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Evolution of innovation system literature: Intellectual bases and emerging trends

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ABSTRACT

The evolution of innovation system literature is scrutinized to delineate the conceptual trends over the past 30 years. We applied the Sigma index which is supposed to include not only the frontier contributions in the field but also the intellectual bases conveying transformative concepts. Our examination shows that after the establishment of the National Innovation System (NIS) as a principal framework, Regional IS literature emerged as a main branch during the period of 2002–2007, while Technological IS developed as the second main branch from 2007 to 2012. Surprisingly, Sectoral IS has not yet generated a separate constellation, whereas the period after 2012 mainly witnessed the emergence of Triple Helix and Agricultural IS as two new branches. The core of the literature has become classified into persistent intellectual bases (e.g. Lundvall 1992 and Nelson, 1993), diminishing pioneers (e.g. Freeman 1987; Edquist, 1997), emerging works (e.g. Hekkert et al., 2008; Bathelt et al. 2004) and fluctuating others (e.g. Carlsson, 1991; Malerba 2002). Conceptual implications are discussed at the end.

1. Introduction

The field of innovation studies has been recently scrutinized to examine the main contributions (Martin, 2012), disciplinary characteristics (Fagerberg et al., 2012a; Fagerberg and Verspagen, 2009), and conceptual developments (Fagerberg et al., 2012b). Other scholars have captured state of the art knowledge by bringing together major contributions in handbooks (Fagerberg et al., 2004; Hall and Rosenberg, 2010), or collections of the most important papers (Fagerberg, 2015; Martin and Nightingale, 2000).

Dialogues among multiple disciplines about a topic continue to shape the Multi-disciplinary fields, while inter-disciplinary fields are those having generated concepts and approaches, including notions from contributing approaches (Bowden, 1995). Scholars engaged in those topics are interested in showing how they have produced such concepts indicating that they are transforming from a multi into interdisciplinary field (such as STS studies, Jasanoff et al., 1995; Hackett et al., 2008; Felt et al., 2017).

The field of innovation studies shares a similar characteristic that has emerged in a cross section of economics of R&D and business studies (Fagerberg et al., 2012b). Among the very important and new concepts within this field, NIS might be the preeminent interdisciplinary approach (Martin, 2012), popularized in the late 1980s in a book edited by Dosi et al. (1988) containing a specific section discussing NIS in four different chapters by Richard Nelson (1988), Christopher Freeman (1988), Bengt-Åke Lundvall (1988) and Pelikan (1988).

Citation analysis of the whole literature of innovation studies has been done by Martin (2012). He showed that IS literature, as one of the main branches of innovation studies, is composed of National, Regional, Sectoral and Technological systems of innovation. Fagerberg et al. (2012b) introduced the J-Index to measure the transformative works in the literature. They found the contributions of Nelson (1993) and Lundvall (1992) on NIS are among the top most notable works in the field.

Although the generation of NIS (Sharif, 2006), its underlying concepts (Lundvall, 2007), its emerging trends (Watkins et al., 2015), as well as its possible strengths and weaknesses (Lundvall, 2010) have been discussed extensively, less has been done to analyse the evolution of NIS, its different variations and the possible ways ahead. Particularly, previous studies have tended to remain qualitative based on the judgments of prominent scholars, except for Doloreux and Gomez (2017), Uriona-Maldonado et al. (2012), and Liu et al. (2015).

Sharif (2006) has conducted several interviews with key persons to determine the origins of the IS approach as well as the conflicting issues that remained unsolved. Watkins et al. (2015) critically reviewed the

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literature and points to three shifts in the role of intermediary institutions as the NIS started from macro approaches (NIS) then moved into meso-level views (RIS, TIS, and SIS) and finally the more recent micro works on the role of intermediaries. Lundvall (2007, 2010) tends to articulate his theoretical arguments regarding the underlying concepts rather than providing a systemic review of the field.

The analysis of Doloreux and Gomez (2017) used a quantitative approach to discuss the evolution of RIS literature and was based on 341 articles published since 1998. The same approach has been conducted for TIS recently, including 311 articles (Uriona-Maldonado and Rodrigues Vaz, 2015). However, they were confined to regional and technological versions of IS without providing a holistic picture of other IS versions.

Uriona-Maldonado et al. (2012), based on 773 articles, highlighted the most citied works, authors, journals and universities by searching "innovation system", "innovation systems", "system of innovation" and "systems of innovation". They found that Lundvall (1992), Nelson (1993), Freeman (1987), Edquist (1997), Porter (1990), Nelson and Winter (1982), and Cohen and Levinthal (1990) were the most cited works in the collection. In a more robust and recent study, Liu et al. (2015) analysed the co-citation network of the literature. Their underlying database included 1565 publications obtained from WoS using similar search keywords. The results of their work are similar to Uriona-Maldonado et al. (2012) about the most important works in terms of citation analysis, yet provided unique results in terms of the co-citation analysis. However, both provide a rather static picture of the field with less emphasis on its evolution.

Regarding their method, a central problem arises from the fact that citation and co-citation analyses are not enough to show the most important works in terms of "burst speed" as well as "centrality" of concepts. To fill this gap, we applied the Sigma index, which is a combination of burst and betweeness centrality indexes developed by Chen (2006). Finally, our search covers a wider dataset as we added NIS and NSI as well as some other related concepts, such as technology parks, in our keyword searches, which in turn resulted in the discovery of 2600 articles. Then we expanded our database by adding the references of this initial result. Our study therefore provides somewhat different results from former studies in terms of important works, but also envisages the evolution of the field.

We use the classification of IS including NIS, RIS, RIS and SIS by Martin (2012), not only because of its popularity and validity, but also for the sake of comparison with the study of Liu et al. (2015), which used a similar taxonomy.

The next section presents a literature review of different versions of the IS innovation system including NIS, RIS, TIS and SIS. The methodology used for the bibliometric analysis is introduced in Section 3. Sections 4 and 5 present the results of our analysis and the discussion of the evolution of literature over time. The paper ends with a section on conclusions and implications.

2. Different versions of innovation systems

It has been argued that the first scholar who used the concept of NIS was Chris Freeman in an unpublished report to OECD in 1982 (Lundvall, 2016). Moreover, the first who used the word "innovation system" was Lundvall himself in his theory of innovation as an interactive learning process (Lundvall, 1985). In contrast, Godin (2009) challenged the novelty of the concept and argued that Freeman took inspiration from OECD's earlier work on national research systems. Nonetheless, there is a general agreement that this concept arose as a result of better understanding of how innovations occur (Fagerberg, 2004); from single and homogenous agents to multiple and diverse agents (Rothwell, 1994), from isolated actors into a network of actors (Edquist, 2005) and by considering the important role of institutions (Martin and Nightingale, 2000) and knowledge (Lundvall et al., 2002). We will explore those literatures as far as they relate to our work in the following sections.

2.1. National system of innovation

In its current format, the edited book by Dosi et al. (1988) popularized the concept of NIS. In a chapter, Richard Nelson defined NIS as a system within which knowledge generation is divided between government and private sectors. He explained how this system is constructed differently in the US and Japan (Nelson, 1988). Although Edquist (1997) referred to his definition as a narrow version of NIS, Nelson (1993) collected a series of studies of national innovation systems rooted in this view.

The chapter by Lundvall made a connection between his theory of innovation as an interactive process (Lundvall, 1985) and the role of national elements in facilitating those interactions (Lundvall, 1988). His conception was referred to as the broader view to NIS (Edquist, 1997) and was used to organize case studies on Denmark's innovation system (Lundvall, 1992).

Freeman adopted a different view to show that Japan's success in closing the technological gap was highly rooted in its national institutions (Freeman, 1987). He referred to those institutions as the National Innovation System of Japan, which in his view was especially well-suited to absorb and use information and communication technologies (ICT) that were forming the new emerging techno-economic paradigm of the 1980s (Freeman, 1988). He published several papers (e.g. Freeman, 1995) discussing various aspects of NIS until his last paper in 2002, which demonstrated how NIS could be used as an analytical device to study not only the experiences of catching-up, but also cases of falling behind (Freeman, 2002; Freeman and Louca, 2001).

2.2. Other versions of Innovation Systems

NIS has strong roots in economic geography (Martin and Nightingale, 2000), and it soon developed into the regional innovation system concept (RIS), contending that geographical parameters are important, especially for sharing tacit knowledge (Saxenian, 1994). Plenty of case studies demonstrated that regional systems differ (Wolfe and Gertler, 1998) and a variety of frameworks developed to capture the local characteristics of innovation (Braczyk and Heidenreich, 1998; Cooke et al., 1997). Policy-makers embraced this approach to understand how innovation could be promoted in specific regions, especially in the context of Europe with the underlying concept of Smart Specialization (Foray et al., 2009; Foray and Goenaga, 2013).

The systemic view on technological changes led to the concept of technological innovation systems (TIS) denoting technology transformation from early entrepreneurial phase to maturity and diffusion (Carlsson and Stankiewicz, 1991, 1994; Carlsson, 1995, 1997). TIS is defined as a system of actors, networks, institutions, and technologies interacting to develop a specific technological field (Bergek et al., 2015). Scholars from Scandinavian countries and the Netherlands developed this approach (Hekkert et al., 2007) and introduced new frameworks for studying technological progress based on a functional view to innovation systems (Bergek et al., 2008). This version of innovation systems is not only interesting for those policy makers who liked to promote specific technological fields (Hillman et al., 2011; Reichardt et al., 2016), but also for scholars intending to understand technological changes from a systemic perspective (Wesseling et al., 2014).

The sectoral view on innovation was first introduced by Breschi and Malerba (1997) in a paper trying to show the sectoral differences in innovation performance, and is seen as one of the most important issues in innovation theories during the past two decades (i.e. Nelson and Winter, 1977). The concept of Schumpeter Mark 1 and Mark II was used as an analytical framework to distinguish two types of sectors with regard to their innovation behaviour (Malerba and Orsenigo, 1995, 1996, 1997). SIS is defined by three building blocks, namely "actors and networks", "institutions", and "technological regime" (Malerba, 2002, 2004). The concept of a technological regime has been used by scholars to study catching-up at the sectoral level (Lee and Lim, 2001; Park and

Lee, 2006; Lee, 2013; Lee and Malerba, 2017; Malerba and Nelson, 2011). Another version which uses different framework is Triple Helix (Etzkowitz and Leydesdorff, 2000) emphasizing on interactions among government, industry and universities (Souzanchi and Zarghami, 2019).

These developments in innovation systems spur important questions about not only the evolution and present status of IS innovations, but also about the future and its possible directions. Although the above classification provides a conceptual framework to analyse the results, it still remains unclear how the field will evolve. Particularly, to what extent each of the above approaches will be embraced by scholars? What are the minor concepts and major branches? What are the future trends?

3. Method of analysis

It is normal in the literature to use burstiness as a measure of identifying important works within a scientific field. This is done by calculating the cumulative citations of works over time. If a work gets increasing citations over time, it means that it is becoming more important (Kleinberg, 2003). Some works might burst in a short period and then become obsolete, or they may continue to get increasing citations for a long period. Some works might have a large number of total citations in the past, but they are no longer getting current citations. Therefore, the total number of citations is not always a good measure for research frontiers, burstiness tries to cover this weakness.

Co-citation analysis is another approach to identify the trend of knowledge in scientific fields (Griffith et al., 1986). It is mainly helpful to delineate development trajectories and is also able to show some hidden patterns in both development and diffusion of knowledge within a field (Nerur et al., 2008). This technique can identify socially constructed network of scientists by linking two works that have been cited in a third publication. Having a high number of co-citations indicates that the two works are strongly related to each other (Small, 1973).

Betweeness centrality (BC) uses the co-citation technique. It is a measure based on finding more important works that lie at the heart of other concepts. High BC shows that a node lies at a shorter distance between other nodes in the network. Central nodes play a connecting role within the network and could be used as a measure for intellectual concepts linking other concepts together (Freeman, 1977). Although this technique can identify intellectual bases and conceptual paradigm, yet it is not able to highlight frontier researches in a field.

Chen (2006) developed the Sigma index in order to bring both features together. We used the measure from Chen et al. (2009) which considers not only the speed of citations over time (burstiness), but also the intellectual bases measured by the BC. It supposes that each paper conveys a concept and co-citation between the two papers means there is a relation between them in a scientific field. With the emergence of a new paper connecting two rather different concepts, we may conclude that a new concept is being adopted within the scientific field (Chen et al., 2009). Therefore, not only is it able to map the network of concepts and their connections together but also the speed at which frontier works are getting citations.

The Sigma index combines intellectual bases and research frontiers. When mapping the network of papers each node or circle represents a contribution and the size of each circle shows its Sigma index. We have drawn 4 networks for 2002, 2007, 2012 and 2016 to capture the dynamic of the literature.

We have undertaken the following steps to evaluate the transition of innovation systems literature:

1. The Web of Science has been searched for the words “Innovation System”, “Innovation Systems”, “System of Innovation” and “Systems of Innovation” in their topics including title, abstract and keywords like former studies until the end of 2016, yielding 2482 articles including book chapters and proceedings. Although it supposed enough in the previous works (Liu et al., 2015; Uriona-Maldonado et al., 2012), we have conducted further complementary searches including, “technology park”, “technology parks”, “science park”, “science parks”, “business incubator”, “business incubators”, “business incubation” and “innovation” specifically in the fields of “business” and “economics” and then removed duplicates from our database. This resulted in 118 further references, ultimately producing a database with 2600 articles recorded in a text format, including at least 1000 more works in comparison to earlier studies.
2. We used the script language Python to analyse the references in selected papers (Peirson et al., 2016). This resulted in a database with 148,374 references covering a variety of publications including journal articles, books, reports, etc.
3. In the first stage, we omitted works with less than five citations labeled as not significant.
4. The database was polished to provide a homogenous list of works. For instance, Lundvall (1992) might have been cited with five different syntaxes.
5. We then calculated burstiness as another important measure indicating the rate of growth of citations for each article. Kleinberg (2003) provided a method for extracting burstiness, and Chen et al. (2009) used Kleinbergs method as a starting point to develop the Sigma index. We follow Chen et al.'s method and normalize Sigma between 0 and 1 (Chen et al., 2009).
6. The next stage included determining betweeness centrality (BC) measured by the following formula:

$$BC = g(v) = \sum_{s \neq v \neq t} \frac{p_{st(v)}}{p_{st}}$$

where g(v) is the amount of BC for the node v and p_{st} is the shortest distance between nodes s and t.

7. Sigma was then measured as in Chen et al. (2009) as follows:

$$\sum(v) = (g(v) + 1)^{Burstness(v)}$$

Where Σ(v) is the Sigma for node (v) which is being calculated by combining both BC and burstiness. This means that the most important works are those that have a good combination of both burstiness and BC.

8. The results are presented in graphical format using Cytospace software.

3.1. Database

As stated above, our initial database included 2600 papers published in the period during 1975 until the beginning of 2017, the details of which are depicted in Tables 1 to 5. As Table 1 shows, the articles are published in 662 different sources, 388 out of which just published one article, with a total of 4022 contributing authors (723 with a single author and the rest with more than one author).

Table 2 shows the trends with an average growth rate per annum of about 7.5%. The most productive authors are listed in Table 3. Leydesdorf, Klerkx, Cooke and Hekkert are all authors with more than 20 articles.

Table 1
General information about initial database.

Attribute	Numbers
Total articles	2600
Number of Sources	662
Number of Authors	4022
Single Authors	723
Multi Authors	3299

Table 2
Number of articles in initial database per year.

1975	1	1998	26	2008	120
1983	1	1999	25	2009	143
1984	1	2000	35	2010	162
1990	1	2001	58	2011	219
1992	4	2002	57	2012	228
1993	5	2003	66	2013	180
1994	8	2004	64	2014	196
1995	19	2005	80	2015	338
1996	11	2006	72	2016	367
1997	10	2007	103		

Table 3
Most productive authors.

Rank	Authors
1	LEYDESDORFF, L
2	KLERKX, L
3	COOKE, P
4	HEKKERT, M
5	TRUFFER, B
6	COENEN, L
7	GUAN, J
8	NIOSI, J
9	HUGGINS, R
10	MARKARD

According to Table 4, the most cited works include the Etzkowitz and Leydesdorff (2000) work on triple helix with almost double the number of citations in comparison to the Cooke et al. (1997) contribution on RIS, followed by the Freeman's (1995) historical view on NIS. It is interesting to note that 7 of the 10 top cited papers have been published in *Research Policy* (Freeman, Hekkert, and Rothaermel are the exceptions). Therefore, it is not surprising that this journal has the most published works with 206 out of the 2600 listed articles, followed by *European Planning Studies* with 147 and *Technological Forecasting and Social Change* which published 116 works.

Nonetheless, as this initial database is extracted from the Web of Science, it only includes journal articles not monographs and contributions to edited books. Our next step was to extract the references of those articles. This resulted in a final database of 148,374 documents, including books, articles, conference papers, working papers, manuscripts, etc. Since the same book or article appears several times in this final database, it cannot be summarized in the same way as when we reported the initial 2600 articles.

4. Results

The results of calculating burstiness, BC, and Sigma are as follows. Fig. 1 shows the burstiness of important papers over periods of 5 years since 1975. Gray areas indicate periods when the burstiness is almost zero, white signifies there is moderate burstiness, and the red areas indicate considerable burstiness. This includes some less known references such as the work of Hayashi on the city of Negoya (Hayashi, 1992), Johnson's work on the importance of MITI in Japan (1981) and Witkin's study on improving the qualities of intercity trains (1973).

Table 5
Most contributing journals.

Journal name	Number of contributions
Research Policy	206
European Planning Studies	147
Technological Forecasting and Social Change	116
International Journal of Technology Management	69
Regional Studies	69
Scientometrics	67
Energy Policy	60
Technovation	60
Technology Analysis & Strategic Management	59
Science and Public Policy	50

The diagram shows how the concept of national innovation system takes off in the first years of the new millennium and that it remains highly topical today. This is the period when both Lundvall's work on NIS (1988, 1992), Nelson's innovation system book (1993), and Freeman's book on Japan's NIS (1987) showing high burstiness.

The groundbreaking work of Rosenberg's *Inside the Black Box* (1982) and Nelson's chief contribution in evolutionary economics (Nelson and Winter, 1982) show high burstiness before the take-off of the NIS-concept and this is also the case for Williamson's seminal work on institutions (1985). These works may be seen as forerunners to the literature on national innovation systems.

Among more recent works that show high burstiness are Tigabu's paper on renewable energies in Kenya and Rwanda (2015), along with the work of Hekkert, both of which are part of TIS literature (Hekkert et al., 2007).

Table 6 reports the results of calculating betweeness centrality (BC) as a measure of the degree to which a specific contribution had a transformative impact on the IS field. The higher the number the more the work is located at the center of the network and the more it connects different contributions. The top four works here were also present in Fig. 1. Lundvall (1992) achieved the highest BC, followed by Nelson (1993), Nelson and Winter (1982), and finally Freeman (1987); they are far ahead of others in terms of BC. The fifth contribution is Cohen and Levinthal's (1990) transformative concept about absorptive capacity, with a BC index that is only one-tenth of that reached by Freeman's work.

Other transformative contributions include Cooke et al.'s (1997) work on regional innovation systems, Edquist's (1997) systemic approach to innovation, Michael Porter's *Competitive Advantage* (1990), Freeman's historical view on NIS (1995), and finally Malerba's sectoral innovation system concept (2002).

Lundvall's paper from 1988, with considerable burstiness, does not appear here and Hekkert's functional view to TIS is also missing among

Table 4
Top cited articles.

Rank	Authors	Year	Journal	Total citations	Citation per year
1	ETZKOWITZ, H; LEYDESDORFF, L	2000	RES. POLICY	1151	67.7
2	COOKE, P; URANGA, M; ETXEBARRIA, G	1997	RES. POLICY	545	27.2
3	FREEMAN, C	1995	CAMBR. J. ECON	534	24.3
4	MALERBA, F	2002	RES. POLICY	532	35.5
5	FURMAN, J, PORTER, M, STERN, S	2002	RES. POLICY	459	30.6
6	HEKKERT, M, SUURS, R, NEGRO, S, KUHLMANN, S, SMITS R	2007	TECH. FORC. SOC. CHANGE	378	37.8
7	ACS, Z, ANSELIN, L, VARGA, A	2002	RES. POLICY	371	24.7
8	ROTHAERMEL, FT, AGUNG, S D, JIANG L,	2007	IND. COR. CHANGE	366	36.6
9	ASHEIM, B, COENEN, L	2005	RES. POLICY	338	28.2
10	LUNDVALL, B, JOHNSON, B, ANDERSEN, E, DALUM, B	2002	RES. POLICY	323	21.5

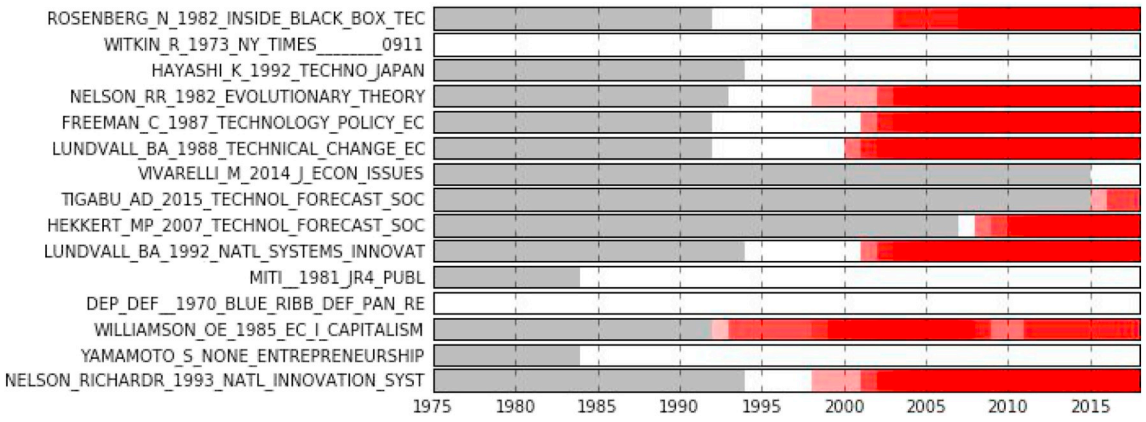

Fig. 1. Burstiness of contributions in innovation system literature over time.

the top central concepts. With the exception of Porter, the top 10 contributions introduce new concepts within the field of innovation. Different approaches to NIS as well as Regional and Sectoral systems of innovation are among the top transformative concepts, and TIS is the only version that does not appear in the top 10 list. However, Seminal works in TIS such as Hekkert et al. (2007) and Carlsson and Stankiewicz (1991), resides at rank 14 and 15.

As mentioned before, the Sigma index is used to show evolution over time by combining burstiness and BC. We used tables and network maps together to show the evolution of this index on a yearly basis. Table 7 shows the top 15 works for each year (222 total works) in terms of their Sigma index (except 2002 when only 12 work obtained a meaningful sigma number). The formula did not generate enough numbers for the years before 2002 because no work got a significant Sigma number the Python software.

Classifyied into books, book chapters and articles (Table 8), books account for 87 items and only 13 book chapters are found among the 222 top works. In the 122 remaining articleswe found that research policy has the most works with 45 studies and 15 distinctive articles, some of which are repeated in several years. Other journals, such as “Agricultural Systems” or “Cambridge Journal of Economics”, were not able to contribute more than 2 distinct papers. “Progress in human geography”, having published Bathelt et al.'s (2004) article, took second place in terms of total repetition in the table, followed by “Administrative Science Quarterly”, “Technological Forecasting and Social Change” and “Journal of Evolutionary Economics”.

Analyses of the results are interesting as it points to five different categories (Table 9). First are the “prime intellectual bases” that have been among the top 15 contributions since 2002. Second are “decreasing intellectual bases” which are those works were initially among the top works but then dropped (i.e. few early years). Third are “shiners” including those works that published later and transformed into central concepts over time. Fourth are “fluctuating others” including works that appeared in the top in some years and not in others.

The first category consists of Lundvall (1992), Nelson (1993) and maybe Nelson and Winter (1982). The first two have been among the top 15 works each year, and they almost always reside at ranks 1st and 2nd on the list. However, Nelson (1993) placed 4th in 2015 and 9th in 2016, which might shows a decreasing trend for this contribution in the future. Nelson and Winter (1982) has been among the top works except for the years 2005, 2007, and the last two years. If it does not come back to the top in the future, it will move to the second category of “decreasing intellectual bases”.

Edquist (1997), Freeman (1987), Porter (1990) and Braczyk and Heidenreich (1998) are the main works in the second category. Edquist (1997) has been among top 15 works since 2002 right up to 2012 with the exception of 2006. Surprisingly, this work has not been among top innovation contributions after 2012. Except for 2004 and 2008, Freeman has been among top innovation system works up to 2009. Then this work lost its seminal place. Porter has not been among the top works after 2012 and Braczyk's work on RIS remained in the top until only 2006.

The third category is called shiners with increasing patterns, including Bathelt et al. (2004), Hekkert et al. (2007), Bergek et al. (2008), Etzkowitz and Leydesdorff (2000), Cohen and Levinthal (1990) and Boschma (2005). Asheim, if we consider his papers in different years, could be added to this category. Bathelt has been among the top works from 2006 and Hekkert shows a similar pattern from 2010. Cohen and Levinthal jumped to the top contributions in 2009, exempting 2014. Since 2011, Bergek has been among top contributions, except for 2013. This holds true for Etzkowitz and Leydesdorff from 2008, with exception in only 2011. Boschma shows a similar pattern since 2011, except for 2014.

The final category includes the works with fluctuating patterns such as Tödtling and Trippl (2005), Markard and Truffer (2008), Rogers (1962), Klerkx et al. (2010) and Malerba (2002). Among them, Cooke (1992) and Cooke et al. (1997, 1998, 2000, 2005) shows an interesting U-shape pattern as he has been among the top works from 2002 to

Table 6
Calculations of BC over time.

Rank	Author/s	BC	Year	Type	Document name
1	Lundvall, B-Å	0.045	1992	Book	National systems of innovation: Toward a theory of innovation and interactive learning
2	Nelson, R R	0.0357	1993	Book	National innovation systems: a comparative analysis
3	Nelson, R R & Winter, S	0.0229	1982	Book	An evolutionary theory of economic change
4	Freeman, C	0.0203	1987	book	Technology policy and economic policy: Lessons from Japan
5	Cohen, W M & Levinthal, D A	0.0197	1990	Article	Absorptive capacity: A new perspective on learning and innovation
6	Cooke, P, Uranga, M G, & Etxebarria, G	0.0186	1997	Article	Regional innovation systems: Institutional and organisational dimensions
7	Edquist, C	0.0183	1997	book	Systems of innovation: technologies, institutions, and organizations
8	Porter, M E	0/0143	1990	book	The competitive advantage of nations
9	Freeman, C	0.0129	1995	Article	The National System of Innovation in historical perspective
10	Malerba, F	0.0119	2002	Article	Sectoral systems of innovation and production

Table 7
Calculations of Sigma index over time.

2002	Sigma	2003	Sigma
NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.352264429	LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.333589
LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.17087421	NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.168465
BRACZYK_HJ_1998_REGIONAL_INNOVATION	0.009283045	JAFFE_AB_1993_Q_J_ECON	0.042629
FREEMAN_C_1987_TECHNOLOGY_POLICY_EC	0.00161856	EDQUIST_C_1997_SYSTEMS_INNOVATION_T	0.022007
NELSON_RR_1982_EVOLUTIONARY_THEORY	0.00161856	GIBBONS_M_1994_NEW_PRODUCTION_KNOWL	0.021662
LUNDVALL_BA_1988_TECHNICAL_CHANGE_EC	0.001348921	BIGGS_SD_1990_WORLD_DEV	0.021662
EDQUIST_C_1997_SYSTEMS_INNOVATION_T	8.09E-04	KUEMMERLE_W_1999_RES_POLICY	0.021662
JAFFE_AB_1993_Q_J_ECON	8.09E-04	DOSI_G_1982_RES_POLICY	0.017356
NELSON_R_1988_TECHNICAL_CHANGE_EC	5.40E-04	FREEMAN_C_1995_CAMBRIDGE_J_ECON	0.007101
PORTER_M_1990_COMPETITIVE_ADVANTAG	2.70E-04	COOKE_P_1997_RES_POLICY	0.003954
STORPER_M_1997_REGIONAL_WORLD_TERRI	2.70E-04	FREEMAN_C_1987_TECHNOLOGY_POLICY_EC	0.003867
BRESCHI_S_1997_SYSTEMS_INNOVATION_T	2.70E-04	NELSON_RR_1982_EVOLUTIONARY_THEORY	0.001548
		HALL_A_2000_KNOWLEDGE_POLICY_TEC	0.001077
		BIGGS_S_1999_PUBLIC_ADMIN_DEVELOP	0.001009
		PORTER_M_1990_COMPETITIVE_ADVANTAG	7.41E-04

2004	Sigma	2005	Sigma
LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.212557	LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.294453346
NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.094195	NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.122974808
EDQUIST_C_1997_SYSTEMS_INNOVATION_T	0.093302	ANSELIN_L_1997_J_URBAN_ECON	0.071894246
PORTER_M_1990_COMPETITIVE_ADVANTAG	0.070023	FELDMAN_MP_1999_EUR_ECON_REV	0.051566188
BRACZYK_HJ_1998_REGIONAL_INNOVATION	0.033193	STORPER_M_1997_REGIONAL_WORLD_TERRI	0.050633763
AUDRETSCH_DB_1996_AM_ECON_REV	0.020865	EDQUIST_C_1997_SYSTEMS_INNOVATION_T	0.040641269
NELSON_RR_1982_EVOLUTIONARY_THEORY	0.018678	PORTER_M_1990_COMPETITIVE_ADVANTAG	0.028481422
STORPER_M_1997_REGIONAL_WORLD_TERRI	0.009704	MORGAN_K_1997_REG_STUD	0.028481422
CAMAGNI_R_1991_INNOVATION_NETWORKS	0.008631	ASHEIM_B_2002_J_TECHNOLOGY_TRANSFE	0.022453604
NONAKA_I_1995_KNOWLEDGE_CREATING_C	0.005907	PORTER_M_1998_HARVARD_BUSINESS_NOV	0.022453604
COOKE_P_2000_GOVERNANCE_INNOVATIO	0.004588	GRANOVETTER_M_1985_AM_J_SOCIOL	0.020443749
DOSI_G_1988_TECHNICAL_CHANGE_EC	0.001493	FREEMAN_C_1987_TECHNOLOGY_POLICY_EC	0.02031769
COOKE_P_1998_ENVIRON_PLANN_A	9.88E-04	COOKE_P_1998_REGIONAL_INNOVATION	0.02010477
COOKE_P_1998_REGIONAL_INNOVATION	8.25E-04	PORTER_ME_2000_OXFORD_HDB_EC_GEOGRA	0.017520256
KRUGMAN_P_1991_GEOGRAPHY_TRADE	5.68E-04	MOULAERT_F_2003_REG_STUD	0.00934284

2006	Sigma	2007	Sigma
LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.286717	LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.2941
PORTER_M_1990_COMPETITIVE_ADVANTAG	0.11665	NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.185283
NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.078385	COOKE_P_2004_REGIONAL_INNOVATION	0.08541
DOLOREUX_D_2002_TECHNOL_SOC	0.043267	BATHELT_H_2004_PROG_HUM_GEOG	0.082715
STORPER_M_1995_EUROPEAN_URBAN_REGIO	0.03938	CARLSSON_B_2002_RES_POLICY	0.05019
FREEMAN_C_1987_TECHNOLOGY_POLICY_EC	0.022672	CARLSSON_B_1991_J_EVOLUTIONARY_EC	0.035788
PUTNAM_R_1993_MAKING_DEMOCRACY_WOR	0.015852	LUNDVALL_BA_2000_OXFORD_HDB_EC_GEOGRA	0.03316
NELSON_RR_1982_EVOLUTIONARY_THEORY	0.011948	ASHEIM_B_2002_J_TECHNOLOGY_TRANSFE	0.026854
COOKE_P_2000_GOVERNANCE_INNOVATIO	0.010056	FREEMAN_C_1987_TECHNOLOGY_POLICY_EC	0.026755
COOKE_P_1998_REGIONAL_INNOVATION	0.007092	TODTLING_F_2005_RES_POLICY	0.02224
DOSI_G_1982_RES_POLICY	0.00596	COOKE_P_1992_GEOFORUM	0.021236
BRACZYK_HJ_1998_REGIONAL_INNOVATION	0.005917	HOWELLS_J_1999_INNOVATION_POLICY_GL	0.019468
BATHELT_H_2004_PROG_HUM_GEOG	0.005256	JAFFE_AB_1989_AM_ECON_REV	0.018773
COHEN_WM_1990_ADMIN_SCI_QUART	0.005256	GRILICHES_Z_1979_BELL_J_ECON	0.017753
EDQUIST_C_1997_SYSTEMS_INNOVATION_T	0.005099	JACOBSSON_S_2000_ENERG_POLICY	0.017357

2008	Sigma	2009	Sigma
LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.208461	LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.272054
NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.10882	NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.121388
CARLSSON_B_2002_RES_POLICY	0.096036	FREEMAN_C_1987_TECHNOLOGY_POLICY_EC	0.033023
EDQUIST_C_1997_SYSTEMS_INNOVATION_T	0.076416	NELSON_RR_1982_EVOLUTIONARY_THEORY	0.032574
COHEN_WM_1990_ADMIN_SCI_QUART	0.071479	PORTER_M_1990_COMPETITIVE_ADVANTAG	0.032213
JACOBSSON_S_2000_ENERG_POLICY	0.058383	EDQUIST_C_1997_SYSTEMS_INNOVATION_T	0.024994
COOKE_P_1997_RES_POLICY	0.055822	ASHEIM_BT_2005_RES_POLICY	0.017289
BATHELT_H_2004_PROG_HUM_GEOG	0.054985	MALERBA_F_2002_RES_POLICY	0.012983
ETZKOWITZ_H_2000_RES_POLICY	0.049458	CARLSSON_B_2002_RES_POLICY	0.012266
NELSON_RR_1982_EVOLUTIONARY_THEORY	0.049447	CARLSSON_B_1991_J_EVOLUTIONARY_EC	0.012084
MORGAN_K_1997_REG_STUD	0.047105	COHEN_WM_1990_ADMIN_SCI_QUART	0.011803
PORTER_M_1990_COMPETITIVE_ADVANTAG	0.042175	BATHELT_H_2004_PROG_HUM_GEOG	0.010501
CARLSSON_B_1991_J_EVOLUTIONARY_EC	0.039849	LIU_XL_2001_RES_POLICY	0.008695
BOSCHMA_RA_2005_REG_STUD	0.036295	COOKE_P_1998_REGIONAL_INNOVATION	0.007024
JACOBSSON_S_2004_IND_CORP_CHANGE	0.028476	ETZKOWITZ_H_2000_RES_POLICY	0.006772

(*continued on next page*)

Table 7 (*continued*)

2010	Sigma	2011	Sigma
LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.231246	NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.154467
ETZKOWITZ_H_2000_RES_POLICY	0.111592	LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.145279
NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.085215	EDQUIST_C_1997_SYSTEMS_INNOVATION_T	0.042821
COHEN_WM_1990_ADMIN_SCI_QUART	0.063717	BATHELT_H_2004_PROG_HUM_GEOG	0.035021
HEKKERT_MP_2007_TECHNOL_FORECAST_SOC	0.041863	ASHEIM_B_2005_OXFORD_HDB_INNOVATIO	0.033773
BATHELT_H_2004_PROG_HUM_GEOG	0.039521	HEKKERT_MP_2007_TECHNOL_FORECAST_SOC	0.033107
NELSON_RR_1982_EVOLUTIONARY_THEORY	0.037224	COHEN_WM_1990_ADMIN_SCI_QUART	0.030293
COHEN_WM_2002_MANAGE_SCI	0.023253	PORTER_M_1990_COMPETITIVE_ADVANTAG	0.02809
MARKARD_J_2008_RES_POLICY	0.021975	BERGEK_A_2008_RES_POLICY	0.022121
COOKE_P_1997_RES_POLICY	0.021657	LEYDESDORFF_L_2006_RES_POLICY	0.021382
ASHEIM_B_2002_J_TECHNOLOGY_TRANSFE	0.018526	MASKELL_P_1999_CAMBRIDGE_J_ECON	0.021022
EDQUIST_C_1997_SYSTEMS_INNOVATION_T	0.018041	EDQUIST_C_2005_OXFORD_HDB_INNOVATIO	0.020266
PORTER_M_1990_COMPETITIVE_ADVANTAG	0.0173	BRESCHI_S_2001_IND_CORP_CHANGE	0.017843
CARLSSON_B_2002_RES_POLICY	0.015647	BOSCHMA_RA_2005_REG_STUD	0.016902
CARLSSON_B_1991_J_EVOLUTIONARY_EC	0.012713	NELSON_RR_1982_EVOLUTIONARY_THEORY	0.016102

2012	Sigma	2013	Sigma
NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.11564	LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.20589
LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.095112	NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.09382
BERGEK_A_2008_RES_POLICY	0.066815	BATHELT_H_2004_PROG_HUM_GEOG	0.079617
EDQUIST_C_1997_SYSTEMS_INNOVATION_T	0.062815	HOWELLS_J_2006_RES_POLICY	0.071749
HEKKERT_MP_2007_TECHNOL_FORECAST_SOC	0.057729	NELSON_RR_1982_EVOLUTIONARY_THEORY	0.059649
BOSCHMA_RA_2005_REG_STUD	0.040175	ETZKOWITZ_H_2000_RES_POLICY	0.056625
COHEN_WM_1990_ADMIN_SCI_QUART	0.038769	ROGERS_EM_1962_DIFFUSION_INNOVATION	0.052087
NELSON_RR_1982_EVOLUTIONARY_THEORY	0.038295	MULLER_E_2001_RES_POLICY	0.049071
MARKARD_J_2008_RES_POLICY	0.033595	BOSCHMA_RA_2005_REG_STUD	0.037351
ASHEIM_BT_2005_RES_POLICY	0.028431	HEKKERT_MP_2007_TECHNOL_FORECAST_SOC	0.032311
BATHELT_H_2004_PROG_HUM_GEOG	0.025036	COHEN_WM_1990_ADMIN_SCI_QUART	0.0322
ETZKOWITZ_H_2000_RES_POLICY	0.023982	ASHEIM_BT_2005_RES_POLICY	0.029268
COOKE_P_2004_REGIONAL_INNOVATION	0.016172	ASHEIM_B_2005_OXFORD_HDB_INNOVATIO	0.02577
HOWELLS_J_2006_RES_POLICY	0.015101	FREEMAN_C_1987_TECHNOLOGY_POLICY_EC	0.022994
TODTLING_F_2005_RES_POLICY	0.014829	LEEUWIS_C_2004_COMMUNICATION_RURAL	0.022442

2014	Sigma	2015	Sigma
LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.20923	LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.081785
NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.129115	COOKE_P_1997_RES_POLICY	0.080367
HEKKERT_MP_2007_TECHNOL_FORECAST_SOC	0.076259	HEKKERT_MP_2007_TECHNOL_FORECAST_SOC	0.068257
ETZKOWITZ_H_2000_RES_POLICY	0.075219	NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.060828
COOKE_P_1997_RES_POLICY	0.065596	BOSCHMA_RA_2005_REG_STUD	0.053764
NELSON_RR_1982_EVOLUTIONARY_THEORY	0.057956	ETZKOWITZ_H_2000_RES_POLICY	0.052111
KLERKX_L_2010_AGR_SYST	0.054319	ASHEIM_BT_2005_RES_POLICY	0.047933
BERGEK_A_2008_RES_POLICY	0.03936	COHEN_WM_1990_ADMIN_SCI_QUART	0.046495
BATHELT_H_2004_PROG_HUM_GEOG	0.02519	HOUNKONNOU_D_2012_AGR_SYST	0.036065
ASHEIM_BT_2011_REG_STUD	0.024512	BERGEK_A_2008_RES_POLICY	0.030534
AUDRETSCH_DB_1996_AM_ECON_REV	0.02427	CARLSSON_B_1991_J_EVOLUTIONARY_EC	0.029111
ASHEIM_B_2005_OXFORD_HDB_INNOVATIO	0.022812	ASHEIM_BT_2011_REG_STUD	0.025901
HOUNKONNOU_D_2012_AGR_SYST	0.022428	BATHELT_H_2004_PROG_HUM_GEOG	0.022839
TODTLING_F_2005_RES_POLICY	0.015423	TODTLING_F_2005_RES_POLICY	0.019579
CHESBROUGH_HW_2003_OPEN_INNOVATION_NEW	0.015067	WORLD_BANK_2006_ENH_AGR_INN_GO_STREN	0.017912

2016	Sigma	2016 (continued)	Sigma
LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVAT	0.156624	NELSON_RICHARDR_1993_NATL_INNOVATION_SYST	0.042912
BERGEK_A_2008_RES_POLICY	0.109244	ETZKOWITZ_H_2000_RES_POLICY	0.039078
COHEN_WM_1990_ADMIN_SCI_QUART	0.089275	BOSCHMA_RA_2005_REG_STUD	0.038844
HEKKERT_MP_2007_TECHNOL_FORECAST_SOC	0.071322	FURMAN_JL_2002_RES_POLICY	0.029699
ROGERS_EM_1962_DIFFUSION_INNOVATION	0.054521	ASHEIM_BT_2011_REG_STUD	0.029247
KLERKX_L_2010_AGR_SYST	0.051158	MALERBA_F_2002_RES_POLICY	0.026294
BATHELT_H_2004_PROG_HUM_GEOG	0.050089	MARKARD_J_2008_RES_POLICY	0.023
COOKE_P_1997_RES_POLICY	0.043906		

2010, then dropped off and eventually reappeared again at the top of the list from 2014 (considering his different contributions). Carlsson's works reached the top between 2007 and 2010 and again 2015.

We also plotted the network mapping of works in four different periods to show the evolution of innovation system literature by Cytospace software. Figs. 2 to 5 show that evolution. For each year, e.g. 2002, the size of the circles reflects their sigma number indicating that the bigger the circle is the more important (as sigma includes both burstiness and BC).

According to Fig. 2, the big circle at the center is Lundvall (1992). Nelson (1993) resides at the right hand of the map indicating that it is not as central as Lundvall. The third big circle in yellow is Braczyk and

Table 8
Types of the top contributions in terms of books, chapters in books or article journals.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
2	B	B	B	B	B	B	B	B	RP	B	B	B	B	RP	RP
3	Ch	QJE	B	JUE	B	B	RP	B	B	B	RP	PHG	TFSC	TFSC	ASQ
4	B	B	B	EER	TS	PHG	B	B	ASQ	PHG	B	RP	RP	B	TFSC
5	B	B	Ch	B	EURS	RP	ASQ	B	TFSC	Ch	TFSC	B	RP	RE	B
6	Ch	WD	AER	B	B	JEE	EP	B	PHG	TFSC	RS	RP	B	RP	AS
7	B	RP	B	B	NCR	Ch	RP	RP	B	ASQ	ASQ	B	AS	RP	PHG
8	QJE	RP	B	RFS	B	JTT	PHG	RP	MS	B	B	RP	RP	ASQ	RP
9	Ch	CJE	B	JTT	B	B	RP	RP	RP	RP	RP	RE	PHG	AS	B
10	B	RP	B	HBR	B	RP	B	JEE	RP	RP	RP	TFSC	RE	RP	RP
11	B	B	B	AJS	RP	G	RFS	ASQ	JTT	CJE	PHG	ASQ	AER	JEE	RE
12	Ch	B	B	B	Ch	Ch	B	PHG	B	Ch	RP	RP	Ch	RE	RP
13		KTP	B	B	PHG	AER	JEE	RP	B	ICC	B	Ch	AS	PHG	RE
14		PAD		Ch	ASQ	BJE	RE	B	RP	RE	RP	B	RP	RP	RP
15		B		RFS	B	EP	ICC	RP	JEE	B	RP		B	B	RP

Complete journal names

Journal name	Ab.	Journal name	Ab.	Journal name	Ab.	Journal name	
Research Policy	RP	Progress in human geography	PHG	Administrative Science quarterly	ASQ	The Quarterly Journal of Economics	QJE
Technological forecasting and social change	TFSC	Journal of evolutionary economics	JEE	Agricultural systems	AS	Technology in society	TS
Journal of technology transfer	JTT	American economic review	AER	Regional & Federal Studies	RFS	World development	WD
Cambridge journal of economics	CJE	Energy policy	EP	The Quarterly Journal of Economics	QJE	Regional studies	RS
Energy policy	EP	The Quarterly Journal of Economics	QJE	Industrial and corporate change	ICC	Management science	MS
The bell journal of economics	BJE	Industrial and corporate change	ICC	European economic review	EER	Harvard business review	HBR
Public administration development	PAD	Knowledge, technology, policy	KTP	Geoforum	G		

Heidenreich's (1998) chapter about regional governance of innovation followed by Freeman (1987), Nelson and Winter (1982), Lundvall (1988) and Edquist (1997), all classic contributions to innovation system. This is in line with the findings of other works regarding innovation system literature such as Uriona-Maldonado et al. (2012) and Liu et al. (2015).

Fig. 3 shows the network up to 2007. Lundvall (1992) and Nelson (1993) are the two biggest circles in brown and blue. The third big circle in green is the Cooke's contribution on RIS in 2004 located at the right side of the map. Fourth is Bathelt et al. (2004) paper on

Table 9
Rank of works in 4 categories from 2002 to 2016 according to Sigma index.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Category 1: persistent works (intellectual bases)															
LUNDVALL_BA_1992_NATL_SYSTEMS_INNOVA	2	1	1	1	1	1	1	1	2	2	1	1	1	1	1
NELSON_RICHARDR_1993_NATL_INNOVATION	1	2	2	2	3	2	2	3	1	1	2	2	2	4	9
NELSON_RR_1982_EVOLUTIONARY_THEORY	5	12	7	–	8	–	10	4	7	15	8	5	6	–	–
Category 2: diminishing works (pioneer bases)															
EDQUIST_C_1997_SYSTEMS_INNOVATION_T	7	4	3	6	15	–	4	6	12	3	4	–	–	–	–
PORTER_M_1998_HARVARD_BUSINESS_NOV	10	15	4	7	2	–	12	5	13	8	–	–	–	–	–
FREEMAN_C_1987_TECHNOLOGY_POLICY_EC	11	–	12	6	9	–	3	–	–	–	–	–	–	–	–
BRACZYK_HJ_1998_REGIONAL_INNOVATION	3	–	5	–	12	–	–	–	–	–	–	–	–	–	–
Category 3: increasing works (emerging trends)															
BERGEK_A_2008_RES_POLICY	–	–	–	–	–	–	–	–	–	–	3	–	8	10	2
COHEN_WM_1990_ADMIN_SCI_QUART	–	–	–	–	–	–	–	–	5	6	5	10	3	3	4
HEKKERT_MP_2007_TECHNOL_FORECAST_SO	–	–	–	–	14	–	5	11	4	7	7	11	–	8	3
BATHELT_H_2004_PROG_HUM_GEOG	–	–	–	–	13	4	8	12	6	4	11	3	9	13	7
ETZKOWITZ_H_2000_RES_POLICY	–	–	–	–	–	–	9	15	2	–	12	6	4	6	10
BOSCHMA_RA_2005_REG_STUD	–	–	–	–	–	–	14	–	–	14	6	9	–	5	11
ASHEIM_BT_2002, 2005, 2011[a]	–	–	–	–	9	8	–	7	11	5	10	12, 13	10, 12	7	13
Category 4: non-stable Works (possible trends)															
MARKARD_J_2008_RES_POLICY	–	–	–	–	–	–	–	–	–	–	9	–	–	–	15
MALERBA_F_2002_RES_POLICY	–	–	–	–	–	–	–	8	–	–	–	–	–	–	14
ROGERS_EM_1962_DIFFUSION_INNOVATION	–	–	–	–	–	–	–	–	–	–	–	7	–	–	5
TODTLING_F_2005_RES_POLICY	–	–	–	–	–	–	–	–	–	–	15	–	14	14	–
KLERKX_L_2010_AGR_SYST	–	–	–	–	–	–	–	–	–	–	–	–	8	–	6
COOKE_P_1992, 1997, 1998, 2004[a]	–	10	15	11, 13, 14	9, 10	3, 11	7	14	10	–	–	–	5	2	8
CARLSSON-B-1991, 2002[a]	–	–	–	–	–	5, 6	3	9, 10	14, 15	–	–	–	–	11	–

[a] Numbers in the row are for different contributions, which are not specified now.

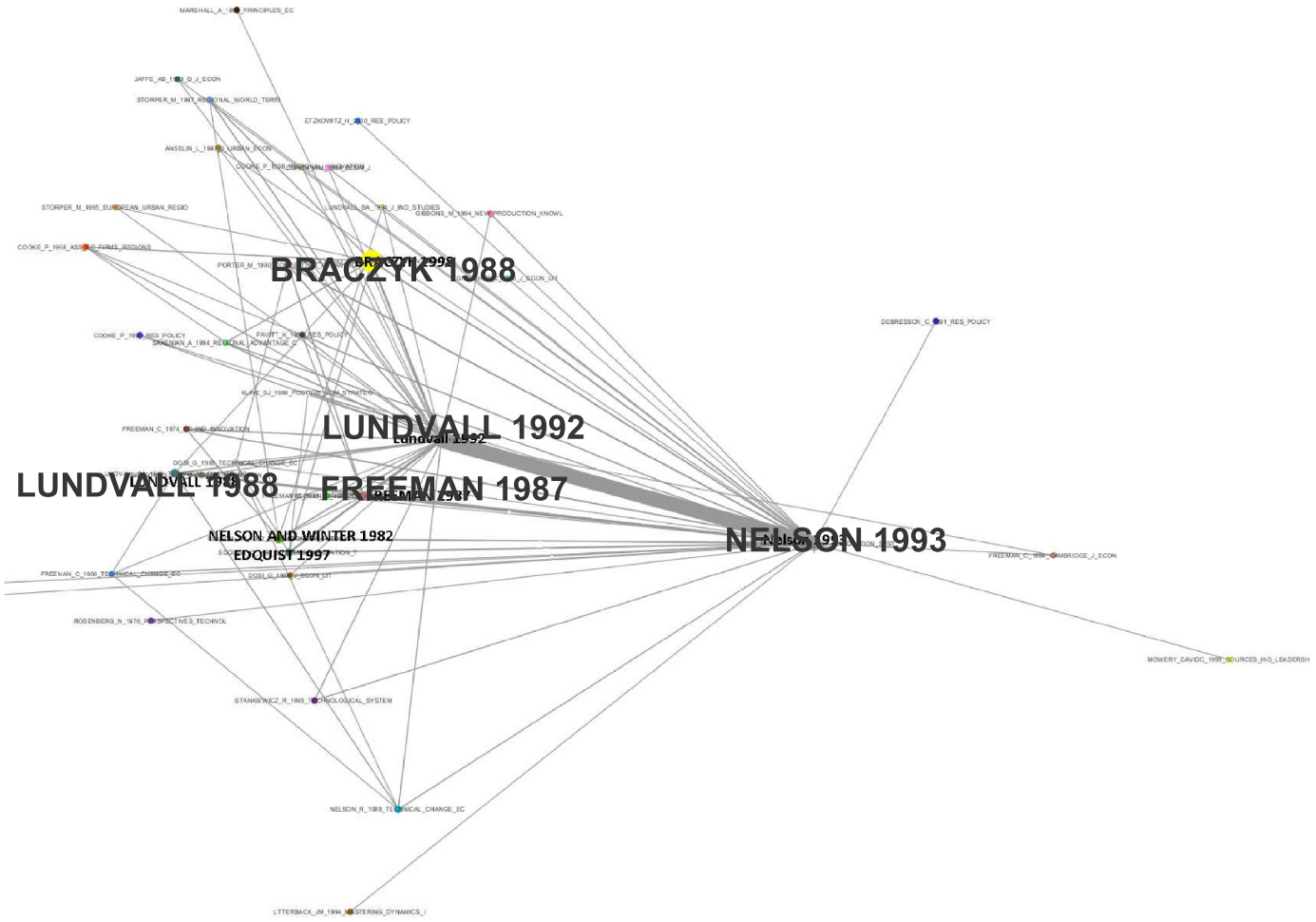

Fig. 2. The plot of Sigma for 2002.

knowledge exchange in the context of a region which resides close to Nelson. The fifth and sixth big nodes are Carlsson et al. (2002) and Carlsson and Stankiewicz (1991) coloured red and dark green, respectively, at the top middle. Other big nodes include Lundvall's chapter in O*xford Handbook of Economic Geography* (2000) that is marked in light brown at the bottom-right, Asheim's work (another green at the bottom-middle) in the Journal of Technology Transfer about RIS (Asheim and Isaksen, 2002), Freeman's book on Japan (connecting Carlsson et al., 2002 and Nelson, 1993) and others such as Tödtling and Trippl (2005), Cooke (1992) and Howells (1999).

Thus, the map of the literature up to 2007 proves that in addition to the classical and early contributions (i.e. Lundvall, Nelson and Freeman), most important works in this period were about regional characteristics of innovation, including Cooke (2004, 1992), Carlsson and Stankiewicz (1991), Carlsson et al. (2002), Bathelt et al. (2004), Lundvall and Maskell (2000), Asheim and Isaksen (2002), Tödtling and Trippl (2005) and Howells (1999). The only work about TIS among the top 15 is Jacobsson and Johnson (2000) published in “Energy Policy” about diffusion of renewable energies.

Fig. 4 shows the development of the network during the next five years. Nelson (1993) appears as the biggest circle in blue and Lundvall (1992) is the second circle coloured in brown. The shape of the network is different from earlier years and many new nodes and links have now emerged. The two very big circles at the top (purple and pink) are Bergek et al. (2008) and Hekkert et al. (2007), along with Markard and Truffer's (2008) work on the multi-level view of TIS (the big circle on the top-right side). Further, major TIS literatures have a higher sigma number in comparison to RIS works (including Bochma, Bathelt, Asheim, etc) in this period and they appear to shape a separate cluster at the top of this network. Edquist's (1997) work on NIS is ranked 4th which is located at the bottom of Bergek and Cohen and Levinthal (1990) which seems to be gradually improving its position at rank 7 in this period.

A more complex graph with Lundvall's book seen at the top (yellow circle at the down right) is the result of Sigma calculations from the beginning to 2016. Bergek and Hekkert (ranks 2 and 4) are two big pink circles at the top of the graph while Markrd decreased to rank 15 in this year. However, other TIS works are not among the top 15 works, showing the establishment of this literature with those 2 major works.

The evolution of literature now shows the emergence of some new literature rather than the classic works of NIS. The third place is Cohen and Levinthal's (1990) (dark green circle at the left side) and the fifth is Rogers' seminal work on diffusion of innovation (1962) labeled by the red circle on the right side of the graph. Nelson (1993) is now in 9th place, shown by the blue circle at the left end of the network.

Bathelt et al. (2004) is ranked 7th, followed by Cooke et al. (1997)

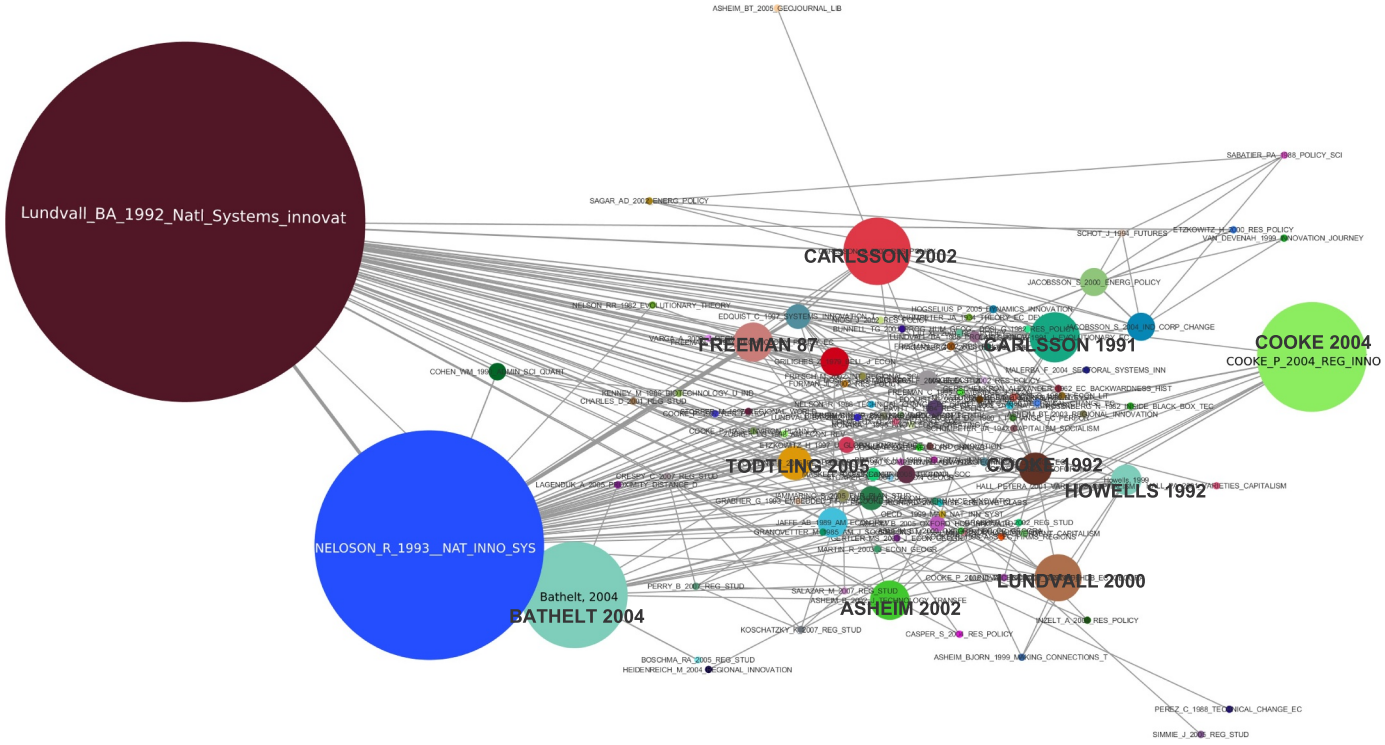

Fig. 3. The plot of Sigma for 2007.

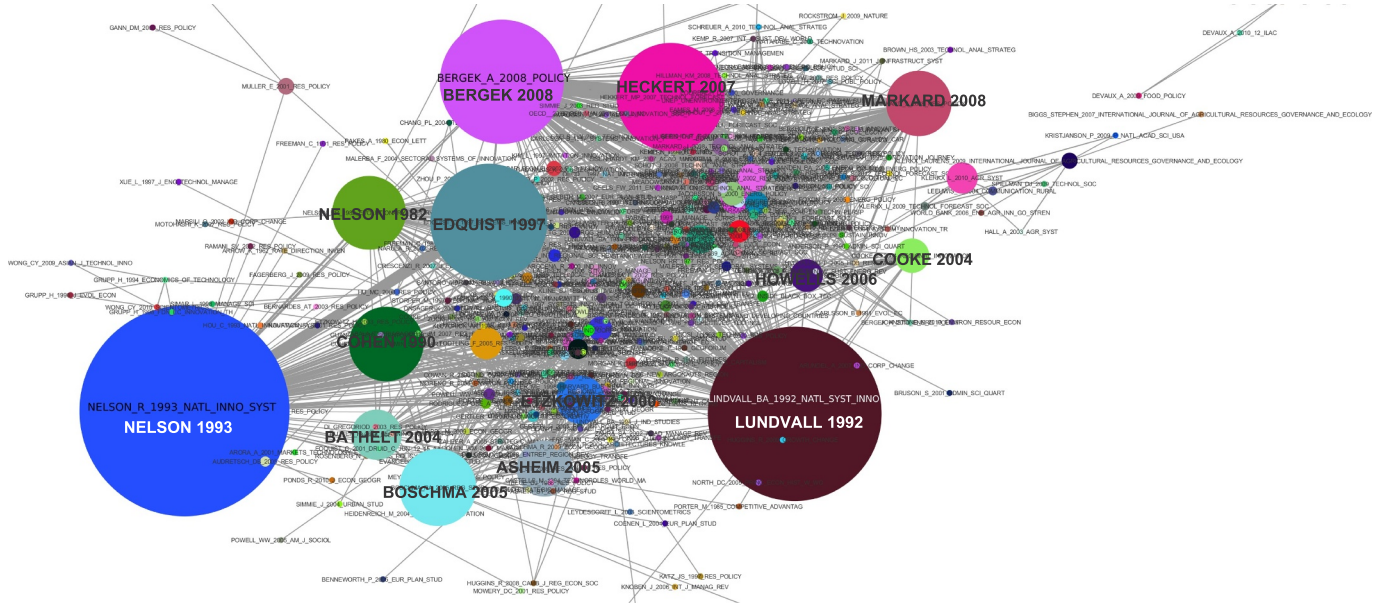

Fig. 4. The plot of Sigma for 2012.
Note: Some negligible works are cropped in the corners for better clarity.

as the 8th important work and then Boschma (2005) who placed 11th on the list; these all represent contributions from the RIS approach and placed at the bottom of the map with their respective networks. This shows the establishment of RIS literature with its prominent contributions, which although they get a smaller sigma number in comparison to the major RIS literature remained among the top 15 works since 2007.

Klerkx et al.'s (2010) work on agricultural innovation systems (the pink circle on the top right side) is very close to Etzkowitz and Leydesdorff's (2000) work on the triple helix (the blue circle at the top of Lundvall, 1992).

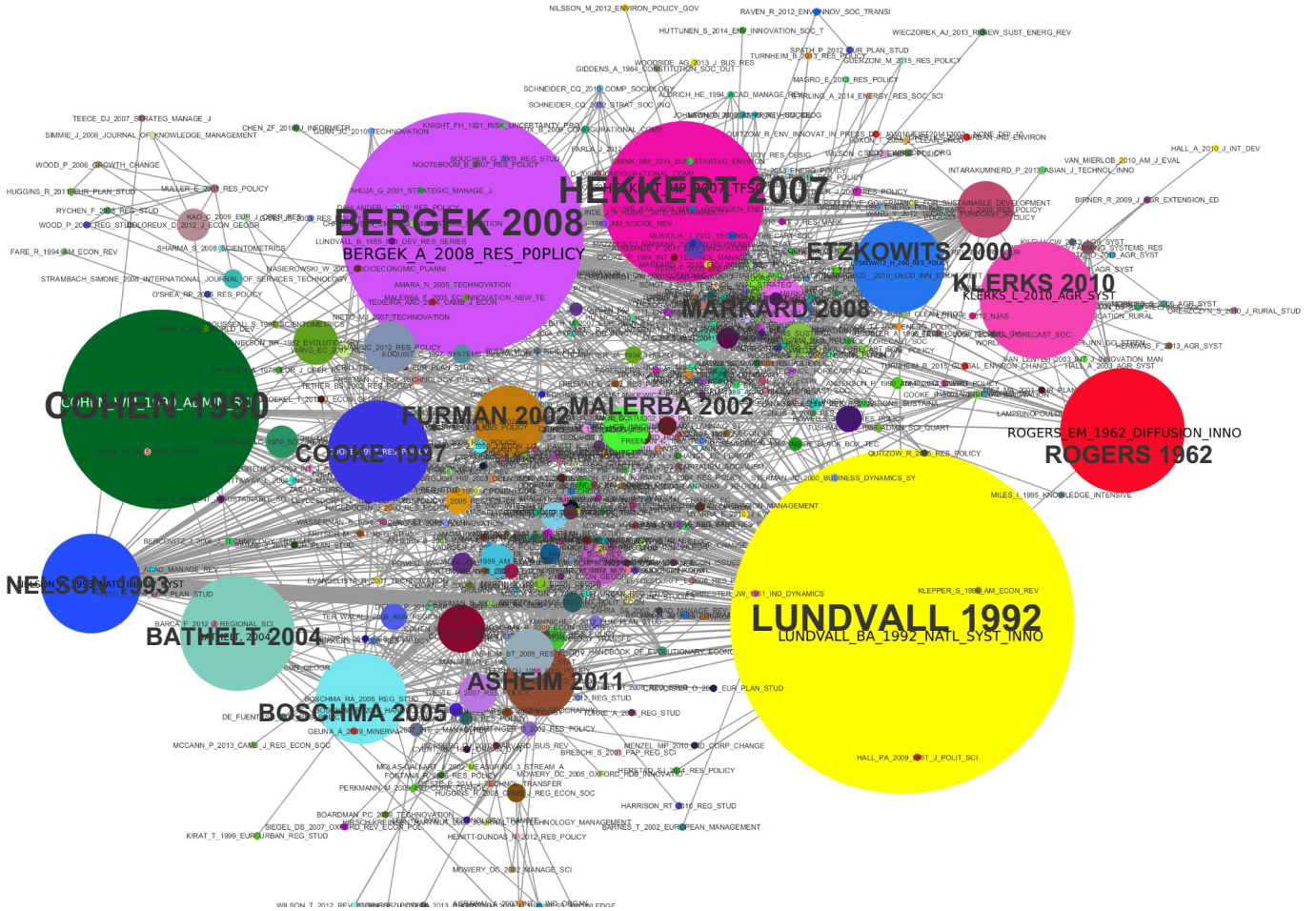

Fig. 5. The plot of Sigma for 2016.
Note: Some negligible works are cropped in the corners for better clarity.

However, they are not deemed to be establishing a distinguished cluster yet. Surprisingly, there is still no network or cluster around SIS as the fourth branch of innovation systems, although Malerba (2002) is ranked 14 in this period (a light pink circle at the center).

Thus, the new emerging concepts in the core NIS literature are the agricultural innovation system (Klerkx), Triple Helix (Etzkowitz) and SIS (Malerba) with some classical works getting more attention in the literature including Rogers and Cohen and Levinthal.

5. Conclusions

Since 1987, national innovation system literature as a new conceptual framework has provided new insights about innovation at the national level. After its first formal appearance in 1988, there have been several approaches regarding the scope and application of innovation systems which are normally classified as NIS, RIS, TIS, and SIS (Martin, 2012).

We tried to analyse and map the trend of evolution of the literature regarding IS by applying the two measures of burstiness and BC, which are integrated into the Sigma index (Chen, 2006). Former works used only one measure, citation (Uriona-Maldonado et al., 2012) or co-citation analyses (Liu et al., 2015) without combining them in the Sigma index. Further, neither analysed the evolution of the field as we have conducted here, nor do they point to possible future directions. Moreover, our search keywords included more keywords resulting in more than 1000 additional references in comparison to Liu et al. (2015).

In terms of burstiness, we found that classical NIS works are top of the list along with Rosenberg and Nathan's (1982) book *Inside the Black Box* and Williamson's (1975) work on economic institutions. The only sub-version of innovation systems which bursts quickly is Hekkert's (Hekkert et al., 2007) concept on TIS in the *Journal of Technological Forecasting and Social Change*. BC then is calculated to show the transformative concepts by applying co-citation analysis. Lundvall, Nelson and Freeman's books on NIS, as well as Nelson and Winter's evolutionary book, reside at the top in the list. Works from RIS and SIS and TIS literature are among the top 15 works in terms of BC.

In addition, the evolution of the literature since 1997 was measured and mapped by the Sigma index. We have shown that there are some persistent intellectual bases such as Lundvall (1992), Nelson (1993) and to some extent Nelson and Winter (1982). Some important pioneer works such as Freeman (1987), Edquist (1997) and Porter (1990) are no longer playing transformative roles in the light of emerging new concepts. The shining works are Hekkert et al. (2007) and Bergek et al. (2008) in the TIS approach, and Bathelt et al. (2004) and Asheim and Isaksen (2002), Asheim and Coenen (2005) and Asheim et al. (2011) in the RIS perspective. There are some other fluctuating works were discussed in more detail above.

We found that in addition to the central nodes of NIS, the two main branches of RIS and TIS emerged in different periods in such a way that they are deemed well established, while SIS was not successful as such. The years 1997 to 2002 was the period of establishment around classical NIS works. The central nodes in 2002 were Nelson and Lundvall followed by Braczyk and Heidenreich (1998). The period between 2002 and 2007 was the time when the geographical characteristics of innovation emerged as the most important works. As it is shown in Fig. 3, geographical works were forming an independent cluster at the bottom of the graph within this period. The next stage from 2007 to 2012 was the time that TIS contributions ranked high in the literature and started

to form an independent cluster at the top of the graph in parallel with RIS works. Finally, from 2012 to 2016, while TIS and RIS works maintained their importance some new approaches, like agricultural system of innovation, triple helix and possibly SIS, are emerging. Some former concepts regarding absorptive capacity and diffusion of innovation are now getting more attention by scholars in IS literature.

5.1. Conceptual implications[1]

RIS is rooted in a geographic view to innovation, very close to Lundvall's original version of NIS, pointing to the importance of national factors in interactive learning (Lundvall, 1985, 1988, 1992). RIS is still very important with a large cluster, this may illustrate why Lundvall is still the central node in the innovation system network. On the other hand, Nelson's work had more to do on comparing knowledge production systems within countries with particular emphasis on R&D (Melson 1988, 1993). Although noticeable in the early years, his version did not continue to maintain its central place in the past few years and may lose its position in the near future.

Although the early versions of TIS have not used a functional view, both Hekkert and Bergek applied the functional view to innovation systems. They both referred to Edquist's (1997) book on NIS within which he coded the main functions of institutions. This might illustrate the importance of Edquist's contribution from 2007 to 2012. Given the fact that Edquist has not continued working on NIS since 2011,[2] later contributions on TIS (2012–2017) do not normally cite Edquist, but prefer to base their work on Hekkert and Bergek. The very pragmatic and policy oriented approach inherited by TIS might illustrate its rapid development, particularly in the Scandinavian countries.

The original version of Freeman (1987) on NIS links directly to technical change and catch-up on the national level with specific attention to the case of Japan. As other versions of innovation system did not adopt the same view this might provide an account why his version of NIS declined later on.

It might be surprising that SIS is the only branch of IS that could not establish its separate cluster yet. Endorsing a less practical view and a looser community of scholars working on sectoral systems[3] might explain this result. As Innovation System is generally a European concept (Fagerberg et al., 2012b), in comparison to the community of scholars working on TIS in Scandinavian countries as well as many other workings on RIS, generally rooted in EU Framework Programs, SIS does not benefit from such strength.

Other concepts close to the innovation system that are rising are the triple helix (Etzkowitz and Leydesdorff, 2000) and agricultural system of innovation (Klerkx et al., 2010). This shows that innovation system research has giving rise to two new versions in addition to its four classical types. Triple helix is developed to capture the dynamics of interactions within a system while the agricultural system of innovation concentrates topic specific systems (such as agriculture) which might pave the way for other similar versions such as Health or Defense innovation systems in the future. Finally, there are new considerations to the concept of absorptive capacity (Cohen and Levinthal, 1990) as well as diffusion of innovation (Rogers, 1962). There is a need for separate research on these two papers and the works citing them in order to find out why they are getting increasing attention.

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[1] The first author has discussed the results of this study with Prof. Lundvall and Malerba directly. Indirect discussions about innovation system literature with Prof. Fagerberg and Edquisthas also been done.

[2] According to personal discussion with him.

[3] According to personal discussion with Franco Malerba.

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