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Combining mapping and citation network analysis for a better understanding of the scientific development: The case of the absorptive capacity field

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ABSTRACT

The general aim of this paper is to show the results of a study in which we combined bibliometric mapping and citation network analysis to investigate the process of creation and transfer of knowledge through scientific publications. The novelty of this approach is the combination of both methods. In this case we analyzed the citations to a very influential paper published in 1990 that contains, for the first time, the term Absorptive Capacity. A bibliometric map identified the terms and the theories associated with the term while two techniques from the citation network analysis recognized the main papers during 15 years. As a result we identified the articles that influenced the research for some time and linked them into a research tradition that can be considered the backbone of the "Absorptive Capacity Field".

1. Introduction

In terms of citations fields or areas of specialization are not just 'formless' sets of articles. On the contrary, they represent sets of papers with a particular structure that emerges from the citation practices of the researchers active in that field. It emphasizes the importance and visibility of certain theoretical and methodological approaches while marginalizing others. We could say that citation practices represent a "knowledge–construction" process that outlines the manner we think about and engage with our research. The emergence of trajectories (Dosi, 1982) implies that the evolution of knowledge is not random.

In every scientific field there are key concepts that set the base for theoretical developments through the years. As De Nooy, Mrvar, and Batagelj (2005) pointed out, citation analysis may focus on the identification of specialties, the evolution of research traditions, and changing paradigms. Researchers from the same specialty tend to cite each other in order to position their work in the field based on previous knowledge. Scientific knowledge is assumed to increment over time following a "smooth path", the papers that introduce important new insights are cited until new results modify or contradict them. The scientific revolutions, sudden paradigmatic changes resulting from new insights (Kuhn, 1962), are reflected by abrupt changes in the citation network.

The objective of our study is analyzing the influence of the introduction of a new concept on a research field through the analysis of scientific publications.

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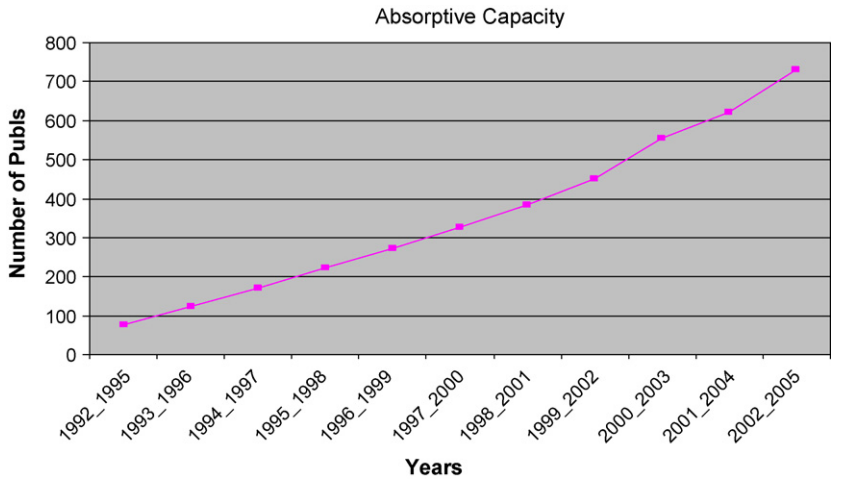

Fig. 1. Number of Publications citing Cohen and Levinthal (1990) during the period 1992–2005 (*source:* Web of Science).

1. How the diffusion of the concept has taken place through the research literature building over the original Absorptive Capacity concept?
2. Which papers and theories are considered the main research streams of the field?
3. Which papers are essential?

The novelty of our approach is that to answer to these questions we combine bibliometric mapping and citation network analysis. The bibliometric co-word map provides insight into the contents of the publication while two techniques from the citation network analysis recognized the main papers during 15 years. This is used for the interpretation of groups of citations that may constitute the backbones of a research tradition or the future of the research.

2. Data and methods

2.1. Data

In the research field Organization the concept "Absorptive Capacity" (AC) is considered as one of the most important introduced in the last 15 years. In their study on international transfer, Kedia and Bhagat (1988) first coined the term "Absorptive Capacity". However, the contribution by Cohen and Levinthal (1990) is generally accepted as the founding paper. It defined AC as "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends". Cohen and Levinthal put R&D at the center of firm's innovative processes by linking it to both learning and innovation (Foss, Lyles, & Volberda, in press). Nevertheless, the Cohen and Levinthal contribution did not emerge out of the blue, and the AC theme overlaps with other themes and fields, such as cognition, knowledge and dynamic capabilities.[1] The theoretical development of AC ranges from the psychological emphasis on cognition and learning to the focus of economics on innovation and competition to the sociological orientation towards co-evolution. (Foss, Lyles, & Volberda, in press)

This influential publication has received more than 1500 citations (up to 2007) in papers published in journals processed for the Web of Science (WoS) published by Thomson Scientific, and as Fig. 1 shows, the attention is growing. Recently there have been two main efforts for reviewing the absorption of the concept of Absorptive Capacity in the literature of Organizational Theories (Foss, Lyles, & Volberda, in press; Lane, Koka, & Pathak, 2006). These papers point out the main streams in the field of Organization related to Absorptive Capacity: organizational learning, innovation, the knowledge-based view of the firm, dynamic capabilities, co-evolution and managerial cognition. Some of these experts were involved in the validation of the results of our study.

The data set consists of the 1213 publications citing Cohen and Levinthal (1990) up to 2005. The publications were extracted from journals covered by the Web of Science. We define this set of publications as the 'Absorptive Capacity field'.

2.2. Bibliometric map analysis

The first step was to get a general overview of the Absorptive Capacity field. We map the structure of all publications citing Cohen and Levinthal (1990) with a bibliometric mapping method based on keyword co-occurrences. With this method we

[1] In economics, the idea of "learning to learn" introduced by Stiglitz' (1987) is clearly a precursor of AC, as is David's (1975) work of localized technological progress.

created a 2-dimensional graph with sub-domains representing topic clusters. The topic clusters were created by applying a co-word analysis to the keywords in the *citing* publications (Noyons, 1999). We collected the keywords of these 1213 publications to assess the contents of the field. These keywords were extracted from the bibliographic fields *keywords plus* and *author keywords*. The former are keywords automatically assigned by Thomson to individual publications on the basis of cited reference information. The latter are the keywords assigned to publications by the authors.

Of the 94 most frequent keywords (with 20 or more occurrences) we selected the 83 most relevant and discriminative. This selection was done by experts in the field of *Absorptive Capacity* in close collaboration with the authors. With these 83 keywords, we calculated the number of times they co-occurred in publications. With this information, we applied a (hierarchical agglomerative, complete linkage) cluster analysis and identified 11 clusters of topics (keywords). We refer to these keyword or topic clusters as sub-domains in the field. Using these topics, we were able to assign individual publications to sub-domains. In addition, we defined the overlap between the clusters, with the publications present in more than one sub-domain. This overlap provides input for the cosine similarity measure between sub-domains. Multi Dimensional Scaling (MDS) was applied to the obtained similarity values, and this application yielded a map of sub-domains. The distances between sub-domains represent their cognitive similarity in terms of common publications. The closer they are in the map, the more similar. The validation (and the label) for each sub-domain was provided by the above mentioned field experts. These labels are compiled to represent application areas of AC. As such they are not directly retrieved from the publication data but rather created by the experts and referring to actual research areas. For further details of the mapping methodology, we refer to Noyons (1999).

This part of the analysis gave us a first overview of the field. We could identify the sub-domains that attract more publications and their growth rate in terms of number of publications over the period. But we still did not know anything about the publications behind these sub-domains.

2.3. Publication content labeling

The next step was to label each of the 1213 publications citing Cohen and Levinthal (1990) with the sub-domain(s) to which they belong. Thus we were able to classify the publications with respect to content.

2.4. Citation network analysis

Subsequently, we created a citation network based on the citation links between the 1213 papers. Citation network analysis began with the study by Garfield, Sher, and Torpie (1964) of Asimov's history of DNA. This study showed that there was "a high degree of coincidence between an historian's account of events and the citation relationship between these events". In our study, we carried out a citation network analysis to investigate the processes of the diffusion of the concept of Absorptive Capacity and the theories around it. The citation analysis allowed us to view the structure of part of the Absorptive Capacity literature that had emerged from current citation practices and showed how this emergent structure elevated certain approaches and marginalized others. In this context, following Small (1978), a cited document stands for a concept. Highly cited documents have a significant content that is shared by a community of scientists. A publication often cited may be seen as a "concept symbol" that represents an author's orientation to a community of scientists or an approach to a topic (Moed, 2005).

The citation network enabled us to study the data from two perspectives in time. In the evolution of knowledge, phases of consolidation of past results coexist with exploration of new approaches. The techniques of longitudinal network analysis, like main path analysis, allowed us to unravel the dynamics of convergence and divergence between streams of investigation (Ramlogan, Mina, Tampubolon, & Metcalfe, 2007). It shows the change over time of the connectedness of the system. The second perspective is a cross-sectional look at the state of the literature in 2005 through the identification of important publications based on a 'hubs' and 'authorities' analysis (Kleinberg, 1999). These two perspectives were important because they highlighted different parts of the citation network.

2.4.1. Main path

If knowledge flows through citations, a citation that is needed in paths between many articles is more important than a citation that hardly plays any role for linking articles (De Nooy et al., 2005). Among all possible "chains" of citations from the most recent records to the oldest, the network algorithm computes the paths that are most frequently encountered, and these can be regarded as the backbones of a research tradition (Batagelj, 2003; De Nooy et al., 2005; Hummon & Doreian, 1989; Hummon & Doreian, 1990; Hummon & Carley, 1993). These results identify the path that is most frequently used to 'walk' from the present to the pass (that is back in time) in a 'field' of papers: the 'main path'. We stress that this method does not involve the absolute count of maximum number of citations received, but the simultaneous computations of all the possible paths through the whole dataset and the choice of the one that is the most frequently encountered through time (Mina, Ramlogan, Tampubolon, & Metcalfe, 2007).

As Batagelj showed in 2003 with the example in SOM (self-organizing mapping) literature, a "main subnetwork" can be extracted applying a similar procedure as the main path analysis. The main subnetwork contains not only the main path but also other important branches from the citation network provide rich information about the development of a field. In this paper though, we were more interested in showing a new methodology that combines different approaches. In order to keep

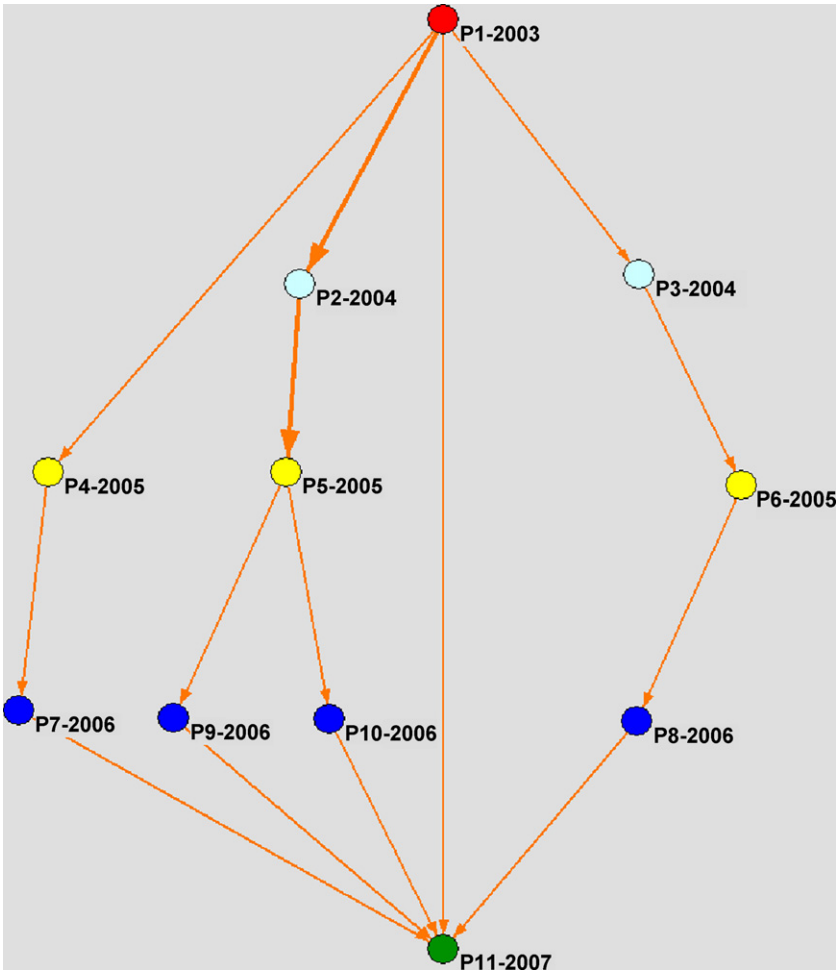

Fig. 2. Traversal weights in a citation network.

things as simple as possible for a better understanding of the methodology, we will apply only a main path analysis. We are quite aware though of the additional information that the main subnetwork can provide us with.

As an illustration of how the main path is extracted from a citation network we have prepared a simple example. Fig. 2 shows a citation network of 11 fictitious papers ordered in time from top to bottom. The vertices (circles) represent papers and the arcs (arrows) indicate cited by. A Source Vertex is an article that is not citing within the data set (*P1-2003*). A Sink Vertex is an article that is not cited within the data set (*P11-2007*). In the network terminology, a path is a walk in which no vertex or arcs in between the source and the sink vertex occurs more than once. For extracting the main path from the citation network we first computed the 'traversal weights'. The traversal weight measures the number of times that a link between articles was involved in connecting other articles in a citation network. The thickness of the arcs in Fig. 2 shows the traversal weight measure. In a citation network, a main path network following the Search Path Count (Batagelj, 2003) is constructed starting from the source vertex and selecting at each step in the end vertex the lines with the highest weight, until the sink vertex is reached. Starting from the source paper (*P1-2003*), the main path algorithm chooses the next link in the path as the outgoing link with the highest traversal weight *(P2-2004),* from this one the highest link drives us to *P5-2005*, from here to *P9-2006* and *P10-2006*, to finish in the sink vertex *P11-2007*. By repeatedly applying this choice rule, we defined a path through the network that follows a structurally determined most used path.

The main path, chosen on the basis of the most used path identified the main stream of the Absorptive Capacity literature between 1990 and 2005, having the Cohen and Levinthal (1990) as source paper. The main path analysis was conducted with the software package Pajek.

2.4.2. Hubs and authorities

Research in bibliometrics and in context of hypertext and the www are concerned with the identification of important nodes in networks. The famous Garfield's impact factor (Garfield, 1972) is basically a ranking measured based on a pure counting of the in-degrees nodes in a journal citation network. Not happy with this measure Pinski and Narin (1976) and

Geller (1978) developed an algorithm that considered not only the number of citations from one journal to the other but also the prestige of the citing journal. Journals that receive many citations from prestigious journals are considered highly prestigious themselves. By iteratively passing prestige from one journal to the other, a stable solution is reached which reflects the relative prestige of journals (Bollen et al., 2006). This way of measuring prestige is behind the PageRank algorithms to evaluate the status of web pages. First developed by the founders of the Google search Engine Brin and Page (Brin & Page, 1998; Page, Brin, Motwani, & Winograd, 1998). The PageRank is calculated by an iterative algorithm which propagates prestige values from one web page to another and converges to a solution (Pillai, Suel, & Cha, 2005)

In the same period that Brin and Page, Kleinberg (1999) was also working on an algorithm to increase the effectiveness of Web search engines using the concepts of *hubs and authorities.* An authoritative publication, in our case, is one that many other publications cite to. But, this idea can be reinforced by observing that citations from all publications are not equally valuable—some publications are better *hubs* for a given publications. Hubs and Authorities are formal notions of structural prominence of vertices in directed graphs (Brandes & Willhalm, 2002). Kleinberg developed an iterative algorithm for computing hubs and authorities. Hubs and authorities stand in a mutually reinforcing relationship: a good authority is a publication that is cited by many good hub, and a good hub is a document citing to many good authorities. He showed examples where the algorithm could help to filter out irrelevant or poor quality documents (they would have low authority scores) and to identify high-quality documents (they would have high authority scores).

From our perspective making the classification in hubs and authorities is a very useful tool to understand the role playing by the publications in this citation network. From the hubs/authorities perspective for a publication being both a hub and an authority at the same time is "the best" position: having a lot of influence (authority) but also being influenced by the best (hub). We could say that in terms of knowledge flow and the quality of knowledge used is a good position. This is the reason why on this study we decided to use Kleinberg's algorithm for identifying the main publications in this citation network. Batagelj adapted for the software Pajek Kleinberg's hubs/authorities algorithm (Batagelj & Mrvar, 2006).

For each paper (p) in our citation network we computed two weights: hub weight (h_p) and authority weight (a_p). They show the strength of a given paper as an authority and/or a hub. Weights are computed according to the citation network (M) by solving the eigenvector problem of matrices MM^{T} (hubs) and $M^{\mathrm{T}}M$ (authorities), where M is the citation matrix (Kleinberg, 1999). Paper x is a better hub than paper y if $h_x > h_y$. Paper x is a better authority than paper y if $a_x > a_y$. The hubs and authorities analysis was conducted with the software package Pajek.

3. Results

3.1. The absorptive capacity bibliometric map

Fig. 3 shows the map of the Absorptive Capacity Field. As explained above, it is the result of clustering keywords (sub-domains) and mapping these sub-domains in a two-dimensional figure, with the size of each sub-domain indicating the number of publications represented and the colour (grey scale) of each sub-domain indicating the growth in the number of publications until 2005 (black: fast growth; grey: growth around average; white: growth below average). The growth rate is calculated by the development of the share of a sub-domain within the entire field. For two 7-years periods we compared

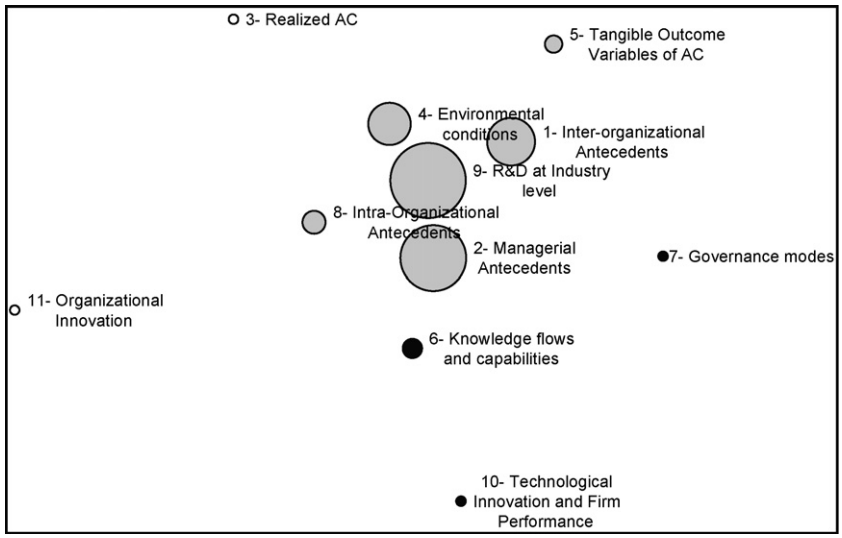

Fig. 3. Bibliometric map of the field of Absorptive Capacity.

these shares. If the share increased in the most recent period with more than 20% it was indicated as a significant growth. Sub-domains closer to one another have more publications in common than sub-domains that were further apart.

Most of the studies in Absorptive Capacity are focused on R&D rates in various industries (sub-domain 9), inter-organizational and managerial antecedents (sub-domain 1 and 2). Fast growing areas of Absorptive Capacity (the black circles) appear to be studies on ***Knowledge flows and capabilities*** (sub-domain 6), the impact of Absorptive Capacity on ***Technological innovation and firm performance*** (sub-domain 10), and the effects of relational (trust) versus formal ***Governance modes*** (sub-domain 7) on Absorptive Capacity. Fig. 3 also shows that ***Organizational Innovation*** (sub-domain 11) and ***Realized Absorptive Capacity*** (sub-domain 3) is underrepresented according to the experts.

3.2. Citation network analysis

3.2.1. Main path

The main path (Fig. 4) shows the main track followed by the researchers in this field to explain industrial innovative processes. The nodes (circles) of the graph represent the publications, the presentation is ordered in time from top to bottom (from 1990 until 2005), the colors (grey scale) represent the year of the publication, and the thickness of the lines relate to the traversal weights. The publications are labeled with the first author's name, publication year and between parentheses appear the sub-domain/s' number.

Fig. 4 illustrates that there were just a few publications that constitute the main stream on the Absorptive Capacity literature. The analysis of the papers along the backbone in Fig. 4 provides the sequence of the papers. As we can see in the graph, these papers are strongly focused on the main sub-domains of the map (1, 2, 4, 9), as we can expect from a map with such a central and big sub-domains. However, in 2001 the paper from Ahuja and Katila (Ahuja & Katila, 2001) included some notions relating with one of the small sub-domain "***Organizational Innovation***". In 2002 the paper from Zahra and George identified key dimensions of absorptive capacity and offered a reconceptualization. This analysis was based on sub-domains 1 and 2, but also on 5 and 6. The nodes on the bottom of the diagram were a sample of the state of the art at 2005.

3.2.2. Hubs and authorities

Table 1 shows the 20 for the hubs and authorities analysis (as explained above). These papers are considered the main hubs and authorities from the citation network. These two lists show the papers that cited the most in general and, in particular, were most cited in our network. As it explained also above, a good hub is a paper that points to many good authorities, and a good authority is a paper that is pointed to by many other good hubs. As we can observe from the date of the publications, the authorities are older paper than the hubs.

The hub papers are in many cases broad literature reviews, but in a few cases these papers attract a lot of attention (i.e., are cited frequently) and thus become authority documents (in bold in Table 1). In this case only one of the three hub/authority papers played a critical role in the main development of the field. The paper from Zahra and George (2002) 'Absorptive capacity: A review, reconceptualization, and extension', that is both an authority as well as a hub, forms part of the basic structure of the main path. The other two papers: one from Kale, Singh, and Perlmutter (2000) 'Learning and protection of proprietary assets in strategic alliances: building relational capital' and the other from Larsson, Bengtsson, Henriksson, and Sparks (1998) 'The interorganizational learning dilemma: collective knowledge development in strategic alliances', does not

Table 1
Authorities and Hubs (bold: papers that are hubs and authorities at the same time).

Ranking	h_p	HUB ID	a_p	Authority ID
1	0.10326	**KALE P-2000 (1) (2) (7) (9)**	0.94172	COHEN WM-1990 (.)
2	0.06417	MARTIN X-2003 (1) (2) (4) (5)	0.12772	SZULANSKI G-1996 (1) (2) (4) (9)
3	0.06124	**LARSSON R-1998 (1) (2) (7)**	0.10879	GRANT RM-1996 (9)
4	0.04842	INKPEN AC-2000 (1) (2) (7)	0.09865	POWELL WW-1996 (1) (4) (9)
5	0.04788	REID D-2001 (2) (7)	0.09707	LANE PJ-1998 (1) (2) (4) (9)
6	0.04775	IRELAND RD-2002 (1) (2) (7)	0.08833	LEVINTHAL DA-1993 (2) (4) (9)
7	0.04703	NIELSEN BB-2005 (1) (2) (4) (6)	0.08572	MOWERY DC-1996 (1) (4) (5) (9)
8	0.04442	MALHOTRA A-2005 (1) (2) (4) (6)	0.07299	DYER JH-1998 (1) (2) (4)
9	0.04374	**ZAHRA SA-2002 (1) (2) (5) (6)**	0.06332	VONHIPPEL E-1994 (4) (9)
10	0.04357	ANDERSSON U-2002 (1) (2) (8) (9)	0.05746	NAHAPIET J-1998 (1) (2) (8) (9)
11	0.04289	SIMONIN BL-2004 (1) (2) (9)	0.05593	CONNER KR-1996 (2)
12	0.04250	CUMMINGS JL-2003 (1) (2) (5) (9)	0.04975	**KALE P-2000 (1) (2) (7) (9)**
13	0.04222	MOLINA LM-2004 (1) (2) (10)	0.04833	**ZAHRA SA-2002 (1) (2) (5) (6)**
14	0.04160	MATUSIK SF-2005 (1) (2) (9)	0.03839	**LARSSON R-1998 (1) (2) (7)**
15	0.04140	ARANDA DA-2002 (1) (2) (6) (9)	0.03769	SIMONIN BL-1999 (1) (2) (4) (6)
16	0.04074	SIMONIN BL-1999 (1) (2) (4) (6)	0.03714	KHANNA T-1998 (1) (2) (8) (9)
17	0.04062	BARRINGER BR-2000 (1) (2)	0.02969	ANDERSON P-1990 (4)
18	0.04017	HOLMQVIST M-2003 (1) (2) (4) (9)	0.02900	GUPTA AK-2000 (1) (2) (4) (9)
19	0.03982	ALMEIDA P-2004 (1) (2) (5) (9)	0.02729	BOWMAN EH-1993 (1) (2) (4) (8)
20	0.03963	JOSHI AW-2003 (1) (2)	0.02689	LIEBESKIND JP-1996 (4) (8) (9)

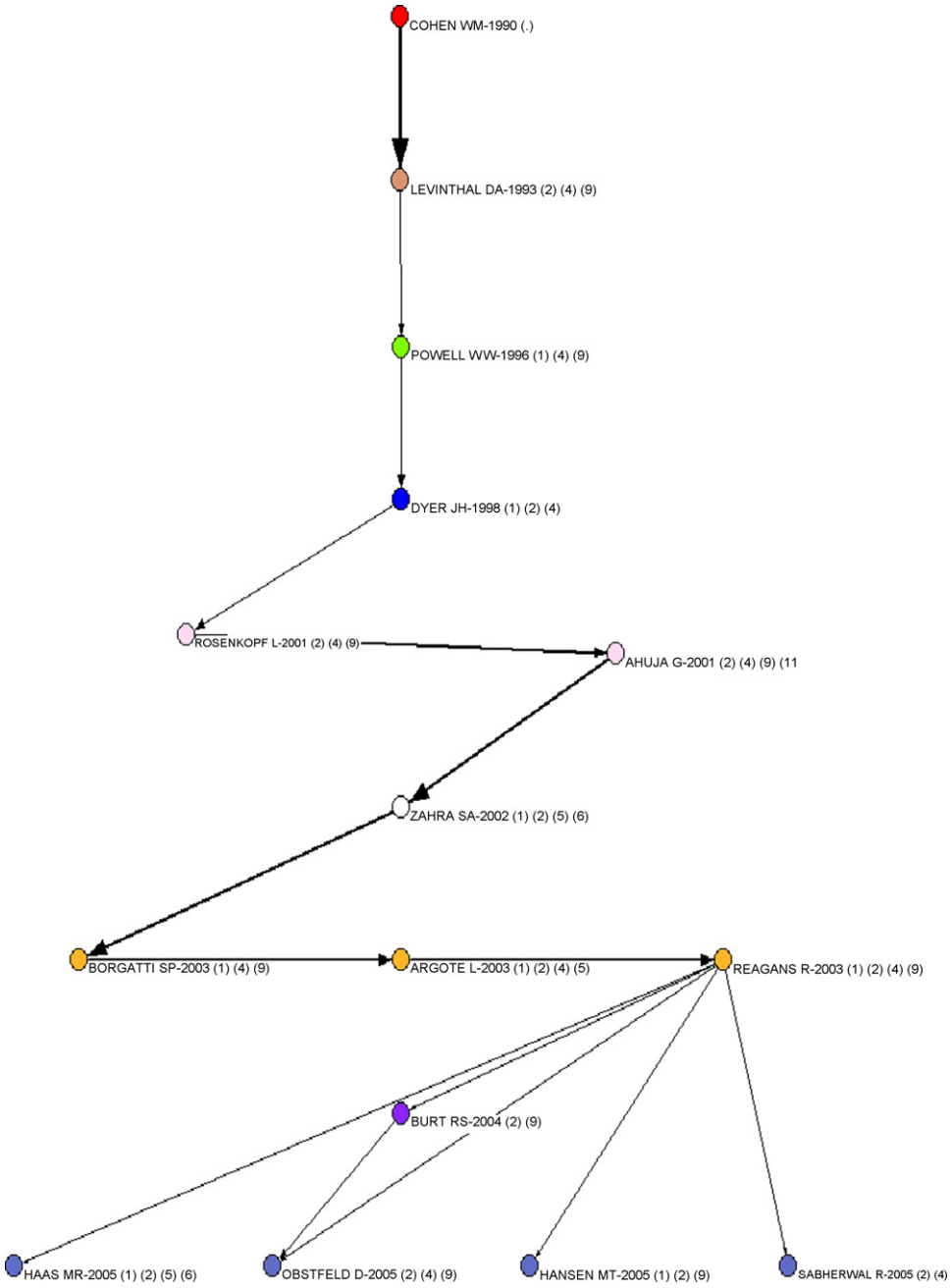

Fig. 4. Main path component of the Absorptive Capacity Field (vertical dimension represents the publications year, horizontal dimension locates the publications in the same year).

appear in the main path, but further study located this paper in the main subnetwork (as we mentioned previously, in this study we focus only on the main path) as part of the other important paths of the field.

4. Concluding remarks and follow-up research

We think that our results show to information scientists the potential of this new methodology as a tool for unraveling the patterns behind a set of publications representing a field. The combination of bibliometric mapping with citation network techniques enables us to follow the influence of the introduction of a new concept in a specific research field. The use of bibliometric mapping with network analysis as a useful tool in the identification of research groups has also been demonstrated in a previous study of the authors (Calero, Buter, Cabello Valdés, & Noyons, 2006).

In this study, as an example, we followed the 'intellectual track' of a specific concept, *Absorptive Capacity* (AC), with a high rate of diffusion through the fifteen years of analysis. The bibliometric map identifies the other concepts (in terms field-specific keywords) and the theories associated with the main concept (AC) while two techniques from the citation network analysis recognized the main papers during these years, the articles that influenced the research for some time and linked them into a research tradition that is the backbone of the 'Absorptive Capacity Field'.

It is important to mention that because of our focus on a specific term, the analysis is based on a few central sub-domains. Of course, the Cohen and Levinthal contribution did not emerge out of the blue, and the Absorptive Capacity topic overlaps with other research themes and fields, such us cognition, knowledge flow and dynamic capabilities as major parts of the field 'Organization'.

Our next goal will be to map and detect all main research streams in a physics–chemistry-related field, and particularly to identify the papers considered as authorities and hubs. Bibliometric maps that are not focused on just a specific topic of a field will show many different parts of that field of which the dynamics will be represented by the main path analysis.

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