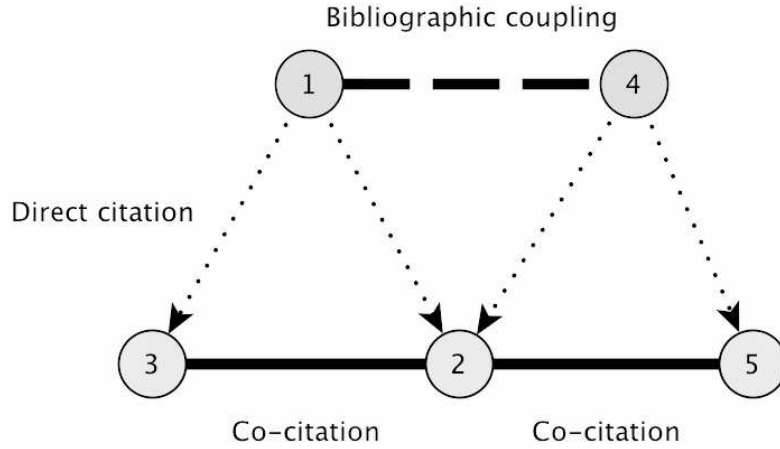


Figure 1: Illustration: Co-Citation and bibliometric coupling in a bipartite citation network

Formally speaking, the strength of the relationship between a publication pair  $i$  and  $j$  denoted as  $c_{i,j}$  is expressed by the number of common citations of common references  $p$ . This logic is also illustrated in figure ?? and formalized in equation ??

$$w_{i,j} = \sum_r c_{i,r}c_{j,r} \quad (1)$$

While it is generally agreed that bibliographic coupling provide more adequate results on the relatedness between articles than simple citation analysis (Boyack and Klavans, 2010), it is not without caveats. The most important one to mention in our context is a possible bias towards literature surveys, aiming to cite a large number of relevant articles within a research community. To adjust for this bias, and following the general intuition that the intensity of a relationship in a projected two-mode network decreases with the number other relationships (Newman, 2001), we correct the coupling strength by the number of cited references in  $i$  and  $j$  ( $N_i, N_j$ ), as well as by the citations received by the reference  $r$  ( $N_r$ ), as illustrated in equation ??:

$$w_{i,j} = \sum_r \frac{c_{i,r}c_{j,r}}{(N_r - 1)(N_i - 1)(N_j - 1)} \quad (2)$$



### **3.3 Topical mapping: Natural language processing: LDA topic modeling**

Our second approach to enrich as such non-contextual documents and their relationships within the empirical analysis, we utilize techniques from the field of natural-language-processing, namely probabilistic topic models. Generally, topic modeling algorithms are linguistically informed Bayesian probabilistic models for discovering hidden thematic structure in text document collections, and are useful for analyzing the massive amount of text exceeding the limits of human annotation (Blei, 2012). They aim to identify “topics” by the way words and word combinations are used within and between text-documents, and assess the strength with which each document exhibits those topics. These topics are then represented as a collection of characteristic words associated with them. In an optimal case, the topics emerged out of the documents linguistic structure can be interpreted in a way that they offer concrete insights on the context of related documents. However, even though topics are automatically inferred from text and are in its essence just word distributions over documents, they usually resemble thematic concepts surprisingly well. We here use the popular Latent Dirichlet Allocation (LDA) topic model to in a data-driven way identify important conversations and themes within the NIS research field. LDA is a generative model, meaning that it takes the end document and tries to find parameters of the process that generated it.

## **4 Results and Discussion**

### **4.1 Cited References**

Table 2 reports the publications which are most frequently cited by the articles of our corpus. In line with previous studies (eg. Fagerberg and Sapprasert, 2011), the original NIS book contributions by Lundvall (1992) and Nelson (1993) constitute together with Nelson and Winter (1982) the by far most prominently cited contributions.

Table 2: Most frequently cited publications

Author	Publication	Year	Cit.	Author	Publication	Year	Cit.\$_w\$
LUNDVALL B	NATL INNOVATION SYST	1992	1497	LUNDVALL B	NATL INNOVATION SYST	1992	62
NELSON R	EV THEORY EC CHANGE	1982	1468	NELSON R	NATL SYSTEMS INNOVAT	1993	59
NELSON R	NATL SYSTEMS INNOVAT	1993	1346	NELSON R	EV THEORY EC CHANGE	1982	43
DOSI G	RES POLICY	1982	808	PORTER M	COMPETITIVE ADVANTAG	1990	29
PORTER M	COMPETITIVE ADVANTAG	1990	757	EDQUIST C	SYSTEMS INNOVATION T	1997	27
COHEN W	ADMIN SCI QUART	1990	696	COHEN W	ADMIN SCI QUART	1990	27
ROMER P	J POLITICAL EC	1990	685	ROMER P	J POLITICAL EC	1990	26
PAVITT K	RES POLICY	1984	645	AGHION P	ECONOMETRICA	1992	26
HELPMAN E	INNOVATION GROWTH GL	1991	634	HELPMAN E	INNOVATION GROWTH GL	1991	25
AGHION P	ECONOMETRICA	1992	614	LIMOGES C	NEW PRODUCTION KNOWL	1994	25
DOSI G	TECHNICAL CHANGE EC	1988	599	DOSI G	RES POLICY	1982	24
LIMOGES C	NEW PRODUCTION KNOWL	1994	555	DOSI G	TECHNICAL CHANGE EC	1988	21
LATOUB B	SCI ACTION FOLLOW SC	1987	550	PAVITT K	RES POLICY	1984	20
FREEMAN C	TECHNOLOGY POLICY EC	1987	537	LATOUB B	SCI ACTION FOLLOW SC	1987	19
EDQUIST C	SYSTEMS INNOVATION T	1997	512	BRACZYK H	REGIONAL INNOVATION	1998	19
LUCAS R	J MONETARY ECON	1988	418	FREEMAN C	TECHNOLOGY POLICY EC	1987	19
NELSON R	RES POLICY	1977	400	ETZKOWITZ H	RES POLICY	2000	17
ROMER P	J POLIT ECON	1986	399	BOSCHMA R	REG STUD	2005	16
KUHN T	STRUCTURE SCI REVOLU	1962	398	LUCAS R	J MONETARY ECON	1988	15
VON HIPPEL E	SOURCES INNOVATION	1988	384	JAFFE A	Q J ECON	1993	15

**Note:** This table lists the 20 most cited articles (extracted from the WoS citation information within the articles) within our corpus, sorted by the number of citations (*Cit.*), and the number of citation weighted by years since publication (*Cit.<sub>w</sub>*).

The book by Freeman (1987), however, appears relatively late on the fourteenth position, far behind the work of Dosi (1982) on *technological trajectories*, Porter (1990) on *national competitive advantage*, Cohen and Levinthal (1990) on *absorptive capacity*, and Romer (1990) on *endogeneous growth*.

Table 3: Most frequently cited authors

Author	Cit.	Author	Cit. <sub>w</sub>	Author	Nr. Pub.
NELSON R	5140	OECD	196	OECD	1555
LUNDVALL B	3104	NELSON R	195	EUROPEAN COMISS	433
FREEMAN C	2948	LUNDVALL B	154	WORLD BANK	398
OECD	2762	COOKE P	115	NELSON R	387
DOSI G	2630	FREEMAN C	114	COOKE P	290
LATOUB B	2306	DOSI G	107	DAVID P	285
PORTER M	2287	PORTER M	103	FREEMAN C	284
SCHUMPETER J	1866	LATOUB B	102	LATOUB B	275
ROMER P	1783	LEYDESDORFF L	76	LUNDVALL B	245
COOKE P	1725	COHEN W	72	BOURDIEU P	234
COHEN W	1668	ASHEIM B	71	DOSI G	227
PAVITT K	1548	AGHION P	70	PORTER M	227
ROSENBERG N	1461	ROMER P	68	SCHUMPETER J	217
TEECE D	1440	TEECE D	65	LEYDESDORFF L	206
GRILICHES Z	1390	EDQUIST C	64	AUDRETSCH D	196
AGHION P	1227	MALERBA F	64	ROSENBERG N	195
CALLON M	1158	AUDRETSCH D	63	KRUGMAN P	192
JAFFE A	1157	BOSCHMA R	62	SIMON H	187
VON HIPPEL E	1107	GEELS F	58	CALLON M	184
MOWERY D	1057	PAVITT K	58	PAVITT K	184

**Note:** This table lists the 20 most cited authors (extracted from the WoS cited references) within our corpus, sorted by (i.) the number of citations, (ii.) the number weighted by years since publication, and (iii.) the number of publications cited in the corpus.

This results roughly remain when weighting the citations by dividing them by years since publication, correcting for the accumulative nature of citations over time. Overall, the basic reference pattern of the articles in our corpus broadly replicate the results of former studies, confirming the validity of our corpus selection, and the reproducibility of stylized facts across different corpora within the NIS literature.

In table 3 we list the most important authors references in the publications of our corpus by a number of measures. First, by the number of citations received within the corpus, where again the three founding fathers Nelson, Lundvall and Freeman are to be found on the first places, interestingly followed directly by the OECD.

## 4.2 LDA topic modeling

To get a first overview over general trends and themes within the NIS related literature, and its development over time, we now perform a LDA topic model analysis on the abstracts of our initial corpus of NIS articles.

Table 4: Selected LDA topics and associated terms

Topic	Description	Associated terms
1	Innovation policy	policy, public, policies, government, development, support, private, state, role, sector, funding, national, innovation policy, makers, promote, governments, many, programs, agricultural, instruments
2	Organizational learning	learning, information, organizational, organizations, services, within, adoption, organization, communication, process, processes, context, users, characteristics, ict, individual, service, collective, ways, implications
3	Sectoral innovation (SIS)	industry, industries, industrial, differences, sectors, sector, large, manufacturing, states, patterns, high, biotechnology, production, structure, united, activities, companies, sectoral, based, pattern
4	Impact/project evaluation	management, design, process, education, projects, project, health, implementation, practices, practice, quality, success, challenges, building, assessment, needs, case, development, decision, evaluation
5	Mode of knowledge production	knowledge, production, transfer, creation, capacity, integration, spillovers, base, diversity, based, knowledge production, mode, within, specific, forms, flows, sources, mechanisms, technology transfer, exchange
6	Barriers, challenges	environmental, problems, make, problem, many, potential, thus, issues, control, rather, possible, uncertainty, risk, lack, conditions, explore, questions, way, must, certain
7	Measurement, Indicators, Patents	analysis, data, patent, time, indicators, level, based, patents, number, intellectual, terms, activity, set, field, method, measures, applied, property, basic, group
8	Science studies, STS	social, science, scientific, work, field, science technology, scientists, practices, practice, studies, cultural, communities, sociology, community, researchers, sciences, academic, drawing, culture, fields
9	Theoretical foundations	theory, political, economics, theories, argues, recent, historical, history, world, past, attention, evolutionary, last, debate, decades, become, century, made, paradigm, power
10	Economic geography, regions	regional, economic, development, local, regions, european, spatial, region, clusters, economy, cluster, industrial, economic development, urban, geography, within, level, areas, europe, creative
11	Networks, Industry-university interaction	role, networks, network, universities, collaboration, university, relationships, important, actors, analysis, interaction, case, interactions, play, linkages, cooperation, key, importance, collaborative, particular
12	Supply/demand, competition	model, market, product, models, competition, products, demand, markets, dynamic, time, costs, supply, variety, lead, based, several, consumption, number, behavior, increasing
13	System transitions, LTS	systems, system, institutional, processes, dynamics, institutions, perspective, approach, changes, sustainable, governance, transition, complex, case, actors, evolution, transformation, path, understanding, sustainability
14	Growth economics	growth, capital, economic, productivity, model, economic growth, human, rate, endogenous, economy, effects, rates, investment, human capital, factor, output, increase, labor, income, models
15	Conceptual, reviews	framework, literature, studies, approach, theoretical, empirical, analysis, approaches, conceptual, concept, review, understanding, implications, issue, perspective, dimensions, future, perspectives, analytical, concepts
16	Applied econometrics, theory testing	results, impact, performance, empirical, relationship, effects, data, effect, factors, financial, positive, influence, evidence, significant, findings, sample, variables, higher, intensity, associated
17	Economic development (macro)	countries, international, national, global, developing, economies, foreign, development, developed, trade, domestic, capabilities, important, investment, developing countries, china, emerging, capability, world, south
18	Technological change, TIS	technology, technological, change, technologies, diffusion, energy, development, technical, climate, power, trajectories, generation, future, changes, emerging, set, important, progress, climate change
19	Innovation processes (micro)	innovation, innovative, firms, innovations, process, activities, small, based, sources, open, smes, product, service, survey, types, innovation process, manufacturing, enterprises, results, radical
20	Strategic management, entrepreneurship	firms, firm, business, strategy, value, external, strategies, resources, competitive, strategic, internal, capabilities, entrepreneurial, entrepreneurship, companies, advantage, corporate, develop, factors, performance

**Note:** This table lists the topics identified with the LDA analysis of the abstracts of our main corpus, and their 20 most associated terms

Table 4 reports the identified topics and associated terms, ranging from more policy oriented topics (eg. topic 1) to more generic science studies (topic 8) and trending themes of economic literature, such as growth economics (topic 14). Overall, the

identified topics appear to appropriately capture different academic and political themes discussed within the NIS literature.

Table 5: Most prominent topics per year

Year	Topic	Description	Nr.Pub.	Year	Topic	Description	Nr.Pub. <sup>cit</sup>
1991	20	Strategic management, entrepreneurship	3	1991	20	Strategic management, entrepreneurship	21
1992	14	Growth economics	8	1992	20	Strategic management, entrepreneurship	158
1993	14	Growth economics	12	1993	14	Growth economics	87
1994	8	Science studies, STS	11	1994	8	Science studies, STS	52
1995	14	Growth economics	13	1995	14	Growth economics	72
1996	8	Science studies, STS	18	1996	20	Strategic management, entrepreneurship	88
1997	9	Theoretical foundations	23	1997	20	Strategic management, entrepreneurship	332
1998	8	Science studies, STS	21	1998	16	Applied econometrics, theory testing	73
1999	14	Growth economics	42	1999	14	Growth economics	127
2000	14	Growth economics	34	2000	14	Growth economics	85
2001	14	Growth economics	27	2001	15	Conceptual, reviews	67
2002	14	Growth economics	36	2002	13	System transistions, LTS	158
2003	14	Growth economics	40	2003	5	Mode of knowledge production	141
2004	14	Growth economics	26	2004	10	Economic geography, regions	90
2005	10	Economic geography, regions	37	2005	10	Economic geography, regions	180
2006	14	Growth economics	30	2006	19	Innovation processes (micro)	144
2007	14	Growth economics	46	2007	20	Strategic management, entrepreneurship	180
2008	8	Science studies, STS	46	2008	8	Science studies, STS	151
2009	8	Science studies, STS	43	2009	8	Science studies, STS	117
2010	8	Science studies, STS	60	2010	8	Science studies, STS	152
2011	8	Science studies, STS	57	2011	8	Science studies, STS	122
2012	8	Science studies, STS	55	2012	7	Measurement, Indicators, Patents	128
2013	14	Growth economics	43	2013	8	Science studies, STS	64
2014	8	Science studies, STS	45	2014	8	Science studies, STS	46
2015	8	Science studies, STS	17	2015	8	Science studies, STS	31

**Note:** This table reports the most prominent topics (identified by the LDA model) per year in our corpus (i.) the number of publications mostly associated with a certain topic, and (ii.) the number of citations recieved,weighted by years since publication.

In table 5 we report the most prominent topics over time, measured by their number of publications mostly associated with the topic (reflecting research activity) as well as by citations per publication (reflecting impact and interest received). Both measures indicate a general shift from macro-oriented topics dealing with economic growth, spillovers and technological change to more generic science studies. This might be explained by the increasing importance of science and research policy, as reflected for instance by the Lisbon agenda, which emphasizes measures to increase overall R&D investments.

### 4.3 Citation Network Analysis - Bibliographic Coupling & Community Detection

The way knowledge is produced - in academia and elsewhere - can to a large extent be explained by its structure of diffusion and relation. After an initial analysis mainly focused in identifying the core contributions within the NIS literature, and followed by an investigation of trending topics, we proceed with a closer investigation of the structure of knowledge production within the field of NIS literature.

While initial data indicates that the field indeed originates from the aforementioned three core contributions, the original theoretical framework(s) as well the focus of research within it has undergone substantial change during its development over the last two decades.

After creating a publication network with the modified bibliographic coupling analysis described in 3 , in a next step, we conduct a community detection analysis, using the “Lovain” algorithm by Blondel et al. (2008). Some basic network statistics are provided in table 6.

Table 6: Summary of identified communities

Nr	Name	Nr. Pub	Citations	Citations <sub>rel</sub>	Cent <sub>degree</sub>	Cent <sub>between</sub>	Cent <sub>close</sub>	Cent <sub>ev</sub>
2	Innovation management	1673	78470	46	0.430	0.006	0.365	0.602
3	Economic geography	1556	39810	25	0.435	0.004	0.141	0.566
5	Triple helix	499	10377	20	0.377	0.013	0.308	0.678
6	Science studies	1995	49686	24	0.472	0.020	0.379	0.731
7	Growth economics	1574	54281	34	0.361	0.003	0.306	0.541
8	Institutions & development	170	2764	16	0.171	0.119	0.255	0.757
9	Sustainable transition	640	13423	20	0.435	0.016	0.375	0.674
10	Agro, public health IS	30	887	29	0.225	0.138	0.032	0.763

Note: This table some basic network statistics on the communities detected within our corpus of WoS articles

In the following, we provide a brief description of selected communities by studying their most central articles, topics and references.

The “triple helix” community brings together studies concerned with the research subsystem and its central position in the new knowledge based economy. The main topics include modes of scientific knowledge production, university industry interactions, university industry government relations and policy. This line of research may be regarded as bridging the three strands of literature, that is new modes of knowledge production, innovation systems and evolutionary theorizing about economic change as reflected in the main sources of inspiration within this community being Nelson (1993) edited book on NIS and Lundvall (1992) edited book on NIS, Gibbons et al. (1994) book on a new mode of scientific knowledge production and Nelson and Winter (1982) evolutionary theory of economic change as well as original contribution by Etzkowitz and Leydesdorff (2000) on Triple Helix of university–industry–government relations. The findings about the main research themes within this sub-community fit well with the results obtained by the LDA topic modeling.

The community labeled by the authors “Science and technology Studies” mainly includes work that belongs to this specific branch of science studies. The most cited references in this sub-community include (Latour, 1987), (Gibbons et al., 1994), (Star and Griesemer, 1989), (Kuhn, 1970), (Cetina, 1999).

The “ transition community” includes sustainability oriented innovation and technology studies with the main focus on the transformation process of socio-technical systems. The articles in the cluster are dealing with the topics such as theoretical foundations of the approach (Smith et al., 2010), modeling sustainable transitions (Faber and Frenken, 2009; Safarzyńska et al., 2012), the functional dynamics of TIS (Bergek et al., 2008), the dynamics of transitions in socio-technical systems (Geels, 2006) and sustainable innovation policy (Nill and Kemp, 2009). The main inspiration along this line of research in terms of most cited references include the seminal paper by Dosi (1982) on technological paradigms and technological trajectories, Lundvall (1992) edited book on NIS, book by Hughes (1993) on history of the evolution of modern electric power systems, ? book on evolutionary theory of economic change as well as more recent contributions such as Hekkert et al. (2007) article on functions of innovation systems and Geels (2002) study on technological transitions. The results on the research themes that appear particularly prominent in this sub-community, as identified by the community detection analysis are in line with the results obtained by the LDA topic modeling.

The “agro and public health” community includes studies mainly focused on the technology transfer, adoption and diffusion in the agriculture and food sector as well as studies on public health issues dealing with topics such as health inequalities in the modern welfare states, changing patterns of mortality and the role of emerging technologies.

#### **4.4 Development of Multidimensionality - Manual Article classification**

What we see from table 7 is that a share of studies that are dealing with the joint effects of – and interaction between – organizations, institutions, and the structure

in which they relate to each others, on either theoretical or empirical level, remains rather unchanged over time. Another interesting development is that there seem to be a disproportional increase over time in the number of studies dealing with the innovation at the organizational level as well as more modest increase in the number of studies with the main focus being on meso level or bridging between the micro and meso level of analysis. Moreover, there is a decrease in the studies with the exclusive focus on institutions at the macro level. One possible explanations is that there are still significant theoretical and methodological challenges involved in bridging the micro-meso-macro divide within the different lines of research.

Table 7: Conceptual focus: Development over time and by community

Focus	Focus by decade			Focus by community							
	until 1995	1996-2005	2006-2015	Innovation mngm.	Economic geography	Triple helix	Science studies	Growth economics	Institutions & dev.	Sustainable transition	Agro, health IS
inst	0.40	0.29	0.18	0.00	0.11	0.14	0.28	0.55	0.00	0.28	0.00
org	0.00	0.09	0.22	0.76	0.00	0.00	0.00	0.00	0.33	0.00	1.00
net	0.00	0.01	0.07	0.02	0.16	0.07	0.04	0.00	0.00	0.00	0.00
inst+org	0.20	0.21	0.09	0.05	0.05	0.07	0.13	0.34	0.33	0.11	0.00
inst+net	0.20	0.10	0.13	0.00	0.16	0.14	0.34	0.00	0.00	0.06	0.00
org+net	0.00	0.06	0.07	0.07	0.26	0.00	0.00	0.00	0.00	0.00	0.00
inst+org+net	0.20	0.24	0.23	0.10	0.26	0.57	0.21	0.11	0.33	0.56	0.00

**Note:** This table shows the distribution of analytical focus along the different dimensions (organizations, institutions, networks) of our manually labeled documents over time and by community

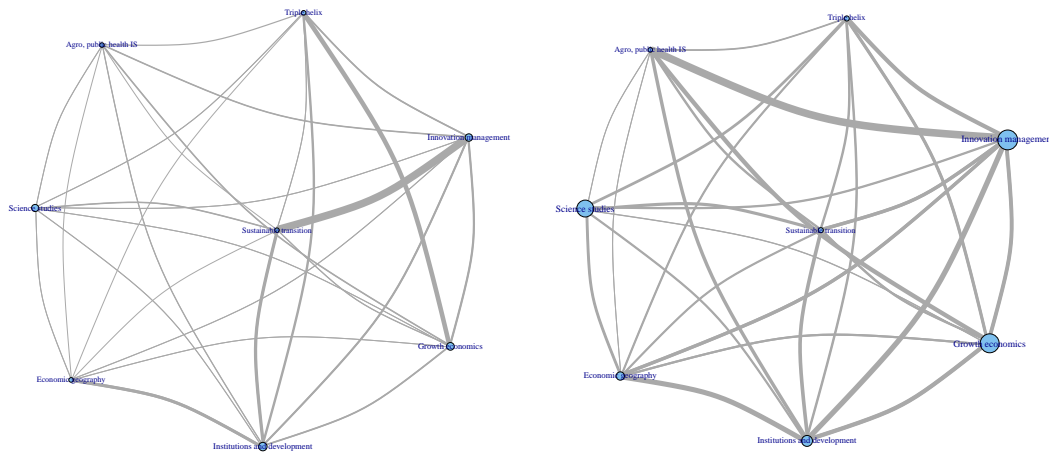
In respect to the developments within the identified communities, the studies within the two sub-communities, that is, Triple Helix and Sustainable transition seem to be working at the multiple levels that could possibly be explained by more successfully solving challenges – both theoretical and methodological – which are associated with bridging between different disciplinary fields. On the other hand, sub-community labeled as Innovation Management tend to be more divided, while focusing mostly on the micro-level of organizations.

#### 4.5 Development of Interdisciplinarity - Community Level Network

Finally, we investigate the development of interdisciplinarity of work between the identified communities, as reflected by a network aggregated on community

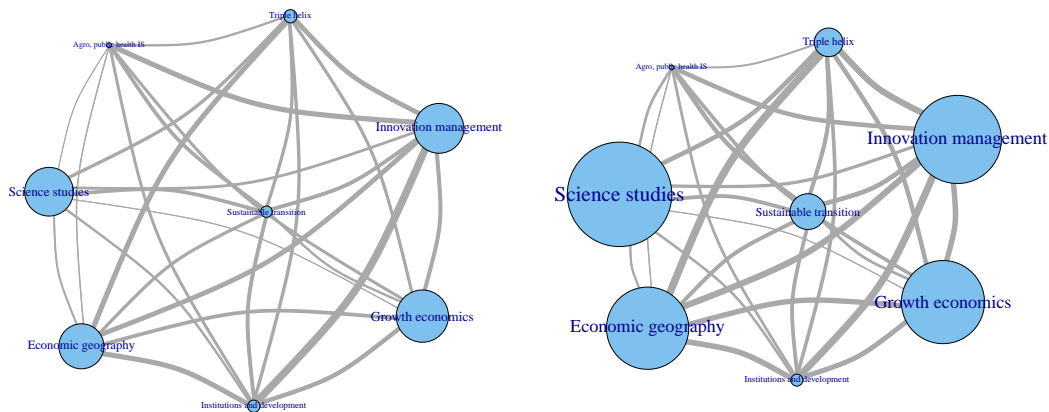
level, where the between-community-contentedness is represented by the coupling-strength between the communities, weighted by their size. A graphical representation can be found in figure 2.

Figure 2: Network Development in Public Funded R&D in Smart-Grid Research



(a) Community network until 1985

(b) Community network 1986-1995



(c) Community network 1996-2005

(d) Community network 2006-2015

*Note:* Bibliographic coupling network on community level by time periods. Node-size reflects the number of cumulative publications within the community. Edge-width reflects the coupling strength, weighted by community size.



Here we can make a set of interesting observations. First, the relative coupling strength between the communities tends to steadily increase over time, indicating an increase of interdisciplinary work drawing from a diverse set of intellectual inputs. This development might be interpreted as a growing cross-fertilization between academic disciplines and communities related to the NIS literature, and a convergence towards a common understanding on important elements and their relations. We also observe communities which show a tendency for multidisciplinary work (with respect to their share of publications classified to work on several analytical dimensions before) also tend to develop towards more central and better connected positions within the bibliographic network. Foremost, the “Sustainable Transition” and “Triple Helix” community with the highest share of multidisciplinary work can also be found in the most central bibliographic network position.

## 5 Conclusion

In this paper, we analyze the knowledge structure within the NIS literature and associated research community as revealed by related academic publications, and relate that to the development of academic contributions towards the theoretical advancements or practical operationalization of the NIS framework. We do so by first examining and comparing the initial versions of NIS concept as introduced in the three main contributions within the NIS literature with respect to the concept definition, the main analytical focus, the elements of the system put forward, and the approach used for studying NISs. Based on the insights gained, we develop a classification scheme to label contributions to the literature according to their analytical focus, theoretical contribution, methodological features and level of aggregation of analysis. After mapping the knowledge structure of the NIS literature as a network of bibliographically coupled publications, and executing a community detection analysis, we apply this classification scheme on the most central articles within the identified communities. Thereby, we are able to investigate advances within the relatively coherent groups of publications in relation to their main research subject.

We complement our mapping of advances within the identified clusters of publications with an linguistic analysis of publication abstracts by deploying methods from the field of natural language processing.

We are able to identify consistent communities related to the building blocks of the NIS framework from various academic fields. We do not find a general development towards more multidimensional work which jointly takes into account the different building blocks of the original NIS framework. We particularly identify a trend towards studies within the field of strategic and innovation management, which primarily focuses on firm-level innovation processes. Yet, also identify certain communities working progressively towards more inclusive analysis and building bridges between academic disciplines. We relate this tendency to interdisciplinary and multidimensional work to (i.) the variety in input as revealed by the communities citation pattern, (ii.) the context of work and influencing trends, as revealed by the manual labeling and statistical NLP analysis, and (iii.) to the network structure of the communities in question.

Our findings overall indicate feasibility of conducting multidisciplinary research in the spirit of the original NIS concept, and to a growing convergence of related literature, but also point towards some disciplines and communities which still tend to focus on isolated dimensions and levels of analysis.

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# Appendix

Table 8: Identified communities, most central articles and most cited references

Most central Publications within the community					Most cited publications by the community	
Authors	Year	Title	Journal	Cen <sub>t</sub>	Reference	Citations
Community 2: Innovation and R&D management						
FREEMAN, C	1994	THE ECONOMICS OF TECHNICAL CHANGE	CAMBRIDGE J ECON	1444	NELSON R-1982-EV THEORY EC CHANGE	586
GARUD, R et al.	2013	PERSPECTIVES ON INNOVATION PROCESSES	ACAD MANAG ANN	1306	COHEN W-1990-35-ADMIN SCI QUART	349
NIETO, M	2003	FROM R&D MANAGEMENT TO KNOWLEDGE MANAGEMENT - AN OVERVIEW OF STUDIES OF INNOVATION MANAGEMENT	TECHNOL FORECAST SOC	1229	DOSI G-1982-11-RES POLICY	335
GU, M; TSE, E	2010	BUILDING INNOVATIVE ORGANIZATIONS IN CHINA: THE "EXECUTION PLUS" ORGANIZATION	ASIA PAC J MANAG	1194	NELSON R-1993-NATL SYSTEMS INNOVAT	301
KIM, M	2013	MANY ROADS LEAD TO ROME: IMPLICATIONS OF GEOGRAPHIC SCOPE AS A SOURCE OF ISOLATING MECHANISMS	J INT BUS STUD	1182	PORTER M-1990-COMPETITIVE ADVANTAG	249
JOHANNESSEN, JA; OLSEN, B	2011	WHAT CREATES INNOVATION IN A GLOBALIZED KNOWLEDGE ECONOMY? A CYBERNETIC POINT OF VIEW	KYBERNETES	1181	LUNDVALL B-1992-NATL INNOVATION SYST	247
NIGHTINGALE, P	2008	META-PARADIGM CHANGE AND THE THEORY OF THE FIRM	IND CORP CHANGE	1171	PAVITT K-1984-13-RES POLICY	245
CROSSAN, MM; APAYDIN, M	2010	A MULTI-DIMENSIONAL FRAMEWORK OF ORGANIZATIONAL INNOVATION: A SYSTEMATIC REVIEW OF THE LITERATURE	J MANAGE STUD	1165	BARNEY J-1991-17-J MANAGE	217
LEWIN, AV et al.	2011	MICROFOUNDATIONS OF INTERNAL AND EXTERNAL ABSORPTIVE CAPACITY ROUTINES	ORGAN SCI	1160	HENDERSON R-1990-35-ADMIN SCI QUART	209
TEECE, DJ	2007	ELUCIDATING DYNAMIC CAPABILITIES: THE NATURE AND MICROFOUNDATIONS OF (SUSTAINABLE) ENTERPRISE PERFORMANCE	STRATEG MANAGE J	1158	TEECE D-1986-15-RES POLICY	199
Community 3: Economic geography, RIS						
SCOTT, A	2006	ENTREPRENEURSHIP INNOVATION AND INDUSTRIAL DEVELOPMENT: GEOGRAPHY AND THE CREATIVE FIELD REVISITED	SMALL BUS ECON	1298	LUNDVALL B-1992-NATL INNOVATION SYST	739
BRITTON, JNH	2003	NETWORK STRUCTURE OF AN INDUSTRIAL CLUSTER: ELECTRONICS IN TORONTO	ENVIRON PLANN A	1266	NELSON R-1993-NATL SYSTEMS INNOVAT	485
BATHELT, H	2003	GEOGRAPHIES OF PRODUCTION: GROWTH REGIMES IN SPATIAL PERSPECTIVE 1 - INNOVATION, INSTITUTIONS AND SOCIAL SYSTEMS	PROG HUM GEOG	1242	PORTER M-1990-COMPETITIVE ADVANTAG	367
LIU, ZG; YIN, YM et al.	2015	VISUALIZING THE INTELLECTUAL STRUCTURE AND EVOLUTION OF INNOVATION SYSTEMS RESEARCH: A BIBLIOMETRIC ANALYSIS	SCIENTOMETRICS	1240	NELSON R-1982-EV THEORY EC CHANGE	302
HUGGINS, R; THOMPSON, P	2010	A NETWORK-BASED VIEW OF REGIONAL GROWTH	J ECON GEOGR	1224	BRACZYK H-1998-REGIONAL INNOVATION	330
BOSCHMA, RA; FRENKEN, K	2006	WHY IS ECONOMIC GEOGRAPHY NOT AN EVOLUTIONARY SCIENCE? TOWARDS AN EVOLUTIONARY ECONOMIC GEOGRAPHY	J ECON GEOGR	1216	EDQUIST C-1997-SYSTEMS INNOVATION T	260
URONNA, MALDONADO, M et al.	2012	STATE OF THE ART ON THE SYSTEMS OF INNOVATION RESEARCH: A BIBLIOMETRICS STUDY UP TO 2009	SCIENTOMETRICS	1203	FREEMAN C-1987-TECHNOLOGY POLICY EC	239
ASHEIM, BT et al.	2010	REGIONAL INNOVATION SYSTEMS: THEORY, EMPIRICS AND POLICY	REG STUD	1202	MORGAN K-1997-31-REG STUD	193
MICELLI, V	2010	TECHNOLOGICAL DISTRICTS: POLICY CRITERIA AND REGIONAL INDUSTRIAL FEATURES IN ITALY	ECON POLIT-ITALY	1201	COHEN W-1990-35-ADMIN SCI QUART	190
LAZZERETTI, L et al.	2014	FOUNDERS AND DISSEMINATORS OF CLUSTER RESEARCH	J ECON GEOGR	1198	LUNDVALL B-1994-1-J IND STUDIES	187
Community 5: Triple helix, University-industry interaction						
LEYDESORFF, L	2010	THE KNOWLEDGE-BASED ECONOMY AND THE TRIPLE HELIX MODEL	ANNU REV INFORM SCI	386	NELSON R-1993-NATL SYSTEMS INNOVAT	206
SALTER, AJ; MARTIN, BR	2001	THE ECONOMIC BENEFITS OF PUBLICLY FUNDED BASIC RESEARCH: A CRITICAL REVIEW	RES POLICY	356	LUNDVALL B-1992-NATL INNOVATION SYST	160
MEYER, M; GRANT, K et al.	2014	TRIPLE HELIX INDICATORS AS AN EMERGENT AREA OF ENQUIRY: A BIBLIOMETRIC PERSPECTIVE	SCIENTOMETRICS	348	ETZKOWITZ H-2000-29-RES POLICY	103
LETTEN, B et al.	2014	SCIENCE OR GRADUATES: HOW DO FIRMS BENEFIT FROM THE PROXIMITY OF UNIVERSITIES?	RES POLICY	343	LIMOGES C-1994-NEW PRODUCTION KNOWL	95
LEYDESORFF, L; ZAWRJE, C	2010	THE TRIPLE HELIX PERSPECTIVE OF INNOVATION SYSTEMS	TECHNOL ANAL STRATEG Z SOZIO	336	NELSON R-1982-EV THEORY EC CHANGE	84
HEINZE, T	2005	SCIENCE-BASED TECHNOLOGIES, ORGANIZATIONS, AND NETWORKS - AN ANALYSIS OF THE COUPLING PROCESS BETWEEN SCIENCE AND ECONOMY	J AM SOC INF SCI	330	PAVITT K-1984-13-RES POLICY	68
LEYDESORFF, L; RAFOLOS, I	2011	LOCAL EMERGENCE AND GLOBAL DIFFUSION OF RESEARCH TECHNOLOGIES: AN EXPLORATION OF PATTERNS OF NETWORK FORMATION	J AM SOC INF SCI	329	DOSI G-1982-11-RES POLICY	65
FIER, H; PYKA, A	2014	AGAINST THE ONE-WAY-STREET: ANALYZING KNOWLEDGE TRANSFER FROM INDUSTRY TO SCIENCE	J TECHNOL TRANSFER	327	FREEMAN C-1987-TECHNOLOGY POLICY EC	59
LEYDESORFF, L; MEYER, M	2003	THE TRIPLE HELIX OF UNIVERSITY-INDUSTRY-GOVERNMENT RELATIONS	SCIENTOMETRICS	324	COHEN W-1990-35-ADMIN SCI QUART	57
BALDINI, N	2006	UNIVERSITY PATENTING AND LICENSING ACTIVITY: A REVIEW OF THE LITERATURE	RES EVALUAT	320	COHEN W-2002-48-MANAGE SCI	57
Community 6: Science studies						
SHARIF, N	2006	EMERGENCE AND DEVELOPMENT OF THE NATIONAL INNOVATION SYSTEMS CONCEPT	RES POLICY	1615	LATOUR B-1987-SCI ACTION FOLLOW SC	521
FAGERBERG, J et al.	2012	EXPLORING THE EMERGING KNOWLEDGE BASE OF "THE KNOWLEDGE SOCIETY"	RES POLICY	1283	LIMOGES C-1994-NEW PRODUCTION KNOWL	367
PINCH, T	2008	TECHNOLOGY AND INSTITUTIONS: LIVING IN A MATERIAL WORLD	THEOR SOC	1157	STAR S-1989-19-SOC STUD SCI	319
KROHN, W; VAN DEN DAËLE, W	1998	SCIENCE AS AN AGENT OF CHANGE: FINALIZATION AND EXPERIMENTAL IMPLEMENTATION	SOC SCI INFORM	1154	KUHN T-1962-STRUCTURE SCI REVOLU	293
KAGHAN, W; PHILLIPS, N	1998	BUILDING THE TOWER OF BABEL: COMMUNITIES OF PRACTICE AND PARADIGMATIC PLURALISM IN ORGANIZATION STUDIES	ORGANIZATION	1136	KNORR-1999-EPISTEMIC CULTURES S	199
LAW, J	2008	ON SOCIOLOGY AND SETS	SOCIOLOG REV	1128	ABBOTT A-1988-SYSTEM PROFESSIONS E	172
TRIBE, J	2010	TRIBES, TERRITORIES AND NETWORKS IN THE TOURISM ACADEMY	ANN TOURISM RES	1112	NOWOTNY H-2001-RETHINKING SCI KNOWL	144
DONALDSON, A et al.	2010	MESS AMONG DISCIPLINES: INTERDISCIPLINARITY IN ENVIRONMENTAL RESEARCH	ENVIRON PLANN A	1093	LATOUR B-1996-ARAMIS LOVE TECHNOLO	141
VAN HOUSE, NA	2004	SCIENCE AND TECHNOLOGY STUDIES AND INFORMATION STUDIES	ANNU REV INFORM SCI	1063	BOURDIEU P-1984-DISTINCTION SOCIAL C	139
MISA, TJ	2003	THE COMPELLING TANGLE OF MODERNITY AND TECHNOLOGY	ANNU REV INFORM SCI	1048	HAAS P-1992-46-INT ORGAN	136

Note: This table reports the most similar publications per topic, calculated by the document-topic similarity resulting from the LDA model.

Table 9: Identified communities, most central articles and most cited references, cont'd

Most central Publications within the community				Most cited publications by the community		
Authors	Year	Title	Journal	Cen%	Reference	Citations
Community 7: Growth economics						
CASTELLACCI, F	2007	EVOLUTIONARY AND NEW GROWTH THEORIES: ARE THEY CONVERGING?	J ECON SURV	1247	HELPMAN E-1991-INNOVATION GROWTH GL	599
GEHRINGER, A	2011	PECUNIARY KNOWLEDGE EXTERNALITIES ACROSS EUROPEAN COUNTRIES - ARE THERE LEADING SECTORS?	IND INNOV	1218	AGHION P-1992-60-ECONOMETRICA	571
CASTELLACCI, F	2008	INNOVATION AND THE COMPETITIVENESS OF INDUSTRIES: COMPARING THE MAINSTREAM AND THE EVOLUTIONARY APPROACHES	TECHNOL FORECAST SOC	1213	ROMER P-1990-98-J POLITICAL EC	567
CASTELLACCI, F	2007	TECHNOLOGICAL REGIMES AND SECTORAL DIFFERENCES IN PRODUCTIVITY GROWTH	IND CORP CHANGE ECON	1198	LUCAS R-1988-22-J MONETARY ECON	323
CANTNER, U;	2009	INNOVATION DRIVING INDUSTRIAL DYNAMICS: BETWEEN INCENTIVES AND KNOWLEDGE	POLIT-ITALY ECON REC	1171	ROMER P-1986-94-J POLIT ECON	273
GUERZONI, M	2003	A SURVEY OF ECONOMIC GROWTH	GAMBRIDGE J ECON	1163	NELSON R-1982-EV THEORY EC CHANGE	224
ROGERS, M	1998	THE AGENDA FOR GROWTH THEORY: A DIFFERENT POINT OF VIEW	J MONETARY ECON	1160	ROMER P-1990-98-J POLIT ECON	204
NELSON, RR						
ROMER, P	1993	IDEA GAPS AND OBJECT GAPS IN ECONOMIC-DEVELOPMENT	J PLAN LIT	1151	SOLOW R-1956-70-Q J ECON	196
KOO, J	2005	TECHNOLOGY SPILLOVERS, AGGLOMERATION, AND REGIONAL ECONOMIC DEVELOPMENT	J PLAN LIT	1151	AGHION P-1998-ENDOGENOUS GROWTH TH	186
LENSINK, R;	2000	RECENT ADVANCES IN ECONOMIC GROWTH: A POLICY PERSPECTIVE		1151	SOLOW R-1957-39-REV ECON STAT	186
KUPER, G						
Community 8: Institutional economic & economic development						
FRANSMAN, M	1985	CONCEPTUALIZING TECHNICAL CHANGE IN THE THIRD-WORLD IN THE 1980S - AN INTERPRETIVE SURVEY	J DEV STUD	99	FREEMAN C-1974-EC IND INNOVATION	49
RATH, A	1990	SCIENCE, TECHNOLOGY, AND POLICY IN THE PERIPHERY - A PERSPECTIVE FROM THE CENTER	WORLD DEV	93	NELSON R-1982-EV THEORY EC CHANGE	43
DOPFER, K et al.	2004	MICRO-MESO-MACRO CORPORATE GOVERNANCE, CONTROL AND INDIVIDUALISM AS A DEFINITION OF BUSINESS SUCCESS: THE IDEA OF A "POST - HEROIC" LEADERSHIP	J EVOL ECON PROC ECON FINANC	87	DOSI G-1988-TECHNICAL CHANGE EC	35
BRONI, G;	2012			81	NELSON R-1993-NATL SYSTEMS INNOVAT	22
VELENTZAS, J						
HODGSON, GM	1996	VARIETIES OF CAPITALISM AND VARIETIES OF ECONOMIC THEORY	REV INT POLIT ECON	77	ROSENBERG N-1976-PERSPECTIVES TECHNOL	20
SUAREZVILLA, L	1984	INDUSTRIAL EXPORT ENCLAVES AND MANUFACTURING CHANGE	PAP REG SCI ASSOC	76	DOSI G-1982-11-RES POLICY	19
MALECKI, EJ	1983	TECHNOLOGY AND REGIONAL-DEVELOPMENT - A SURVEY	INT REGIONAL SCI REV	74	NELSON R-1977-6-RES POLICY	19
WITT, U	2001	EVOLUTIONARY ECONOMICS: AN INTERPRETATIVE SURVEY	REC ECON TH ECON GEOGR	72	FREEMAN C-1987-TECHNOLOGY POLICY EC	15
THOMAS, MD	1980	EXPLANATORY FRAMEWORKS FOR GROWTH AND CHANGE IN MULTIREGIONAL FIRMS	ECON GEOGR	72	HODGSON G-1993-EC EVOLUTION BRINGIN	14
NIJKAMP, P	1982	LONG WAVES OR CATASTROPHES IN REGIONAL-DEVELOPMENT	SOCIO ECON PLAN SCI	72	SCHMOOKLER J-1966-INVENTION EC GROWTH	14
Community 9: Sustainable transition, MLP, TIS						
MARKARD, J et al.	2012	SUSTAINABILITY TRANSITIONS: AN EMERGING FIELD OF RESEARCH AND ITS PROSPECTS	RES POLICY	477	DOSI G-1982-11-RES POLICY	157
GEELS, FW	2004	FROM SECTORAL SYSTEMS OF INNOVATION TO SOCIO-TECHNICAL SYSTEMS - INSIGHTS ABOUT DYNAMICS AND CHANGE FROM SOCIOLOGY AND INSTITUTIONAL THEORY	RES POLICY	452	LUNDVALL B-1992-NATL INNOVATION SYST	131
SAFARZYNSKA, K et al.	2012	EVOLUTIONARY THEORIZING AND MODELING OF SUSTAINABILITY TRANSITIONS	RES POLICY	450	HUGHES T-1983-NETWORKS POWER ELECT	117
NILL, J; KEMP, R	2009	EVOLUTIONARY APPROACHES FOR SUSTAINABLE INNOVATION POLICIES: FROM NICHE TO PARADIGM	RES POLICY	445	NELSON R-1982-EV THEORY EC CHANGE	116
FOXON, TJ	2011	A COEVOLUTIONARY FRAMEWORK FOR ANALYSING A TRANSITION TO A SUSTAINABLE LOW CARBON ECONOMY	ECON ECON	438	GEELS F-2002-31-RES POLICY	110
TRUFFER, B;	2012			424	KEMP R-1998-10-TECHNOL ANAL STRATEG	100
COENEN, L						
FABER, A;	2009	MODELS IN EVOLUTIONARY ECONOMICS AND ENVIRONMENTAL POLICY: TOWARDS AN EVOLUTIONARY ENVIRONMENTAL ECONOMICS	TECHNOL FORECAST SOC	420	HEKKERT M-2007-74-TECHNOL FORECAST SOC	93
FRENKEN, K	2010	COMPARING SYSTEMS APPROACHES TO INNOVATION AND TECHNOLOGICAL CHANGE FOR SUSTAINABLE AND COMPETITIVE ECONOMIES: AN EXPLORATIVE STUDY INTO CONCEPTUAL COMMONALITIES, DIFFERENCES AND COMPLEMENTARITIES	J CLEAN PROD	416	NELSON R-1993-NATL SYSTEMS INNOVAT	90
COENEN, L;						
LOPEZ, FJD						
BERGEK, A et al.	2008	ANALYZING THE FUNCTIONAL DYNAMICS OF TECHNOLOGICAL INNOVATION SYSTEMS: A SCHEME OF ANALYSIS	RES POLICY	414	NELSON R-1977-6-RES POLICY	86
TRUFFER, B	2008	SOCIETY, TECHNOLOGY, AND REGION: CONTRIBUTIONS FROM THE SOCIAL STUDY OF TECHNOLOGY TO ECONOMIC GEOGRAPHY	ENVIRON PLANN A	412	UNRUH G-2000-28-ENERG POLICY	82
Community 10: IS application in agro, public health, education						
USECHE, P et al.	2009	INTEGRATING TECHNOLOGY TRAITS AND PRODUCER HETEROGENEITY: A MIXED-MULTINOMIAL MODEL OF GENETICALLY MODIFIED CORN ADOPTION	AM J AGR ECON	21	ROGERS E-1962-DIFFUSION INNOVATION	19
FORTE-GARDNER, O;	2004			19	FEDER G-1985-33-ECON DEV CULT CHANGE	8
YOUNG, FL et al.						
CALATRAVA, J;	2011	INCREASING THE EFFECTIVENESS OF TECHNOLOGY TRANSFER FOR CONSERVATION CROPPING SYSTEMS THROUGH RESEARCH AND FIELD DESIGN	RENEW AGR FOOD SYST	19		
FRANCO, JA	2014	USING PRUNING RESIDUES AS MULCH: ANALYSIS OF ITS ADOPTION AND PROCESS OF DIFFUSION IN SOUTHERN SPAIN OLIVE ORCHARDS	J ENVIRON MANAGE	19	GRILICHES Z-1957-25-ECONOMETRICA	4
BIZOZA, AR	2014	THREE-STAGE ANALYSIS OF THE ADOPTION OF SOIL AND WATER CONSERVATION IN THE HIGHLANDS OF RWANDA	LAND DEGRAD DEV	19	MUELLBAUJ-1974-64-AM ECON REV	4
MACKENBACH, JP	2012	THE PERSISTENCE OF HEALTH INEQUALITIES IN MODERN WELFARE STATES: THE EXPLANATION OF A PARADOX	SOC SCI MED	18	NOWAK P-1987-52-RURAL SOCIOL	4
ZEPEDA, L	1994	SIMULTANEITY OF TECHNOLOGY ADOPTION AND PRODUCTIVITY	J AGR RESOUR ECON	18	ERVIN C-1982-58-LAND ECON	3
BIDOGEZA, JC;	2009	A TYPOLOGY OF FARM HOUSEHOLDS FOR THE UMUTARA PROVINCE IN RWANDA	FOOD SECUR	18	FEDER G-1993-43-TECHNOL FORECAST SOC	3
BERENTSEN, FBM et al.						
ASEFAW, A;	2004	THE ROLE OF EDUCATION ON THE ADOPTION OF CHEMICAL FERTILISER UNDER DIFFERENT SOCIOECONOMIC ENVIRONMENTS IN ETHIOPIA	AGR ECON	18	GOLDMAN L-1984-101-ANN INTERN MED	3
ADMASIE, A						
SKAGGS, RK;	2005	FARM SIZE, IRRIGATION PRACTICES, AND ON-FARM IRRIGATION EFFICIENCY	IRRIG DRAIN	18	IRONMONGER D-1972-NEW COMMODITIES CONS	3
SAMANI, Z	2013	CHANGING PATTERNS OF MORTALITY IN 25 EUROPEAN COUNTRIES AND THEIR ECONOMIC AND POLITICAL CORRELATES, 1955-1989	INT J PUBLIC HEALTH	18	MADDALA G-1983-LTD DEPENDENT QUALIT	3
MACKENBACH, JP;						
LOOMAN, CWN						

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