ON THE USE OF BIBLIOMETRIC INDICATORS FOR THE ANALYSIS OF EMERGING TOPICS AND THEIR EVOLUTION: SPIN-OFFS AS A CASE STUDY

Uso de indicadores bibliométricos para el análisis de temas emergentes y su evolución: *spin-offs* como caso de estudio

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Abstract

Spin-offs are one of the most attractive areas of research; associated with the phenomena of entrepreneurship, innovation, and knowledge transfer. The present study shows that the selection and use of appropriate bibliometric indicators are a highly valuable method for studying emerging topics and analyzing the development and diffusion of the topic under research, including its process of emergence and growth. The primary aspects observed in relation to the development of university spin-off research includes the boom in the number of publications on the topic after a long period of latency and the pronounced multidisciplinary nature of the research. Our approach encompasses the evolution of scientific publication activity in the area, the scientific agents involved with it, and the cooperative practices and structural characteristics of the co-authorship network at different analytical levels. Also, this research explores cited literature, the evolution of key biblio-

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metric indicators, and adds a validating qualitative analysis of content by an expert in the field. Moreover, the emergence of the topic is shown to overlap between seminal authors' early research contributions to the topic and the time when they become investigators of reference in the field, with their work featured among the most highly cited documents. Last but not least, the age of the cited bibliography constitutes a prominent indicator for establishing the emerging nature of a topic as well as its stage of development.

Keywords

Spin-offs; University; Bibliometrics; Indicators; Network analysis; Emerging topics; Topic evolution; Co-citation.

Resumen

Las spin-offs constituyen una de las áreas de investigación más atractivas, ya que están asociadas con fenómenos como el emprendimiento, la innovación y la transferencia del conocimiento. El presente estudio muestra que la selección y el uso de indicadores bibliométricos permite identificar y caracterizar el desarrollo y la difusión de temas de investigación emergentes como el analizado. Los principales aspectos observados en relación con el desarrollo de la investigación sobre las spin-offs son que se produce un auge en el número de publicaciones después de un largo período de latencia y la marcada naturaleza multidisciplinar del área. El presente enfoque ha analizado la evolución de las publicaciones científicas, los agentes científicos involucrados en las mismas considerando diferentes niveles analíticos, las prácticas cooperativas y las características estructurales de la red de coautorías. Asimismo, se ha analizado la bibliografía citada, la evolución de los indicadores bibliométricos clave, habiéndose efectuado un análisis cualitativo de validación de contenido por parte de un experto en el campo. Se ha determinado el carácter emergente del tema a través de varios indicadores, observando que existe una superposición entre las contribuciones de los autores seminales y el momento en que se convierten en investigadores de referencia en el campo. La antigüedad de la bibliografía citada constituye un destacado indicador para establecer la naturaleza emergente del tema y monitorizar su desarrollo.

Palabras clave

Spin-offs; Universidad; Bibliometría; Indicadores; Análisis de redes; Temas emergente; Evolución del tema; Co-citación.

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1. Introduction

1.1. Emerging topics: concept and bibliography review

Although no formal definition for *emerging topic* has been well established, the concept is relatively well known and accepted in the literature as referring to a "research topic that is important and in the growth stage". That is, drawing parallels with the life cycle (birth, growth, maturity, and death), the development of the field is still in an early stage (**Tu**; **Seng**, 2012). In their study, **Small**, **Boyack** & **Klavans** (2014) point out that despite the widespread use of the term "emergence" in different contexts, the concept is only vaguely defined in the bibliography as denoting novelty (or newness) and growth. Similarly, **Rotolo**, **Hicks** & **Martin** (2015) note the lack of consensus regarding the features that characterize the concept of "emerging technology" despite its relevance in the area of research and with regard to scientific policies. A qualitative bibliography review focused on the term "emerging" reveals five attributes that define it: radical novelty, relatively fast growth, coherence, prominent impact, and uncertainty and ambiguity. The concept of emergence is also related to other terms like "hot topic," which would be one that appears frequently over a period of time but corresponds to a mature or consolidated phase in the development of the research and in the knowledge of the subject area (**Chen**; **Luesukprasert**; **Chou**, 2007); the term can also be used to describe an area of intense, but relatively short-lived research activity, which often attracts interest due to temporary circumstances or events, for example research related to nuclear accidents like Chernobyl in 1986 and Fukushima in 2011, to the influenza pandemic in 2009, or more recently other epidemics like the Ebola virus disease (EVD) or the Zika virus (**Mryglod** *et al*., 2016; **Yi**; **Yang**; **Sheng**, 2016).

The main research interest with regard to emerging topics has been the development of methodologies for their identification. In a detailed bibliographic review, **Small**, **Boyack** & **Klavans** (2014) discuss three approaches for doing so: 1) analyses of the boom in publications related to an existing category or vocabulary structure; 2) methods based on data mining, for example, using co-occurrence clustering techniques like co-word analysis or co-citation to identify novel and rapidly growing or evolving clusters; and 3) hybrid methods that combine the first two approaches (**Small**, 1973; **Braam**; **Moed**; **Van-Raan**, 1991; **Willig**, 2008; **Vadasz**, 2008; **Tseng** *et al*., 2009; **Boyack**; **Klavans**, 2010; **Glänzel**, 2012; **Glänzel**; **Thijs,** 2012; **Zhang**; **Glänzel**; **Ye**, 2016). Among the most recent contributions to this area is the paper by **Jesen** *et al*. (2016), who propose a model for analyzing the evolution of research topics and identifying the scientific agents that most contribute to their development. These so-called "topic evolution trees" integrate different bibliographic concepts (e.g. papers, authors or keywords) and their indicators (e.g. PageRank) into heterogeneous bibliographic networks

(**Jensen** *et al*., 2016). Indeed, **Wang** (2018) uses the first four attributes mentioned by **Rotolo**, **Hicks** & **Martin** (2015) to propose a bibliometric model that enables the identification of emerging research topics, albeit assuming a certain degree of subjectivity, acknowledging that the application of these criteria for identifying emerging topics depends on the choice of the parameter values.

Studies that analyze the evolution of the bibliography on an emerging topic over a long period of time are less frequent. In that sense, several studies such as the one by **Mryglod** *et al*. (2016) have called attention to the interest in describing the features of this evolution, given that the results of numerous case studies can be used in detecting the typical patterns, universal for different topics (**Mryglod** *et al*., 2016). Researchers like **Jarić**, **Knezević-Jarić** & **Lenhardt** (2014) have also speculated that trends in the relative age of references might be also indicative of emerging research fields. In the present paper, we aim to address both of these aspects.

1.2. Spin-offs as a case study

A spin-off can be defined as a corporation, project or product that emerges as an extension or derivation of a previous one. This polysemic concept can be applied in different arenas:

- *corporate spin-offs* (or spin-outs) refer to a type of corporate action where a company splits off sections as a separate business or when an employee or group of employees leave a company to create a new but related one;
- *government spin-offs* are new companies that apply the findings of government or military research; and
- *research spin-offs* denote commercial enterprises that use technology or research findings that were developed in a university (*university spin-offs*) or in another public research organization (**Pirnay**; **Surlemont**; **Nlemvo**, 2003; **Corley**; **Gioia**, 2004; **Mustar** *et al*., 2006; **Rothaermel**; **Agung**; **Jiang**, 2007).

The study of spin-offs constitutes a prominent area of research because of their relationship to the phenomena of entrepreneurship, innovation, and knowledge transfer. Their promotion is also a top priority for governments of developed countries because of their potential to generate wealth, maximize the use of research results, and serve as instruments to foster regional growth (**Dahlstrand**, 1997; **Wright** *et al*., 2006). Although the concept has been appearing in scientific literature for decades, the great interest in research on the topic is relatively new, as we show in the present study, gaining traction beginning in the 1990s. Thus, although spin-offs cannot be considered a current emerging topic, it is possible to analyze its development and evolution as such (**Morris**, 2005).

With regard to the bibliometric contributions to the study of the bibliography on spin-offs, **Wallin** (2012) analyzed the topics addressed and the ties that exist between different scientific fields in 215 articles published between 1957 and 2006; more specifically, **Abramo** *et al*. (2012) used bibliometric indicators to study the relationship existing between academic spin-off generation and the research performance of enterprise founders in Italian universities, finding no negative effects on the scientific performance of the founders.

The main aim of the present study consists of analyzing the genesis of the area of knowledge related to spin-offs as an emerging topic and characterize its evolution from the bibliometric perspective, based on the study of scientific publications in the field. We chose the topic of spin-offs for the performance of this study because the concept has been used in research for decades, permitting a broad perspective on its evolution and on the interest that it has attracted at a researcher level. The concept is also of special interest due to its relationship with the processes of innovation and knowledge transfer, and because it is a highly multidisciplinary field, allowing the analysis of processes related to interaction, positioning within the field and appropriation of the concept among scientific disciplines.

This study addresses the following research objectives:

1) Analysis of the evolution of publication activity in this research field over time.

2) Identification of the key actors (authors, institutions and countries) of the most frequently used publication channels and their assignment to categories.

3) Identification of the most relevant collaborative practices and structural characteristics of the coauthorship network at different analytical levels.

4) Assessment of the impact of the research output in the research field.

5) Analysis of the cited references in order to identify the "core publications" of the research field and their evolution in different periods.

2. Methodology

The methodological process can be broken down into the following phases:

2.1. Identification of the population of documents under study, retrieval and treatment of bibliographic information

To retrieve the most relevant documents of the research field under study, we designed a search strategy considering the main term that denominates the concept of interest as well as synonyms and derivations of it:

"Spin-off* OR spinoff* OR spin-out OR spinout*"

The terms employed are accepted expressions in general use among the scientific community that precisely represent the concept in question. The use of other terms, such as "start-up" or "entrepreneurship" was ruled out despite their relation to the field under study and the potential they offer for a more exhaustive assessment, as their meaning is different and could compromise the analysis performed. Previous publications (**Djokovic**; **Souitaris**, 2008; **Wallin**, 2012) have also used the search strategy in this paper, which has been validated by a topic expert and co-author of the present study. The search was carried out on the "topic" field in the *Web of Science* (*WoS*) *Core Collection* databa-

ses. We selected the *WoS Core Collection* because it has a broader retrospective coverage of the bibliographic references included in the documents compared to other databases like *Scopus*, in addition to a more specific classification of areas of knowledge and standardized citation indicators —all aspects of great relevance to our study. Although initially we did not apply any restrictions, in order to obtain information on all document types, for the calculation of the indicators described below, we only considered the types of article and review[1]. These types of documents are more important in generating knowledge, as they record the results of original studies or synthesize the existing knowledge on the topic of interest. Furthermore, they include the most comprehensive bibliographical information in this database.

The period of study (1965-2014) was also divided into 10 five-year periods in order to characterize the temporal evolution of the indicators obtained.

> The development of spin-offs research includes the boom in the number of publications after a long period of latency of little or only moderate research attention to the topic

2.2. Analyses and indicators

We performed the following four groups of analyses:

A) Analysis of the population of documents on spin-offs

Two aspects were analyzed in relation to the publications identified:

A.1) Publication activity in the field

We analyzed the evolution of the number of documents published, together with the distribution of those documents in scientific journals and thematic categories. Moreover, we studied the evolution by five-year time period of the number of authors, authorships (signatures or scientific contributions), institutions, journals, countries and thematic categories implicated in the research.

A.2) Scientific collaboration

For the study of the cooperative practices captured in the scientific publications of the area, we analyzed the mean number of authors per paper and the percentage of international collaborations. The analysis via bibliometric indicators was then complemented by a network analysis, based on the creation of a coauthorship network, wherein the size, relationships and structural characteristics of the research community were established for each five-year period:

- Number of nodes or vertices: the number of authors making up the network.
- Number of links: the number of co-authorship links. Both unique and repeating links were identified.
- Average node degree: average number of collaborators per author.
- Betweenness centralization: variation in the betweenness centrality of vertices divided by the maximum variation in betweenness centrality scores possible in a network of the same size.
- Size of the giant or largest component: the highest number of authors connected directly or indirectly, considering all links and without applying any collaboration threshold, within the entire network. The absolute number of vertices (authors) in the giant component is given, along with the percentage that they represent with regard to the total number of authors in the network.
- Network density: proportion between the number of real links in the network and the maximum number of links that are theoretically possible.
- Clustering coefficient: calculated according to the measure proposed by Watts and Strogatz, as the average of the local clustering coefficients of all the nodes, where the local clustering coefficient of each node is the proportion of real connections between it and its neighbors, compared with the number of all links that could possibly exist between them.
- Percentage of isolates: researchers who are not connected with any other researcher.

The co-authorship network and all of the indicators of the above-mentioned networks were calculated using the Pajek program for network analysis (**De-Nooy**; **Mrvar**; **Batagelj**, 2005).

The purpose of this first block of analysis was to study the evolution of the scientific activity in the area, the scientific agents involved in it, and the cooperative practices and structural characteristics of the co-authorship network at different analytical levels.

B) Analysis of the cited bibliography in the publications about spin-offs

With regard to the analysis of the bibliography cited in the population of documents on spin-offs, we performed the following processes:

B.1) Analysis of the age of the cited bibliography.

We processed all bibliographic references contained in the documents under analysis, identifying the years of publication of all works cited. We calculated the mean years elapsed between each paper's year of publication and the median publication year of their references, analyzing the evolution of the age of the cited bibliography. We chose to use the median year of publication to avoid possible distortions caused by outliers, as done in the calculation of the "cited half-life."

B.2) Identification, characteristics and evolution of the core cited documents in publications on spin-offs.

We identified the most frequently cited documents for each period studied, generating co-citation networks to show the connections tying together the most cited documents and the evolution of thematic clusters in the research, the way new contributions are integrated into the structure of knowledge in the field, and the prominent role played by some papers due to their centrality and intermediation in the network.

In order to generate the corresponding co-citation networks,

we selected the 50 most frequently cited documents for each period considered in the analysis. In total and considering overlaps, we identified 309 cited documents. According to the number of publications retrieved, the citation threshold required for the selection of the top 50 documents varied for each time period: from two citations in 1960-1989 and 1990-1994, to three citations in 1995-1999, five in 2000-2004, thirteen in 2005-2009, and sixteen in 2010-2014. We used Pajek software for network visualization and analysis, generating co-citation networks for each period and identifying the clusters comprising them. We show all co-citation pairs with a co-citation threshold >1. In the constructed networks, the size of the nodes represents their centrality within the network. To facilitate their visualization, we have only labeled the most frequently cited documents (>29 cites).

The purpose of analyzing the bibliography cited was to study the features associated with the evolution of the intellectual basis and knowledge of the area, which are largely defined by the core documents of each period under study.

C) Analysis of citations received by publications on spin-offs

We analyzed the evolution of the following bibliometric indicators of impact, both in general and according to thematic category:

- Category-normalized citation impact (CNCI), that is, the citations per paper, normalized for subject, year and document type.
- Percentage of documents cited.
- Percentage of documents among top 1% and top 10% of most cited documents, calculated according to the corresponding *WoS* categories for the corresponding publication year in *InCites*. The top 10% is usually considered a measure of "excellence".
- Percentage of highly cited papers, defined in *InCites* as top 1% most cited papers in the corresponding *ESI* (*Essential Science Indicators*) category, which is much broader than the *WoS* categories (22 *ESI* categories). These are only calculated for the last ten years according to the percentile data available in *ESI*.

In citation analyses on journal level, we considered the number of citations, the percentage of documents cited, the category-normalized citation impact, the *eigenfactor* score, the journal impact factor, and the five-year impact factor.

All of the indicators mentioned were obtained from the *InCites* database of *Clarivate Analytics*. This block of analyses characterizes the impact that the research has generated, through a comprehensive study of its evolution over time and a comparative analysis of the different analytical levels used (journals and *WoS* categories).

D) Focus analysis

We extended the bibliometric analysis through the identification and visualization of the most relevant keywords. For this purpose, we generated co-occurrence maps for each time period using the *KeyWords Plus* function in the ID field, available in *WoS Core Collection*. The resulting terms consist of words and phrases harvested from the titles of the cited articles, as reported in the database. Additionally, these keywords were normalized according to three criteria: 1) terminology: avoiding synonyms or quasi-synonyms; 2) grammar: unifying singular and plural, verbal forms, etc.; and 3) spelling variations (e.g. spin-off *vs* spinoff; licence *vs* license).

The *KeyWords Plus* indicator has proven to be the most appropriate, as preliminary analyses performed with title words or author keywords (labeled as DE in *WoS Core Collection*) have corroborated. Indeed, title words lacked relevance, and author keywords were not available for almost half of the retrieved items in *WoS Core Collection* (874 items; 48.29%).

Data processing, cleaning and normalization were performed with the help of *BibExcel* (**Persson**; **Danell**; **Schneider**, 2009), while the maps were created with *VoSviewer* (**Van-Eck**; **Waltman**, 2011), a tool enabling to identify thematic clusters and their evolution attracting the attention of the publishing scholar community.

3. Results

A) Analysis of the population of documents on spin-offs

We identified 2796 documents, consisting of 1,700 original articles (60.8%), 110 reviews (3.9%), and 986 (35.3%) documents corresponding to other document types (554 proceedings papers, 216 news items, 124 editorial material, 36 notes, 27 letters, 18 book reviews, and 11 documents of other, less common types). Figure 1 shows the evolution of published documents by type and five-year period, which in the case of articles corresponds to an exponential rate of growth (R^2=0.95).

The two most significant aspects regarding the scientific

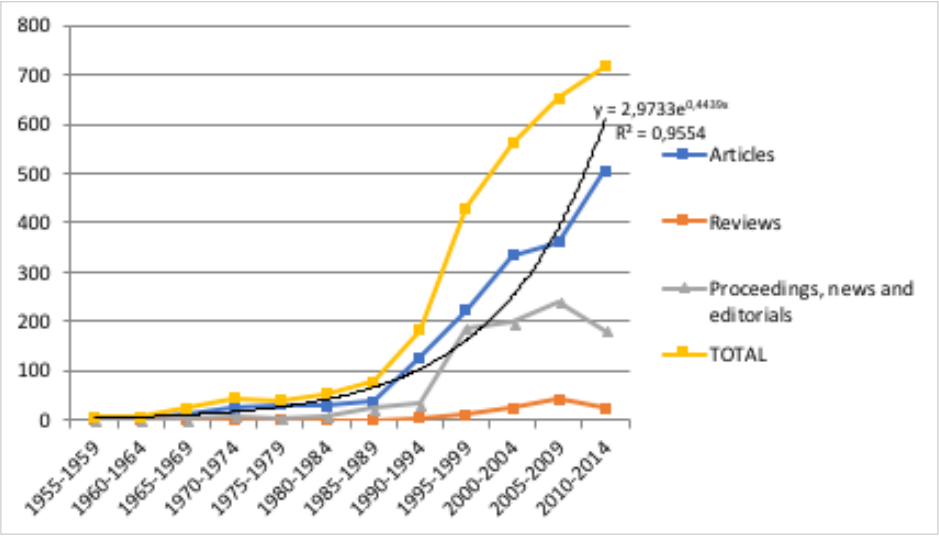

Figure 1. Number of documents published on spin-offs and indexed in the *Web of Science*

activity on this topic include the boom in the number of documents published beginning in 1990-1994, after a decades-long period characterized by few publications (1-15 papers/year), and the relatively equal weight between articles and proceedings, news and editorials during the initial stages of development and during the expansionary period. This trend has changed in the most recent years, when the exponential growth has continued for original research articles but has notably dissipated for the rest of document types.

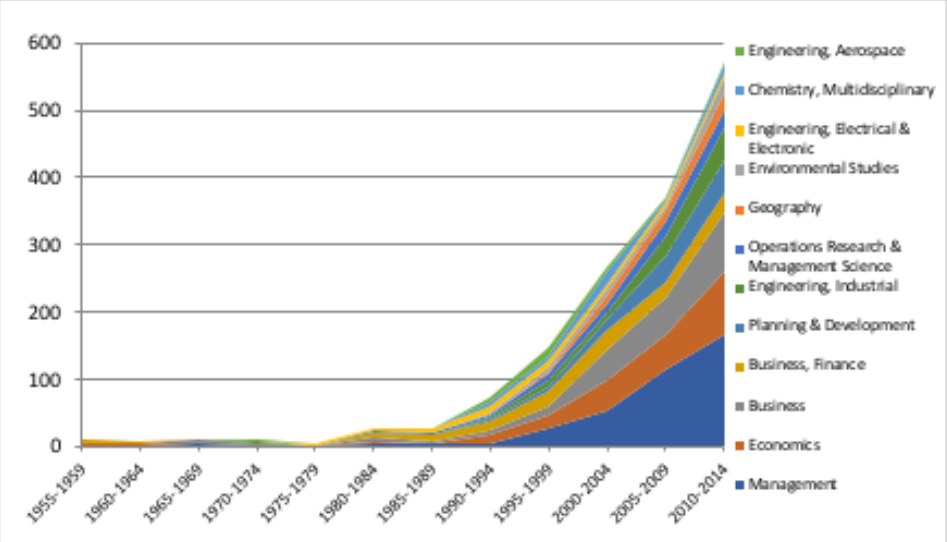

Figure 2. Evolution of the number of documents on spin-offs published, by *Web of Science* categories

The evolution of the number of scientific "agents" involved in the research, considering different analytical levels (documents, authors, journals, countries and thematic categories) demonstrates similar behavior, with moderate rates of growth until the research boom in 1990-1994. For institutions and countries, this expansion lasts throughout the decade, and in the following periods, growth continues, although at much more moderate rates than during the peak five-year period.

With regard to the *WoS* thematic categories (figure 2), in addition to the gradual increase in the number of categories implicated in research on the topic (particularly since the 1990-1994 period), it is noteworthy that the most productive categories have been present since the initial stages of development, but they gradually begin to stand out from the rest. For example, only 4.5% of the documents pertained to the "Management" category in 1990-1994, compared to 31.7% in the most recent period of 2010-2014. The same occurs with "Business" (5.3% in 1990-1994; 12.6% in 2000-2004; and 16.2% in 2010-2014) and "Economics" (9.1% in 1990-1994; 12.6% in 2000-2004; and 17.5% in 2010-2014). Delving into this aspect through an analysis of the growth rates, we see that some categories show an upward trend in the number of published papers, including the three mentioned above but also others such as "Engineering, Industrial" and "Planning & Development." Publication rates are more stable or show more moderate growth in other categories, such as "Business, Finance"; "Engineering, Electrical & Electronic"; "Chemistry, Multidisciplinary"; and "Multidisciplinary Sciences." In a few categories, such as

Table 1. Evolution of the number of documents (%) published in the top 10 most productive journals for documents on spin-offs, indexed in the *Web of Science*

Journal	1955-1959	1960-1964	1965-1969	1970-1974	1975-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	Total
Research policy	—	—	—	—	—	—	—	1 (1.67)	4 (6.67)	7 (11.67)	25 (41.67)	23 (38.33)	60 (3.31)
Technovation	—	—	—	—	—	1 (2.32)	2 (4.65)	1 (2.32)	3 (6.98)	7 (16.28)	13 (30.23)	16 (37.21)	43 (2.37)
The journal of technology transfer	—	—	—	—	—	—	—	—	—	—	10 (31.00)	22 (69.00)	32 (1.77)
Journal of taxation	6 (24.00)	2 (8.00)	1 (4.00)	—	—	1 (4.00)	-	2 (8.00)	5 (20.00)	7 (28.00)	1 (4.00)	—	25 (1.38)
Chimia	—	—	—	—	—	—	—	1 (4.20)	1 (4.20)	17 (71.00)	—	5 (21.00)	24 (1.32)
Small business economics	—	—	—	—	—	—	—	—	—	5 (23.80)	3 (14.30)	13 (61.90)	21 (1.16)
R&D Management	—	—	—	—	—	—	—	—	2 (10.00)	8 (40.00)	4 (20.00)	6 (30.00)	20 (1.10)
Acta astronautica	—	—	—	—	—	—	—	4 (22.22)	4 (22.22)	1 (5.56)	4 (22.22)	5 (27.78)	18 (0.99)
International journal of technology management	—	—	—	—	—	—	—	—	5 (27.78)	4 (22.22)	6 (33.33)	3 (16.67)	18 (0.99)
Technology analysis & strategic management	—	—	—	—	—	—	—	—	1 (5.55)	1 (5.55)	5 (27.78)	11 (61.11)	18 (0.99)

Table 2. Mean number of authors per paper and international collaborations in documents on spin-offs indexed in the *Web of Science*

Five-year period	N documents	Mean number of authors per paper	Maximum number of authors	N international collaborations (%)
1955-1959	6	1	1	0
1960-1964	6	1.17	2	0
1965-1969	14	1	1	0
1970-1974	25	1.16	3	0
1975-1979	31	1.26	3	0
1980-1984	30	1.4	3	0
1985-1989	38	1.84	7	0
1990-1994	132	1.93	10	3 (2.27)
1995-1999	236	2.16	19	14 (5.93)
2000-2004	358	2.43	20	56 (15.64)
2005-2009	404	2.55	15	93 (23.02)
2010-2014	530	2.72	17	153 (28.88)
TOTAL	1810	2.38	20	319 (17.62)

"Engineering, Chemical"; "Operations Research & Management Science"; and "Engineering, Aerospace", there is even a downward trend in publication growth.

As shown in figure 2, all of the different spheres related to spin-offs are present in the related research: the financial and business perspective in the categories "Business", "Business Finance" and "Economics", and the governmental aspect linked to technical research and engineering through bodies like *NASA* or universities, in the categories "Management," "Engineering" and "Planning & Development."

With regard to the publication channels, the papers were published in 953 journals, of which 75.97% (n=724) have published only one paper. We observed (see table 1) that a single journal, *Journal of taxation*, monopolizes publication of the pioneering papers on the topic and has maintained a relatively continuous production since then, albeit with some pauses. Apart from this journal, no others stand out from the rest in terms of early publications; rather, in the first decades we see the usual pattern of widely dispersed publication among journals that have only published one or two papers each. Only in an advanced stage of a research topic's development, when the boom in publications occurs, do a few journals begin to show greater interest through increased publications, and these journals then emerge as the most productive in the field. This is the case for *Research policy*, *Chimia*, and *R&D Management*, which only publish one or two papers in 1990-1994 and four or fewer in 1995-1999, before a notable increase in production in the following periods. A few of the top-producing journals, such as *The journal of technology transfer* and *Small business economics*, did not even begin to publish papers on the topic until an even higher stage of development (the decade of 2000). The top 10 most productive journals account for the 15.41% of all the documents on spin-offs.

The degree of collaboration at the author level increased gradually throughout the period under study, reaching 2.7 authors per paper in the 2010-2014 period (table 2). The analysis of international collaborations is even more significant: these begin to appear in 1991, coinciding with the boom in the number of documents published on the topic. The percentage of documents published with coauthors from different countries is initially quite low, but it has risen gradually in each five-year period, now standing at about 30% (Table 2).

The evolution of indicators for the co-authorship network (Table 3) shows a moderate increase in the number of nodes making up the network, and a very slight increase with regard to the number of links >1, the average node degree and the percentage of authors integrated in the giant component, which presents a very low value even in the latest period (just 3.45% in 2010-2014). The increase in betweenness centralization is more notable, as is the gradual decrease in the percentage of isolates, which falls to 9.59% in the most recent period. The density decreased gradually, and the clustering coefficient remained quite stable at 0.95 to 1.00.

The indicators of the co-authorship network analysis present values that reflect a limited degree of collaboration and an atomized state of research, with the existence of numerous collaborative research groups that consist of just a few authors and isolated collaborations. These

Table 3. Social network indicators for the co-authorship network of the documents on spin-offs indexed in the *Web of Science* (see methodology section for the definition of indicators)

Five-year period	Nodes	N links (N links >1)	N Components	Average node degree	Betweenness centralization	Nodes giant component	% giant component	Density	Clustering coefficient	Isolates	% isolates
1955-1989	85	100 (2)	31	2.40	0	7	8.23	0.0285	1	97	53.30
1990-1994	171	278 (6)	51	3.32	0.00102260	10	5.85	0.0195	0.99	71	29.34
1995-1999	373	710 (7)	106	3.84	0.00098075	19	5.09	0.0103	0.99	99	20.97
2000-2004	695	1,380 (20)	200	4.03	0.00002472	20	2.88	0.0058	0.98	119	14.62
2005-2009	808	1,366 (55)	235	3.38	0.00045597	27	3.34	0.0042	0.96	100	11.01
2010-2014	1159	2,065 (66)	300	3.68	0.00085595	40	3.45	0.0031	0.9541	123	9.59

Figure 3. Evolution of the most frequently cited core documents in publications on spin-offs indexed in the *Web of Science*

Table 4. Distribution of the cited references according to their publication years (5-year intervals) for each period

Citing documents	N cited references (%)													Total
	2010-2014	2005-2009	2000-2004	1995-1999	1990-1994	1985-1989	1980-1984	1975-1979	1970-1974	1965-1969	1960-1964	1955-1959	Before 1955	
2010-2014	3204 (12.13)	8146 (30.85)	6355 (24.06)	3218 (12.19)	2008 (7.60)	1222 (4.63)	760 (2.88)	375 (1.42)	264 (1.00)	202 (0.76)	160 (0.61)	97 (0.37)	398 (1.51)	26,409
2005-2009	-	2858 (15.87)	6698 (37.19)	3511 (19.49)	2041 (11.33)	1139 (6.32)	670 (3.72)	349 (1.94)	246 (1.37)	152 (0.84)	108 (0.6)	71 (0.39)	168 (0.93)	18,011
2000-2004	-	-	2171 (20.31)	3733 (34.93)	1924 (18.00)	1098 (10.27)	624 (5.84)	341 (3.19)	223 (2.09)	147 (1.38)	95 (0.89)	61 (0.57)	271 (2.54)	10,688
1995-1999	-	-	-	1774 (24.80)	2331 (32.58)	1307 (18.27)	733 (10.25)	379 (5.30)	198 (2.77)	118 (1.65)	106 (1.48)	57 (0.8)	151 (2.11)	7,154
1990-1994	-	-	-	-	843 (25.65)	1164 (35.41)	523 (15.91)	287 (8.73)	155 (4.72)	99 (3.01)	68 (2.07)	40 (1.22)	108 (3.29)	3,287
1985-1989	-	-	-	-	-	94 (30.62)	131 (42.67)	53 (17.26)	10 (3.26)	4 (1.30)	2 (0.65)	3 (0.98)	10 (3.26)	307
1980-1984	-	-	-	-	-	-	62 (21.45)	98 (33.91)	71 (24.57)	17 (5.88)	15 (5.19)	12 (4.15)	14 (4.84)	289
1975-1979	-	-	-	-	-	-	-	56 (24.35)	64 (27.83)	22 (9.57)	17 (7.39)	11 (4.78)	60 (26.09)	230
1970-1974	-	-	-	-	-	-	-	-	33 (23.57)	48 (34.29)	25 (17.86)	16 (11.43)	18 (12.86)	140
1965-1969	-	-	-	-	-	-	-	-	-	86 (31.85)	69 (25.56)	32 (11.85)	83 (30.74)	270
1960-1964	-	-	-	-	-	-	-	-	-	-	14 (45.16)	14 (45.16)	3 (9.68)	31

are normally limited in number to just one, as reflected by the fact that indicators such as the number of links >1 or density show very low values compared to those observed in other areas of knowledge. The high number of components observed, together with the low percentages of authors integrated in the giant component, reflects the existence of numerous research clusters made up of investigators who tend to be interconnected (given the high values observed in the clustering coefficient); however, the groups are small in size and are not well communicated with the rest, as it is observed by the reduced values of the betweenness centralization.

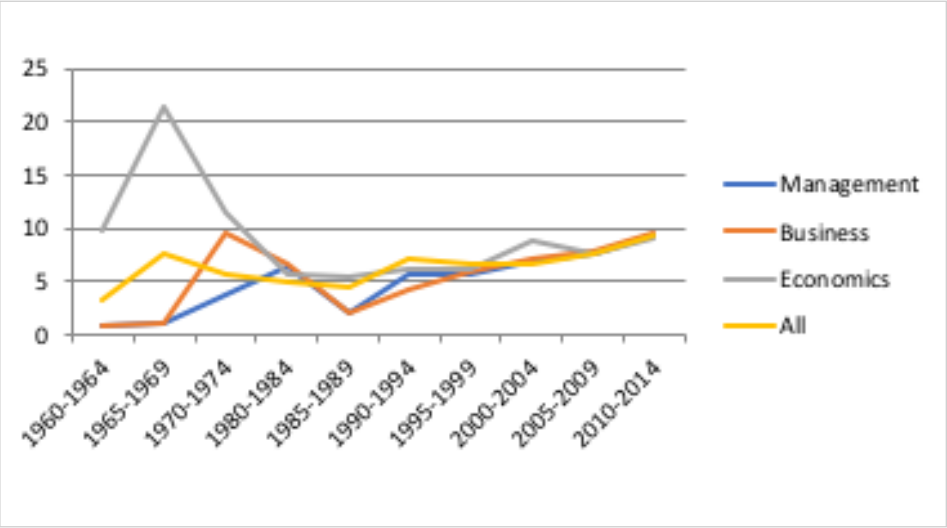

Figure 4. Evolution of the average age of the cited bibliography in published documents on spin-offs, according to *Web of Science* categories

B) Analysis of the cited literature in the publications about spin-offs

The documents analyzed collectively cited 50,987 bibliographic references. The percentage of journal articles among the cited references increased progressively: from 59.07% in 1960-1989 to 62.61% in 1990-1994, 60.2% in 1995-1999, 64.54% in 2000-2004, 66,47% in 2005-2009, and 70.84% in 2010-2014. Figure 3 shows the evolution of the most frequently cited core documents in publications on spin-offs indexed in the *Web of Science*. Two features are especially noteworthy with regard to the contributions of these authors to the documents studied and the citation analysis performed: there is an evident overlap between authors' early research contributions to the topic and the time when they become investigators of reference in the field, with their work featured among the most highly cited documents. Thus, for 62.07% (n = 18) of the authors whose research tops the citations ranking, this occurred with their first published study on the research topic; and many of the most highly cited authors have had a short-lived contribution to the field. Indeed, 75.86%

Table 5. Citation indicators for documents on spin-offs indexed in the *Web of Science* (1980-2014)

Publication year	*Web of Science* documents	Category normalized citation impact	% Docs cited	N top 1%	% Documents in top 1%	N top 10%	% Documents in top 10%	Highly cited papers*	% Highly cited papers
1980	6	0	0	0	0	0	0	-	-
1981	8	0.23	62.50	0	0	0	0	-	-
1982	1	1.01	100	0	0	0	0	-	-
1983	8	4.07	75.00	0	0	5	62.50	-	-
1984	7	0.19	28.57	0	0	0	0	-	-
1985	5	0.04	20.00	0	0	0	0	-	-
1986	10	0.33	70.00	0	0	0	0	-	-
1987	9	0.33	77.78	0	0	0	0	-	-
1988	7	0.10	57.14	0	0	0	0	-	-
1989	6	0.11	33.33	0	0	0	0	-	-
1990	6	1.04	66.67	0	0	2	33.33	-	-
1991	37	0.76	78.38	1	2.70	4	10.81	-	-
1992	23	0.56	78.26	0	0	2	8.70	-	-
1993	29	0.89	79.31	1	3.45	2	6.90	-	-
1994	32	0.62	68.75	0	0	3	9.38	-	-
1995	33	1.46	78.79	1	3.03	6	18.18	-	-
1996	48	0.41	62.50	0	0	2	4.17	-	-
1997	43	0.86	76.74	0	0	5	11.63	-	-
1998	44	1.87	77.27	2	4.55	5	11.36	-	-
1999	56	1.17	76.79	1	1.79	10	17.86	-	-
2000	63	0.56	68.25	0	0	5	7.94	-	-
2001	61	0.61	77.05	0	0	2	3.28	-	-
2002	68	1.13	75.00	2	2.94	11	16.18	-	-
2003	69	0.75	76.81	0	0	8	11.59	-	-
2004	73	1.17	86.30	4	5.48	10	13.70	-	-
2005	70	1.71	87.14	3	4.29	19	27.14	2	2.86
2006	64	1.01	87.50	0	0	7	10.94	0	0
2007	71	1.82	87.32	3	4.23	16	22.54	2	2.82
2008	85	1.29	90.59	1	1.18	17	20.00	0	0
2009	71	1.16	90.14	0	0	11	15.49	0	0
2010	90	1.36	90.00	1	1.11	16	17.78	1	1.11
2011	98	1.84	84.69	3	3.06	20	20.41	2	2.04
2012	105	0.97	78.10	0	0	9	8.57	0	0
2013	96	1.13	73.96	0	0	10	10.42	0	0
2014	116	1.20	57.76	1	0.86	16	13.79	0	0

* This indicator is only available for the last 10 years (since 2006). In this case, the publication has received enough citations to place it in the top 1% based on a highly cited threshold for the corresponding academic field (AF) and publication year.

Table 6. Citation indicators of the top 15 journals (>14 papers) publishing documents on spin-offs and indexed in the *Web of Science*

Name	*Web of Science* documents	Times cited	% Docs cited	Category-normalized citation impact	*Eigenfactor* 2014	5-year impact factor 2014	Impact factor w/o self cites 2014	Journal impact factor 2014
Research policy	60	3,258	100	3.88	0.01533	4.257	2.777	3.117
Technovation	43	1,018	95.35	1.89	0.00391	3.636	1.778	2.526
The journal of technology transfer	32	475	93.75	1.88	0.00151	1.804	0.744	1.181
Chimia	24	44	33.33	0.07	0.00287	1.110	1.306	1.349
Small business economics	21	500	95.24	1.88	0.00504	2.401	1.265	1.795
R&D Management	20	564	95.00	1.13	0.00196	2.343	0.772	0.848
Acta astronautica	18	60	72.22	0.64	0.00751	1.117	0.776	1.122
Technology analysis & strategic management	18	111	88.89	0.61	0.00144	1.146	0.627	0.942
International journal of technology management	18	96	83.33	0.43	0.00108	0.702	0.552	0.625
*Journal of taxation**	16	3	18.75	0.01	-	-	-	-
Journal of financial economics	16	853	100	3.02	0.05796	5.876	3.740	4.047
Strategic management journal	15	303	93.33	1.35	0.01911	6.061	3.067	3.341
Industrial and corporate change	15	1,152	100	4.98	0.00460	2.183	1.150	1.260
Journal of corporate finance	15	85	93.33	0.66	0.00419	1.770	0.873	1.193
European planning studies	15	178	86.67	0.90	0.00324	1.275	0.955	1.228

* The analysis was carried out on documents published from 1980 on; therefore, the nine documents published before that date in this journal are not included.

(n = 22) of them have signed just one to three of the research papers on spin-offs that we analyzed for our study (11 authors with one paper, 8 authors with two papers, 3 authors with three papers, and 7 authors with four papers or more).

It is noteworthy that we can clearly observe the important role of some documents as intermediaries that favor the connectivity between the two research clusters since 2000. This is the case for papers by **Krishnaswami** & **Subramaniam** (1999, node 28), **Nelson** & **Winter** (1982, node 19), **Penrose** (1959, node 40), **Klepper** & **Sleeper** (2005, node 8), **Agarwal** *et al*. (2004, node 17), **Daley**; **Mehrotra**; **Sivakumar** (1997, node. 18), **Mustar** *et al*. (2006, node 14) and **Berger** & **Ofek** (1995, node 29) in the most recent five-year period (2010–2014).

Table 4 shows the distribution (number and percentage in parentheses) of the cited references in each time period according their publication year (five-year intervals). It is interesting that the percentage of publications from the most recent interval decreases throughout time, from 30.62% in 1985-1989 to 12.13% in 2010-2014.

With regard to the age of the cited bibliographic references, according to the methodology introduced by **Jarić** *et al.* (2014), we observed that the early publications on the topic use a relatively old bibliography, but the mean age of the references gradually falls over time; that is, investigators use increasingly recent papers to support their research. For example, the average age of the bibliography decreases from 7.6 years in 1965-1969 to 4.4 years in 1985-1989. However, in more advanced stages, the age of the bibliography once again begins to rise, reaching 7.2 years in 1990-1994 and 9.2 years in the most recent period of 2010-2014. This same pattern can be observed in the three most productive thematic categories related to the topic (Figure 4).

C) Analysis of citations received by publications on spin-offs

With regard to the indicators of impact for spin-offs publications (Table 5), the citation values increase as the topic becomes more consolidated. This is the case for the percentage of documents cited, which garners the highest values (more than 80%) from 2004 onward. It is noteworthy that the percentage of spin-offs documents in the top 1% (the first appears in 1991) and top 10% appear to be linked to the research boom in the 1990s, as there are no documents within these categories except in the top 10% in 1983.

With regard to the citations at the journal level (table 6), we can point out that *Research policy* has maintained its position as the main journal of reference with regard to the topic, ranking first in all indicators, together with *Journal of financial economics* and *Industrial and corporate change*. Additionally, *Strategic management journal* also stands out among the rest of the most productive journals with regard to 5-year impact factor indicator.

All of the most productive categories generally have a greater than average impact (except in "Business, Finance"). The "Planning & Development" category is clearly more prominent that the others with regard to the category-normalized citation impact and the rest of the citation indicators. "Management" also presents relatively high values (Table 7).

In general, the categories citing papers on spin-offs correspond very well with the categories most frequently assigned to the publications in this research field, especially the top three (Management, Business and Economics). However, some other categories like "Geography" and "Environmental Studies" are also highly ranked for their citations of research on the topic.

> The age of the cited bibliography constitutes a prominent indicator for establishing the emerging nature of a topic as well as its stage of development

Concerning citing journals, a very similar trend is apparent. The three most frequently citing journals (*Research policy*, *The journal of technology transfer* and *Technovation*) also account for the highest number of publications in this research field. However, some journals are more present as citing sources than as publishing media, for instance *Scientometrics* (rank 7 versus 16 in 2010-2014), while others such as *PLoS one* (rank 6 as most citing journal) have never directly published an article on spin-offs. In the case of *PLoS one*, the highly multidisciplinary focus of the journal serves as an explanation.

It is also noteworthy that in some journals like *Small business economics*, *European planning studies*, *Regional studies* and *Strategic management journal*, high activity citation in the previous period (2005-2009) resulted in a higher production (number of publications) in the following period (2010-2014).

> Some features that may be associated with pioneering publications on emerging topics are their prominence in scientific congresses and events; their presence in specialized journals of modest production and impact; and the rapid positioning of researchers as authors of reference in relation with the topic

D) Thematic analysis

The analysis of the frequency and co-occurrence of the *KeyWords Plus* in each of the periods in the form of networks (figure 5) shows the evolution of the difference thematic foci examined by the research. The first (1995-1999) and also second (2000-2004) period exhibit simple networks, dominated by an economic approach focusing on markets and companies. Starting in the mid-2000s, however, research began to concentrate on the analyses of innovation processes, competitive advantages, and research and development (2005-2009), aspects that continued to attract research interest in the most recent period (2010-2014).

4. Discussion

Our study analyzes the emergence and development of spin-offs research from a bibliometric perspective. However, the potential application of our findings from this single

Table 7. Citation indicators of the top 15 *Web of Science* categories where documents on spin-offs are published

WoS category	*WoS* documents	Category-normalized citation impact	% docs cited	N top-1% *WoS* citations	% documents in top 1% *WoS* citations	N top-10%	% documents in top 10% *WoS* citations	Highly cited papers	% highly cited papers
Management	358	1.94	87.71	5	1.40	74	20.67	6	1.68
Business	198	1.70	82.32	4	2.02	34	17.17	1	0.51
Economics	225	1.59	83.56	2	0.89	41	18.22	1	0.44
Planning & Development	115	2.44	91.30	7	6.09	41	35.65	4	3.48
Business, Finance	130	0.99	73.08	0	0.00	14	10.77	0	0.00
Engineering, Industrial	96	1.73	86.46	2	2.08	27	28.13	1	1.04
Operations Research & Management Science	77	1.67	89.61	2	2.60	17	22.08	0	0.00
Oceanography	37	1.28	86.49	0	0.00	7	18.92	0	0.00
Geography	59	1.34	93.22	0	0.00	6	10.17	0	0.00
Genetics & Heredity	15	1.88	46.67	1	6.67	3	20.00	0	0.00
Environmental Studies	48	1.35	91.67	1	2.08	3	6.25	0	0.00
Food Science & Technology	9	4.25	77.78	1	11.11	1	11.11	0	0.00
All	1618	1.13	77.75	24	1.48	223	13.78	7	0.43

case study to the broader area of emerging research topics and their evolution remains largely speculative. Additional studies examining different cases should test the generalizability of our conclusions. However, we believe that one strength of the case study design is that it enables the generation of new hypotheses. The most significant aspect of the analysis on scientific production related to spin-offs is the boom observed in the number of papers published beginning in 1990-1994, with much higher growth rates than those in other established disciplines or in scientific bibliography in general (**Schaltegger**; **Gibassier**; **Zvezdov**, 2013). This research boom occurs after a long latent period —more than three decades of little or only moderate research attention to the topic. These two features (long latent period followed by a boom in the number of publications) have been highlighted in a number of prior studies related to other emerging topics (**Bontekoning**; **Macharis**; **Trip**, 2004; **Klincewicz**, 2016; **Liu**; **Gui**, 2016; **Shapira**; **Kwon**; **Youtie**, 2017). **Klincewicz** (2016) notes that an emerging topic might initially remain dormant, with the scientific community gradually learning about new concepts, but a breakthrough discovery spurs the subsequent increases. For their part, **Small**, **Boyack** & **Klavans** (2014) identify the factors that can explain this emergence: a scientific discovery, technological innovation, or exogenous event. In this case, one prominent milestone related to academic spin-offs is the widespread adoption —at an international level- of legislation permitting universities and other bodies to patent inventions derived from research financed with public funds, thereby opening up the possibility for companies to use the technology. According to the model proposed by **Wang** (2018), 1990-2004 is when spin-offs could have been considered an emerging research topic, as the highest growth rates were concentrated during this period; afterwards, growth was much more moderate.

Another significant aspect, which we have not been able to contrast with previous studies on emerging topics (as these generally limited their searches to certain document types), is the high number of papers pertaining to document types other than articles and reviews. Only after the research boom began did journal articles start to stand out from other types in terms of the number of documents produced, constituting 70% of the total in the 2010-2014 period, a value that is more consistent with the usual distribution of document types in scientific research (**Zhang**; **Rousseau**; **Glänzel**, 2011). With regard to this aspect, we can speculate that emerging topics contribute more intensely as novel topics in scientific congresses and meetings, being presented there as a way to gauge the interest that they attract in the scientific community. Documents may be frequently published as proceedings papers (19.8% of the documents published in the whole study period pertain to this document type, although values in specific periods peak at 28.2%). However, in the area of social sciences, this categorization may be incorrect; the "proceedings papers" that appear in the *WoS* may actually be summaries of articles that have been presented in a scientific congress or meeting (**Harzing**, 2013). In any case, this fact would not invalidate the reflection that new contributions would initially have an outsized presence in scientific meetings

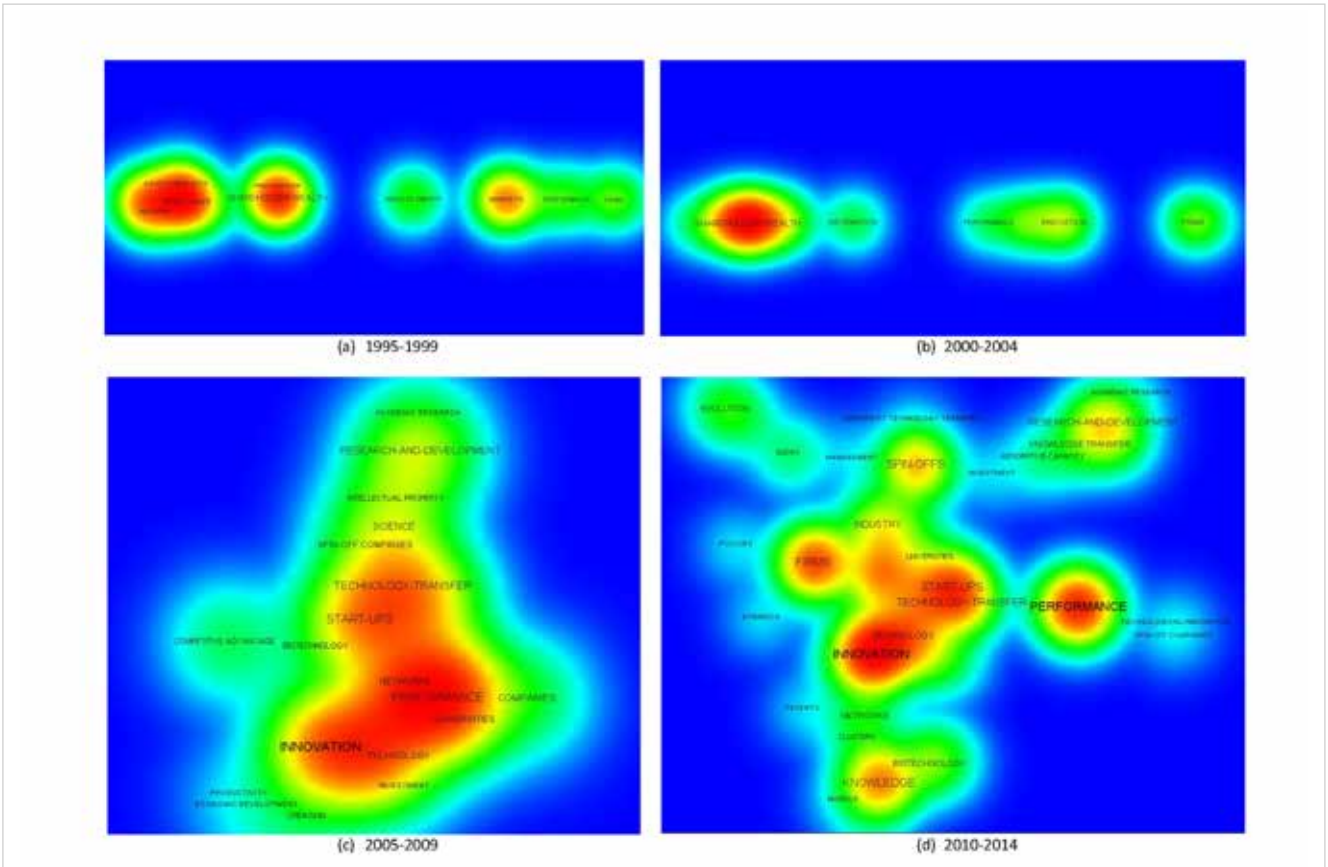

Figure 5. Evolution of the interrelationships between the main words used in document titles of works cited in publications on spin-offs

and events. The high number of news items and editorial material may also reflect the nascent stages of a topic's development, as it attracts growing interest among editors of scientific journals, which leads to more formal research in the form of original articles and reviews during advanced stages of development.

With regard to the acceptance and interest in an emerging topic, **Schaltegger**, **Gibassier** & **Zvezdov** (2013) note the importance of publishing and disseminating research in multidisciplinary journals of high impact. In that sense, we have identified 30 papers on spin-offs published in *Science* and *Nature*, which not only favors the degree of knowledge about the topic and strengthens the interest in it among the research community, but also illustrates the importance it holds at a global level. The presence of the topic in prestigious journals specializing in areas that are not specifically concerned with spin-offs, as is the case with *Scientometrics*, favors its multidisciplinary dissemination and research approach (**Schaltegger**; **Gibassier**; **Zvezdov**, 2013).

In terms of the thematic categories and also the scientific journals publishing the papers, we have observed a phenomenon of dispersion and expansion along the edges of the field, with an increasing number of journals and categories on the periphery (illustrated by the long "tail" in the list of journals and categories that have published a limited number of papers). This phenomenon coincides with a simultaneous concentration in the core, wherein the most productive categories and journals increase their absolute and relative contributions to research on the topic. This phenomenon has become well known from Bradford's observations, but it has not been studied in depth as an evolutionary process (**Morris**, 2005).

Our finding regarding the increase in the number of thematic categories, together with the gradual reduction in the percentage of categories that produce only one or two papers (which drops from 84% in 1980-1984 to 54% in the most recent period of 2010-2014) coincides with the observations made by **Goldman** (2014) regarding the investigation of "system biology", or the greater diffusion and growing interest in the topic from new corners (**Rafols**; **Meyer**, 2010; **Goldman**, 2014). In relation to this aspect, one of the main challenges in the areas of interdisciplinary knowledge or those that take a multidisciplinary approach —which is especially important in spin-offs due to the fragmentation observed in the analysis of co-authorships and research fields- is in favoring the integration of contributions from different disciplines by means of creating conditions that favor collaboration among researchers from different areas (**Anholt**; **Stephen**; **Copes**, 2012).

Regarding collaboration, the most noteworthy aspect observed is that the boom in research was associated with the presence and the increase in international collaboration (prior to 1990, no documents were signed in international collaboration). This fact may suggest that in the initial stages of development, this topic only attracted interest at a national level, or researchers may have found it difficult to find collaborators due to the low level of the topic's development and the existence of a very small research community (**Mryglod** *et al.*, 2016; **Shapira**; **Kwon**; **Youtie**, 2017).

Although the average node degree rose slightly over the period of study, it remained relatively stable, probably because no specialization has emerged among experts contributing from different fields, such as statisticians, technicians or PhD students, nor have different lines of specialized or specific research been launched within the topic, which would implicate a broad research community working on it and which would lead to a higher average degree. In terms of the number of isolates, which decreases steadily and sensibly despite a moderate increase in collaboration, this responds to the fact that it is increasingly rare to work individually, without collaborative links captured by co-authorships in scientific publications. **Mund** & **Neuhäusler** (2015) have observed a lower degree of collaboration among authors studying emerging topics. Among the possible factors that might contribute to that pattern, in addition to those previously mentioned, the researchers suggest a lack of trust among investigators, or a desire to protect their innovative scientific contributions, which may constitute barriers that impede collaboration.

> "The analysis of the information contained in the *KeyWords Plus* field in the *Web of Science* databases (words and phrases harvested from the titles of the cited articles), allows to thematically characterize the aspects covered by research"

Jarić, **Knezević-Jarić** & **Lenhardt** (2014) noted that the age of the cited bibliography in the documents could be an indicator of reference for monitoring the emergence of a new topic. We test this hypothesis in the present study, confirming that the cited bibliography is more recent as the development of the topic begins to take off. In addition, we also found that prior to this boom, in the initial stages of development, the bibliography used is older; likewise, following the boom period, the age begins to increase once again. Moreover, **Small**, **Boyack** & **Klavans** (2014), in their analysis of the top 10 most-cited works, noted a pronounced decrease in the age of the bibliography cited therein, coinciding with the boom of documents published or the emergence of the topics analyzed, followed by a gradual increase in the age of the bibliography cited over the next several years. This U-shaped distribution is probably due to the fact that authors of early publications have few specific sources on which to build their work, prompting them to resort to drawing parallels with other topics and to use older references or papers that contribute more general knowledge. By contrast, as papers begin to be published on the topic, they must be cited, so the average age of the cited bibliography falls. As more specific bibliography on the topic becomes available, the age of the cited bibliography begins to rise once again (**González-Alcaide**; **Llorente**; **Ramos**, 2016).

The fact that a large proportion of authors responsible for the most highly cited documents have only contributed a few papers to the topic (and in many cases their first paper has the highest impact), together with the rapid positioning of researchers as references in the field, may be considered characteristic features of emerging topics. These observa-

tions probably reflect the fact that consolidated researchers with a large body of work on other topic(s) are attracted to the emerging topic, and they publish isolated work on it within the context of a mature research career (**Gordon**, 2007). This hypothesis would explain both the low level of contribution and the wide uptake of the same, a phenomenon that does not usually occur in more consolidated areas, where investigators gradually accumulate prestige, or where the work of new authors with pioneering contributions to the research area is not usually considered a main reference for the discipline (**González-Alcaide**, 2014).

Although the citation indicators do not seem to be useful in identifying the seminal publications on emerging topics, they can help to monitor their boom. In that sense, several papers have reported a marked increase in the citation degree, coinciding with the emergence of the topic (**Chen** *et al.*, 2012; **Liu**; **Gui**, 2016; **Small**; **Boyack**; **Klavans**, 2014). In the specific case of the present study, we have observed a notable spike in the percentage of documents in the top 1% and top 10% of cited documents in the *Web of Science*. Another significant aspect observed is that each discipline and thematic area involved in spin-offs research has its own journal of reference, which stands out from the rest in terms of citation and impact indicators. These are general subject area journals within a discipline, addressing a range of topics. The next desirable step in the process of the area's consolidation would be the launch of specific journals specializing in spin-offs, as these would allow a greater dissemination of specialized knowledge related to the topic and would favor the articulation of a stable research community around the journals (**Gordon**, 2007).

5. Limitations

The main limitation of the study is its narrow scope, which covers the emergence and development of a research topic based on a single case study. Other limitations include the coverage of the database used, which could have overlooked relevant books, doctoral theses, and other papers related to the topic at a national level. Moreover, in relation to the analysis of the disciplines, there may be a possible bias stemming from the automatic assignment of the documents according to the preconceived WoS categories that have been established for journals, without any specific evaluation of the articles' contents. Finally, it is important to highlight that the observations made correspond to a single area of knowledge. Our findings should be confirmed or elaborated on based on the in-depth study of other topics.

6. Lines of future research

The literature on emerging topics has so far emphasized the indicators and methodologies that can be used to identify them, which is logical given the interest that this holds for both researchers and funding bodies. However, there should also be room for the development of studies that contribute to defining a theoretical and conceptual framework for emerging topics, for example in order to establish a definition of what they are and what bibliometric features characterize them, particularly the milestones that mark their evolution and their transition from emerging to mature development.

7. Conclusions

The present study describes the emergence and evolution of scientific literature on spin-offs using a bibliometric approach, contextualizing our observations with previous studies examining emerging topics from this perspective. Our findings add to the growing body of literature on the dynamics of research topic development. Furthermore, this type of approach may be of great help to researchers in the area, especially those who wish to specialize in it. It is also worth highlighting the bibliometric interest of the information collected through the *KeyWords Plus* function in the *Web of Science* database (words and phrases harvested from the titles of the cited articles), which thematically characterize the aspects covered by existing research, as in this study. We consider that the comprehensive vision put forward on the diachronic evolution of bibliometric indicators is the most novel contribution to the present study. From a bibliometric perspective, analyzing the information contained in the *Web of Science KeyWords Plus* (ID) field is also innovative, as we are not aware of any previous work that has employed this method.

Some of the main aspects observed with regard to the bibliometric indicators calculated include the age of the cited bibliography, which constitutes a prominent indicator for establishing the emerging nature of a topic as well as its stage of development. Certain citation indicators (percentage of documents in the top 1% and top 10% of their categories) and the existence of international collaboration appear to be associated with more advanced stages of research topic consolidation. Other features that may be associated with pioneering publications on emerging topics are their prominence in scientific congresses and events; their presence in specialized journals of modest production and impact; and the rapid positioning of researchers as authors of reference in relation with the topic, which often occurs with their first study. With regard to the scientific journals and thematic categories, we have observed a simultaneous phenomenon of dispersion and expansion around the edges of the field (with growing numbers of journals and thematic categories), along with a concentration in the core areas of the topic, with certain journals and thematic categories contributing more in both absolute and relative terms to the topic's development. All of the aspects mentioned should be contrasted with studies on additional cases that confirm and expand on the observations reported here.

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Note

1. In *WoS*, proceedings papers are also classified as articles since 2009.

8. References

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