Evolution of advanced technology studies: searching for a communication core

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Abstract. The term of advanced technology is primarily associated with computer electronics and microelectronics actively developing since 1960s. Although there is no single conventional definition of the notion or specific class of technology that is associated with it, discussions on what may be considered as technical advancements in the current perspective evolve over time. As long as there is continuous interest in rise, development and dissemination of new technologies, especially from the policy-making perspective, it is important to understand which specific issues arise in professional discourse over certain time periods. This paper focuses on evolution of a communication core in academic discussions on advanced technologies identified with the use of betweenness centrality and PageRank metrics applied to a co-citation network of publications from 1960 until 2015. It is shown that there is observable penetration of the term from social sciences to natural and engineering disciplines.

Keywords: Advanced technology, technology evolution, graph analysis, bibliometric analysis, co-citation, betweenness centrality, page rank.

1 Introduction

Since 1960-s, there is growing interest in the development and use of new technologies accompanied by a strong trend on behalf of decision makers to regulate related processes at institutional and national levels. As a result, a series of efforts were put to establish relevant classification categories and statistical frameworks, allowing standardised measurement of science and technology in terms of inputs and outputs (Gokhberg et al., 2013).

One of the key categories, which emerged together with a set of definitions and distinction criteria for R&D, was a notion of advanced technology. Perhaps, first papers using the concept appeared in early 1960s in relation to a problem of growing need for sufficient training of technical specialists (e.g. see Venables, 1962). Almost 30 years later the definition of advanced technology appears in the Frascati Manual in relation to manufacturing (OECD, 1994). However, the definition vanishes from the later editions of the Manual as well as from other OECD manuals; it remains one of the key categories used in professional literature until present (see Fig. 1).

In our study, we suggest looking precisely at the identification and analysis of the communication core of those academic discussions that set up agenda for further research in advanced technology.

2 Literature review

A variety of methods have been developed to detect and analyse social and disciplinary structures of knowledge as well as dynamics of scientific networks. In offering their approaches authors suggested focusing on exploring the current 'knowledge base' of certain fields (Fagerberg & Verspagen, 2009; Fagerberg et al., 2012a, 2012b) or revisiting and conceptualising information on the current use of selected concepts (Rotolo et al., 2015).

As long as our task is to identify the central part of communication network that feeds further academic discussions on advanced technology within the certain period, we refer to the approaches focusing on the analysis of citation distributions. Specifically, we pay attention to the co-citation analysis initially introduced in 1973 (Small, 1973; Marshakova-Shaikevich, 1973) for studies of linkages between the documents and adopted further to mapping invisible colleges (Gmür, 1973) and clusters of science (Small, 1999) and searching for emerging topics (Small, et al., 2014). As a measure of the frequency with which at least two papers are cited together in other documents, co-citation analysis allows identification cognitively related knowledge clusters accepted (through citations) by a wider network of followers as mostly valuable in the field.

Similar approaches can be found in graph theory. It shows that spatial configuration of elements may characterise their role in a network. For instance, Bavelas (1948, 1950) demonstrated the relationship between centrality and communication processes in small networks. He showed that optimally positioned actors could accumulate information

flows from dislocated parts of a network and therefore play a gatekeeping role. Smith (1950) and Leavitt (1951) suggested that authors holding central positions might also influence behaviour of other linked members.

Following ideas of R.K. Merton (Merton, 1988) we can assume that those actors in academic networks that gain more attention from their colleagues through received citations will have a higher social status and therefore hold more central positions (Small, 2004). Subsequently, a centrality position would mean the author's association with a communication core. Recent papers suggest using PageRank algorithm for placing actors in co-citation networks (Ding et al., 2009). Compared to other centrality metrics (e.g. Eigenvector Centrality, Katz Centrality), PageRank may be applied to any collection of entities with reciprocal quotations and references. It assigns a numerical weighting to each element of a linked set of documents with the purpose of measuring its relative importance within the set. This makes PageRank algorithm appropriate for further analysis. Following recommendations provided in (Ding et al., 2009) in order to compare different centrality measures for the verification of results, we also consider betweenness centrality to look at the group of authors connected by shortest paths passing through a vertex. Papers with high betweenness are essential in a network as long as they mark structural holes that provide opportunities for mediating knowledge flows in a wider community of actors (e.g. see Burt, 2002).

3 Method

The concept of a communication core is based on the idea of natural social hierarchies that emerge in knowledge networks along with the evolution of the agenda in academic discussions. In order to identify a communication core in co-citaton networks that structure discussions on advanced technology within the selected periods the following four steps were taken.

First, a set of documents for further analysis was identified. The data were extracted from the Web of Science Core Collection database for the period from 1961 until the end of 2015. The dataset included 8190 documents of all types, extracted from all citation indexes (accessed: 15.04.2016).

Then, based on the overall publication dynamics we identified several shorter time periods of active growth. As seen from Fig. 1, while emergence of early papers in the field goes back to 1960s, the overall number of studies remains insufficient for the co-citation analysis until mid-1990s (by 1995 the overall amount of papers exceeds 300 with annual growth of 10 papers). Therefore, the first period taken into consideration was 1961 – 1990. Further periods include papers for the next two decades (1991 – 2000 and 2001 – 2010) and a 5-year interval from 2011 to 2015.

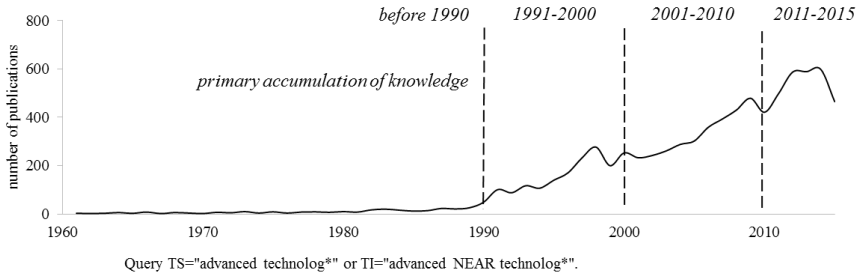

Fig. 1. Number of documents on advanced technology by year

At the third stage, we used VOSviewer software (http://www.vosviewer.com) for constructing co-citation networks for each of the distinguished time periods that were later analysed in UCINET (for betweenness calculation) and R programming language (for PageRank calculation). Formulas for centrality measures were adopted from (Ding et al., 2009). Parameters of co-citation networks are provided in Table 1. Chosen thresholds allow conducting a not overwhelming analysis with redundant nodes, while providing sufficient data for core identification.

Table 1. Metrics of co-citation networks on advanced technology studies

Period	Number of references	Network threshold	References meeting threshold	Connected nodes	
				number	share
1961-1990	1268	2	33	20	60%
1991-2000	18827	2	424	186	44%
2001-2010	66533	3	453	154	34%
2010-2015	79484	3	565	252	45%

Finally, after calculation of centrality metrics, we took top-30 authors according to each of the selected metrics and compared the lists. Key results of comparisons are provided below.

4 Results

4.1 1961 – 1990

The period from 1961 to 1990 is less connected and is likely to be associated with the primary accumulation of knowledge on advanced technology. Although subset of data for the period included 20 connected nodes, all betweenness measures are equal to zero; PageRank mean value is equal to 0.05. The latter centrality measure allowed distinction of the leader node, but no coinciding references were identified.

4.2 1991 – 2000

The network of the second period shows a greater variety in terms of values. Top-30 papers by both metrics is slightly matching: there are only three papers that are presented in both rankings (for details here and after see tables provided in the Appendix). Publications that appear in both lists consider specific issues related to economic and social effects of technology development. Hence, Bartlett & Ghoshal (1989) address management problems of companies that operate in multinational environment. A study of Howells (1990) focuses on the relationship between forms of organization and positioning of corporate R&D. Finally, Barley (1986) touches upon the role of new technologies on altering organizational structures (for the summary of top ranked papers see Fig. 2).

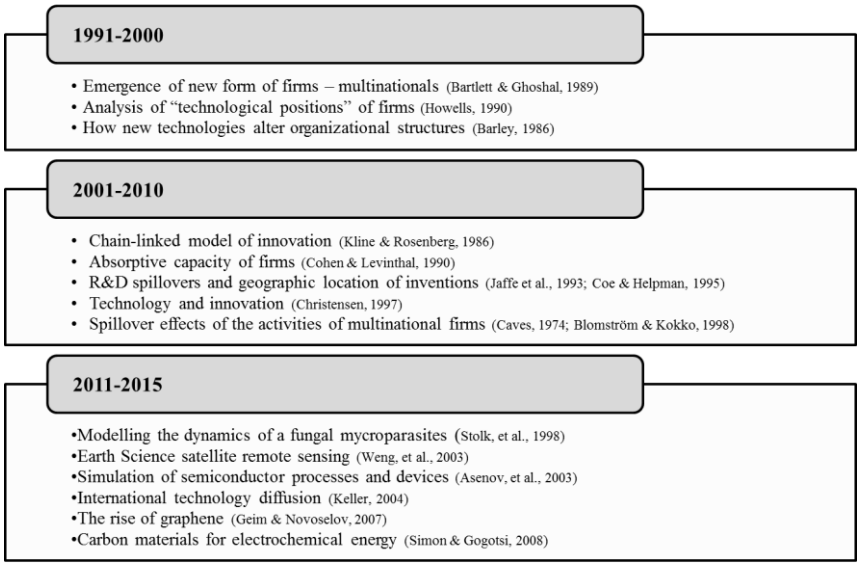

Fig. 2. Core network papers, by period

4.3 2001 – 2010

The third period is characterised by a higher number of common papers (Table A.2 in the Appendix), all of which are still focusing on economic and social issues. Here, we can see two important works of innovation economists paying attention to the role of technologies in inovation development of a firm (Kline & Rosenberg, 1986) and to the idea of absorptive capacity (Cohen & Levinthal, 1990), including, above all, an ability of a firm to be aware of, identify and take effective advantage of technology (e.g. see Seaton & Cordey-Hayes, 1993). Other works of the period introduce methods of patent analysis to explore R&D spillovers and geographic location of inventions (Jaffe et al., 1993; Coe & Helpman, 1995); a book on relationship between new technologies and

success of innovation (Christensen, 1997); papers on spillover effects of the activities of multinationals (Caves, 1974; Blomström & Kokko, 1998).

4.4 2011 – 2015

The forth period include six common documents (Table A.3 in the Appendix) of which five come from natural and engineering sciences and are oriented towards the development and use of specific technologies. The occurence of these papers in the core network can be considered as a certain level of acceptance of the advanced technology concept by hard sciences and as its correspondence to certain groups of technologies like mathematical modelling of living systems (Stolk, et al., 1998), remote sensing (Weng, et al., 2003), simulation of technical processes (Asenov, et al., 2003), and new materials (Geim & Novoselov, 2007; Simon & Gogotsi, 2008). The only economic paper in the core addresses issues related to international diffusion if technology (Keller, 2004).

5 Conclusion

The paper represents evolution of a communication core in academic discussions on advanced technologies identified with the use of betweenness centrality and PageRank metrics applied to co-citation networks for the period from 1961 to 2015. The combination of these methods allowed identifying and considering key alterations in professional discourse on advanced technology development. Further analysis of co-citation networks eliminated a common background for the papers in each of the observable time periods, while the application of centrality metrics helped to distinct key works. It was shown that there is an observable penetration of the concept from social sciences to natural and engineering disciplines. At least three phases with foci on different issues can be distinguished: studies in R&D and technology management (1991 – 2000), analyses of technology diffusion and innovation development (2001 – 2010), and discussions on specific technologies and materials (2011 – 2015). Further work can be aimed at deeper analysis of disciplinary structures in communication networks and at identification of specific technologies considered as advanced in certain time periods.

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A Appendix

Table A.1. Centrality metrics for co-citation network top-30 papers: 1991 – 2000

Betweenness	Page Rank
Pavitt K., 1991	**Barley S.R., 1986**
Helpman E., 1991	Alexander S.J., 1980
Howells J., 1990	von Hippel E., 1988
Balachandra R., 1997	**Bartlett C., 1989**
Yelle L. E., 1979	Dunning J.H., 1994
Crawford C.M., 1992	Granstrand O., 1993
Brown S.L., 1995	Basberg B.L., 1987
Kodama F., 1995	Behrman J.N., 1980
Topel R., 1991	Cantwell J., 1995
Keats B.W., 1988	Cantwell J., 1992
Cohen W.M., 1990	Demeyer A., 1993
Jaikumar R., 1986	Forsgren M., 1995
Greene W., 1990	Hakanson L., 1981
March J.G., 1958	Hakanson L., 1993
Morone J., 1993	Hakansson L., 1995
Gupta A.K., 1985	Hedlund G., 1986
Saaty T.L., 1980	Hedlund G., 1994
Quinn J.B., 1985	Hedlund G., 1995
Barley S.R., 1986	Hedlund G., 1996
Cohen W.M., 1989	Hedlund G., 1990
Bartlett C., 1989	Holm U., 1994
Wilkinson B., 1983	**Howells J., 1990**
Nelson R., 1993	Jacquemin A.P., 1979
Teece D. J., 1976	Johanson J., 1975
Meyer M.H., 1988	Johanson J., 1977
Schmookler J., 1966	Kogut B., 1989
Harrison B., 1992	Kogut B., 1990
Walker R., 1989	Pavitt K., 1988
Liberatore M.J., 1983	Prahalad C.K., 1987
Porter M.E., 1980	Ridderstrale J., 1997

Key statistics:
Coinciding references (in bold): 3
Mean top-30 betwenness: 1183.3
Mean top-30 PageRank: 0.0032

Table A.2. Centrality metrics for co-citation network top-30 papers: 2001 – 2010

Betweenness	Page Rank
Nelson R., 1982	**Blomstrom M., 1998**
Cohen W., 1990	Hamel G., 1994
Moore J., 1969	Grant R., 1996
Hoffert M., 1998	Saaty T., 1980
Prahalad C., 1990	Lundvall B., 1992
Eisenhardt K., 1989	**Kline S., 1986**
Christensen C., 1997	Buckley P., 1976
Jaffe A., 1993	Globerman S., 1979
March J., 1991	**Cohen W., 1990**
Jaffe A., 1989	Florida R, 1995
Williamson O., 1985	Nakicenovic N., 2000
Nelson R., 1993	Martin S., 2000
Kline S., 1986	Saaty T., 1977
Von Hippel E., 1986	Vernon R., 1966
Wigley T., 1996	Dunne T., 1994
Rosenberg N., 1982	Porter M., 2000
Teece D., 1997	**Caves R., 1974**
Kogut B., 1992	Aitken B., 1999
Churchill G., 1979	Freeman C., 1988
Kaplan R., 1986	Helpman E., 1991
Caves R., 1996	**Christensen C., 1997**
Cooper R., 1993	Howells J., 1999
Holland J., 1975	Keeble D., 1998
Blomstrom M., 1998	**Jaffe A., 1993**
von Hippel, E. 1994	Markusen A., 1996
Caves R., 1974	Morgan K., 1997
Brown S., 1995	Saxenian A., 1994
Hobday M., 1995	Lundvall B., 1994
Cantwell J., 1995	**Coe D., 1995**
Coe D.T., 1995	Borensztein E., 1998

Key statistics:
Coinciding references (in bold): 7
Mean top-30 betwenness: 195.9
Mean top-30 PageRank: 0.012

Table A.3. Centrality metrics for co-citation network top-30 papers: 2011 – 2015

Betweenness	Page Rank
Bradley T., 2009	**Weng F., 2003**
Rogers E., 1995	Weng F., 2012
Tsang Y., 2007	Grant R., 1996
Fornell C., 1981	**Simon P., 2008**
Simon P., 2008	**Geim A., 2007**
Hair J., 1998	Ahlbin J., 2009
Geim A., 2007	Calin T., 1996
Tarascon J., 2001	Wang H., 2010
Novoselov K., 2005	**Keller W., 2004**
Kim K., 2009	Aumann H., 2003
Tian B., 2010	Seifert N., 2010
Asenov A., 2003	Stoller M., 2008
Weng F., 2003	Weng F., 2013
Zhao W., 2006	Zhang L., 2009,
Moore G., 1965	Winter M., 2004
Borkar S., 2005	Nakada N., 2007
Griliches Z., 1957	Cohen W., 1990
Rogers E., 2003	Surussavadee C., 2007
Keller W., 2004	Surussavadee C., 2008
Asenov A., 1998	Surussavadee C., 2008
Mizuno T., 1994	Chatterjee I., 2011
Weng F., 2000	Takeuchi K., 2007
Shannon M., 2008	Han Y., 2007
Asenov A., 2003	Amusan O., 2006
Stolk P., 1998	Harris B., 2001
Benotti M., 2009	Nonaka I., 1995
Baron R., 1986	Weng F., 1994
Ferraro R., 2005	**Asenov A., 2003**
Kuhn K., 2007	**Stolk P., 1998**
Aitken B., 1999	Copeland B., 2004

Key statistics:
Coinciding references (in bold): 6
Mean top-30 betwenness: 1075.6
Mean top-30 PageRank: 0.0077

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