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The rise and fall of interdisciplinary research: The case of open source innovation

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ABSTRACT

A large, and purportedly increasing, number of research fields in modern science require scholars from more than one discipline to understand their puzzling phenomena. In response, many scholars argue that scientific work needs to become more interdisciplinary, and is indeed becoming so. This paper contributes to our understanding of the evolution of interdisciplinary research in new fields. We explore interdisciplinary co-authorship, co-citation and publication patterns in the recently emergent research field of open source innovation during the first ten years of its existence. Utilizing a database containing 306 core publications and over 10,000 associated reference documents, we find that inquiry shifts from interdisciplinary to multidisciplinary research, and from joint puzzle solving to parallel problem solving, within a very few years after the inception of the field. "High-involvement" forms of interdisciplinary exchange decline faster than "low-involvement" forms. The patterns we find in open source research, we argue, may be quite general. We propose that they are driven by changes in task uncertainty and the ability to modularize research, among other factors. Our findings have important implications for individual scholars, research organizations, and research policy.

1. Introduction and overview

Many fields in modern science require scholars from more than one discipline to effectively address principal research questions (Becher and Trowler, 2001; Hessels and van Lente, 2008). Interdisciplinary fields are also more likely to provide findings of high novelty (Dogan and Pahre, 1990; Bartunek, 2007). Many scholars have argued that scientific work needs to become more interdisciplinary, and is indeed becoming so (Chubin, 1976; Nissani, 1997; Metzger and Zare, 1999; Forman and Markus, 2005).

At the same time, interactions across disciplines can be more costly than within-discipline interactions (Klein and Porter, 1990). Whether or not the benefits outweigh the costs of interdisciplinary research is contingent on the nature of the scientific problem at hand as well as the availability and distribution of prior related knowledge (Birnbaum, 1981; Kötter and Balsiger, 1999). Changes in these factors can therefore be assumed to affect the effectiveness and efficiency of interdisciplinary research.

However, there are very few studies to date that measure how interdisciplinary collaboration among researchers evolves over time and theorize the contingencies. We believe that this is an important gap to address. It has wide-ranging implications for individual researchers, research organizations and research policies that seek to adopt or promote the most efficacious research strategies. Scholars as well as research practitioners and managers will wish to know when interdisciplinary work is most appropriate.

This paper contributes to filling this gap by investigating three principal questions:

(I) Do scholars from different disciplinary backgrounds jointly solve the puzzles of the new research field, or do they mostly co-evolve their understandings without tight integration?
(II) How does this change, as the field matures?
(III) What factors can explain such changes?

To address these questions, we use a comprehensive set of comparative-static bibliometric analyses to conduct a longitudinal study of one research field, open source innovation, a fast-growing and supposedly interdisciplinary field. Our analyses rest on several databases of researchers' attributes and co-authoring, publishing and citation behaviors. We analyze 306 core publications on open source innovation and over 10,000 reference documents cited therein.

We find a close and continual relatedness of content, i.e. strong substantive coherence of OS research as a field. However, we find that the substitute preference of interdisciplinary work decreases

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as the field matures. Researchers from different disciplines still study the same topics years into the creation of the field, but do so increasingly from their own disciplinary lenses (co-authoring within their discipline, citing within their discipline, publishing within and for their discipline). Interestingly, we find that "high-involvement" forms of interdisciplinary exchange such as co-authoring and cross-disciplinary publishing drop sharply only a few years after the inception of the research field. "Low-involvement forms" such as cross-disciplinary citations are slower to decline.

We propose, based on extant studies of other fields, that the pattern we have found in open source research may in fact be quite general: inquiry into a new field often shifts from interdisciplinary to multidisciplinary research, and from joint puzzle solving to parallel problem solving. This pattern may be particularly prevalent among phenomenon-based research fields.

Finally, we explore the contingency factors underlying these patterns. We explain initial high levels of interdisciplinary work as being driven by researchers' need to draw upon theories or methods established in disciplines other than their own to achieve their research goals (functional dependence). Interdisciplinary functional dependence declines over time, as the understanding of the field increases. Increased understanding enables modularization of further problem solving, often within disciplinary boundaries. Moreover, we argue that task uncertainty declines over time, and that expanding research fields enable researchers to deploy lower-cost strategies of accessing knowledge from other disciplines.

Our paper contributes to the literature in several ways. First, we propose a set of bibliometric tools that allows a comprehensive assessment of the cohesion of research fields. For any field, cohesion among disciplines, but also among geographies or schools of thought, can be studied from multiple angles by applying this set of tools.

We advocate using more than one publication database (e.g. Google Scholar, Ebsco, and the Institute for Science Information (ISI) database) and show that the common practice of using just one source may come at the cost of a substantial loss of relevant data.

Next, we apply this tool-set in one case, which future work on interdisciplinary research can use as a reference case. Our bibliometric findings relating to our specific case, the thriving field of open source research, are relevant to scholars interested in that field as well as to scholars interested in the emergence of successful new research fields.

Further and more generally, we theorize how changes in three underlying variables affect the disciplinary nature of research undertaken in a field at any point in time. We advance testable propositions that can guide future research. Our findings have important implications for individual researchers, research organizations, and research funding policies that seek to design and promote optimal research strategies, and to science media that assess and publish scholarly work.

The remainder of the paper is structured as follows: Section 2 describes prior related research and outlines important gaps. Our research methodology and data collection are explained in Section 4, the main findings section, we analyze the coherence of the OS field, and its change over time, along multiple dimensions. In Section 5, we consider the generality of our bibliometric findings and advance propositions to explain them. Finally, Section 6 discusses the contribution of this paper in relation to prior research and derives implications for future research, practice and policy.

2. Prior research and research gap

2.1. Background and definitions

A scientific discipline is "a specialized field of knowledge" (Chubin et al., 1986a). Disciplines "represent historical, evolutionary aggregates of shared scholarly interest," which typically gain legitimacy in a university as departments (Chubin et al., 1986a, p. 4). Throughout this paper, when referring to disciplines, we mean aggregations as represented in university departments, e.g. management studies, psychology, or law. Following Qin et al. (1997, p. 894), we define interdisciplinary research as "the integration of disciplines within a research environment." This integration consists of interactions among scientists (possibly mediated by their research outputs) and is motivated by a common problem-solving purpose.

A research field, or specialty, is an area of science that is defined by its intellectual coherence as well as its social coherence (Chubin, 1976, p. 451). Research fields cluster around 'central problems'; they address specific and recognizable sets of questions (Darden and Maull, 1977).

Building on groundwork laid by Kuhn (1962), Merton (1973), and Chubin (1976), among others, many scholars study the emergence and evolution of new research fields (Bonaccorsi and Vargas, 2010). They find that new research fields often (but not always) form around a puzzling phenomenon that deviates from what theory tells us to expect (Davis, 1971; Christensen, 2006). The goal is to distinguish, describe and theorize the puzzling phenomenon (von Krogh et al., 2012b).

Chubin (1976) suggests that new research fields tend to fall between research disciplines and that core researchers advance their field by drawing inspiration and insight from its margins (cf. Dogan and Pahre, 1990). As a consequence, researchers in new fields, and in phenomenon-based ones in particular, often have shared interests but different educational backgrounds (Chubin, 1976; Birnbaum, 1981; Gibbons et al., 1994). With sometimes very little common ground among them, they need to create a shared set of concepts, goals, and norms – a liability that phenomenon-based fields have often struggled with (Merton, 1973).

Some new research fields attract so much immigration and make findings that are so distinct from researchers' home disciplines, that a new discipline begins to emerge. (Such was the case for material science, for instance, that did not disintegrate back into metallurgy and ceramics.) In most cases, however, cross-disciplinary research fields remain narrower, more or less formalized, and sometimes long-lasting, "hybrids" (Dogan and Pahre, 1990). Our paper focuses on such hybrids and their evolution, arguing that they may be inherently unstable.

2.2. Overview of related literature

Many scholars argue that, in order to extend our understanding of the evolution of emergent new research fields, it is important to study how scholars jointly create and recombine knowledge within and across disciplines (Birnbaum, 1981; McCain, 1998; Hessels and van Lente, 2008; Tsai and Wu, 2010). Our contribution builds on three streams of literature:

(1) A number of studies conduct comparative-static analyses of particular research fields. E.g., for the field of strategic management, Ramos-Rodríguez and Ruíz-Navarro (2004) and Nerur et al. (2008) find that different time periods exhibit different co-citation patterns. While the initial stage was more cohesive, subsequent stages showed a greater number of clusters (Nerur et al., 2008). However, these studies do not systematically investigate the disciplinary anchoring of the authors and their works, nor intend to generalize from such findings (one exception being, e.g. Ponzi, 2002).

(2) Another and mostly distinct literature rooted in information science and library science investigates interdisciplinarity, its measurement, prominence, costs and benefits, and organizational practices (see http://transdisciplinarity.ch/e/for an extensive bibliography). These studies mostly remain at the macro/meso levels, focusing on disciplines, subject categories and

journals, rather than researchers and research teams. E.g., van Leeuwen and Tijssen (2000) analyze macro-level data on the prevalence of boundary-crossing co-citations in many *disciplines* of modern science; they compare their findings for 1985 and 1995, but in most cases find little change at the aggregate discipline level.

Perhaps more important to our research, Morillo et al. (2003) show that *research fields* that have been added to the ISI list of subject categories more recently are more multidisciplinary than established fields in the following sense: they feature a higher percentage of journals assigned to more than one subject category. In addition, such multi-assignations link them to a greater number and diversity of other subject categories. McCain (1998) conducts a journal-level investigation of the interdisciplinary roots and evolution of neural networks research, using co-citation analysis. In much of this literature, management studies are neglected; and they are usually not regarded as being among the vanguard of interdisciplinary scholarship (Knights and Willmott, 1997; van Leeuwen and Tijssen, 2000).

(3) A third stream of literature focuses on individual researchers' motivations, incentives, and research strategies (Aksulu and Wade, 2010; von Krogh et al., 2012a). Fundamentally, researchers are known to have a preference for *intra*-disciplinary work (Whitley, 2000). Individual expertise and communication skills, career incentives and rewards, the orientation of publication outlets, and the organizational structures of research institutions all tend to favor disciplinary research (Klein and Porter, 1990).

This general preference notwithstanding, scholars sometimes encounter conditions that call for interdisciplinary inquiry. Birnbaum (1981) finds that interdisciplinary research tends to yield superior results when the problem is little understood and when many interrelationships engender high complexity. Novel research fields are usually believed to host more interdisciplinary research than mature fields (Dogan and Pahre, 1990).

2.3. Research gap and objectives

As shown in the previous section, interdisciplinary collaboration has been studied from various vantage points. However, prior literature mostly lacks a *longitudinal*, *micro-level approach* that is central to measuring and understanding the evolution of interdisciplinary research (McCain, 1998; Pieters and Baumgartner, 2002; Moody, 2004; Fagerberg and Verspagen, 2009).

Our study therefore examines scholars' micro-level choices relating to interdisciplinary research, their changes over time, and the reasons that may explain these changes. We believe that a micro-level analysis of scholars' research-related choices is crucial for understanding the extent to which scholars *actually collaborate*, and integrate their findings, across epistemic divides (Smeltzer, 1994; Forman and Markus, 2005 and references cited therein). This point is also argued by Smeltzer (1994, p. 158) who emphasizes that macro-level multidisciplinarity should not be mistaken for micro-level interdisciplinarity.

It is particularly important to better understand researchers' choices of disciplinary or interdisciplinary approaches in emergent new research fields. The early development of research fields is shaped by a relatively small number of researchers who affect the future of the field to a large extent. The diversity of knowledge they import, its subsequent integration, and its recombination shape the development of the field.

3. Methodology

3.1. Research design and choice of research field

Our research design is exploratory in nature. Our findings rest on a detailed and comprehensive analysis of very extensive data on one research field. We have no conclusive proof that this field is representative of many others. However, there is evidence to corroborate our findings, as we will show in the discussion section (Section 6).

We devote great care to measuring interdisciplinarity in this field along multiple dimensions, and to establishing what kinds of interdisciplinary research behavior scholars do or do not engage in at any point in time. We use extensive bibliometric and other secondary data, which has the advantage of being comprehensive and objective (De Glas, 1986; Gmür, 2003). We then advance causal propositions that seek to explain the observed patterns. The propositions are derived from the interpretation of our bibliometric data as well as conceptual arguments that leverage prior literature as available.

For our study, we selected the research field of open source innovation. "Open source" refers to the source code of software, revealed for anyone to access, inspect, utilize, modify, and re-distribute in changed or unchanged form (Raymond, 1999). Open source innovation refers to the creation of products and services incorporating the principles of free access to the design source as mainly found in, but not limited to, the software industry (Baldwin and von Hippel, 2011). We follow this expansive use of the term.

Open source innovation is not a new phenomenon. In the 1970s, practically all software was free (Stallman, 1999). Hacker communities shared the source code of operating systems and applications without hesitation or restriction (Levy, 1984). Still, OS development (also called free software) was not on the agenda of most researchers until 1998/1999, when Netscape first released the source code of its widely used Mozilla web browser suite, Oracle announced its support of Linux, and Eric Raymond, a practitioner, published his catalyzing book, "The Cathedral and the Bazaar" (Raymond, 1999). Today, open source software is ubiquitous in software-creating as well as software-consuming organizations, with companies expending billions of dollars on its creation (Ghosh, 2006).

The empirical context of OS is particularly well suited to our research for several reasons. First, it is a recently emergent and successful field (at the time of this writing, Thomson Reuters Web of Science lists approx. 10,500 publications pertaining to "open source") that attracted researchers from many disciplines. Second, the term *open source* is used by researchers throughout the field. It refers to a specific and narrow phenomenon that is distinct, comprehensive, and self-contained. This facilitates exhaustive data extraction. Third, several studies review the literature on open source innovation in substance and methods (Rossi, 2006; von Krogh and von Hippel, 2006; Dalle et al., 2008; Crowston et al., 2012; Aksulu and Wade, 2010; von Krogh et al., 2012a), and thereby provide valuable qualitative input for interpreting and theorizing our findings. In this respect, our own familiarity with the field is an additional asset.

3.2. Research method

Bibliometry analyses ties among researchers, specifically in co-authorship and co-citation networks, taking them as indicators of knowledge exchange (Small, 1978; Lievrouw, 1990; Hoffman and Holbrook, 1993). Co-authorship is an indicator for collaboration; interdisciplinary co-authorship can be seen as a sign that researchers depend on methods and knowledge from other disciplines to solve their research puzzles (Moody, 2004). Document co-citation analysis seeks to identify relationships between publications that are considered to be important by authors in the research field, suggesting a relatedness of content (Small and Griffith, 1974; Gmür, 2003). Whether these indicators are valid and reliable has been subject to extensive scholarly debate (Small, 1973). Some limitations notwithstanding, bibliometric analysis is mostly considered a legitimate method for analyzing the cognitive

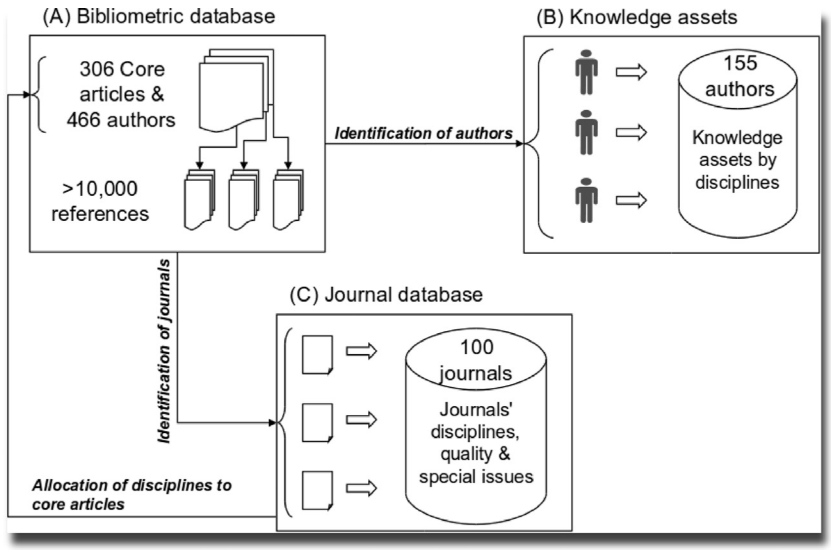


Fig. 1. Data sources and their purpose in this study.

and social structures of research fields (Merton, 1973; White and Griffith, 1981; Ramos-Rodríguez and Ruíz-Navarro, 2004; Eom, 2008).

We compiled three principal databases (Fig. 1): (A) an extensive database of OS publications, which we use to analyze the bibliometric structure of the research field; (B) a database of researchers "knowledge assets," used for the analysis of their disciplines; (C) a database of journals publishing OS articles, including information on discipline, quality, and special issues.

3.3. Bibliometric data (database A)

Our bibliometric database was created in four steps: (1) identification and selection of data sources, (2) search of OS-related literature, (3) qualitative filtering of documents, and (4) creation of the bibliometric database.

(1) In order to reduce the risk of missing publications, four separate sources were mined: ISI Web of Science, GoogleScholar, EbscoHost, and ProQuest. A redundancy rate[2] of only 27% suggests that a multi-source approach improves the composition of the database. At the same time, it casts doubt on the comprehensiveness of findings drawing on just one of these sources (an approach which has been dominant in bibliometric research to date).

(2) Next, we extract from each of the four sources all the publications that include the term "open source" or "open-source" in the title, abstract, or keywords. Due to our focus on the OS phenomenon, we can run a search-term based analysis (cf. Ponzi, 2002; Charvet et al., 2008). This approach has the advantage of being the most comprehensive but comes at the cost of a very large number of entries that require extensive screening. Our search yielded more than 60,000 documents (as of May 2009).

(3) The majority of these documents were then excluded from further analysis by means of three filtering procedures:

First, we only consider (i) journal publications that (ii) belong to the management discipline or are interdisciplinary and relate to management studies and that (iii) do more than mention OS in passing. Publication in a scholarly journal is commonly regarded as an indicator of 'certified knowledge' (Callon et al., 1995). The last criterion excludes many papers that do not investigate OS development but simply use OS software for their analyses. To increase reliability, two authors independently rated all papers (inter-rater reliability: 95.7%). Differential opinions were aligned by means of a more in-depth study of the paper in question, followed by a discussion between both raters as well as a third author. By applying these criteria, we reduced the preliminary database to 701 non-redundant items.

Second, we asked leading scholars of OS innovation to verify our preliminary set of papers. Based on their total number of citations in the preliminary database, 15 out of the leading 30 scholars were randomly chosen and contacted. Seven of these scholars verified our preliminary database and occasionally pointed out missing or inapposite papers.

As a third qualitative filter, we applied JCR Social Science 2005 (ISI), Jourqual2, and six other journal rankings to cut down the number of papers to those published in 'A', 'B', or 'C' journals (or equivalent in other metrics).[3]

This three-step filtering process gives us a database of 306 'core articles', of which 83% are included based on Journal Citation Reports (JCR) Social Science 2005 and/or Jourqual2.[4]

(4) We then filled in the references cited in each of the 306 core articles. For each reference of each paper, we collected the names of all the authors, title, year of publication, and publication outlet. Since none of our four data sources offered the extraction of all of this information, considerable manual input effort was required. E.g., none of the sources allows the retrieval of information on *all* authors of a reference; the ISI convention just provides first authors, for instance (Eom, 2008). More than 10,000 references were thus included in our bibliometric database.

As a final step, we corrected errors and inconsistencies, spelling mistakes, and non-uniform abbreviation formats. From the resulting database, co-citation and co-authorship tables were calculated.

[2] Number of redundant pre-filtered publications divided by the number of total pre-filtered publications.

[3] Since many rankings cover only a subset of the journals found in the preliminary database, we use an ordered list of eight ranking systems, which can be obtained from the authors.

[4] The list of core papers will be shared upon request.

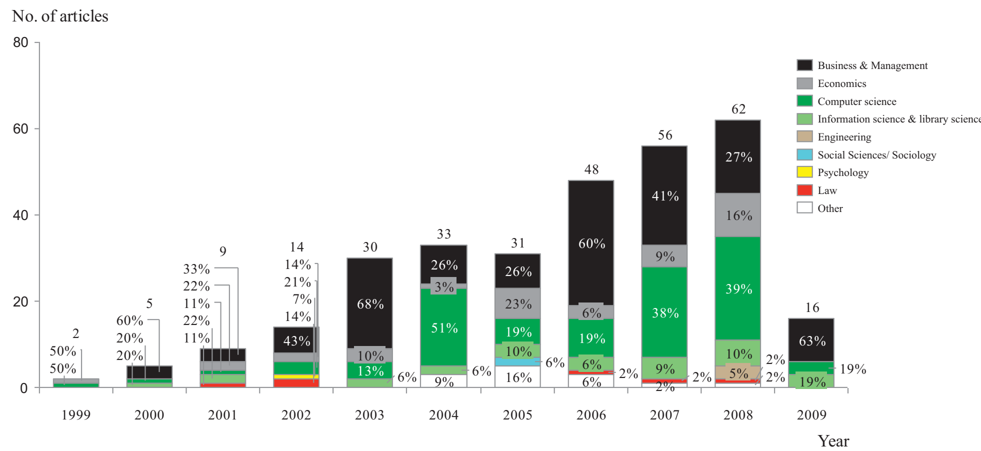


Fig. 2. Number of OS articles by year (as of May 2009).

3.4. *Data on scholars' disciplines (database B)*

Using ISI Web of Science, we tracked the publication history of 94 out of 466 OSS scholars.[5] We recorded each author's number of overall publications, year of first publication, number of "open source" publications and first year of OS publication, as well as the number and disciplines of publications prior to the first OS publication ("knowledge assets"). For all pre-OS publications we registered the subject areas as indicated on ISI, as selected by the authors. If more than one category was assigned, the article was allotted to all of these categories. A knowledge asset can thus belong to one or more disciplines. Based on the aggregate of their knowledge assets, all researchers could be assigned one or multiple disciplines.

Disciplinary co-author analysis required discipline information of an additional 61 authors for whom no knowledge asset data was available (typically due to the lack of ISI knowledge assets predating their first OS publication). We determined the disciplinary affiliation of those scholars based on information from their websites and their research institutes. At least two of the authors of this paper independently researched the disciplines of each of these scholars; in 82% of all cases, the ratings agreed. Where there were discordant findings, further research was undertaken by three of the authors of this paper until consensus was reached.

Our findings are summarized in a database showing the disciplinary background of 155 OS scholars. We distinguish ten disciplinary categories: business and management, economics, computer science, information science and library science, engineering, natural sciences, psychology, social sciences, law, and "other disciplines". The first nine disciplines account for 90% of the knowledge assets in our database. None of the remaining "other" disciplines exceeds a share of 1% of knowledge assets.

3.5. *Data on journals and journal disciplines (database C)*

We also identified the disciplines of all journals in which at least one of the 306 core OS articles was published. We included the ISI impact factor for each year of our study (1999–2009), according to availability. For all journals covered by ISI, we added journal disciplines as derived from ISI subject areas (on the advantages of using the ISI classification, cf. Morillo et al., 2003). Where these were not available, three of the authors jointly determined the discipline of each journal, based on their prior knowledge of the journal and additional investigation.

4. Coalescence and fragmentation of open source research

In this section we study the coherence of the OS research field over time, focusing on integration between disciplines. We begin by giving a short overview of the field and our set of core papers (Section 4.1). Next, we show that open source is *one* research field – although several different themes are being researched, there is strong substantive coherence (inter-relatedness of content) among them (Section 4.2). The next three sub-sections investigate to what extent different disciplinary bodies of knowledge are integrated in a joint puzzle solving process. We analyze four different measures of interdisciplinary integration: interdisciplinary co-authorships (Section 4.3), publications in journals outside the authors' home disciplines and publications that are relevant for scholars from several disciplines (Section 4.4), and cross-disciplinary co-citations (Section 4.5). While the former two can be considered to be "high-involvement" (involving substantial engagement in and commitment to interdisciplinary work), the latter two may be seen as requiring lower involvement. In brief summary, we find that the OS field is fragmenting along disciplinary faultlines. Scholars make increasingly intra-disciplinary contributions, co-authoring within their discipline, publishing within and for their discipline, and citing within their discipline.

4.1. *Overview of the OS research field*

The disciplinary composition and temporal distribution of our set of 306 core papers are shown in Fig. 2: It indicates the expansion of the OS field and shows the preponderance of management, economics, computer science, and information and library science papers in our dataset.

Within the management discipline, both general management journals, such as Management Science and Long Range Planning, and more specialized journals, mostly in innovation management and organization studies, are the most prolific publishers of OS research (Table 1).

Our database contains 468 unique authors. Two scholars, Eric von Hippel and Georg von Krogh, stand out by their high number of OS publications (our database contains 12 open source publications by each). They are experienced scholars with a strong research record in other, related fields. Other leading scholars include Lerner and Tirole (6 publications each), and Dahlander, Henkel, O'Mahony and Spaeth (5 publications each).

[5] We tracked all authors who published in phase 1 (1999–2002) as well as the 30 most-cited scholars.

Table 1
Leading journals by number of open source publications in our database.

	Journal name	No. of publications	% of publications
1	IEEE Software	35	11.1
2	Research Policy	26	8.3
3	Communications of the ACM	18	5.7
4	Management Science	16	5.1
5	Information Economics and Policy	12	3.8
6	IEEE Transactions on Software Engineering	11	3.5
7	Journal of Management and Governance	9	2.9
8	MIT Sloan Management Review	8	2.5
9	R&D Management	7	2.2
10	Organization Science	7	2.2
11	Journal of Database Management	7	2.2
12	Harvard Business Review	7	2.2
13	Long Range Planning	5	1.6
14	Journal of the American Society for Information Science & Technology	5	1.6
15	Information & Management	5	1.6
16	Industrial and Corporate Change	5	1.6
17	Oxford Review of Economic Policy	4	1.3
18	MIS Quarterly	4	1.3
19	Journal of Management Information Systems	4	1.3
20	Journal of Industrial Economics	4	1.3

Table 2
Most-cited publications, sorted by citations.

Title of publication	First author
1. The Cathedral and the Bazaar (1999)	Raymond ES
2. Some simple economics of open source (2002)	Lerner J
3. Motivation of software developers in open source projects (2003)	Hertel G
4. Open source software and the “private–collective” innovation model (2003)	von Hippel EA
5. How open source software works: “Free” user-to-user assistance (2003)	Lakhani KR
6. The Cathedral and the Bazaar (2001, book)	Raymond ES
7. Community, joining, and specialization in [OSS] innovation (2003)	von Krogh G
8. Why hackers do what they do: understanding motivation and effort (2005)	Lakhani KR
9. Satisfying heterogeneous user needs via innovation toolkits (2003)	Franke N
10. Guarding the commons: how community managed software projects (2003)	O’Mahony SC
11. Working for free? Motivations for participating in open-source projects (2002)	Hars A
12. Two case studies of [OSS] development: Apache and Mozilla (2002)	Mockus A
13. Why open source software can succeed (2003)	Bonaccorsi A
14. The sources of innovation (1988)	von Hippel EA
15. A case study of open source software development: the Apache serve (2000)	Mockus A
16. Innovation by user communities: learning from open-source software (2001)	von Hippel EA
17. Essence of distributed work: the case of the Linux Kernel (2000)	Moon JY
18. Democratizing innovation (2005)	von Hippel EA
19. The Boston consulting group Hacker survey	Lakhani KR
20. How communities support innovative activities: an exploration (2003)	Franke N

Seminal OS publications, by their number of citations, are listed in Table 2. Three interesting observations stand out: first, citation concentration is not very high. On average, an OS paper cites only 2.4 of the 20 most cited papers in the field (this contrasts with studies of more mature fields, e.g. by Fagerberg and Verspagen, 2009). Second, almost all of the 20 most-cited publications relate to the OS phenomenon itself, rather than theory, methods, or other related phenomena. 2 out of those 20 publications (Franke and Shah, 2003; von Hippel, 2005) focus on user innovation and user innovation communities, a closely related field. Third, 6 out of 8 papers published in the special issue of Research Policy (2003) are among the 15 most-cited OS papers overall. This illustrates the power of a special issue of a high-ranking journal, published early in the development of a new research field, to shape subsequent research.

4.2. Substantive coherence of the OS research field

In their editorial to the special issue of Research Policy, von Krogh and von Hippel (2003) identify three central themes of open source research, as presented in that issue. von Krogh and Spaeth (2007) show that research on each of these themes is undertaken from within several disciplines.

The first theme concerns the *motivations* of rational actors to devote private resources to the creation of a public good, the open source code, instead of free-riding on the contributions of others (Lerner and Tirole, 2002; Osterloh and Rota, 2007). Second, researchers have wondered about the effective *governance* of innovation processes carried by volunteers beyond the reach of hierarchical managerial control (O’Mahony and Ferraro, 2007; von Krogh and Spaeth, 2007). And third, research has been conducted on *competition and complementarity* between open source innovation and traditional models of for-profit firm innovation (Bonaccorsi et al., 2006; Fosfuri et al., 2008).

As we include and review more recent literature, we find that these three focal themes have been surprisingly stable, while some additional topics are slowly coming to the fore. Among all core papers published in journals ranked A or B (Table 3), we find 29 papers (19.8%) relating to the design and justifiability of policies supporting OS software development and use, or “other” topics such as specific legal aspects of open source licenses.[6]

[6] For studies on OS developers’ sources of motivation, Research Policy is the most prolific outlet. Research Policy, Industrial and Corporate Change, and Organization Science are particularly strong publishers of studies relating to the organization, governance, and the process of OS development. Management Science focuses on contributions on competitive dynamics, but also organizational issues. Papers on policy and “other” issues are mostly published in law journals.

Table 3
Open source publications in A and B journals by year and main theme.

Year	Motivation to contribute	Governance, organization, and innovation process	Competitive dynamics	Policy	Other	Total
2000		1	1			2
2001	3	1		1		5
2002	1	3			1	5
2003	6	7	2	2	1	18
2004		3	2	2	1	8
2005	2	11	2	2	1	18
2006	6	15	4	1	6	32
2007	2	11	3	1	3	20
2008	1	14	8	2	5	30
2009[a]	1		1			2[a]
Total	22	66	23	11	18	140

Motivation to contribute: addresses issues such as "individual incentives, impact of firms' participation on individual motives, impact of community participation on individual motives, relationship between incentives and technical design"[b]
Governance, organization, and innovation process: addresses issues such as "reconciliation of diverse and distributed contributor interests, governance of project architecture [. . .], governance of the public good, functioning and types of organizations [. . .], roles taken by contributors [. . .], coordination of innovation, processes of OSS maintenance and development"[b]
Competitive dynamics: addresses issues such as "impact of OSS on competition in the software industry, hybrid strategies for melding commercial and OS platforms, firms' resource allocation to OSS projects, relationship between firms and OSS projects, free revealing amongst competitors of improvements to common software platforms"[b]
Policy: addresses issues such as government policies to support OSS, rationales for such policies, contributions of OSS adoption toward achieving political goals[c]

[a] Data till May 2009.
[b] *Source*: von Krogh and von Hippel (2006, p. 977).
[c] *Source*: Based on Comino and Manenti (2003).

Table 4
Co-citation assortativity by focal research theme.

Period	Theme-based assortativity
1999–2002	0.044
2003–2005	−0.007
2006–2009	0.000

Research on these principal themes, although somewhat specialized, is closely connected and co-evolving. This is shown by co-citation analysis. To measure inter-theme co-citation behavior, we first calculate CoCit scores between any two publications, a measure of co-citation frequency (Gmür, 2003).[7] Next, we aggregate these individual scores by computing the *assortativity coefficient*[8] of the co-citation network. This coefficient captures the tendency of nodes of the same type (in our case, the same theme) to be connected and is thus a measure of the extent of mixing in the network (Newman, 2003). Values of r close to -1 indicate a disassortative network (i.e., publications on different themes are co-cited more frequently), values close to zero indicate random co-citation across themes, and values of r close to 1 characterize assortative networks (publications on the same topic are preferentially co-cited).

We find that research on different research themes is co-cited to a similar and substantial extent across all three phases. There is no preferential co-citation of publications on the same theme; assortativity remains close to 0 for all three phases (Table 4). In other words, OS publications tend to draw equally on prior literature on two or more focal themes, rather than specialize on just one theme. These findings indicate a close and continual relatedness of content, i.e. strong substantive coherence of OS research as a field.

4.3. Interdisciplinary co-authorship

Substantive coherence notwithstanding, the *researcher network* appears to fragment over time along disciplinary divides. We can observe this both by inspecting the co-authorship network and from computing discipline assortativity of the co-authorship network.

In the co-authorship network of phase 1, interdisciplinary dyads and triples are prominent. In phases 2 and 3 larger clusters form that are mostly intra-disciplinary and often intra-institutional.[9] (A notable exception in phase 3 is a cluster of 9 co-authors around Richard Watson and Donald Wynn that comprises both management scholars and computer scientists.)

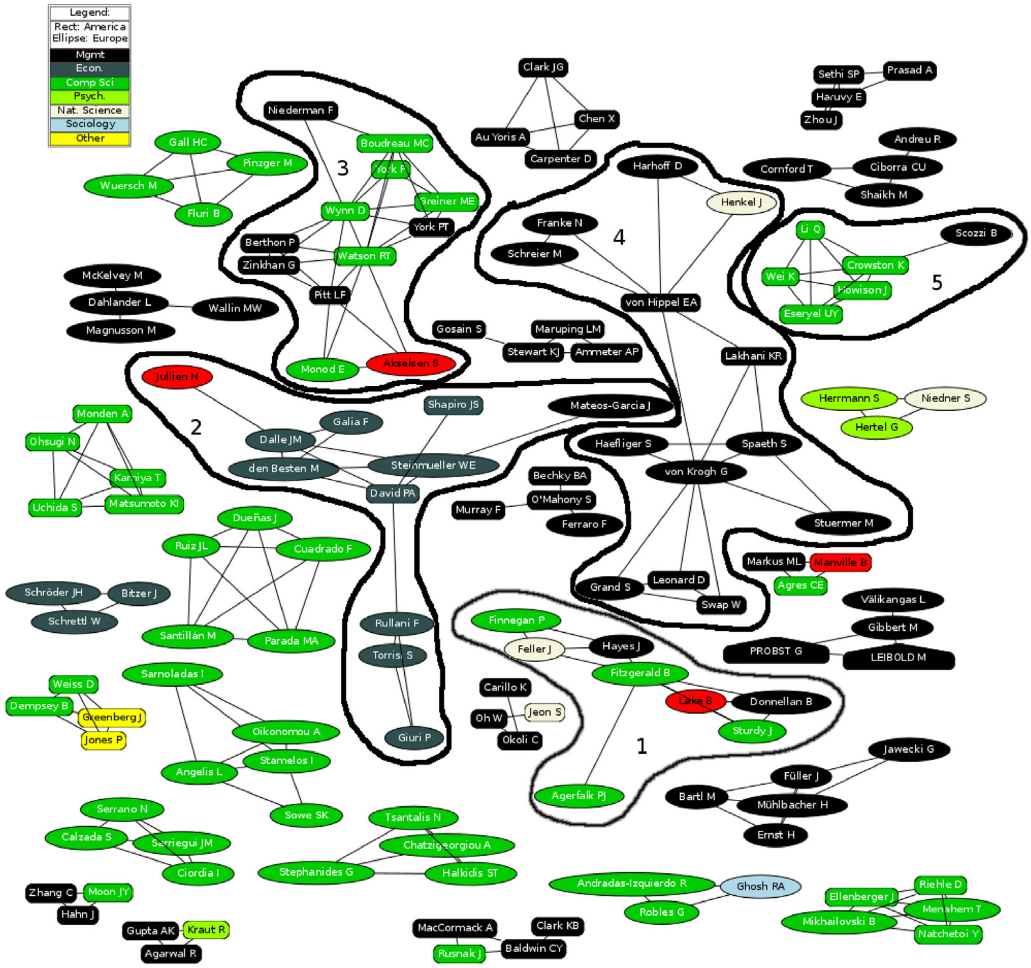
Due to space constraints, Fig. 3 shows the co-authorship network across all three phases, rather than for each phase separately. We find five clusters of more than five authors each. They represent invisible colleges around leading scholars (Beaver and Rosen, 1978; Chubin et al., 1986b). Most of the scholars within each invisible college have similar disciplinary backgrounds and often related research agendas, the cluster descriptions contain details.

While network density and centrality should be interpreted with caution due to their sensitivity to network size (which increases over time), they indicate a less dense co-author network over time. To quantify intra-disciplinary co-authoring, we again use the assortativity coefficient (Table 5). The phase 1 network is weakly assortative – scholars from the same discipline co-author slightly more often. In phase 2, we see a marked increase in *intra*-disciplinary co-authorships. This suggests that, rather early in the development of the research field, scholars return to mostly disciplinary publication strategies.

[7] The CoCit score relates the absolute number of *co-citations* of two publications to their overall *citation* occurrence (Meyer et al., 2009). It ranges from 0 to 1. If we denote the number of co-citations between two references i and j by C, the CoCit score $S_{ij} = C_{ij}^2/[\min(C_{ii}, C_{jj}) \times \text{mean}(C_{ii}, C_{jj})]$ (Gmür, 2003; Schäffer et al., 2006). Usually, a CoCit threshold is applied in order to suppress coincidental co-citations (Meyer et al., 2008). In line with common practice that uses threshold values between 0.2 and 0.4 (Gmür, 2003; Meyer et al., 2008), we apply a threshold of 0.3.

[8] $r = (\sum_i eii - \sum_i a_i^2)/(1 - \sum_i a_i^2)$, where e_{ii} is the fraction of vertices between type i and type j. a_i is the fraction of vertices that is connected to a node of type i, i.e. $a_i = \sum_j e_{ij}$.

[9] Geographic proximity, too, appears to favor co-authorship – inter-continental collaborations are below 15%. US-based (49%) and European (45%) research groups prevail.



Coauthors (total)

Cluster 1	This cluster is mainly composed of scholars from computer science and information systems, with Brian Fitzgerald as the most central scholar. Their work focuses on commercial firms in OS software development, particularly their business models, value networks, and their relationship and interdependencies with the community.
Cluster 2	Economists dominate this cluster, with Paul David as the most central scholar. They investigate, e.g., developer motivation and activities, often conducting dynamic system-level analyses. The division of labor and competitive dynamics likewise constitute focal research themes.
Cluster 3	Scholars specialize in management information systems, exploring the influence of communication technology in creating new forms of community. The most central scholar is Richard Watson who is surrounded by his (former) Ph.D. students and visiting scholars at the University of Georgia.
Cluster 4	This cluster, the largest overall, comprises scholars of innovation management and strategy. They study, e.g., the workings of OS communities, the principles and limitations of free knowledge sharing, and the involvement of firms in OS projects. Eric von Hippel and Georg von Krogh are leading scholars, with Ph.D. students, post-docs and faculty colleagues surrounding them.
Cluster 5	This information science cluster is built around Kevin Crowston of Syracuse University. Research investigates new virtual forms of organizing that rely on the application of new information technology.

Fig. 3. Co-author network across all three phases (all clusters >3 nodes are shown).

Table 5
Coauthor network characteristics.

Period	Discipline assortativity	Density	Degree centrality
1999–2002	0.291	0.0255	0.0241
2003–2005	0.696	0.0111	0.0248
2006–2009	0.691	0.0057	0.0152

Table 6
Interdisciplinary publications.

Period	Publications in 'foreign' discipline (%)	Relevance for multiple disciplines (%)
1999–2002	45	42
2003–2005	18	35
2006–2009	19	30

4.4. Interdisciplinary publications

Publication behavior, too, becomes more *intra*-disciplinary over time. We study two indicators: the fraction of papers published in journals outside the authors' home disciplines[10] and the fraction of publications that the authors consider relevant for multiple disciplines.[11] Both indicators give us an idea of whom OS researchers regard as their community and the audience for their work. If they publish outside their home discipline, and/or indicate that their paper is relevant for other disciplines, they must be aware of the interdisciplinary relevance of their findings and want to disseminate them to other disciplines. The former indicator can be interpreted as involving a stronger commitment to interdisciplinary work.

As shown in Table 6, we find that the fraction of publications published in 'foreign' disciplines declines sharply in phase 2, and that the fraction of publications that the authors consider relevant for multiple disciplines declines too, albeit more slowly.

4.5. Interdisciplinary co-citations

In this final sub-section, we show that, as the research field matures, scholars tend to co-cite within a discipline, rather than across disciplines. Again, we use a dual approach of visual inspection of the co-citation networks and computation of various indicators.

The co-citation networks for the three phases are shown in Figs. 4–6.

The phase 1 co-citation network is composed of only 10 nodes, 9 of which form a cluster. It is indicative of a nascent research field, characterized by a strong standing of practice-based papers (especially Raymond's 1999 essay) as well as cohesion around a small phenomenon-based core. The paucity of prior, non-phenomenon-focused works in the network indicates the diversity of the epistemic backgrounds of early OSS scholars. There is also a dearth of high-ranking, peer-reviewed journal publications, with half of the nodes being books or conference proceedings (called "other"). (Disciplinary affiliations were established for journal publications only.)

In phase 2, more documents are co-cited. The CoCit network of this phase features a single, tightly connected, interdisciplinary

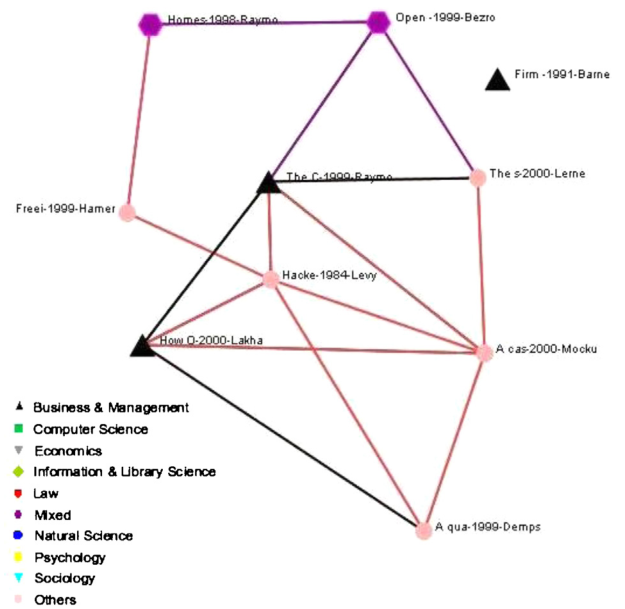


Fig. 4. Co-citation network for phase 1 (1999–2002) (including all publications co-cited at least three times).

cluster. While management is the dominant discipline, it also contains economics, information science, and mixed-discipline papers.[12] The co-citation network indicates that many articles from this period rely on findings from multiple disciplines to build and support their claims. As the field is not yet very large, researchers tend to know and cite each other's work irrespective of disciplinary boundaries. In addition, they also discover shared foundations from several disciplines, e.g. Allen (1983), Arrow (1962), Olson (1965), and Demsetz (1967).

By phase 3, several clusters evolve which clearly follow disciplinary demarcation lines. There are several management clusters. Similarly, there is one large computer science and information science cluster, surrounded by a number of smaller ones. Another cluster is rooted in sociology and also contains papers on the theory and analysis of social networks. In addition, 12 chains, mainly consisting of two or three nodes, have formed. None of these chains combines management, economics and/or computer science.

We also note that seminal theoretical contributions from different disciplines have not (yet) become landmarks for interdisciplinary (or even intra-disciplinary) co-citation. A large number of seminal publications from different theoretical lenses are isolates in the co-citation network, even when viewed over the entire period. Among them are generalized exchange theory (Ekeh, 1974) and collective action (Olson, 1965); endogenous growth theory (Romer, 1994); transaction cost economics (Coase, 1937); evolutionary economics (Nelson and Winter, 1982); property rights theory (North, 1990); the resource-based theory of the firm (Barney, 1991) and dynamic capabilities (Teece et al., 1997), as well as the knowledge-based view of the firm (Nonaka, 1994). Most of these seminal publications are infrequently cited. Olson's book on "The Logic of Collective Action" (1965) is the only one of the aforementioned contributions that is among the 50 publications most cited by OS research. The diversity of these seminal papers, and the sparsity of

[10] We compare researchers' disciplinary affiliation, as indicated by their knowledge assets, with the disciplinary affiliation of their chosen publication outlets. If economists publish in economics journals, we infer that they focus on disciplinary progress (cf., Pierce, 1999).

[11] We examine the subject areas to which authors indicate their work to contribute to in ISI. The disciplines that these areas are associated with are taken as a proxy for the disciplines for which the publication is relevant.

[12] The predominance of management publications in the co-citation diagrams needs to be interpreted carefully. Recall that one of our conditions for including a paper in our sample was that it had some relation to business and management research. Note, however, that this does not, per se, account for the increasing paucity of interdisciplinary linkages.

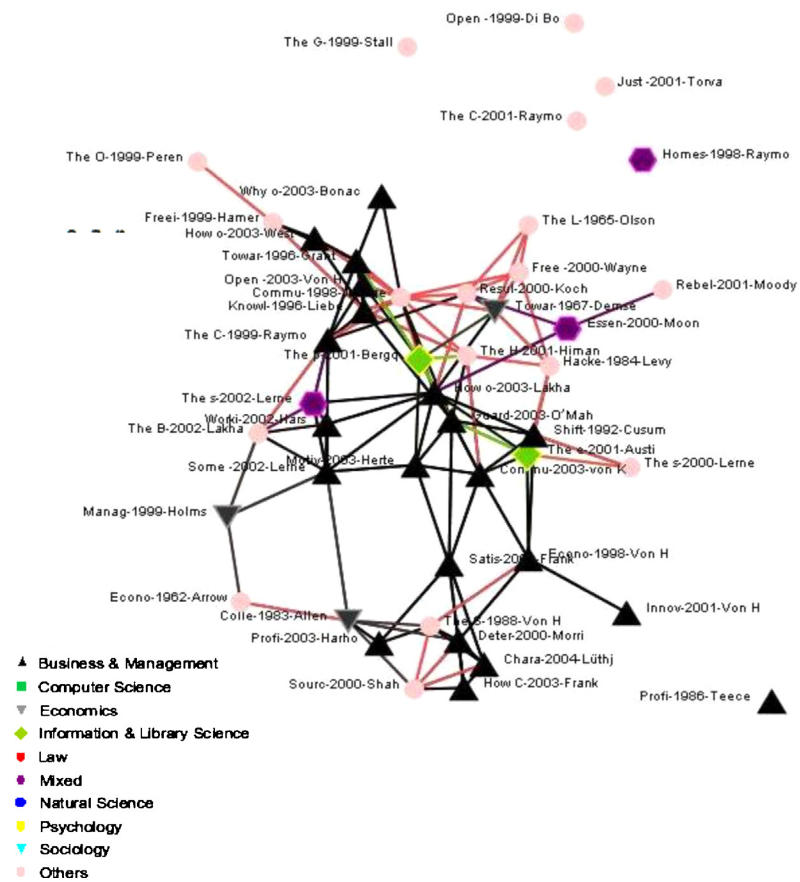


Fig. 5. Co-citation network for phase 2 (2003–2005) (including all publications co-cited at least five times).

their citations, seems indicative of a field in search of its theoretical anchoring.

Indicators capturing interdisciplinary co-citation behavior are shown in Table 7. We find that density and centrality decrease, indicating increasing fragmentation. (Note, however, that the decrease in density may also be influenced by increases in network size over time.) Assortativity by discipline increases very markedly in the last phase, indicating that publications from the same discipline are co-cited considerably more often than publications from different disciplines. (Recall that a value of 1 indicates a perfectly assortative network.) These numbers support the interpretation that co-citation behavior shifts toward single-discipline citations over time.

5. Propositions on interdisciplinarity in nascent research fields

5.1. Summary

Researchers have many choices about how they want to conduct their research. Most fundamentally, they may (or may not) elect to contribute to a specific research field. Subsequent choices include the choice to collaborate with others, the choice to adopt knowledge from others, and the choice to share findings with others.

We conducted an in-depth longitudinal study of one research field, open source innovation, a phenomenon-based and supposedly interdisciplinary field. Specifically, we studied scholars' choices pertaining to interdisciplinary research, using bibliometric and other secondary data.

We found the open source field to have substantive coherence in the sense that different branches of research within it (focusing on different focal themes) are closely connected. To show this, we studied theme-based assortativity of co-citations across three phases of the development of the research field. We found no preponderance of within-theme citations, nor any trend in this direction. The puzzles presented by the phenomenon seem to be so inter-related that they act as a bracket, keeping the research field together as it evolves.

Despite this substantive coherence, careful analysis revealed that the field is fragmenting along disciplinary faultlines. We studied different aspects (interdisciplinary co-authorships, interdisciplinary publishing, and interdisciplinary citation behavior), and they all support this diagnosis. OS scholars study a set of closely related issues, but increasingly do so within and for their own disciplines. The shift from interdisciplinary toward multi-disciplinary research could be observed even within a relatively short time period, 10 years, in the case of our study. Interestingly, we found that "high-involvement" forms of interdisciplinary research such as co-authoring or publishing across disciplinary divides plummet only a few years after the inception of the research field. "Low-involvement forms" such as cross-disciplinary citations or publishing work that is relevant beyond the author's own discipline also decline, but later and less sharply.

Table 7
Characteristics of the co-citation network.

Period	Discipline assortativity	Density	Degree centrality
1999–2002	0.11	0.084	0.113
2003–2005	–0.072	0.0710	0.077
2006–2009	0.727	0.0086	0.063

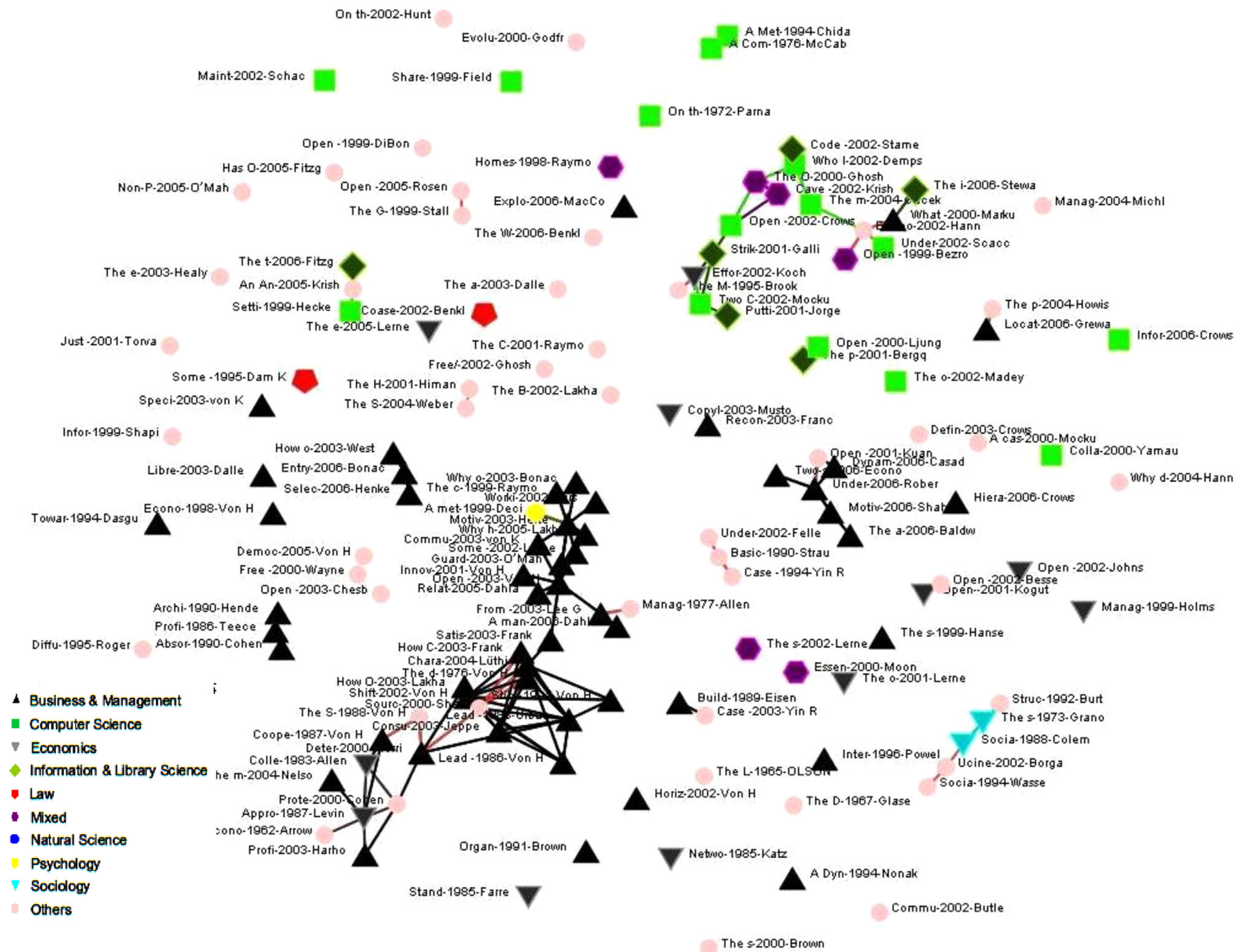


Fig. 6. Co-citation network for phase 3 (2006–2009) (including all publications co-cited at least five times).

5.2. Limitations and generalizability of findings

Our study comes with several limitations, many of which are typical of bibliometric studies (White and Griffith, 1981; Ramos-Rodríguez and Ruíz-Navarro, 2004). Specifically, our measures of interdisciplinary integration and exchange, while having the advantage of utilizing objective, comprehensive data, come at a cost in terms of qualitative richness of information. Bibliometric studies have inherent limitations when a research objective is to understand scholars' intentions, motivations, and reasoning. Future research should address these aspects, examining substantive as well as strategic motivations, to verify and extend our propositions.

Moreover, our study offers an in-depth analysis of one case only. We devoted great care to measuring interdisciplinarity along multiple dimensions. This required extensive data and analyses, which rendered a multi-field study impractical within the scope of this paper. We therefore cannot be certain that the findings would be the same in other fields.

However, there is some evidence that the pattern we uncovered may be a quite general one:

P1: The prevalence of interdisciplinary research tends to decline as research fields mature.

Some studies of other research fields, within and outside management studies, reveal similar patterns. A related study in the field of strategic management finds increasing fragmentation over time, without going into as much detail regarding researchers' disciplines (Nerur et al., 2008). Studies of entrepreneurship research find that scholars have separated into more homogeneous, disciplinary communities, sometimes with a rather weak commitment to entrepreneurship as a field (Landstrom and Lohrke, 2010). Outside management studies, research fields, particularly phenomenon-based ones, are likewise observed to fragment along disciplinary lines (e.g. terrorism research, Gordon, 2010).

There is some reason to believe that this fragmentation into disciplinary clusters is particularly likely to befall phenomenon-based research fields, such as OS research. They are often fields that have no single "natural" disciplinary home base (Chubin, 1976; von Krogh et al., 2012b). Scholars join forces, united by a shared interest in the puzzling phenomenon, rather than shared mental frames, social networks, or epistemic base. These differences make phenomenon-based fields prone to fragmentation, particularly splitting into various disciplinary clusters that examine the phenomenon from different angles. We found this to be true even in a field where the phenomenon itself exerts a strong integrating force (cf. Section 4.2).

5.3. Explanatory propositions

There are many reasons that lead scholars to prefer disciplinary to interdisciplinary research. Disciplinary homophily in research networks can be explained by strategic concerns of career advancement within the discipline, better-aligned research interests, and lower costs of communication and knowledge exchange, among other factors (Whitley, 2000).

Emergent research fields, we argue, are more likely to present research conditions and needs that override that preference for disciplinary research. We propose that such fields tend to be high in interdisciplinary functional dependence, i.e. interdependence among researchers from different disciplines that is created by the substance matter of the new field (Whitley, 2000). Functional dependence creates the requirement for researchers to rely on each others' expertise to achieve their research objectives. It relates to the identification of good research questions as well as the finding of good answers. As interdisciplinary functional dependence declines over time, as we will argue that it tends to do, scholars return to more intra-disciplinary work. We propose

P2: Interdisciplinary functional dependence tends to be higher in nascent research fields than in mature fields.

We suggest at least three reasons that drive this tendency: search costs, task uncertainty, and modularity.

First, in the very early stages of a research field, it is often unclear what other disciplines can contribute in terms of theories and related prior knowledge. Thus, there is considerable risk for any scholar of formulating questions that are either illegitimate or already solved, viewed from a different disciplinary angle. To guard against this risk, the scholar would need to find out what is known in other disciplines that might have bearing on her research problem at hand – a rather costly search, especially as her own objectives may be rather fluid in this early stage. In this situation, interdisciplinary co-authorship may be both more efficient and less in danger of missing important aspects from other disciplines. It is a way of "knowing what nobody knows". Later in the development of the field, publications from different disciplinary angles have produced an overview of relevant theories as well as areas pointed out for research that our researcher could more comfortably rely on. This may be a reason why we find co-authorship to decline earlier than co-citation. E.g., a management scholar interested in OS developers' motivation and incentives to create software code for free, has access to multiple studies by, e.g., psychologists and economists, that reassure her that she is asking a legitimate research question and using an appropriate theoretical framing.

Second and more fundamentally, emergent research fields are typically characterized by high uncertainty regarding the most *important* problems to be studied and the most suitable methods of studying them (Edmondson and McManus, 2007). Whitley (2000) refers to this situation as bearing high technical and strategic task uncertainty. The "importance of results has to be negotiated and demonstrated rather than being assured by the dominant theoretical structure." (Whitley, 2000, p. 137). Assessments are likely to be subject to rapid change. In the field of OS research, we showed that scholars identified and increasingly focused on governance issues as an important area of research. While earlier work emphasized OS licenses as a key element of governance, later studies prioritized actual decision-making in the absence of formal hierarchy – a focus that required different theories as well as methods of data extraction and analysis. (While the former emphasized legal perspectives, the latter spotlighted organizational issues.)

Interdisciplinary research can be a way for researchers to address this task uncertainty. By co-authoring and citing and across disciplinary boundaries and by writing papers that are relevant to more than one discipline, researchers create options for themselves – multiple avenues to finding novelty, understanding, framing and publishing results, and earning a reputation. If and as requirements and intellectual priorities in the field change, or if their own work evolves in a somewhat unexpected direction, they are more likely to be able to accommodate these changes. Later, as research conditions become more stable and predictable, the need for this "insurance" is likely to decline.

P3: Task uncertainty tends to decline as research fields mature. Ceteris paribus, lower task uncertainty reduces the benefits of interdisciplinary research.

Third, the degree of modularity typically changes as research fields evolve. Like other complex systems, scientific knowledge creation benefits from modularization (Baldwin and Clark, 2004). As research fields mature, it is desirable to create modules such that scholars doing research in one area, or module, need not be deeply knowledgeable in other areas (what Parnas, 1972 calls this "information hiding").

It is well known that modularization follows understanding – it is very difficult to create a yet unknown system in a modular way (Simon, 1969; Baldwin and Clark, 2000). At the inception of a research field, it is not clear what the modules will be and how they will connect to create an understanding of the research field. Eventually, as some elements become better understood, they begin to group into more closely connected themes or clusters. Scholars can mostly work within these clusters and import and cite, e.g., stylized facts from other areas as needed, while details can remain 'hidden'.

There are strong reasons to believe that, ceteris paribus, efficient modularizations tend to be disciplinary ones: As previously explained, interdisciplinary exchange typically involves high costs. According to Birnbaum,"interdisciplinary research is a very difficult process and one which should not be undertaken lightly. . . If the problem can be decomposed before research is begun and parts of it allocated to different experts without the need for integrated effort,. . . the time, the effort, and cost of interdisciplinary research can be avoide" (Birnbaum, 1981, p. 1281). If and as modularization can help to contain functional dependence within each discipline, total transaction costs are lowered (Baldwin, 2008). We summarize our argument as follows:

P4: Increasing understanding of a research field facilitates the modularization of research efforts. Modularization will tend to follow disciplinary faultlines. As a consequence, interdisciplinary research tends to decline as research fields mature.

6. Conclusion

6.1. Discussion of contribution and future research

The prevalence, workings, and benefits of interdisciplinary research have been a focus of scholarly attention for many years. However, there are very few studies to date that measure and explain how interdisciplinary collaboration among researchers evolves over time.

In this paper, we used objective bibliometric data and other secondary data to carefully document the evolution of the field of open source research. We showed that the prevalence of interdisciplinary research in this field decreases over time and suggested some reasons behind this tendency to return to disciplinary research. We found that the unity of the phenomenon exerts cohesive power, even as disciplinary faultlines begin to cut across the research field.

Our detailed analysis of the evolution of the field will be of interest to scholars within this growing field itself and to others beyond who can use it as a reference case. The patterns we found were surprisingly clear; and they were manifest surprisingly early in the evolution of the field. It is interesting to note that OS research is commonly thought of as a strongly interdisciplinary field. This suggests that assessing the prevalence of interdisciplinary research in a field requires careful and timely analysis – it cannot be deduced from the presence of researchers from multiple disciplines within a field.

Our paper also makes a methodological contribution by proposing a tool-set of qualitative and quantitative analyses for assessing the level of interdisciplinary integration of research fields in a comprehensive way.

Also on a methodological note, this study used four different data sources. This allowed us to show that redundancy rates among these data sources was rather low – suggesting that the practice common to most bibliometric studies of using only a single data source may not be adequate.

Finally, we advanced propositions about the contingency factors driving the disciplinary fragmentation of research fields. These propositions can be operationalized and tested in future studies. If supported, they can help us make better predictions about the evolution of research fields.

6.2. Implications for research practice and research policy

Our findings will be relevant to individual researchers, research organizations, and funding agencies.

Individual scholars and research organizations can optimize their programs by better understanding the rules by which scholarly work in their field evolves. Our findings do not imply that it is always advisable to elect interdisciplinary research in nascent fields and eschew it in mature fields. Rather, it suggests that, in some, perhaps even in many, fields, most researchers find those approaches optimal in relation to their specific projects. This should encourage each scholar to carefully consider the costs and benefits of different forms of interdisciplinary research in relation to her project, particularly if she plans to diverge from the patterns, and possibly expectations, prevalent in her field at the time.

Our findings also have implications for research evaluation in academia and industry and for research policy. In evaluations of individual scholars' research output, corporate research, and public funding decisions, the (inter)disciplinary nature of the research (to be) undertaken often plays a role: e.g., funding schemes often demand an interdisciplinary composition of the research scheme (Huutoniemi et al., 2010). Similarly, research organizations such as university departments as well as science media often use the yardstick of a supposedly appropriate level of interdisciplinary research in assessing scholarly work (it may actually be biased against interdisciplinary approaches; cf. Fagerberg et al., 2012).

Our findings suggest that the appropriate level of interdisciplinarity against which a project proposal, a manuscript, or a research record should be held, is contingent on the stage of development of the research field. E.g., funding schemes and policies that favor interdisciplinary exchange among scientists may be misaligned with the situation of the field they seek to support, thus impairing research efficacy. In some fields, it may be better to support the re-export of findings into the disciplines involved in a field, e.g. disciplinary synthesis and integration of phenomenon-based findings.

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