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CELEBRATING 30 YEARS OF INNOVATION SYSTEM RESEARCH: WHAT YOU NEED TO KNOW ABOUT INNOVATION SYSTEMS

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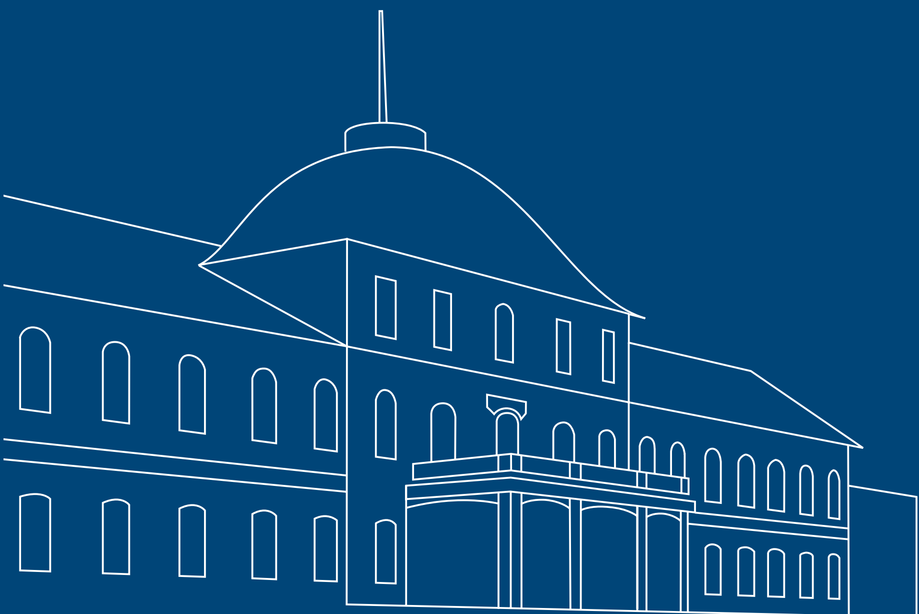

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Celebrating 30 years of Innovation System research: What you need to know about Innovation Systems

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Abstract

On the occasion of the 30th anniversary of Innovation System research, this paper presents an extensive literature review on this large field of innovation research. Building on an analytical basis of the commonalities "system" and "innovation", the authors analyze the four main Innovation System approaches: National Innovation Systems (NIS), Regional Innovation Systems (RIS), Sectoral Innovation Systems (SIS) and Technological Innovation Systems (TIS). The analysis is structured systematically along ten comprehensive criteria. Starting with the founder(s) of each theory and the research program within each Innovation System approach was developed (1), the basic thoughts of each Innovation System approach are explained (2). For five case studies most cited (3), spatial boundaries are examined (4) and units of analyses are derived (5). By comparing the underlying theoretical concept and empirical results, the authors show patterns in the evolution of Innovation System research overall. By studying the basic components (6) and a functional analysis (7), each Innovation System approach is broken down into structural pieces and functional processes. If available, the authors present one or several taxonomies (8) for each Innovation System approach and summarize similar approaches (9), in order to classify and integrate the approaches into the ongoing innovation research. The identification of further research (10) shows which steps will need to be taken in the next years in order to evolve Innovation System research further and deeper. After the conclusion, the extensive table of comparison is presented which can serve as a guideline for academics and practitioners from basic and applied science, industry or policy that need to understand which Innovation System approach may be best for their specific analytical purposes.

Keywords: Innovation System; National Innovation System; Regional Innovation System; Sectoral Innovation System; Technological Innovation System.

Introduction

In the age of the Cold War, innovation scholars around Chris Freeman (Freeman, 1987) and Giovanni Dosi (Dosi et al., 1988) have studied comparative advantages[1] of nations and set the foundation for Innovation System research. Having lived through a time when nationalist thinking was very important in many countries that tried to position themselves in the bi-polar world of the Cold War, scholars started to develop a National Innovation System (NIS) approach. The NIS approach allowed to compare the innovative capacity of nations overall and therefore move much further and deeper into an understanding of how innovation is systematically created, which drivers and barriers there are and what impact it can have on the future of a country and the position of its economy and science in an increasingly global competition without just focusing on basic numbers of economic performance in the past. On occasion of its 30th anniversary, this paper discusses several alternations of Innovation Systems that have been created and applied; the most common next to NIS being Regional Innovation Systems (RIS), Sectoral Innovation Systems (SIS), and Technological Innovation Systems (TIS). In general, Innovation Systems study the emergence of new technologies from complex interactions between actors (Binz et al., 2016). The study of Innovation Systems has become a large field of research, relevant particularly for scholars and policy makers. For example, the OECD has adopted the approach in its analysis and has run several studies using Innovation Systems as a basis (OECD, 1997, 2016).

As the field of Innovation System research has become increasingly large and confusing, this paper aims to trace back the evolution of the manifold concepts of Innovation Systems and systematically analyze their differences and commonalities. The paper is structured as follows: In the first part, the authors discuss the underlying commonalities of all four Innovation System approaches. Afterwards, the four concepts are discussed along ten criteria.[2] Finally, the authors derive a conclusion and the extensive table of comparison is presented.

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[1] English political economist David Ricardo (1772-1823) is popularly deemed to have coined the term „comparative advantage“ in his book „On the Principles of Political Economy and Taxation“ (1817). Over decades and centuries however, scholars understood that not only cost efficiency for itself is mostly deciding over how well a country performs in the international competition, but that many more factors and especially their use and interaction play a role. This becomes obvious when Ricardo’s theory is compared to the modern concept of „competitive advantage“ coined by Michael E. Porter in his book „The competitive advantage of nations“ (1990). But the concept of Innovation System analysis takes a completely different, more profound approach.

[2] The authors have presented a poster on this topic, but limited to SIS and TIS, titled „Comparison of the TIS and the SIS approaches along ten criteria based on renewable energy technology case studies“ at the 16th International Schumpeter Society (ISS) conference 2016 in Montreal, Canada, of the International Joseph A. Schumpeter Society from July 6-8, 2016.

Methodology

This paper presents an extensive literature review on the Innovation System research, structured systematically along ten criteria. The authors have followed a stringent four step research outline: First, by general literature review using Web of Science and the keywords "Innovation System" the most common approaches have been identified: NIS, RIS, SIS, and TIS. At the same time it became clear that the four frameworks agree on certain foundations, which is the understanding of "innovation" and "systems". Yet both terms need some discussion in order to clarify them. The results of this discussion are included in the section below - commonalities. Second, in order to be able to compare the four frameworks, a list of comparing criteria has been formulated. The final list includes ten criteria: 1) Founder of theory/Research program; 2) Basic study/thought; 3) Five case studies most cited; 4) Spatial boundaries (conceptually/empirically observed); 5) Unit of analysis (conceptually/empirically observed); 6) Basic components; 7) Functional analysis; 8) Taxonomy/typology; 9) Similar approaches; 10) Further research. While especially criteria 1 and 2 can be answered by seminal literature identified in step one of the research outline, especially criteria 3 through 5 require additional literature reviews. Thus in a third step, using Web of Science, the five most cited case studies applying the respective Innovation System approaches have been identified[3]. The authors have followed systematic search strategies: Search strategy 1 looks for *title* "national innovati* system*"; Search strategy 2 looks for *topic* "national innovati* system*"; Search strategy 3 looks for *title* "national system* of innovati*"; Search strategy 4 looks for *topic* "national system* of innovati*". These alternations are necessary, as scholars use different terms but mean the same. All four search strategies have been applied for the respective Innovation System approach, thus substituting "national" with "sectoral", "regional", and "technological", respectively. The five case studies with most citations have been included in the list. In the fourth and last step of the research outline applied in this paper, the authors have filled out the ten criteria formulated with content as gathered through the extensive literature review. The list of criteria has been marginally adjusted throughout the process of literature review. An overview of the complete table can be found in the appendix.

Commonalities: System and Innovation

Innovation Systems and their variances (national, regional, sectoral, technological) have two common underlying concepts: *System* and *Innovation*. These two concepts build the basis for Innovation System research and are thus highly important to be defined accurately.

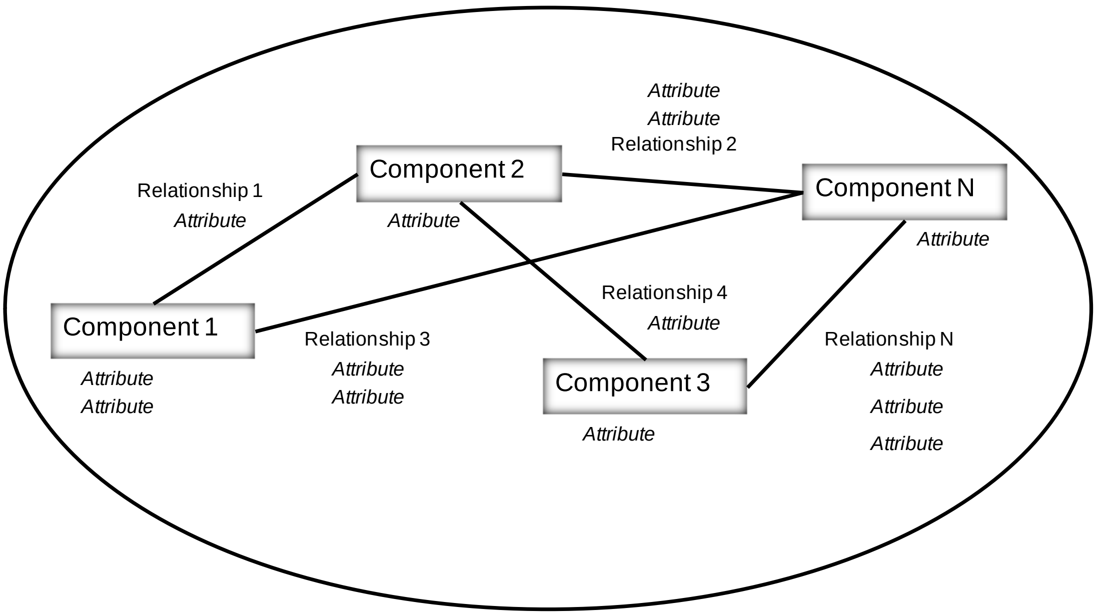
[3] As of June 2015.

What is “a system”?

Generally speaking, a system can be defined as “a set or arrangement of things so related or connected as to form a unity or organic whole” (Webster’s Collegiate Dictionary). More precisely, a system is a set of interrelated components that work towards a common purpose. Thereby, systems consist out of three blocks: components, relationships, and attributes. To sum it up shortly, *components* are the operating parts of a system, *relationships* are links between components, and *attributes* are the properties of both, components and relationships (Carlsson et al., 2002).

To visualize these three blocks, the figure below should help to clarify the concept of a system. As can be seen, a system may be composed out of N components (here represented by rectangles). These components are interrelated, thus they have relationships (the lines, which connect the rectangles). Finally, both components and relationships have different attributes. The number and variance of attributes is not closely defined. Here, there is one system depicted. It may be possible that there is another system parallel to this one. The two (or more) systems may even be connected. One could call this an intersystem-relationship[4]. In such an intersystem-relationship two (or more) systems may be connected by a number of components, which have direct relationships. Yet the two (or more) systems do not merge, since they follow different objectives. It is possible though that the systems may merge, once the purposes of the different systems align during the evolution.

Figure 1: Graphical illustration of a system



Source: Own illustration based on Carlsson et al. (2002)

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[4] Existing Innovation System literature does not follow this thought to the authors’ knowledge.

In order to elaborate further on a system, one has to define components, relationships and attributes more precisely.

As already mentioned, *components* are the operating parts of a system in a variety of types. A component can be actors or organizations (such as individuals, firms, research institutions, associations, and so on). They can also be so called artifacts (here referring to a technology) like wind power plants, electrochemical energy storages, machinery equipment, and so on. The third dimension of a component are institutions and their artifacts (in this context legislative artifacts), as for example laws, standards, or traditions.

Relationships are the connections of the components. As the components are linked to each other, the behavior and property of a component is influenced by the property and behavior of the system as a whole. One component is at least dependent on one other component of the system. Due to this interdependence of the components through relationships, a number of components cannot build an independent subset of the system. As a consequence, “the system is more than the sum of its parts.” (Blanchard and Fabrycky, 1990; Carlsson et al., 2002, p. 234) These relationships may be market- and non-market- based. At the same time, relationships foster feedback between components. Feedback again leads to a dynamic system. The more feedback between the components, the more dynamic the system is. Without feedback, the system is static.

As one of the major components is technology-related, feedback regarding technology (technology transfer or technology acquisition) is one of the most important features of a system. Technology transfer may occur through “spillovers” (thus unintentionally) or by intention (in the case of merger and acquisition, e.g. between technology supplier and customer). Intentional technology transfer even needs a ‘more than market-based relationship’. As this relationship involves constant feedback and collaboration, it is not a “once-for-all transaction” (Carlsson et al., 2002, p. 234). The example of technology transfer shows that the capabilities of different components (in this case firms) shift – thus the configuration of the system also shifts.

Attributes are the characteristics of the system. Both components and relationships have attributes. Due to the interaction between components, the attributes can be derived from the system (Carlsson et al., 2002; Hughes, 1987). In order to understand the system and to be able to derive the attributes, one must know the objective of the system. In the case of an Innovation System, the goal (or function) is to generate, diffuse, and utilize technology. In the special case of innovation[5], it is thus the capability of actors to generate, diffuse, and utilize a

[5] More on „innovation“ in the section below, What is “innovation”?

technical innovation (Carlsson et al., 2002). By the nature of a technical innovation, it drives technological change and eventually creates economic growth. The sum of the capabilities is thus economic competence (being the ability to generate rent).

Carlsson et al. (2002) differentiate between four different shades of economic competence as basic drivers of rent generation: 1) selective (or strategic) capability; 2) organizational (integrative or coordinating) ability; 3) functional ability; 4) learning (or adapting) ability.

Ad 1) s*elective (strategic) capability* describes the ability to make innovative choices with respect to markets, products, technologies or the organizational structure. This capability stresses the role of the entrepreneur in the Schumpeterian sense to engage in entrepreneurial activity. An important ability is the absorptive capacity, thus to develop relevant information into economical and technical opportunities. As the strategy is concerned with the overall direction of a firm, strategic capability can be regarded as the effectiveness (Are we doing the right thing?).
Ad 2) *organizational ability*; the main owner within a firm of the integrative or coordinating ability is the middle management. It has the objective to organize and coordinate the existing resources and generate new combinations.
Ad 3) *functional ability* is concerned with the efficiency (as opposed to the effectiveness, here the main question is: Are we doing things right?). Once the strategic alignment is set, the functional ability describes the execution of the necessary tasks to follow the strategy.
Ad 4) *learning (adaptive) ability*; it describes the ability of a firm and its subunits to learn from their actions. Actions may be successful or have lead to failure. In any case, it is most important to learn from them and adapt accordingly. It is thus essential for a sustainable success on the market. (Carlsson et al., 2002)

What is “innovation”?

Innovations and in particular their origin, their deployment and diffusion as well as their impacts are now in the interest of numerous scientific disciplines and studies. From each specific use of the term "innovation", many nuances emerged that complicate the commitment to one single, pivotal definition of the theoretical construct.

The Organisation for Economic Co-operation and Development (OECD) has created a definition in the context of its work to collect and interpret innovation-related data, which is quoted very often:

“An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations.” (OECD, 2005, p. 46)

This definition reflects the four types of innovations which the OECD has committed to, namely product, process, marketing and organisational innovations. Product and process innovations have a close relationship with the concepts of technological product innovations and technological process innovations according to this construct.

However, this definition covers only the content dimension of the term "innovation", while four other dimensions can be distinguished: An intensity dimension, a subjective dimension, a process dimension and a normative dimension (Hauschildt and Salomo, 2011). Only by incorporating all of the dimensions mentioned, a comprehensive assessment of an innovation can be carried out.

The distinction of innovations can also be based on their intensity, which may result in the division into four groups of incremental innovations, radical innovations, changes of the technological system and technological revolutions (Grupp, 1997). Suggestions for further typologies have been developed, for example of "continuous" and "discontinuous" innovations (Tushman and Anderson, 1986) or "sustaining" and "disruptive" innovations (Christensen, 1997). All typologies ultimately differ only by the role they admit innovations as a driver of technological change and how they embellish it, respectively. Already Joseph Schumpeter worked out in 1912 that from the "given circumstances, from which the static theory starts, in the implementation of new combinations of existing economic opportunities" lies the emergence of innovations. They would for example "[be based] on the ongoing change of production due to new machinery and technical processes" (Schumpeter, 1912), and constitute the basis of the capitalist economic process, which thrives on the dynamics of technological change (Grupp, 1997).

In Innovation System research, the understanding of innovations as the introduction of new knowledge or new combinations of existing knowledge in the economy is central (Edquist, 1997). Thus, innovations result from the interactive learning process, in which ideally all actors of an Innovation System participate. This interrelation is shown in detail with the following definition:

“Innovation is an evolutionary, cumulative, interactive and regenerative process of the transfer of information, tacit and explicit knowledge in innovations with technological and organizational character. This process is characterized by uncertainty, information search, information encoding and decoding as well as mutual learning. The link between innovation and space is the interaction that is the distant exchange of tangible

and intangible resources between innovation actors. This concept of innovation includes socio-cultural factors explicitly, as they influence the interaction ability, style and intensity between the various actors in the innovation process as well as the respective learning processes decisively." (Koschatzky, 2001, p. 61)

In the context of Innovation System research, two conceptions of "innovation" have been established, with a different narrow and broad sense. In the narrow sense, some authors concentrate only on technological innovations (Nelson, 1993); however, they do not only consider their origin, but also their deployment and diffusion (Carlsson, 1995). Schumpeter's determination quoted above however, regarding the emergence of innovations as "new combinations of existing economic opportunities", goes much further and includes all four types of innovations which were captured by the OECD in its definition quoted above as well. Other authors of Innovation System research also tried to find a broader definition, which takes into account non-technological innovations (Freeman, 1987; Lundvall, 1992b). Because there strictly speaking is no right or wrong definition of the term "innovation", there may be more useful and less useful definitions depending on the intended purpose of use (Edquist, 1997).

Innovation Systems

National Innovation System (NIS)

1 Founder of theory/Research program/2 Basic thoughts

The theory of National Innovation Systems (NIS) goes all the way back to German Friedrich List, who was the first academic to specifically write about a „national system" in the sense that „wealth, culture and power of Germany would have to be fostered in a national economic way" (List, 1844). Having studied the means of transportation and their impact on the intellectual and political life, the sociable traffic, the productive strength and power of a nation within its general impact as a national transportation system (List, 1838), List followed his conviction that nations would leave one of the richest sources of wealth, civilization and power untapped, if they would not strive to realize division of labor and the network of productive strength on a national scale, as soon as they possess the economic (advanced agriculture), intellectual (advanced education) and societal (institutions and laws) means required (List, 1844).[6] In order to achieve his aim of Germany catching up with and overtaking industrialized England, List rooted not only for protecting infant industries, but supported a wide range of policies designed to allow for and spur on industrialization and economic growth (Freeman, 1995).

[6] For further analysis and context, please see the comprehensive introduction „The National System of Friedrich List" in Freeman (1995).

Almost 150 years later, English Christopher Freeman was the first academic to specifically discuss a „National Innovation System“, analyzing the Japanese NIS and drawing conclusions for other countries (Freeman, 1987). Having been impressed by Japans intense efforts to catch up to the leading industrial nations and potentially overtake Western Europe and the United States with immense rates of technological change, Freeman presented the statistical evidence of the growing lead in industrial research and development and technical innovation which was supposedly underlying Japans trade performance. His work was made possible by a research grant from the Economic and Social Research Council (ESRC) and largely based on a report prepared for the ESRC, the UK's leading research and training agency addressing economic and social concerns[7]. Freeman himself documented two powerful developments on an international level that had a large influence both on policy-makers and on researchers in the 1980s: There was the extraordinary success of first Japan and then South Korea in technological and economic catch-up, and then the collapse of the Union of Soviet Socialist Republics (USSR) and the end of the Cold War (Freeman, 1995).[8]

Another founder of the theory of NIS was American Richard R. Nelson, who wrote the preface to a chapter with the title „National Innovation Systems“ (Dosi et al., 1988), in which the NIS of the United States of America (USA) and Japan at the time were compared, with many similarities between the two NIS, but some important differences, too. The main concern of the essay on the USA was to show the institutional structures that fostered the technical lead of modern capitalist countries, a chain of thought once again clearly hinting towards a background of cold war thinking.[9]

Interestingly, Swedish Bengt-Åke Lundvall took the stage in this book, too.[10] He looked at NIS from a different perspective, focusing on user-producer interactions and arguing plausibly that geographical and cultural closeness facilitate effective interaction. In other words, while Freeman and Nelson accepted the borders of a country as given and looked from the outside onto a specific NIS, Lundvall proposed that national borders tend to enclose networks of technological interactions which define NIS, hence looking from the inside onto a

[7] ESRC (2016): Economic and Social Research Council (ESRC). What we do. Link: http://www.esrc.ac.uk/about-us/what-we-do/, last accessed October 5, 2016

[8] Interestingly, British Angus Maddison conducted an analysis comparing the economic growth in Japan and the USSR and published it already in 1969 (Maddison, 1969). Although the approach taken seems to be very similar to the NIS approach, the authors could not find any link between Madison and the Innovation System community.

[9] The chapter concludes with an essay written by Czech Pavel Pelikan, which tried to theoretically explore whether a capitalist Innovation System can be out-performed by a socialist Innovation System, in which officials appointed by a central authority control the use and creation of technology.

[10] In 1985, he had published a paper in which he outlined a „system of innovation“ and discussed „national systems of production“, but didn't merge the two concepts yet.

specific NIS. Both Lundvall and Nelson went on to contribute to and edit seminal book volumes on „National Innovation Systems: Towards a theory of innovation and interactive learning“ (Lundvall, 1992a) and „National Innovation Systems: A Comparative Analysis“ (Nelson, 1993), respectively.

Another standard work was contributed to and edited by Swedish Charles Edquist, who formed the „Systems of Innovation Research Network“ in 1994: It had the objective to contribute to building a more solid and sophisticated conceptual and theoretical foundation for the continued study of innovations in a systemic context (Edquist, 1997). The network's work was paper-based, and the papers that were developed in three different meetings throughout 1994 and 1995 became chapters in the book mentioned. By the year 1997, several approaches to „systems of innovation“ had emerged with different characteristics, and the excellent introduction written by Edquist should still be part of a basic reading list on the topic for innovation researchers today.

3 Five case studies most cited/4 Spatial boundaries

The five case studies most cited regarding NIS will be discussed while comparing their spatial boundaries, both conceptually and empirically observed. Conceptually, the concept of 'national' system was considered to be potentially too broad, as institutions supporting technical innovation in one field may have very little overlap with the system of institutions supporting innovations in another field (Nelson, 1993). Whether a system of innovation should be spatially or sectorally delimited should depend on the object of study, as systems of innovation could be supranational, national, or subnational (regional, local) and at the same time sectoral within any of these geographical demarcations (Edquist, 1997). For a NIS, the country's borders normally provide the boundaries (Edquist, 2005). However, it could be argued that the criteria for RIS are just as valid for NIS. In other words, if the degree of coherence or inward orientation is very low, the country might not reasonably be considered to have a NIS. And it should be mentioned that the NIS approach is less relevant for large than for smaller countries.

These remarks are supported empirically, at least taking into account the five case studies most cited regarding NIS: The NIS of Germany, Japan and the former USSR are analyzed (Freeman, 1995), the NIS of the USA and various OECD countries (Furman et al., 2002), the NIS of Germany (Meyer-Krahmer and Schmoch, 1998), the NIS of China (Liu and White, 2001) and the NIS of Japan and other East Asian economies (Mowery and Oxley, 1995). Most case studies discuss national or supranational SI, the latter in case a NIS comparison with more than one nation is conducted.

5 Unit of analysis

Conceptually, the unit of analyis for NIS is a „nation state“, and the quest for defining the term of a „nation“ in its various notions has taken a lot of effort already. Interestingly, the ideal, abstract nation state as one where the two national-cultural and étatist-political dimensions coincide, meaning where all individuals belonging to a nation defined by culture, ethical and linguistic characteristics are gathered in one single geographical space controlled by one central state authority (without foreign nationalities), is difficult to find in the real world, at least in this strict sense (Lundvall, 1992). It has to be noted that there are sharp differences among various NIS in such attributes as institutional set-up, organizational set-up, investments in R&D, and performance (Edquist, 2005). And another reason to focus on NIS is that most public policies influencing innovation processes or the economy as a whole are still designed and implemented at the national level. So although the NIS approach is only one of several possible specifications of the generic Innovation Systems concept, it certainly remains one of the most relevant and the analysis and comparison of various Innovation Systems on a national level will remain one of the main means for analysis for a long time to come.

Empirically observed, the five case studies most cited conduct an economic analysis with historic examples of Germany, Japan and the former USSR (Freeman, 1995), measure the national innovative capacity of the USA and various OECD countries (Furman et al., 2002), analyze the technology transfer within the German NIS (Meyer-Krahmer, 1998), offer a generic framework for analyzing Innovation Systems applied to a comparison of China’s NIS under central planning and since reforms (Liu et al., 2001) and document the role of NISs in the inward transfer of technology in Japan and other East Asian economies (Mowery et al., 1995).

6 Basic components/7 Functional analysis

In order to name the basic components of NIS, a definition can look like the following:

> *A national system of innovation is the system of interacting private and public firms (either large or small), universities, and government agencies aiming at the production of science and technology within national borders. Interaction among these units may be technical, commercial, legal, social, and financial, in as much as the goal of the interaction is the development, protection, financing, or regulation of new science and technology.“ (Niosi et al., 1993, p. 212)*

Depending on the complexity wished for, this definition can be broadened easily of course, considering other public and private organizations that play a role in the NIS, e.g. public laboratories, technology transfer organization, joint research institutes, patent offices, training organizations and so on (OECD, 1999).

For functional analysis, there are five “primary functions” of an NIS as defined above: The creation of „new“ knowledge, guidance in the direction of the search process, the supply of resources, e.g. capital and competence, facilitation of the creation of positive external economies (in the form of an exchange of information, knowledge, and visions) and facilitation of the formation of markets (Johnson et al., 2000; according to Feinson, 2003).[11] This list can be enlarged easily, too, e.g. with the creation of human capital, the legitimization of technology and firms and the creation of a labor market that can be utilized (Rickne, 2000 in Edquist, 2001, according to Feinson, 2003).

8 Taxonomy/9 Similar approaches

Regarding a taxonomy of NIS, different approaches have been made already: Type 1 would be the size and income of countries (Nelson, 1993), Type 2 would be the distance from the innovation process (narrow vs. broad NIS)[12] and the level of formality (formal vs. informal) (Schoser, 1999, according to Feinson, 2003), Type 3 would be the eight dimensions for quantitative NIS analyses (Godinho et al., 2006) and Type 4 would be the time series perspective for drivers of NIS (Castellacci et al., 2013).

With all these possible taxonomies on offer, only one similar approach for the NIS has been found by the authors: With the so-called “*Input-output analysis*”, Wassily W. Leontief presented a radically different method. By being much better suited to manipulation of very large sets of simultaneous relationships and making it possible to conduct the empirical analysis of the national economy as a whole in terms of the peculiar structural characteristics of its many individual parts, it combines the virtues of general equilibrium analysis with the obvious, but all-too-often neglected advantages of direct detailed observation (Leontief, 1953).

[11] Regarding the quote of (Johnson et al., 2000) in (Feinson, 2003), the authors suspect that (Bergek et al., 2003) is meant. It has to be noted however, that at this point, Anna Johnson (later on Anna Bergek) and Staffan Jacobsson had already begun to write about Innovation Systems with a technological background or technological systems respectively, without naming them explicitly „Technological Innovation Systems“, but writing about their functionality. This shows one example how difficult it can be to exactly distinguish different developments in Innovation System approaches.

[12] A distinction has been made between narrow (actor-oriented, National Innovation System) and broad (institution-oriented, National Innovation Environment) NIS (OECD, 1999). The NIS linkages, which reflect the absorptive capacity of the system, are determined by the ways in which knowledge and resources flow between the narrow and broad levels (Feinson, 2003).

10 Further research

Regarding further research, it has been mentioned that a more explicit combination of the NIS approach with economic growth is still missing, the interplay between a country's Innovation System and other economic subsystems (e.g. the labor market or the financial system) is far from being studied exhaustively and knowledge on the dynamic properties of NIS is still limited, especially with regards to their stability and their structural evolution (Balzat et al., 2004). Other aspects for further research especially regarding system dynamics include a time series perspective, as most empirical research on NIS and economic growth has so far adopted an explicitly comparative perspective – focusing on cross-country differences in technological capabilities – and largely neglected the time series dimension (Castellacci and Natera, 2013). The dynamics and determinants of innovative capability are another aspect, as only a limited number of studies have empirically investigated the dynamics of innovative capability over time and the main factors that may explain its long-run evolution. Also, the dynamics and multifaceted nature of absorptive capacity has to be studied further, as it is indeed important to adopt a multifaceted description and measurement of the various factors that contribute to shape the absorptive capacity of nations. Considering the dynamics and long-run evolution of absorptive capacity, it should not simply be regarded as a set of exogenous control factors in cross-country growth regression exercises. Last but not least, the coevolution between innovative capability and absorptive capacity needs to be examined, especially when adopting a time series perspective, as it is important to investigate the existence of a two-way relationship (coevolution) that links together the dynamics of these dimensions in the long run. Current research examines six research strands that challenge the classical NIS framework by pointing to a wider range of actors, institutions and innovation modes relevant for the innovation landscape: User innovation, social innovation, collaborative innovation, new innovation intermediaries, venture philanthropy, social and relational capital and non-R&D intensive industries (Warnke et al., 2016). Each of these phenomena points to relevant contributions to national or regional innovation capacities that are not well captured by the established NIS framework yet.

Regional Innovation System (RIS)

1 Founder of theory/Research program/2 Basic thoughts

When Swedish Bengt-Åke Lundvall and American Richard R. Nelson contributed to and edited their seminal book volumes on „National Innovation Systems: Towards a theory of innovation and interactive learning“ (Lundvall, 1992) and „National Innovation Systems: A Comparative Analysis“ (Nelson, 1993), English Philip Cooke published a paper titled „Regional Innovation Systems: Competitive Regulation in the New Europe“ (Cooke, 1992).

Cookes paper resulted from earlier research on regional innovation, e.g. in Baden-Württemberg/Germany and Emilia-Romagna/Italy for various ‚Regional Industrial Research Reports‘ granted by the Economic and Social Research Council (ESRC), the UK's leading research and training agency addressing economic and social concerns[13]. The bare term „Innovation System" or „system of innovation" appears only three times in the paper, showing that the main intent laid more on the concept of regulation in its changing role as a form of proactive support for industry in a modern Europe: The preferred spatial level for regulatory intervention according to Cookes paper is that of the region rather than the central state. But the idea of the ‚region‘ as a subnational sphere for innovation, which needs to be fostered by specific regional technology policies depending on the model of regional technology transfer that can differentiated, was absolutely spot-on and expanded the current debate on National Innovation Systems on an important aspect: Systemic innovation can be found at the regional (and even subregional) level as well as at the national and global levels (Cooke et al., 1997).

Cooke continued to work on the topic, and several years later, he contributed to and edited the first seminal book volume on „Regional Innovation Systems – The role of governances in a globalized world" (Braczyk et al., 1998). The book is a collaborative effort of the Centre for Advanced Studies in the Social Sciences (CASS), University of Wales, Cardiff, and the Centre for Technology Assessment in Baden-Württemberg (CTA) that started in the year 1995. Meanwhile, other researchers justified the necessity of a new spatial boundary of Innovation Systems, as it made sense to talk about a regional or local technology system (Carlsson et al., 1995).

More publications by other researchers focused on the proper understanding of technological developments and their dissemination throughout the economy and society. They took into account the notion of systems of innovation, either local, regional, sectoral or national that has been widely used to map and explain the interactions between agents that generate and use technology and stated that RIS provide an additional layer to "a systems approach to innovation" (Howells et al., 1999). Aspects like the proximity between firms (Maskell et al., 1999) caught increasingly more attention, and were applied to regional examples worldwide – like three regional clusters in Norway dominated by shipbuilding, mechanical engineering and electronics industry that exploit *both* place-specific local resources as well as external, world-class knowledge in order to strengthen their competitiveness (Asheim et al., 2002). Lessons learned were drawn, and the concept of RIS was solidified and extended, and

[13] ESRC (2016): Economic and Social Research Council (ESRC). What we do. Link: http://www.esrc.ac.uk/about-us/what-we-do/, last accessed October 5, 2016

questions regarding the underlying theoretical perspectives, its place among other forms of industrial organization, different forms of RIS and failures of the concept were studied (Doloreux, 2002).

3 Five case studies most cited/4 Spatial boundaries

The five case studies most cited regarding RIS will be discussed while comparing their spatial boundaries, both conceptually and empirically observed. Conceptually, the diversity of the units of analysis utilized in studies of RIS presents a major problem in developing a unified conceptual framework for the construct of 'the region' as a theoretical object of study (Doloreux, 2005). As a result, it prompts renewed confusion vis-à-vis not only the application and assessment of an Innovation System at the regional level (however defined), but also its territorial boundaries. The confusion mentioned may also feed from the observation that Innovation Systems embrace a wide variety of ideas and theoretical perspectives, and the concept of RIS draws from four different perspectives: (1) an Historical perspective, (2) an Institutional perspective, (3) an Evolutionary perspective, and (4) a Social perspective (Doloreux, 2002).

Empirically, these remarks find confirmation, at least taking into account the five case studies most cited regarding RIS: Several RIS/metropolitan statistical areas within the United States of America are observed (Acs et al., 2002), several RIS in various regions/federal states within Norway and Sweden (Asheim et al., 2005), regions in Japan, Germany and France, the United Kingdom and Wales (Cooke, 1992), NUTS 1 ("major socio-economic") and NUTS 2 ("basic") regions within the EU-25 (Rodríguez-Pose et al., 2008)[14] and several RIS/federal states within Germany (Fritsch et al., 2004). So, most case studies discuss regional or national IS, the latter in case a RIS comparison with more than one region within one nation or supranational in case a RIS comparison with more than one region in more than one nation is conducted.

5 Unit of analysis

Conceptually, the diversity of the unit of analysis for RIS is immense and entails cities, metropolitan regions, districts within cities or metropolitan regions, regions defined within the NUTS 2 classification, and areas on the supra-regional/sub-national scale. Yet, the literature on RIS provides substantial description and analyses of relationships between innovation, learning and the economic performance of particular regions (Doloreux, 2005).

[14] The „Nomenclature of Territorial Units for Statistics" (NUTS) is a geocode standard for referencing the subdivisions of countries for statistical purposes. The standard is developed and regulated by the European Union, and thus only covers the member states of the EU in detail. Wikipedia (2015).

Empirically observed, the five case studies most cited analyze the regional innovative activity in 125 US metropolitan statistical areas (MSAs) (Acs et al., 2002), they discuss different types of RIS with five empirical illustrations: Furniture industry in Salling/Denmark, wireless communication industry in North Jutland/Denmark, functional food industry in Scania/Sweden, food industry in Rogaland/Norway, electronics industry in Horten/Norway (Asheim et al., 2005), the role of regulation for regional innovation with material evidence from Japan, Germany and France, within the United Kingdom and with particular reference to Wales (Cooke, 1992), the impact of innovation on regional economic performance in Europe with multiple regression analyses for all regions of the EU-25 (Rodríguez-Pose et al., 2008) and the impact of knowledge spillovers and R&D cooperation on innovation activities in the three German regions of Baden, Hanover-Brunswick-Goettingen in Lower Saxony and Saxony (Fritsch et al., 2004).

6 Basic components/7 Functional analysis

Starting with the first list of key elements of the successfully regulated, networked region, they include a thick layering of public and private industrial support institutions, high grade labour market intelligence and associated vocational training, rapid diffusion of technology transfer, a high degree of inter-firm networking and, above all, receptive firms well-disposed towards innovation (Cooke, 1992). All these have been confirmed with numerous empirical studies in the last years. A more basic list of components of a RIS contains firms, institutions, knowledge infrastructures, and policy-oriented regional innovation (Doloreux, 2002). For the functional analysis, the principal mechanisms are interactive learning, knowledge production, proximity and social embeddedness (Doloreux, 2002). In general, the concept of RIS has no generally accepted definitions, although it is typically understood to be a set of interacting private and public interests, formal institutions, and other organizations that function according to organizational and institutional arrangements and relationships conducive to the generation, use, and dissemination of knowledge (Doloreux et al., 2005).

8 Taxonomy/9 Similar approaches

Regarding a taxonomy of RIS, different approaches can be found (Doloreux, 2002): Type 1 would be the regional potential (Cooke et al., 2000), Type 2 would be the level of regional integration (Howells, 1999), Type 3 would be the social cohesion (Asheim et al., 1997), Type 4 would be the governance modes of technology transfer (Braczyk et al., 1998) and Type 5 would be the regional barriers (Isaksen, 2001). Type 6 would be the type of RIS[15] (territorially embedded/grassroots RIS, networked/network RIS, regionalized national/dirigiste RIS) vs.

[15] A distinction has been made between a narrow (knowledge exploration and diffusing, knowledge exploitation) and a broad (including a wider system supporting learning and innovation) definition of RIS.

the type of knowledge (analytical/science-based, synthetic/engineering-based, symbolic/artistic-based) (Asheim, 2009).

For RIS, several similar approaches have been identified (Doloreux, 2002): Industrial districts (Marshall et al., 1879; Belussi et al., 2009), the technopole (Technopolis Japan/Technopolis policy France, 1970s – e.g. Simmie, 1994), an innovative milieu (GREMI study group 1980s, e.g. Crevoisier et al., 1991) and learning regions (Florida, 1995).

The concept of “*local/regional economies*” gained more traction when a study about the Silicon Valley in California and Route 128 in Massachusetts that were leading centers of electronics innovation and entrepreneurship in the 1970s revealed how the performance of these two regional economies diverged in the 1980s (Saxenian, 1994). Despite similar histories and technologies, Silicon Valley developed a decentralized industrial system that encourages experimentation, collaboration, and collective learning among networks of specialist companies, while Route 128 came to be dominated by a few self-sufficient corporations. As it was demonstrated, Route 128 was slow to adjust to changing markets because skill and technology remained confined within independent firms. In contrast, companies in Silicon Valley created a regional advantage by drawing on local knowledge and relationships to create new markets, products, and applications at a rapid pace. In doing so, they blurred the traditional boundaries between customers, suppliers, and competitors. The result of the study underscored the need to develop regional as well as national and sectoral economic policies.

10 Further research

Regarding further research, RIS address elusive elements that make it difficult to provide a clear definition with a clear application, the concept appears to be a mélange of different sources, the concept of RIS tends to be confined to high-tech and/or manufacturing sectors and for a more complete view, RIS should also incorporate findings from regions where this concept has been empirically tested (Doloreux, 2002). Moreover, only a few empirical studies have applied this approach to peripheral regions, rural areas, and declining economies. Current research examines six research strands that challenge the classical RIS framework by pointing to a wider range of actors, institutions and innovation modes relevant for the innovation landscape: User innovation, social innovation, collaborative innovation, new innovation intermediaries, venture philanthropy, social and relational capital and non-R&D intensive industries (Warnke et al., 2016). Each of these phenomena points to relevant contributions to national or regional innovation capacities that are not well captured by the established RIS framework yet.

Sectoral Innovation System (SIS)

1 Founder of theory/Research program/2 Basic thoughts

The Sectoral Innovation System (SIS) is a multidimensional, integrated and dynamic approach founded by Italian Franco Malerba, Malerba (2004) being the main reference. Main questions tackled by the SIS approach are what the main characteristics of the networks of innovators are, what the factors responsible for change and transformation of the sector are or how relevant national institutional frameworks are. Earlier versions of the approach have been published by Breschi and Malerba (1997), Breschi et al. (2000) and Malerba (2002). The SIS was founded within a research program from the European Union, targeted at Socio-economic research. The project was called "Sectoral System in Europe: Innovation, Competitiveness and Growth". The basic thought of the approach is to explore the path dependencies of innovation and technological change. The idea is that different sectors have different path dependencies and consequently sectors have different characteristics, which are in turn shaped by knowledge, actors and institutions. The approach is based on three foundations: 1) The market structure and innovation approach from Kamien and Schwartz (1982); 2) A technology regime according to Nelson and Winter (1977; 1982); 3) Sources of innovation and the mechanism of appropriability (Levin et al., 1987; Mowery and Nelson, 1999; Nelson, 1993; Pavitt, 1984; Rosenberg, 1976, 1982).

3 Five case studies most cited/4 Spatial boundaries

Nowadays, SIS is a widely used framework applied in research (Beerepoot and Beerepoot, 2007; Cooke, 2002; Miyazaki and Islam, 2007; Oltra and Saint Jean, 2009; Sapsed et al., 2007). Conceptually, the spatial boundaries of a SIS are not necessarily national (Malerba, 2004). What is empirically applied from scholars is a regional, national or supranational spatial boundary. The national boundary is most commonly used and appreciated (Beerepoot and Beerepoot, 2007; Cooke, 2002; Miyazaki and Islam, 2007; Oltra and Saint Jean, 2009; Sapsed et al., 2007).

5 Unit of analysis

Malerba (2004) argues for a flexible use of the unit of analysis and indicates that firms are not necessarily the appropriate choice. Furthermore he suggests that individuals, R&D departments or groups of firms could as well be considered as the unit of analysis. Scholars applying the framework show a high diversity in their unit of analysis and thus follow Malerba's suggestions. The broad concept of technology, science and its actors, industries, clusters and (entrepreneurial) firms are considered to be the respective unit of analysis in published research (Beerepoot and Beerepoot, 2007; Cooke, 2002; Miyazaki and Islam, 2007; Oltra and Saint Jean, 2009; Sapsed et al., 2007).

6 Basic components

Malerba defines a sector as a "a set of activities which are unified by some related product groups for a given or emerging demand and which share some basic knowledge." (Malerba, 2004, pp. 9–10) Thereby firms within a sector are heterogeneous as they serve different layers of the innovation system, but also have certain commonalities as they are part of the same sector. Moreover, it is assumed that an innovation has features that relevant for the innovation system. Agents, being firms for example, interact within the system on a market and non-market basis. The goal of the agents is to develop and diffuse sector-relevant products. "The agents are individuals and organizations at various levels of aggregation, with specific learning processes, competencies, organizational structure, beliefs, goals and behaviors." (Malerba, 2004, p. 10) Through a process of communication, exchange, cooperation, competition and command the agents interact in a framework shaped by institutions. Consequently, a SIS changes and transforms through the coevolution of its various elements. Following this argumentation, a SIS is composed out of three basic components institutions, actors and networks, and knowledge and technology.

Institutions

Institutions are shaped from agent's cognition, action and interactions. Institutions may have different characteristics, such as binding, (in)-formal or national and sectoral. Thus they include norms, routines, laws, and standards, among others. The national patent system, sectoral labor markets or sector-specific financial institutions are examples that come to mind. Institutions and their organizations may differ in terms of types from binding or imposing from enforcements, formal and informal or national and sectoral. Institutions have different impacts on innovation in a specific sector. Depending on the patent system, property rights or antitrust regulations, the innovation process in a sector has a different mechanism. At the same time, institutions differ from country to country and thus affect innovation differently. Consequently, a SIS should be investigated for each country individually, in case multiple countries are examined. Moreover, national institutions support sectors that fit their specificities. Lastly, a sector may become so important on a national level regarding employment, competitiveness or strategic relevance that sectoral and national institutions merge. "Demand is a key part of a sectoral system. (…) Demand is made up of individual consumers, firms and public agencies, each characterized by knowledge, learning processes, competencies and goals, and affected by social factors and institutions." (Malerba, 2005, p. 67) Usually, demand is the aggregation of similar buyers with similar needs. In a SIS though, demand is created from heterogeneous agents whose interactions with producers are shaped by institutions. Demand and especially the emergence and transformation of it plays an important role in the dynamics and evolution of a SIS.

Actors and Networks

Consumers, entrepreneurs, scientists and others are examples for heterogeneous agents in a sector. Consequently, agents can be organizations and individuals. Organizations may be firms, such as producers and input suppliers, but also non-firm organizations (universities, financial institutions, government agencies, trade-unions, or technical associations). Firms are considered to be key actors in a SIS. They are involved in innovation, production and sales of sectoral product. Firms are involved in the generation, adoption and use of new technologies. Users and suppliers are two types of firms. Several sectors are user- driven (agro-food, instrumentation or apparel)[16], while other sectors are supply driven. Components suppliers and technological subsystems increase the competitiveness of downstream sectors. The importance of suppliers varies across sectors (Malerba, 2004). Firm heterogeneity is a key feature of SIS. A high or low degree of heterogeneity[17] depends on a number of factors. It stems from characteristics of the knowledge base, experience and learning processes, firm-specific interactions with demand, working of dynamic complementarities, firms' histories and differential rates and trajectories of innovation and growth. Besides firms, other types of agents are non-firm organizations such as universities, financial organizations, governmental agencies or local authorities. These organizations support the firms and its activities to generate and diffuse innovations. The heterogeneity of agents (firms and non-firm organizations) is connected within the system through market or non-market relationships. The relationships might be either informal or formal.

Knowledge and Technologies

Another basic component of SIS is represented by knowledge and technologies, whereas more than one technology may be relevant. The system boundary is mainly defined by links and complementarities among technologies. Static complementarities are input-output links, while dynamic complementarities are interdependencies and feedbacks. Dynamic complementarities are the source for transformation and growth of a system. They are relevant to set in motion virtuous cycles of innovation and change and are related to Dahmén's (1988) concept of so-called "filieres"[18] and development blocks. The literature of evolutionary economics (e.g. Metcalfe, 1998; Nelson, 1994) is based upon the thought that

[16] At this point, similarities to the concept of the Global Commodity Chain can be found, where Gereffi (1999) differentiates between buyer- and producer- driven commodity chains. Also, see Gereffi (1999) or Bair (2005) for examples and an extensive discussion.

[17] Heterogeneity is deducted from the literature of evolutionary economics literature and is concerned with types, beliefs and competencies of firms.

[18] An interpretation of „clusters".

knowledge is at the base of technological change and is key to innovation. The accessibility of knowledge is differentiated between being internal and external. The internal accessibility to knowledge implies lower appropriability. Lower appropriability means that competitors have fewer difficulties to imitate a product, gain knowledge and a market share. External accessibility is related to scientific and technological opportunities in terms of level and sources, while technological opportunities in some sectors derive from universities, in others by the R&D of firms. Moreover, knowledge is characterized as being cumulative. New knowledge builds upon current knowledge. Cumulativeness[19] of new knowledge at the firm level creates first-mover advantages and leads to high concentration of knowledge. Overall, knowledge is defined by the three key dimensions accessibility, opportunity and cumulativeness. It is directly associated with technological and learning regimes. Firms with a high level of cumulativeness are expected to have a high persistence in innovative activities (Malerba, 2004). At the sectoral level, the organization of innovative activities is related to the distinction between Schumpeter Mark 1 and Schumpeter Mark 2 models. High technological opportunities, low appropriability and low cumulativeness represent the Mark 1 pattern and thus creative destruction. High appropriability and high cumulativeness represent the Mark 2 pattern and thus creative accumulation. Both technological regimes and Schumpeterian patterns change over time according to the industry life cycle view and consequently a Schumpeter Mark 1 pattern my turn into a Schumpeter Mark 2 pattern (Malerba, 2004).

7 Functional analysis

According to Malerba (2004) the evolution of the SIS is shaped by two key evolutionary processes: Variety creation and selection (Metcalfe, 1998; Nelson, 1994). Within the SIS approach, variety creation and selection are responsible for many differences across several SIS. Variety creation describes the process which refers to products, technologies, firms and institutions and their strategies and behavior. New agents entering the sector (both firm and non-firm organizations) are important for the dynamics of sectoral system since new firms bring new varieties in terms of approaches, specialization and knowledge in innovation and production process. On the other hand, the process of selection describes the reduction of heterogeneity in the sector and is relevant for firms, products, or technologies.

Coevolution and the transformation of SIS

- During the evolution of the system, change may occur in the technological and learning regimes and the patterns of innovation.

[19] Cumulativeness has three sources: 1) Cognitive, 2) Related to the firm and to its organizational capabilities, 3) Feedback from the market, such as the “success breeds success” process.

- A system may transform from Schumpeter Mark 1 to Schumpeter Mark 2 (or in the presence of major knowledge, technological or market discontinuities, a Mark 2 pattern may be replaced by a Mark 1 pattern).
- The coevolutionary process has various elements: Technology, demand, knowledge base, learning processes, firms, non-firm organizations and institutions; Nelson (1994) and Metcalfe (1998) have discussed these processes focusing on the interaction between technology, industrial structure, institutions and demand.
- These processes are sector-specific.
- Coevolution is related to path-dependent processes (Arthur, 1988; David, 1985); examples can be seen from Cowan (1990), Foray and Grubler (1990), Mowery and Nelson (1999).
- The transformation of sectors may involve the emergence of new clusters.

8 Taxonomy/9 Similar approaches

There is no taxonomy for Sectoral Innovation Systems existent so far and this leaves room for further research[20]. Malerba himself does not mention similar approaches to the SIS framework yet the work from Leontief (1953) about input-output analysis and Industry social systems by Van de Ven, Andrew H (1993; 1987) can be considered to have many similarities.

10 Further research

Literature formulates following room for further research: a) Analysis of SIS along similar dimensions; b) Construction of taxonomy; c) Development of policy recommendations; d) Conceptual and theoretical work, contrasted by empirics.

Technological Innovation System (TIS)

1 Founder of theory/Research program/2 Basic thoughts

The Technological Innovation System (TIS) early foundations were published first from Carlsson and Stankiewicz (1991). The paper was an outcome of a research project under the lead of Bo Carlsson on “Sweden’s Technological System and Future Development Potential”. The basic thought to initialize the concept was that the economic growth of countries is a function of the technological systems in which various economic agents participate (Carlsson and Stankiewicz, 1991). The boundaries of technological systems may or may not coincide with national borders and may vary from one techno-industrial area to another. Throughout the early 2000’s, Carlsson and Stankiewicz (1991)’s idea was conceptually developed further by several researchers (Hekkert et al., 2007a; Johnson, 2001; Rickne, 2000). A main

[20] Malerba introduced a first approach for taxonomies on the Schumpeter Conference 2016 in Montreal: “Sectoral systems: Taxonomies, evolution and modeling”.

contribution to develop the Technological Innovation System approach was published in Research Policy as the outcome of several earlier case studies by Bergek et al. in 2008a[21].

3 Five case studies most cited/4 Spatial boundaries/ 5 Unit of analysis

The new research outline was adopted and appreciated by many scholars (Bergek et al., 2008b; Foxon et al., 2010; Hekkert and Negro, 2009; Hekkert et al., 2007a; Markard and Truffer, 2008). Methodologically, the spatial boundaries of TIS are global in character and a strong international focus is recommended. Moreover, the unit of analysis is a specific technology, whereby the focus is on a specific knowledge field (level of aggregation; e.g. wind power, ethanol, etc.) or on a set of related knowledge field (e.g. biotechnology). In opposite to the level of application, the range of applications defines the use in specific applications, products or industries (e.g. on-shore wind power) (Bergek et al., 2008a). The most recognized case studies apply a regional, national or supranational (comparative analysis of more than one country) spatial boundary. Regarding the unit of analysis, the most appreciated case studies apply the framework to sustainable/ renewable technologies (Bergek et al., 2008a; Foxon et al., 2010; Hekkert and Negro, 2009; Hekkert et al., 2007a; Markard et al., 2009).

6 Basic components

Within the following definition, the basic components of TIS are mentioned:

> *"A technological system may be defined as a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology. Technological systems are defined in terms of knowledge/competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks. In the presence of an entrepreneur and sufficient critical mass, such networks can be transformed into development blocks[22], i.e. synergistic clusters of firms and technologies within an industry or a group of industries." (Carlsson and Stankiewicz, 1991, p. 111)*

Actors, networks and institutions are today commonly understood as the basic components, e.g. by Jacobsson et al. (2000) or Bergek et al. (2008a). Actors may be firms, individuals or industry associations. Methods for identification of the main actors of TIS are patents research, bibliometric analyses or interviews and discussions with industry and/or technology experts. Networks may be either formal or informal. Formal networks are existing buyer-seller relationships, standardization networks or social communities. The identification of informal

[21] While Bergek et al. (2008a) represents a functional approach towards TIS, several other conceptual developments of TIS have been identified, e.g. specifications for selected TIS functions, a strategic perspective on system building, international ties within TIS, and suggestions for the analysis of TIS contexts (Markard et al., 2015).

[22] Further discussions of the term ‚development blocks' can be found in Dahmén (1988).

groups may in turn require interviews with industry experts. The third structural component of institutions is concerned with the existing culture, regulations or routines in specific TIS.

7 Functional analysis

Regarding the functional analysis, seven functions have been identified by Bergek et al. (2008a) and are named and explained in Table 1.

Table 1: Functions and their content of Technological Innovation Systems (TIS)

Function	Content
Knowledge development and diffusion	"[...] breadth and depth of the current knowledge base of the TIS, and how that changes over time, including how that knowledge is diffused and combined in the system."
Influence on the direction of search	"[...] sufficient incentives and/or pressures for the organizations to [enter a TIS], the combined strength of such factors [and] the mechanisms having an influence on the direction of search within the TIS, in terms of different competing technologies, applications, [...] etc."
Entrepreneurial experimentation	"[...] the main source of uncertainty reduction is entrepreneurial experimentation, which implies a probing into new technologies and applications, where many will fail, some will succeed and a social learning process will unfold [...]".
Market formation	"Market formation normally goes through three phases with quite distinct features: [...] "nursing markets" need to evolve [...] so that a "learning space" is opened up, [...] "bridging market[s]" [allow] for volumes to increase and for an enlargement in the TIS in terms of number of actors. Finally, in a successful TIS, mass markets (in terms of volume) may evolve [...]."
Legitimation	"Legitimacy is a matter of social acceptance and compliance with relevant institutions: the new technology and its proponents need to be considered appropriate and desirable by relevant actors in order for resources to be mobilized, for demand to form and for actors in the new TIS to acquire political strength."
Resource mobilization	"As a TIS evolves, a range of different resources needs to be mobilized[, for example] competence/human capital [...], financial capital (seed and venture capital, diversifying firms, etc.), and complementary assets such as complementary products, services, network infrastructure, etc."
Development of positive externalities	"[...] the generation of positive external economies is a key process in the formation and growth of a TIS. [...] These external economies, or free utilities, may be both pecuniary and non-pecuniary. [...] Entry of new firms into the emerging TIS is central to the development of positive externalities. [...]"

Source: Own elaboration based on Bergek et al. (2008a)

With slight variations, these seven functions cover all previous approaches by renowned Innovation System scholars, including an earlier draft by Johnson (2001) herself[23], Edquist (2005), Hekkert et al. (2007). Elaboration of specific functions has taken place, too, e.g. Bergek et al. (2008b).

In the original paper by Bergek et al. (2008a), the authors begin by explaining the content of each function, continue to give a brief illustrative example from various case studies that they have undertaken and then show examples of indicators that may reflect the extent to which a function is fulfilled. The indicators can be of a qualitative or quantitative nature, and the composite judgment on a function may be based on both. In Figure 2, the authors of this paper allocate the indicators given by Bergek et al. (2008a) to the three pillars of Innovation Systems in general, Academia/Science and Technology, Industry/Economy, Politics/Policy according to their experience in Innovation System research and with the background of case studies in the technological realms of bioethanol, wind energy and energy storage.

It is striking to see that the influence of each of these pillars may differ from indicator to indicator, hinting towards an agenda for each pillar of the Innovation System. Regarding the function of influence on the direction of search for example, politics/policy has a strong influence and a leading role on/regarding e.g. regulations and policy, which may be more decisive for the development of a TIS and therefore stronger than e.g. the actors' assessments of technological opportunities in Academia/Science and Technology or e.g. the articulation of demand from leading customers in Industry/Economy. The same applies to the function of legitimation, whose fulfillment is most strongly influenced by politics/policy that decide e.g. the strength of the legitimacy of the TIS, and how the alignment between TIS and current legislation and the value base in industry and society looks like. The influence of Academia/Science and Technology with e.g. what (or who) influences legitimacy, and how, or of Industry/Economy with e.g. how legitimacy influences demand, (legislation) and firm behavior, must be assessed as weaker.

Regarding the development of positive externalities, each pillar of an Innovation System in general has the same strong influence on/leading role regarding e.g. information flows and knowledge spillovers in Academia/Science and Technology, e.g. emergence of specialized intermediate goods and service providers in Industry/Economy, e.g. emergence of pooled labor markets in Politics/Policy. Insights from many more case studies should be analyzed regarding the involvement of each institution regarding the development of certain/specific

[23] Johnson was Anna Bergek's maiden name.

indicators, in order to understand the influences/roles better and deduce scientific/industrial/political agendas for each pillar of an e.g. TIS.

Figure 2: Functions and examples of indicators that may reflect the extent to which the function is fulfilled in a Technological Innovation System (TIS), per pillar

Functions	Academia/Science and Technology	Industry/Economy	Politics/Policy
Knowledge development and diffusion	E.g. scientific, technological knowledge (→ publications)	E.g. production, market, logistics and design knowledge (→ patents)	E.g. learning from new applications, production, etc.
Influence on the direction of search	E.g. actors' assessments of technological opport.	E.g. articulation of demand from leading customers	E.g. regulations and policy
Entrepreneurial experimentation	E.g. the breadth of technologies used	E.g. number of new entrants	E.g. number of different types of applications
Market formation	E.g. what phase the market is in (nursing, bridging, mature)	E.g. who the users are, the demand profile has been clearly articulated	E.g. if there are institutional stimuli for market formation
Legitimation	E.g. what (or who) influences legitimacy, and how	E.g. how legitimacy influences demand, (legislation) and firm behavior	E.g. the strength of the legitimacy of the TIS, alignment between TIS and current legislation and the value base in industry and society
Resource mobilization	E.g. changes in complementary assets	E.g. increasing volume of seed and venture capital	E.g. changing volume and quality of human resources
Development of positive externalities	E.g. information flows and knowledge spill-overs	E.g. emergence of specialized intermediate goods and service prov.	E.g. emergence of pooled labor markets

Source: Own elaboration based on Bergek et al. (2008a)

Dark grey = Strong influence/Leading role of the institution on/regarding the indicator stated.
Light grey = Influence/Associated role of the institution on/regarding the indicator stated.

8 Taxonomy

Regarding a taxonomy of TIS, there is no taxonomy existing and hence, lots of room for further research. According to taxonomies for RIS, TIS could be classified according to their national potential, the level of national integration, social cohesion, the governance modes of technology transfer and national barriers – with a different spatial boundary (empirically observed regional, national or supranational in case of TIS comparison in >1 nation, see above). Different types of TIS could be distinguished e.g. regarding the technologies at hand. Many more distinctions seem to be feasible and would need to be analyzed thoroughly.

9 Similar approaches

In terms of similar approaches, a wealth of different methods has been mentioned in literature: Thomas P. Hughes analyzed the growth of the electrical power system (the so-called "*Network of Power*", (Hughes, 1983), seen as a long process of technological innovation and development (Barnes and Hughes, 1984). Hughes treated technologies as systems and described both the internal dynamics within a technological system and external dynamics. As Barry Barnes (Barnes and Hughes, 1984) puts it in his review, "the great merit of Hughes' 'systems' thinking is that it produces a marvelous sensitivity to context", allowing him to conceive perfectly how technological systems in particular grow and change.

With the so-called "*Science and Technology Studies (STS)*" movement, a relatively new academic field emerged, when historians and sociologists of science, and scientists themselves, became interested in the relationship between scientific knowledge, technological systems, and society shortly after the middle of the 20th century (Harvard College, 2016). STS merges two broad streams of scholarship: Research on the nature and practices of science and technology (S&T), and the impacts and control of science and technology, with particular focus on the risks that S&T may pose to peace, security, community, democracy, environmental sustainability, and human values. The intertwined "*Socio-technical systems*" approach is used to better understand the development processes of technological artifacts, in this case the example of an early plastic called Bakelite or polyoxybenzylmethylenglycolanhydride (Bijker, 1987).

The "*development block*" concept refers to a sequence of complementarities which by way of a series of structural tensions, i.e. disequilibria, may result in a balanced situation (Dahmén, 1988). These complementarities appear in many different forms as important elements of industrial dynamics. Economic success of certain stages in a development process might require the realization of one or more specific complementary stages. The development potential(s) implied will be released as soon as missing stages have come into place or are expected to do so before long. The period in between is characterized by the aforementioned structural tensions. In other words by the same author, the notion of a development bloc signifies a cluster or a network of integrated physical production and distribution activities that created strong economic synergies at some higher level of aggregation and particularly over time (Eliasson and Eliasson, 1996).

In a "*network approach*", the analysis evolves around how companies handle their technological development in relation to external clients and organizations, particularly in terms of collaborative projects (Hakanson, 1990). Using research undertaken on Swedish companies, it becomes obvious that collaborative relationships are of strategic importance to companies, these relationships are investment-intensive, which makes the handling of them important, that the type of counterpart used for collaboration is important (suppliers and customers), and that collaborative relationships generally evolve organically and informally.

Within a dissertation, a case study treated the emergence of new industrial structures as a path-dependent process of accumulation, driven by technological as well as social factors (Lundgren, 1991). It was argued that the traditional definition of industry as a group of naturally selected producers was insufficient when it came to the analysis of the embryonic phases of the development of new industries. Instead, a historic and contextual perspective was suggested, defining the industry on the basis of complementary activities rather than from competitive ones. The industrial structure was perceived as "*industrial networks*" and divided into two interrelated systems: technological systems and networks of exchange relationships. The emergence and evolution of the Swedish image processing network was studied in order to illustrate how mobilization of resources and actors and coordination of activities affect the evolution of a network (Lundgren, 1992).

Knowledge about the process by which new industries emerge is invaluable both to industrial policy makers and to corporate managers and entrepreneurs (Van de Ven, 1989). A framework for viewing an industry as a so-called "*social system*" has been proposed at the interorganizational community level, adopting an accumulation theory of change and to examine industry emergence. The framework examines the processes by which industries emerge over time, as well as the roles of individual firms in creating an industry. Later on, it was refined to examine how an industrial infrastructure emerges to facilitate and inhibit technological innovation (Van de Ven, 1993). This infrastructure includes institutional arrangements, resource endowments, and proprietary activities that are necessary to develop and transform basic scientific knowledge into commercially viable products or services. The practical implications of this perspective emphasize that innovation managers must not only be concerned with micro developments of a proprietary technical device or product within their organization, but also with the creation of a macro industrial system, which embodies the social, economic, and political infrastructure that any technological community needs to sustain its members.

A "*competence bloc*" in contrast to the aforementioned development bloc, is defined from the product or market side (Eliasson and Eliasson, 1996). It is the total infrastructure needed to create (innovation), select (entrepreneurship), recognize (venture capital provision), diffuse (spillovers) and commercially exploit (receiver competence) new ideas in clusters of firms.

The competence bloc is dominated by human-embodied competence capital (Eliasson, 1989, 1990) that determines the efficiency characteristics of all other factors of production, including the organization of all economic activities that constitute the competence bloc. This means that the choice of market and hierarchical organization is part of the competence bloc. In a specific case study, the nature and formation of the biotech competence bloc are investigated, the experimental nature of its development clarified and the critical importance of competent venture capitalists explained.

In 1990, Michael E. Porter modeled the effect of the local business environment on competition in terms of four interrelated influences, graphically depicted in a "*diamond (model)*": Factor conditions (the cost and quality of inputs), demand conditions (the sophistication of local consumers), the context for firm strategy and rivalry (the nature and intensity of local competition), and related and supporting industries (the local extent and sophistication of suppliers and related industries) (Porter 1990; 1998). Diamond theory stresses how these elements combine to produce a dynamic, stimulating, and intensely competitive business environment.

A cluster is the manifestation of the diamond at work. Proximity – the collocation of companies, customers, and suppliers – amplifies all of the pressures to innovate and upgrade. That is why one focus of the research of Michael E. Porter became "*(industrial) clusters*", critical masses – in one place – of unusual competitive success in particular fields (Porter, 1998). According to him, clusters are a striking feature of virtually every national, regional, state, and even metropolitan economy, especially in more economically advanced nations. Clusters build on a paradox: The enduring competitive advantages in a global economy lie increasingly in local things – knowledge, relationships, motivation – that distant rivals cannot match. Although location remains fundamental to competition, its role today differs vastly from a generation ago. Untangling the paradox of location in a global economy reveals a number of key insights about how companies continually create competitive advantage. What happens *inside* companies is important, but clusters reveal that the immediate business environment *outside* companies plays a vital role as well. Therewith, clusters affect competitiveness within countries as well as across national borders. Clusters represent a new way of thinking about location, challenging much of the conventional wisdom about how companies should be configured, how institutions such as universities can contribute to competitive success, and how governments can promote economic development and prosperity.

Widely referred to as the "S*ocial construction of technological systems (SCOT)*", the literature offers detailed accounts of the micro-processes associated with technology emergence (Pinch et al., 1987, Garud et al., 2003). In SCOT, the developmental process of a technological artifact is described as an alternation of variation and selection. This results in a "multidirectional" model, in contrast with the linear models used explicitly in many innovation studies and implicitly in much history of technology. Such a multidirectional view is essential to any social constructivist account of technology, Trevor J. Pinch and Wiebe E. Bijker write. Their and other like-minded accounts suggest that human agency is distributed across actors who are embedded in emerging technological paths. Raghu Garud and Peter Karnøe offered a perspective on technology entrepreneurship that highlights the distributed nature of agency. Actors from the domains of production, use, evaluation and regulation become involved in the development of a technology. The development of technologies entails not just an act of discovery by alert individuals or speculation on the future, but also the creation of a new path through the distributed efforts of many. Path creation results in a steady accumulation of artifacts, tools, practices, rules and knowledge that begin shaping actors in the domains of design, production, use, evaluation and regulation. These accumulating inputs become the fabric within which and with which actors interact with the artifact and with one another to forge a new technological path. That is, agency is not only distributed but is embedded as well.

Starting with the question of how the potential of more sustainable technologies and modes of development may be exploited, René Kemp, Johan Schot and Remco Hoogma described how technical change is locked into dominant technological regimes, and present a perspective, called strategic niche management, on how to expedite a transition into a new regime (Kemp et al., 1998), a so-called "*regime shift*". The perspective consists of the creation and/or management of niches for promising technologies.

Within the same stream of research, a particular perspective on technology, stemming from sociology of technology (in this perspective technology, of itself, has no power, does nothing. Only in association with human agency, social structures and organizations does technology fulfill functions) lead to the question how technological transitions (TT) come about and if there are particular patterns and mechanisms in transition processes. As societal functions are fulfilled by "*sociotechnical configurations*", TT consist of a change from one sociotechnical configuration to another, involving substitution of technology, as well as changes in other elements (Geels, 2002). Such reconfiguration processes do not occur easily, because the elements in a sociotechnical configuration are linked and aligned to each other. TT is defined as major, long-term technological changes in the way societal functions are fulfilled. TT does not only involve changes in technology, but also changes in user practices, regulation, industrial networks, infrastructure, and symbolic meaning or culture. As a result, a multi-level perspective on TT is being developed, where two views of the evolution are combined: (i) Evolution as a process of variation, selection and retention, (ii) Evolution as a process of unfolding and reconfiguration.

10 Further research

Regarding further research on TIS, research on the nature of the different phases of development to assess the relative goodness of different systems should be done, e.g. in order to better understand the formative phase (Bergek et al., 2008a).[24] Another demand would be to establish a comprehensive taxonomy that is still missing and offers massive room for further research (see above, aspect **8 Taxonomy**).

Conclusion

In the context of this paper, the authors present the results of an extensive literature review on Innovation System research. Starting with the analytical basis of the commonalities "system" and "innovation", the authors show the evolution of Innovation System research over four main Innovation System approaches: National Innovation Systems (NIS), Regional Innovation Systems (RIS), Sectoral Innovation Systems (SIS) and Technological Innovation Systems (TIS). The analysis is structured systematically along ten comprehensive criteria. With this paper, the authors intend to give a guideline through the more and more confusing field of Innovation System research. Academics may find it to be a great reader as an introduction into the field, practitioners from basic and applied science, industry or policy may find it indispensable in order to understand which Innovation System approach may be best for their specific analytical purposes. Within a forthcoming paper, the more modern SIS and TIS approaches will receive special attention, they will be compared to each other and a discussion will present insight/a guideline on when or for which specific case study to use which one of the two approaches.

Further Innovation System research should also integrate an analysis of the latest approach of the Innovation System framework, which is being proposed by Binz et al. and is titled *Global Innovation Systems*. This new Innovation System approach stresses the transnationality of innovation. It builds upon existing Innovation System approaches as presented in this paper but repositions them towards literature on global value chains, global production networks or global innovation networks (Coe et al., 2004; Gereffi et al., 2005; Liu

[24] The authors have presented a poster on this topic titled „Extension of the phase model for assessing the functionality of TIS“ at the 16th International Schumpeter Society (ISS) conference 2016 in Montreal, Canada, of the International Joseph A. Schumpeter Society from July 6-8, 2016.

et al., 2013). As the Global Innovation System (GIS) approach is not established yet, there has been no application and case studies cannot be found yet.

Therewith, it has been shown that Innovation System research is in the process of continuous evolution. The very beginnings with the NIS approach are already about 30 years ago. Over the following decades, the Innovation System approach has established itself as the most influential paradigm within the international innovation research communities (Lindner et al., 2016). This perspective does not only frame the scientific debates dealing with innovation, it also provides conceptual orientation and strategic guidance for many governments and international and supranational organizations. And although there has been a growing amount of criticism regarding the Innovation System approach, researchers still claim that it continues to provide useful analytical lenses and constitutes a valuable conceptual frame of reference for the design of science, technology and innovation (STI) policies (Lindner et al., 2016; Markard et al., 2015). These researchers revise and continue to develop the Innovation System approach further in order to respond to the challenges posed, specifically directionality and normative orientation. They propose four capacities for reflexive governance of innovation systems as follows: Self-reflection capacities, bridging and integration capacities, anticipation capacities and experimentation capacities (Lindner et al., 2016). This and forthcoming research will need to be observed closely in the coming years, as it not only addresses challenges of the Innovation System framework, but it also resonates with and responds to a number of interrelated phenomena and developments observed by contemporary innovation research.

Appendix

#	Differentiation criteria	**National Innovation System (NIS)**	**Regional Innovation System (RIS)**	**Sectoral Innovation System (SIS)**	**Technological Innovation System (TIS)**
1	Founder of theory (year)[25]	List (1844), Freeman (1987), Dosi et al. (1988), Lundvall (1992b), Nelson (1993), Edquist (1997)	Cooke (1992), Braczyk et al. (1998), Howells (1999), Maskell and Malmberg (1999), Asheim and Coenen (2005), Doloreux (2002)	Breschi and Malerba (1997); Breschi et al. (2000); Malerba (2002; 2004; 2005)	Carlsson and Stankiewicz (1991); Jacobsson and Johnson (2000), Rickne (2000), Johnson (2001), Hekkert et al. (2007a); Bergek et al. (2008a)
	Research program	Freeman (1987) "was made possible by a research grant from the Economic and Social Research Council [, largely] based on a report prepared for the ESRC", "the UK's leading research and training agency addressing economic and social concerns"	Cooke (1992) resulted from earlier research on regional innovation e.g. in Baden-Württemberg and Emilia-Romagna for various Regional Industrial Research Reports granted by the Economic and Social Research Council (ESRC) (see left)	Malerba (2002) refers to the research program from the European Union Targeted Socio-economic Research "Sectoral System in Europe: Innovation, Competitiveness and Growth" Project	Carlsson and Stankiewicz (1991) was developed within the framework of a research program under the lead of Bo Carlsson of Sweden's Technological System and Future Development Potential
2	Basis study/thoughts	„The National System of Political Economy" (List 1844), policies for industrialization and economic growth for underdeveloped Germany in relation to England (Freeman, 1995). After WWII, catch-up success of first Japan (Freeman, 1987) and then South Korea, collapse of the Socialist economies of Eastern Europe (Freeman 1995). „National Innovation Systems" in (Dosi 1988) and (Lundvall 1992) later on.	„(...) the preferred spatial level for regulatory intervention is that of the region rather than the central state." (Cooke 1992) „It may make sense to talk about a regional or local technology system (...)" (Carlsson, 1995), „systemic innovation is appropriately sought at the regional (and even subregional) level as well as at the national and global levels" (Cooke et al., 1997). RISs „provide an additional layer to (...) a systems approach to innovation." (Howells, 1999)	Innovation and technological change have different paths dependencies, dependent on the sector in which they happen. Thus they have different characteristics, shaped by knowledge, actors and institutions. (Malerba, 2004)	„(...) the economic growth of countries (...) is a function of the technological systems in which various economic agents participate. The boundaries of technological systems may or may not coincide with national borders and may vary from one techno-industrial area to another." (Carlsson et al. 1991) „The existing innovation system approaches seem to have a shared understanding of a number of basic functions that are (or should be) served in innovation systems." (Johnson 2001)

[25] Most important conceptual publications according to the author's view of this article.

3	Five case studies most cited („Best Practice")	Web of Science Results 1. Freeman 1995 (440) 2. Furman et al. 2002 (395) 3. Meyer-Krahmer and Schmoch 1998 (245) 4. Liu and White 2001 (204) 5. Mowery and Oxley 1995 (132)	Web of Science Results 1. Acs et al. 2002 (310) 2. Asheim and Coenen 2005 (256) 3. Cooke 1992 (184) 4. Rodríguez-Pose and Crescenzi 2008 (114) 5. Fritsch and Franke 2004 (97)	Web of Science Results 1. Miyazaki and Islam 2007 (54) 2. Oltra and Saint Jean 2009 (44) 3. Cooke 2002 (40) 4. Beerepoot and Beerepoot 2007 (39) 5. Sapsed et al. 2007 (35)	Web of Science Results 1. Hekkert et al. 2007 (270) 2. Bergek et al. 2008b (52) 3. Foxon et al. 2010 (51) 4. Hekkert and Negro 2009 (51) 5. Markard and Truffer 2008 (28)
4	Spatial boundaries Conceptually/Empirically observed[26]	**Conceptually** Nelson and Rosenberg (1993) write that the concept of a 'national" system may be too broad, as institutions supporting technical innovation in one field may have little in common with the institutions supporting another field. (Edquist, 1997) For a NIS, the country's borders normally provide the boundaries. However, it could be argued that the criteria for RIS are as valid for national ones. In other words, if the degree of coherence or inward orientation is very low, the country might not reasonably be considered to have a NIS. It was also mentioned above that the NIS approach is less relevant for large than for smaller countries. (Edquist, 2005) - NIS of Germany, Japan and the former USSR (Freeman, 1995) - NIS of the United States of America and various OECD countries (Furman et al. 2002) - NIS of Germany (Meyer-Krahmer 1998)	**Conceptually** The diversity of the units of analysis utilized in studies of regional innovation systems presents a major problem in developing a unified conceptual framework for the construct of 'the region' as a theoretical object of study. As a result, it prompts renewed confusion vis-à-vis not only the application and assessment of an innovation system at the regional level (however defined) but also its territorial boundaries (Doloreux and Parto, 2005). - RISs/metropolitan statistical areas within the United States of America (Acs et al. 2002) - RISs (TISs?) in various regions/federal states within Norway and Sweden (Asheim et al. 2005 - Regions in Japan, Germany and France, the United Kingdom and Wales (Cooke 1992) - NUTS 1 ("major socio-economic") and NUTS 2 ("basic")	**Conceptually** National boundaries are not necessarily appropriate, yet most case studies follow a national paradigm and compare sectoral systems on a national level (Malerba, 2004) - (French) system (Oltra 2009) - Regional sectoral (Germany, Cambridge, Massachusetts, Cambidge, UK) (Cooke 2002) - (UK) system (Sapsed et al. 2007) - Japan, United States, European Union (Miyazaki et al. 2007) - (Dutch) system (Beerenpoot et al. 2007) **Empirically observed** Regional or national (most often) or supranational (in case of transnational sector)	**Conceptually** Generally global in character; geographical delimitation should not be used alone; strong international component is needed (Bergek et al., 2008a) - (Swiss) system (Markard et al. 2009) - (Swedish and German) system (Bergek et al. 2008) - UK system (Foxon et al. 2010) - German and Dutch system (Hekkert et al. 2007; 2009) **Empirically observed** Regional or national or supranational (in case of TIS comparison in >1 nation)

[26] Based on all case studies analyzed by the authors.

		- NIS of China (Liu et al. 2001) - NIS of Japan and other East Asian economies (Mowery et al. 1995) **Empirically observed** National or supranational (in case of NIS comparison in >1 nation)	regions within the EU-25 (Rodríguez-Pose et al. 2008)[27] - RISs/federal states within Germany (Fritsch et al. 2004) **Empirically observed** Regional or national (in case of RIS comparison in 1 nation) or supranational (in case of RIS comparison in >1 nation)		
5	Unit of analysis Conceptual/Empirically observed[28]	**Conceptually** Although NIS is only one of several possible specifications of the generic systems of innovation concept, it certainly remains one of the most relevant. [...] there are sharp differences among various national systems in such attributes as institutional set-up, organizational set-up, investments in R&D, and performance. [...] Another reason to focus on NISs is that most public policies influencing innovation processes or the economy as a whole are still designed and implemented at the national level (Edquist, 2005). **Empirically observed** - Economic analysis with historic examples of Germany, Japan and the former USSR (Freeman 1995) - National innovative capacity of	**Conceptually** Cities, metropolitan regions, districts within cities or metropolitan regions, regions defined within the NUTS II classification, areas on the supra-regional/sub-national scale – the diversity of the units of analysis is immense. Yet – "the literature on regional innovation systems provides substantial description and analyses of relationships between innovation, learning and the economic performance of particular regions (Doloreux 2005). **Empirically observed** - Regional innovative activity in 125 US metropolitan statistical areas (MSAs) (Acs et al. 2002)	**Conceptually** "Flexibility has to be used in the choice of the unit of analysis" (Malerba, 2005, p. 68); appropriate unit of analysis is not necessarily firms; they could be individuals, firms subunits (such as R&D department) or groups of firms (industry consortia) (Malerba, 2004) **Empirically observed** - (Nano-) Technology and Science and its actors (countries, firms, authors) (Miyazaki and Islam, 2007) - (French automotive) industry (Oltra and Saint Jean, 2009) - (Biotechnology) clusters (Cooke, 2002) - (energy efficiency) technologies (Beerepoot and Beerepoot, 2007) - (entrepreneurial) firms (Sapsed et al., 2007)	**Conceptually** A specific technology; level of aggregation: one specific knowledge field (e.g. wind power; biogas) or a set of related knowledge fields (e.g. biotechnology); range of applications: limit the use in specific applications, products or industries (e.g. on-shore wind power) (Bergek et al., 2008a) **Empirically observed** - (Renewable/Sustainable) Technologies (Bergek et al., 2008b; Hekkert and Negro, 2009; Hekkert et al., 2007b; Markard et al., 2009)

[27] The „Nomenclature of Territorial Units for Statistics“ (NUTS) is a geocode standard for referencing the subdivisions of countries for statistical purposes. The standard is developed and regulated by the European Union, and thus only covers the member states of the EU in detail. (Source: Wikipedia by Wikimedia Foundation, Inc. (2015). Link: https://en.wikipedia.org/wiki/Nomenclature_of_Territorial_Units_for_Statistics, last retrieved on July 8, 2015)

[28] Based on all case studies analyzed by the authors.

		the United States of America and various OECD countries (Furman et al. 2002) - Technology transfer within the German NIS (Meyer-Krahmer 1998) - Generic framework for analyzing innovation systems applied to a comparison of China's NIS under central planning and since reforms (Liu et al. 2001) - Role of NISs in the inward transfer of technology in Japan and other East Asian economies (Mowery et al. 1995)	- Discussion of different types of RIS with five empirical illustrations: Furniture industry in Salling/Denmark, wireless communication industry in North Jutland/Denmark, functional food industry in Scania/Sweden, food industry in Rogaland/Norway, electronics industry in Horten/Norway (Asheim et al. 2005 - Role of regulation for regional innovation with material evidence from Japan, Germany and France, within the United Kingdom and with particular reference to Wales (Cooke 1992) - Impact of innovation on regional economic performance in Europe with multiple regression analysis for all regions of the EU-25 (Rodríguez-Pose et al. 2008) - Impact of knowledge spillovers and R&D cooperation on innovation activities in the three German regions of Baden, Hanover-Brunswick-Goettingen in Lower Saxony and Saxony (Fritsch et al. 2004)		
6	Basic components	1. Private and public firms 2. Universities 3. Government agencies (Niosi et al., 1993)[29]	1. Firms 2. Institutions 3. Knowledge infrastructure 4. Policy-oriented regional	1. Institutions 2. Actors and Networks 3. Knowledge and Technology (Malerba, 2004)	1. Actors (and their competencies) 2. Networks 3. Institutions (Carlsson et al. 1991, Jacobsson

[29] Interactions between the actors mentioned imply a network structure: "The innovative performance of a country depends to a large extent on how these actors relate to each other as elements of a collective system of knowledge creation and use as well as the technologies they use" (OECD (1997), in accordance with Freeman (1987), Lundvall (1992b), Nelson (1993) among others). "Innovation is thus the result of a complex interaction between various actors and institutions. [...] For policy makers, an understanding of the national innovation system can help identify leverage points for enhancing innovative performance and overall competitiveness."

			innovation (Doloreux, 2002)		et al. 2000)
7	Functional analysis (Evolution/Transition)[30]	Five "primary functions"[31]: 1. Create „new" knowledge 2. Guide the direction of the search process 3. Supply resources, e.g. capital and competence 4. Facilitate the creation of positive external economies (in the form of an exchange of information, knowledge, and visions); and 5. Facilitate the formation of markets (Johnson and Jacobsson (2003), according to Feinson (2003), and an expanded list by Rickne (2000), as cited in Edquist (2001))	1. Interactive learning 2. Knowledge production 3. Proximity 4. Social embeddedness (Doloreux 2002)	Moallemi et al. (2014): "Generation of dynamics in two processes: variety creation and selection" Malerba (2004): Two key evolutionary processes: **variety creation and selection** (Nelson, 1995; Metcalfe, 1998) affect industrial dynamics and account for many of its differences across sectoral systems. Variety creation: refers to products, technologies, firms and institutions (new firms bring variety of approaches). Processes of selection: key role of reducing heterogeneity[32]	1. Knowledge development and diffusion 2. Influence on the direction of search 3. Entrepreneurial experimentation 4. Market formation 5. Legitimation 6. Resource mobilization 7. Development of positive externalities (Bergek et al., 2008a)
8	Taxonomy/Typology	1. Type 1: Size and income of countries (Nelson and Rosenberg, 1993) 2. Type 2: Distance from innovation process (Narrow vs. Broad NIS)[33] and Level of Formality (Formal vs. Informal) (Schoser (1999) according to Feinson (2003)) 3. Type 3: Eight dimensions for quantitative NIS analyses	1. Type 1: Regional potential (Cooke, 2002), 2. Type 2: Level of regional integration (Howells 1999) 3. Type 3: Social cohesion (Asheim and Isaksen, 1997) 4. Type 4: Governance modes of technology transfer (Braczyk et al., 1998) 5. Type 5: Regional barriers (Isaksen, 2001)	Not existent; room for further research	Not existent; room for further research

[30] According to the author's view, we understand functions as being critical for evolution and progress of the Innovation System.

[31] According to the author's view, we note a difference between the goal (also labelled „the main function" by Edquist (2005)) of any innovation system (which is to foster innovation) and the functions (also labeled „activities" by Edquist (2005) within an innovation system that lead to this very goal and „influence the development, diffusion, and use of innovation" (Edquist, 2005). The choice of labels has to be explained properly.

[32] According to the authors, the seven functions of the TIS also contribute to the evolution and progress of SIS.

[33] A distinction has been made between narrow (actor-oriented, National Innovation System) and broad (institution-oriented, National Innovation Environment) NISs (OECD 1997). The NIS linkages, which reflect the absorptive capacity of the system, are determined by the ways in which knowledge and resources flow between the narrow and broad levels (Feinson 2003)

		(Godinho et al., 2006) 4. Type 4: Time series perspective for drivers of NIS (Castellacci and Natera, 2013)	(Doloreux 2002) 6. Type 6: Type of RIS[34] (Territorially embedded/grassroots RIS, Networked/network RIS, Regionalised national/dirigiste RIS) vs. Type of knowledge (Analytical/science-based, Synthetic/engineering-based, Symbolic/artistic-based) (Asheim, 2009)		
9	Similar approaches[35]	1. Input-output analysis (Leontief, 1953)	1. Industrial districts (Belussi and Caldari, 2009; Marshall, 1879) 2. Technopole (Technopolis Japan/Technopolis policy France, 1970s – e.g. Simmie (1994) 3. Innovative milieu (GREMI study group 1980s, Crevoisier et al. (1991)) 4. Learning regions (Doloreux, 2002; Florida, 1995) 5. Local/regional economies (Saxenian, 1994)	1. Input-output analysis (Leontief, 1953) 2. Social system (Van de Ven, 1989; 1993) Not mentioned36	1. Network of Power (Hughes, 1983) 2. Socio-technical systems (Bijker et al., 1987) 3. Development block (Dahmén, 1988) 4. Network approach (Hakanson, 1990; Lundgren, 1992; 1993) 5. Social system (Van de Ven, 1989; 1993) 6. Competence bloc (Eliasson, 1989; 1990, Eliasson et al., 1996) 7. Diamond model (Porter, 1990, 1998) 8. Industrial clusters (Porter, 1998) 9. Social construction of technological systems (Garud and Karnøe, 2003; Pinch and Bijker, 1987) 10. Regime shift (Kemp et al., 1998) 11. Sociotechnical configurations (Geels, 2002)

[34] A distinction has been made between a narrow (knowledge exploration and diffusing, knowledge exploitation) and a broad (including a wider system supporting learning and innovation) definition of RIS

[35] Necessary condition: Same objective („benchmarking of an innovation system“); sufficient condition: Same unit of analysis

[36] Malerba (2004) uses three foundations: 1) Market structure and innovation approach from Kamien and Schwartz (1982); 2) technology regime according to Nelson and Winter; Nelson and Winter (1977); (1982); 3) sources of innovation and the mechanism of appropriability in Levin et al. (1987); Mowery and Nelson (1999); Nelson (1993); Pavitt (1984), Rosenberg (1976, 1982)

10	Further research[37]	1. A clearer and more explicit combination of the NIS approach with economic growth is still lacking 2. The interplay between a country's innovation system and other economic subsystems is far from being studied exhaustively 3. Limited knowledge on the dynamic properties of NIS, especially with regard to their stability and their structural evolution (Balzat and Hanusch, 2004) 1. A time series perspective 2. The dynamics and determinants of innovative capability 3. The dynamics and multifaceted nature of absorptive capacity 4. The coevolution between innovative capability and absorptive capacity (Castellacci and Natera, 2013) Six research strands challenge the classical NIS/RIS framework: User innovation, social innovation, collaborative innovation, new innovation intermediaries, venture philanthropy, social and relational capital and non-R&D intensive industries. Each of these phenomena points to relevant contributions to national or regional innovation capacities that are not well captured by the established NIS/RIS framework. (Warnke et al., 2016)	1. RIS addresses elusive elements that make it difficult to provide a clear definition with a clear application 2. The concept appears to be a mélange of different sources 3. The concept of RIS tends to be confined to high-tech and/or manufacturing sectors 4. For a more complete view, RIS should also incorporate findings from regions where this concept has been empirically tested. (...) Moreover, only a few empirical studies have applied this approach to peripheral regions, rural areas, and declining economies (Doloreux, 2002) Six research strands challenge the classical NIS/RIS framework: User innovation, social innovation, collaborative innovation, new innovation intermediaries, venture philanthropy, social and relational capital and non-R&D intensive industries. Each of these phenomena points to relevant contributions to national or regional innovation capacities that are not well captured by the established NIS/RIS framework. (Warnke et al., 2016)	Analysis of sectoral systems along similar dimensions; construction of a taxonomy; development of policy recommendations; conceptual and theoretical work, contrasted by empirics (Malerba, 2002)	Research on the nature of the different phases of development to assess the relative goodness of different systems; better understand the formative phase; establish a taxonomy (Bergek et al., 2008a)

[37] Further research regarding the Innovation System framework overall proposes four capacities for reflexive governance of innovation systems as follows: Self-reflection capacities, bridging and integration capacities, anticipation capacities and experimentation capacities (Lindner et al., 2016). This and forthcoming research will need to observed closely in the coming years.

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