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Structure and evolution of innovation research in the last 60 years: review and future trends in the field of business through the citations and co-citations analysis

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Abstract The field of innovation studies has grown considerably in the last four decades, which has led to the emergence of new approaches and theoretical aspects that need to be examined and considered. Therefore, this paper aims to understand what are the main theoretical pillars that support the structure of innovation theories and fields, how it evolved over the years and what are the directions that lead to future trends in innovation research. The procedure consists in a mix-methods using the citation and co-citation analysis associated with bibliometric methods, Social Network Analysis, and a systematic review of the literature. The results were validated by Delphi with academic specialists in innovation. Considering publications between 1956 and 2016 divided into four 15-years timespan, the longitudinal analysis results indicate the evolution of the main streams of thoughts that support the current innovation research fields and depict a research orientation for future works that can be developed to generate relevant contributions for the theoretical development of the area. This paper differentiates itself bringing results based on a large database, by the research methods employed, and by the perspective adopted

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provides solid contributions to the understanding of the past, present, and future of the scientific research in innovation to business administration field.

Keywords Bibliometrics · Innovation · Social network analysis · Systematic literature review · Co-citation analysis · Citation analysis

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Introduction

Researchers from any academic discipline tend to group in informal networks, or called "invisible colleges," which focus on common problems in common ways (Price 1963; Burt 1977). Within these networks, the concepts and discoveries made by a researcher from these networks are absorbed, tested and improved by other researchers in the network, making the work of one researcher to be built on the work of another (Culnan 1986). The history of exchanges between the members of these groups in a discipline describes the intellectual history of the field and the subsequent citation that a researcher makes of the work of an earlier researcher provides a means of documenting this history (Price 1963, 1965; Culnan 1986, 1987; Culnan et al. 1990; Burt 1977).

Scholars and researchers from all academic disciplines benefit from an understanding of the intellectual development and evolution of their fields of study because both provide a sense of the future (Culnan 1986). Understanding the intellectual roots of a field also identifies the basic intellectual engagements that serve as the foundations of a field of study (Culnan 1986, 1987; Culnan et al. 1990; Beyhan and Cetindamar 2011; Shafique 2013; Burt 1977).

In the innovation studies field, there are no studies dedicated to the investigation of intellectual history and the evolution process of the innovation theories from informal networks of collaboration or "invisible colleges". Nor do they identify the major disciplines that emerges from literature over time or reveal their dynamics. Some studies that present some kind of literature review on innovation include Nelson and Winter (1977) and Abernathy and Clark (1985). However, there is a need for more recent studies and new analytical techniques. More recently, works such as Gopalakrishnan and Damanpour (1997), Garcia and Calantone (2002), Fagerberg (2004), Ortt and van der Duin (2008), Crossan and Apaydin (2010), Bhupatiraju et al. (2012), Fagerberg et al. (2012), Shafique (2013), Kotsemir et al. (2013), Simonse et al. (2015), Fagerberg and Verspagen (2009), Merigó et al. (2016) and Cancino et al. (2017) carried out some kind of literature review of the innovation concept, but nothing like work here proposed. Existing works focus on a specific area within innovation or address different areas, including innovation. Others focused on a review analysis of countries production, or author's productivity and reputation. In addition, the existing works use different methods like Multidimensional Scaling (MDS), Factor Analysis or bibliometric indexes. This work distinguishes itself by the multi-methods approach using techniques such as bibliometrics, analysis of social networks and systematic review of the literature focusing only on the innovation area related to business management. Besides, we present results coming from a timespan and data volume unprecedented, differing itself also by focusing on the invisible colleges that formed the innovation research field, showing an evolutionary view.

In addition, "innovation is studied by various areas and has been defined from different perspectives", as Damanpour and Schneider (2006) points out, causing an overlap between the various definitions of innovation and leading to a fragmented and diffuse understanding of the applications of innovation, resulting in a disciplinary vacuum capable of impacting the practices of innovation (Baregheh et al. 2009; Adams et al. 2006; Cordero 1990; Ettlie et al. 1984). It is fundamental to highlight the importance of distinguishing the different types of innovation (Daft and Becker 1978; Duchesneau et al. 1979; Garcia and Calantone 2002; Tavassoli and Karlsson 2015; Damanpour et al. 1989) and how they are directed as areas of research for future studies.

Thus, some challenges emerge, such as (1) the importance of a longitudinal understanding of the evolution of innovation theories from informal collaboration networks; (2) the understanding of the main themes or research areas that form the basis of knowledge in innovation that emerge from the analyzes carried out; and (3) a better understanding of the theme, publications and authors that form the basis for sustaining innovation over time; challenges that this work aims to supply by reducing the theoretical gaps exposed to the moment.

Therefore, the objective of this work is to identify, from the informal networks of collaboration, the structure and evolution of innovation over time, understanding how they were formed and contributing to the formation of research areas that emerge from the literature, analyzing also the main publications, authors, and periodicals that contribute to the formation of innovation, as well as their directions, identifying the informal networks of collaboration, focused only in the business management context.

With this study, methodological and theoretical contributions are presented through the association of the use of bibliometric methods, analysis of social networks and techniques of systematic review of the literature for the treatment of an unpublished data volume, and with a procedure of longitudinal evaluation of the evolution of innovation over time, and the way research areas emerge, contributing to filling the theoretical gaps already indicated, to indicate new avenues for future contributions and the improvement of the current management practices provided by the improvement in the understanding of the emerging issues of innovation.

In this sense, the following paragraphs will present the necessary definitions for the delimitation of this study. In the following sections, we present the literature review necessary to support the understanding of the co-citation analyzes, as well as detailing the methodological procedures followed by the presentation and discussion of the results. The objectives are taken up in the final considerations, where we also point out study limitations and suggestions for future studies.

Literature review

To achieve a deeper analysis of the structure and evolution of innovation, this article applies an analysis of citations and co-citations for the first time, in order to understand more broadly the field of studies of innovation and its subareas. Despite the increasing use of bibliometric techniques and analysis of social networks in publications between 1956 and 2016, there are still few studies dedicated to innovation. The number of papers that present an analysis of citations and co-citations is even more restricted.

To date, few published works have moved in the same direction as the work proposed here, including Cottrill et al. (1989) and Verspagen and Werker (2004) which present an

analysis of the intellectual structure with a focus on diffusion and transfer of technologies, or in the economy of technology and innovation formed around the publications of Keith Pavitt. Years later, Fagerberg and Verspagen (2009) published another study dedicated to innovation that presents, through the use of social network analysis, the cognitive and organizational characteristics resulting from a survey applied on the web. Another paper published by Fagerberg et al. (2012) explores the knowledge base in innovation through bibliometrics and analysis of social networks from the main books and handbooks published in the innovation area. And in the same year, Martin et al. (2012) and Di Guardo and Harrigan (2012) present a study that explores the knowledge base in science and technology from books and academic publications in the area and with focus in strategic alliances for innovation. It is still important to highlight the work of Shafique (2013) which analyzes the intellectual structure of knowledge produced in the innovation area, using bibliometric data and social network analysis, considering the four major disciplines of the social sciences: economics, sociology, psychology and administration. It is important to emphasize that all the works so far, have focused on subareas of innovation, or focused on large areas of social sciences, including innovation, but not giving the area the deserved highlight. Also, they used another unit of analysis, such as book-based studies. None of them has proposed the focus, technique of analysis or methodological procedure as the present work.

From the studies to date (Verspagen and Werker 2004; Fagerberg and Verspagen 2009; Fagerberg et al. 2012; Martin et al. 2012; Shafique 2013; Cottrill et al. 1989; Di Guardo and Harrigan 2012), the works of Cottrill et al. (1989) and Shafique (2013) were the first to carry out an analysis of authors' co-citations. However, Shafique (2013) was the only one to use social analysis to identify the authors' relationship. All other studies use factorial analysis techniques, cluster analysis or multidimensional scaling modeling in an attempt to map the relationship between authors' production and research fields.

Differently from all the studies indicated so far, this study aims not only to focus the research within the innovation area, but also to extend the use of social network analysis associated with the analysis of co-citation of authors offering a different perspective and until then not investigated in the field of innovation. The objectives of the work are therefore: (1) to detect the most influential articles (and, implicitly, from the most influential authors) and (2) journals within the field, besides (3) identify the main research fronts in the innovation area and its research interrelations from the perspective of its users.

Moving forward: what is new?

Although different approaches and methods are presented by literature to explain the innovation concept bases, few studies were dedicated to an evolutionary view that shows the formation of the intellectual structure of the innovation research fields as we proposed here. Due to this, we spur the reading of this paper associated with these different studies in order to get a wide view created from a complementary perspective.

Different procedures, methods, and perspectives have been adopted by authors to describe the studies in the innovation field (e.g. Cottrill et al. 1989; Verspagen and Werker 2004; Fagerberg and Verspagen 2009; Di Guardo and Harrigan 2012; Fagerberg et al. 2012; Martin et al. 2012; and Shafique 2013) as discussed at the beginning of this work. However, our paper contributes in a complementary way with other studies published recently (Cancino et al. 2017; Merigó et al. 2016) helping to the creation of a wide sight about the studies in the innovation field. Merigó et al. (2016) have carried out a study analyzing the academic research in innovation through a country analysis. On his study,

was analyzed the leading countries in innovation research in a 24-year period (1989–2013) presenting results from a supranational and global perspective, indicating those countries and regions most productive and influent in innovation research. Based on some bibliometric indicators like h-index, and backed up by VOSviewer software, the authors stand out the countries performance on innovation research, like the US and UK leadership, and the relevance growing of Asian countries. Likewise, but focused on the authors' relevance, Cancino et al. (2017) indicate the most influential authors from the Innovation Field over the last 25 years (1989–2013) according to with the h-index. They also highlight that the most productive authors, with the higher number of publications, do not necessarily are the most influent authors, being something valid to any research field.

However, we present in this paper some differential aspects such as (1) the main concept behind our paper is the "invisible colleges" formed by the informal authors' networks that helped to form the main clusters that underpin each research field on innovation; (2) for that, our data were based on the references of the references justly to provide a comprehension about which papers give sustainability to the most cited papers in innovation field currently, and which are the relationships between them, and the papers that used them to sustain their theories; (3) our results were based on an unprecedent data volume, analyzing a considerable timespan, and providing an evolutionary view of the research fields in innovation, focused on business management context; (4) the research fields in innovation that emerged from each period of analysis were validated by specialists using a Delphi method, and are useful findings to provide a good comprehension about the past, the present and directions for the future researches on innovation field. Associating other papers to this study, it is possible to get wider the sight and comprehension, aggregating aspects related to country production in innovation or others still to be discovered.

Methods and data

Bibliometric approach's stages

The analysis of citations and co-citations is a widely used bibliometric method that supports empirical investigations of the structure and academic activity of various disciplines (Üsdiken and Pasadeos 1995). In line with the research objectives of the present study, methodological procedures were performed in several steps, as indicated by McCain (1990), along with a previous citation analysis. First, the development of a list of references already cited as seminal articles by the main studies that have already reviewed the general literature on innovation (Shafique 2013; Adams et al. 2006; Simonse et al. 2015; Gopalakrishnan and Damanpour 1997; von Zedtwitz et al. 2015; Fagerberg et al. 2012; Fagerberg and Verspagen 2009; Crossan and Apaydin 2010), of the published studies that already present some review about the "types of innovation" found in the literature (Damanpour et al. 1989; Propris 2002; Oke 2007; Tödtling et al. 2009; Garcia and Calantone 2002) and of all the articles of the field of innovation obtained from the Social Science Citation Index (SSCI) collected manually during four multi-year periods of 15 years each: 1956–1970, 1971–1985, 1986–2000 and 2001–2016,[1] according to Ramos-Rodríguez and Ruíz-Navarro (2004), and Shafique (2013), covering a total of 60 years of academic publications in the field of innovation.

[1] For the year 2016, data were collected referring to the articles published until February 17th.

Secondly, an analysis of the citations of these data that revealed the most cited publications, authors and journals by innovation scholars (objective 1). Third, through the analysis of co-citation, the 300 most cited authors were measured and weighed to detect their affinity according to the perception of their citations (Gmür 2003; White and Griffith 1981). The result was an "author x author" matrix that served as the basis for later multivariate analyzes and for social network analysis. Fourth, in order to represent the structure of the discipline (objective 2), the results of the analyzes were mapped in such a way that the groups of co-citations would represent different fields of innovation (McCain 1990; White and Griffith 1981; Small 1973, 1999). Unlike literature reviews, this analysis may reveal interrelationships between different schools of thought and offer greater objectivity, precisely because it is the result of a judgment composed by the citation of many authors (White and Griffith 1981; Bayer et al. 1990). Thus, the analysis will not influence the result, precisely because the authors' allocation to the co-citation groups were not based on subjectivity, or from the point of view of the authors of this study (Ramos-Rodríguez and Ruíz-Navarro 2004).

Citation analysis

One of the basic assumptions of citation analysis is that it is able to reveal the influence of a particular article by the citation it receives in another article (Culnan et al. 1990; Shafique 2013). Thus, the sum of citations of a given article, author or periodical, from a representative sample (e.g. articles of innovation published in the period covered by this study) is able to provide evidence that the influence of a given article, author or periodical corresponds to a particular field of research (Culnan 1986, 1987). The comparison of the four periods investigated was based on a Citation Value (CV) calculated as the ratio of "number of individual citations" by "total citations received", in a specified period. This is because publications are usually cited once per article, the denominator for this unit of analysis is equal to the total number of publications investigated. For authors or journals, the total number of citations is equal to the sum of all references, because several citations are possible in this case. In these cases, multiple citations may distort the evaluations of their influence, so that the analysis includes only the authors for whom the number of citing articles represents at least 30% of the sum of citations received (see Waugh and Ruppel 2004).

Co-citation analysis

Co-citation analysis is a form of bibliometric network analysis that, according to White (1990) and McCain (1990), can reveal the intellectual structure of academic research fields. It records the frequency with which two authors are cited, for example, in a set of articles, thus indicating their perceived affinity (Small 1973; Bellardo 1980; Small et al. 2014). The groups of cited and closely related coauthors summarize certain areas, research specialties or schools of thought within the discipline (McCain 1990) and can be interpreted as a view of itself (White and Griffith 1981). Consequently, this type of analysis is capable of providing a suitable means to explore the intellectual structure of a scientific discipline (White and Griffith 1981; Nerur et al. 2008). Many studies have validated the results of the co-citation analysis as well as the broad structure they provide, corresponding with the judgment of researchers and other studies in the field.

The determination of the co-citation groups may rely on several methods, which differ mainly in the value of similarity applied. Possible values include absolute co-citation

count, Pearson correlation coefficients, and factor loads (Nerur et al. 2008; White and Mccain 1998; Small and Griffith 1974). In line with the research objectives of this study, a similarity value introduced by Gmür (2003) is used, which, compared to other values, offers especially well-balanced networks with very different groups. To obtain a macroscopic view of the discipline, the single author was adopted as a unit of analysis, used in several publications according to their authors, allowing to reveal more information within the limited space of a network image. Thus, the name of each author represents all or part of his or her body of work and, therefore, the great conceptual theme that this author develops along with his co-authors (McCain 1986; Nerur et al. 2008; White and Griffith 1981). This approach provides a broader view of the structure of the field of study, which would be an equal number of individual publications (such as the unit of analysis) represented in a network image or map.

For ease of comparison, the input for co-citation analysis in all four periods is a similar number of absolute authors. Based on the "citation value", the 300 most cited authors are selected. This threshold was found to be sufficient as input for the analysis of co-citation data in previous studies on the mapping of research fields of similar sizes, such as Accounting, to identify the five or ten most influential research tracks per period (Meyer et al. 2007; Chen and Paul 2001). In the case of a tight ranking, the cutoff value is changed to the nearest 300. Thus, the number of authors for each of the four periods are: 301 (1956–1970), 332 (1971–1985), 309 (1986–2000) and 308 (2001–2016). Regarding the similarity value, Gmür (2003) demonstrated that counting absolute citations among authors is not suitable for the generation of clearly defined groups. Thus, this study uses the value of relative co-citation, the "CoCit" score, as a measure of similarity between authors A and B. The counting of absolute citations is set in relation to the individual citation count of each author, as indicated below:

$$\mathrm{CoCit}_{\mathrm{AB}} = \frac{(\mathrm{Co}-\mathrm{citation}_{\mathrm{AB}})^2}{\mathrm{Minimum}\ (\mathrm{Citation}_{\mathrm{A}} : \mathrm{Citation}_{\mathrm{B}}) \times\ \mathrm{Average}\ (\mathrm{Citation}_{\mathrm{A}} : \mathrm{Citation}_{\mathrm{B}})}$$

where A = Author A and B = Author B.

Two less cited authors (both cited 40 times) with an equal absolute co-citation count (20 co-citations) compared to two most cited authors (both cited 100 times) with similar absolute values could thus receive a higher CoCit score (0, 25 vs. 0.04) because the latter are probably more closely related to the content they publish. The CoCit score ranges from 0 to 1. Several citations and citations from authors within a reference list are counted only once. Based on the CoCit score, the upper part of 1.25% of the investigated co-citation relationships (e.g. pairs of authors) with a minimum of at least three absolute co-citations provide data for further investigation. Since the number of pairs of authors at the beginning of periods is significantly lower than in later periods, a minimum entry threshold of 175 pairs per period has been applied to ensure sufficient insights into the intellectual structure for each period. The relationship between the selected citations is visualized using Pajek (Batagelj and Mrvar 1996; De Nooy et al. 2011), with authors as nodes and the lines between them representing the respective co-citation relationships.

The proximity of the authors within the maps was determined algorithmically (with the Fruchterman–Reingold algorithm) to their perceived affinity. This algorithm assumes that all nodes repel each other, even between the nodes connected to each other, by means of a force of attraction that joins the divergent nodes. Beginning with a random positioning, a stable system can be created through interactions (Fruchterman and Reingold 1991) in which it positions the authors close to the co-cited authors. They form a group if there are

at least four authors who are linked together by means of co-citation relationships. Authors connected only to another author, called isolates, were eliminated. To confirm the innovation structure detected within the maps, a cluster analysis (single-linkage) was also performed.

Database

The data used for the analysis were collected from the Social Science Citation Index (SSCI) of the Web of Science (Reuters 2015) and frequently used in several similar studies, such as Backhaus et al. (2011), Shafique (2013), Crossan and Apaydin (2010), Fagerberg and Verspagen (2009). In addition, all the publications pointed out in the main literature review articles on innovation that are designated as seminal for the area such as (Shafique 2013; Baregheh et al. 2009; Ortt and van der Duin 2008; Simonse et al. 2015; von Zedtwitz et al. 2015; Fagerberg et al. 2012; Fagerberg and Verspagen 2009; Crossan and Apaydin 2010), except for duplicates, were included in the sample. The result consists of 33.182 articles, covering a period of 60 years of publications in the field of innovation (March 1956 to February 2016). The process of searching for publications was done in a few steps: (1) Following the path indicated by Shafique (2013), this result was obtained by searching[2] the keyword "*innovat**" in the advanced search field of the Core Collection[3] of Web of Science™, with the use of an asterisk, in order to obtain publications containing the word innovation and its variants contained in the titles, abstracts, keywords or additional keywords (*Keywords Plus®*)[4] made available by the system, resulting in 73.297 articles. (2) In order to filter the results, excluding the publications that fall outside the scope of this work, (73.297 articles), only the articles that were indexed belonging to the categories *"Management", "Business", "Economics", "Business, Finance", "Operations Research & Management Science"* from Web of Science™ (*Web of Science Categories*) and published in journals classified as belonging to the research field *"Business & Economics" (Research Area)*. (3) As a final result, 33.182 innovation-related articles were obtained which, after clearing and normalizing their respective bibliographic references, resulted in a knowledge base of 803.907 articles used as source for the production of knowledge in the innovation area throughout the period of analysis of this study (Table 1).

For a longitudinal study of the evolution of innovation, the database was divided within the study period, resulting in four equal periods of 15 years each to reduce short-term random variations (Van Raan 1996), allowing the comparison of the state of the art of scientific publications over time. Despite the formation of the data base of the articles that

[2] Search formula with the use of Boolean operators: "*(TS = Innovat*) AND ((WC = Management) OR (WC = Business) OR (WC = Economics) OR (WC = Business, Finance) OR (SU = Business & Economics)) AND (SU = Business & Economics) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article).*

Indexes = SSCI Timespan = All years", being: TS = Topic (includes the search for titles, abstracts, keywords, and additional keywords; WC = *Web of Science Categories*; SU = *Research Area*, Language = Only articles in the English language; and Document types = Only articles (excluding reviews, books, editorials, among others).

[3] The core collection of Web of Science (*Web of Science™ Core Collection*) was chosen because it contains a complete set of available data from each reference, including the references cited in each paper, important for the later stage that will use these data for the co-citation analysis.

[4] *Keywords Plus®* are keywords with indexing terms created by Thompson Reuters. These terms are derived from the titles of the articles cited by the author of the article that was indexed. The "*Keywords Plus®"* broadens search results by keywords or titles (See http://images.webofknowledge.com/WOKRS521R5/help/WOS/hp_full_record.html).

Table 1 Data base *Source*: Research data

	1st period 1956–1970	2nd period 1971–1985	3rd period 1986–2000	4th period 2001–2016	Total 1956–2016
Total # of published articles[a]	550	2.133	21.638	59.960	73.407
Base of innovation articles[b]	176	790	5.063	27.153	33.182
Cited references (total)[c]	3.524	21.356	322.635	457.274	803.907
Citations per year[d]	58,73	474,58	10.754,50	30.484,93	13.398,45
h-index[e]	29	67	250	220	305
g-index[f]	57	134	450	320	511
# of different periodicals[g]	39	114	395	660	736

[a]The total number of articles published in the Social Sciences Citation Index (SSCI) database with the word *"Innovat*"* in the title, abstract, keywords or additional keywords (*keywords plus*®)

[b]Base of innovation articles after the exclusion of all articles that have not been published in journals classified as being in the area of "*Business & Economics"* and non-published articles in the area of *Business, Management, Business & Finance, Economics* OR *Operational Research & Management Science*

[c]Sum of the total number of unique references cited in each of the articles of the base of innovation articles

[d]Value referring to the sum of citations that all articles of the period received by the number of years of the period

[e]The h-index is defined as the value "h" that a scientist receives for his "Nh" (number of articles) that has at least "h" citations each. That is, an author or journal that has an h-index = 20 means that it has at least 20 publications with at least 20 citations each. Thus, h-index is a joint that evaluates the number of publications (number of articles) and the quality of the publications (impact or number of citations received) (Hirsch 2005)

[f]G-index is considered an improvement of h-index, which is calculated based on the distribution and citations received by the publications of a given researcher, since, given a set of articles in decreasing order by the number of citations received, G-index is the largest and only number, in which the top g articles received on average at least c citations, in order to give greater weight to the most cited articles, as a way of getting around an existing disadvantage in h-index. Thus, the moment an article reaches the position of being among the top g articles, the subsequent citations received by it will no longer affect its position among the top g. This is the reason for g-index being considered as an improvement of h-index, generating higher values than for the h-index correspondent to the same data base (Egghe 2006)

[g]The number of distinct journals resulting from the analysis of the collected data base

were used in this work for the analysis, published since 1956, the main literature review publications in the innovation area (Shafique 2013; Fagerberg et al. 2012; Fagerberg and Verspagen 2009; Crossan and Apaydin 2010) point out the works of Schumpeter (1939, 1942)[5] as the ones that determined the beginning of studies in the field of innovation.

It is important to highlight that any references without the specification of an author have been removed from the analysis, as well as statistical documents, publications of institutions, working papers, white papers, articles of non-scientific journals, reviews, books or any other kind of work that is not a scientific paper published in an academic journal. Also, only the works published in the English language were considered, precisely

[5] Although the seminal works of Schumpeter (1939, 1942) were not included in the sample, primarily because they are books, and secondly, because they are publications prior to the year of beginning the collection of articles published in innovation, Schumpeter appears in a relevant way in the citations analysis, highlighting the importance of this technique of analysis, which allows us to gather the core literature used as reference by the scientific production in the field of innovation.

to take into account the power of dissemination of knowledge on a global scale. Thus, summarizes the final database used in the analyzes of this work.

Main assumptions and limitations

The basic assumption of citation and co-citation analysis is that authors cite their influences, so citations are adequate substitutes for the influence of the cited work (Smith 1981). However, the reasons authors make specific citations may be extremely different (Üsdiken and Pasadeos 1995), as some authors cite other researchers, not according to the content they publish, but as a mutually friendly way to increase the count of citations (Garfield 1979) or as a way to meet a requirement of the journal where it is intended to be published, citing, for example, articles previously published in that journal. Because it is impossible to distinguish behavioral citations such as those mentioned above, it is important to note that this type of behavior may affect the study results. However, the amount of citations motivated by some factor other than the actual influence is a small percentage. In addition, most of the non-scientific reasons end up being controlled by the peer review processes used by journals (Ramos-Rodríguez and Ruíz-Navarro 2004). Regarding the unit of analysis, the main limitation of this study is that only the first cited author of a reference is recorded in the database of the Social Sciences Citation Index (SSCI) to be used in the citations analysis. In this case, Garfield and Merton (1979) indicate that the influence of the co-authors may be underestimated, and some authors, depending on the way in which they use their names to each publication, may be under or over represented, although in this work a standardization and normalization in the references have been done. In this way, the names of the authors in the network maps represent the conceptual themes developed by the contribution made by them, and not themselves (Culnan 1987; Nerur et al. 2008; White and Griffith 1981).

Results of the citation analysis

Citation analysis answers the question of how knowledge dynamics in innovation are generated and transferred over time (e.g. Shafique 2013; Backhaus et al. 2011). In this study we present the evaluation of the knowledge transfer process involved (1), citing behaviors, (2) the origins of the cited references, (3) the most cited references, and (3) the characteristics of the key references.

First, the average number of references serves as an indicator of the dynamics and the development state of a discipline. In Table 2 the average number of publications per year grew steadily and considerably, from the average of 11.73 publications in the period of 1956–1970 to the average of 1.810,20 publications per year in the period of 2001–2016 (+15.332%). The growth in the volume of publications, in addition to being consistent and significant, reflects the popularization of innovation (Fagerberg and Verspagen 2009) and the growth of the specific knowledge base in the innovation area, mainly due to the relevance that the area has been gaining from being associated with the achievement of differentiation and sustainable competitive advantage (Zahra and Covin 1994). Another factor to be considered is the growth of electronic databases that facilitate the search, acquisition and diffusion of knowledge in innovation. In addition, the average number of references per article increased significantly, going from 20.02 to 63.72 (+ 218%) from the 1st to the 3rd period and only in the 4th period (2001–2016) there was a reduction in the

Table 2 Citation behavior *Source*: Research data

Citation behavior	1st period 1956–1970	2nd period 1971–1985	3rd period 1986–2000	4th period 2001–2016
Average number of publications per year[a]	11,73	52,66	337,53	1.810,20
Average number of references per article[b]	20,02	27,03	63,72	16,84
Average age of references (absolute)[c]	50,06	36,60	20,28	6,03
Average age of references (relative)[d]	4,05	5,60	4,27	6,03
Self-citation rate[e]	0,68%	2,12%	2,98%	5,12%
Average number of authors per article[f]	1,30	1,42	1,79	2,30

[a]Values referring to the average number of publications per year, within each of the indicated periods, taking into account the final collected database (composed of 33.182 articles). The calculation is given by dividing the total number of articles published in the period by the number of years of each period

[b]Values resulting from the division of the result of the sum of all the references of each article by the total number of articles of each indicated period

[c]Average age of the references taking into account the absolute value from the year 2016

[d]Average age of references taking into account the relative value from the end year of each indicated period, being 1970 for the references of the first period, 1985 for the references of the second period, 2000 for the references of the third period and 2016 for the references of the fourth period

[e]Percentage of self-citation of analyzed articles

[f]Average number of authors per article within the analyzed period

average of the cited references, reducing from 63.72 to 16.84 (− 73.6%), showing that the growth in the average number of annual publications from the 3rd to the 4th period (+ 436%) has impacted on the reduction in the number of references used by the most recent articles. This reduction can be explained by the trend towards the acceptance of publications with less pages (15–25 pages) that have been occurring in the last decade, than the older publications, when it was common to find publications with more than 30–40 pages. Even a major trend in academic production is the preference for quality overlapping with quantity. On the other hand, it is possible to observe the aging of the cited references, which increased from 4.05 to 6.03 (+ 49.1%) from the 1st to the 4th period, which implies stagnation in the evolution of the discipline. However, it is common to have some classic and seminal articles that persist in the knowledge base of a discipline, being able to influence knowledge to the present day, which is common in scientific disciplines (Backhaus et al. 2011). The self-citation rate provides another indicator to explore the dynamics of the research. The lack of alternative references leads researchers from more recent areas to self-citation practice more often than researchers in research areas that have been established for the longest time (Garfield 1979; Porter 1977). Thus, the growth rate of the self-citation rate, from 0.68% in the 1st period to 5.12% (+ 652.95%) in the 4th period indicates the lack of innovation maturity as a scientific discipline and there is still room for potential contributions and growth.

Second, the origin of the cited references indicates the generation process and the transfer of knowledge to the area. Table 3 presents the origin of the references through the most cited journals, bringing evidence of the great dynamism among the journals that publish articles in the innovation area. From the 1st period to the 4th period there was a reduction in the general influence of journals, going from 40.1% to 26.6% (− 33.7%), reflecting the importance of journals in the process of generating knowledge in the

Table 3 Ranking of most cited journals[a] *Source*: Research data

Overall ranking		1st period 1956–1970		2nd period 1971–1985		3rd period 1986–2000		4th period 2001–2016	
Journals	CV (%)	Journals	CV (%)	Journals	CV (%)	Journals	CV (%)	Journals	CV (%)
RP	4.9	AER	7.4	RM▲	7.1	RP▲	6.2	RP	4.6
TFSC	2.9	QJE	5.1	RP▲	6.7	IJTM▲	4.3	TFSC▲	2.9
IJTM	2.7	RM	4.5	TFSC▲	3.8	JPIM▲	3.5	IJTM▼	2.4
JPIM	2.3	JBUS	4.5	IEEE TEM▲	3.3	TFSC▼	2.5	TNV▲	2.2
TNV	2.1	JMKT	3.4	R&DM▲	3.0	R&DM	2.4	JPIM▼	2.2
TASM	1.7	BH	3.4	OMEGA▲	2.9	SMJ▲	2.1	TASM▲	1.8
R&DM	1.6	ASQ	3.4	LRP▲	2.3	IEEE TEM▼	1.9	JBR▲	1.6
JBR	1.4	HBR	2.8	FUTURES▲	2.0	RTM▲	1.9	R&DM▼	1.4
IMM	1.3	CMR	2.8	IMM▲	2.0	MS▲	1.6	IMM▲	1.3
RS	91.2	TDJ	2.8	AER▼	1.8	TASM▲	1.6	ICC▲	1.2
Total	22.1	Total	40.1	Total	34.9	Total	28	Total	26.6

RP Research Policy, *TFSC* Technological Forecasting and Social Change, *IJTM* International Journal of Technology Management, *JPIM* Journal of Product Innovation Management, *TNV* Technovation, *TASM* Technology Analysis & Strategic Management, *R&DM* R&D Management, *JBR* Journal of Business Research, *IMM* Industrial Marketing Management, *RS* Regional Studies, *AER* American Economic Review, *QJE* Quarterly Journal of Economics, *RM* Research Management, *JBUS* Journal of Business, *JMKT* Journal of Marketing, *BH* Business Horizons, *ASQ* Administrative Science Quarterly, *HBR* Harvard Business Review, *CMR* California Management Review, *TDJ* Training and Development Journal, *RM* Research Management, *IEEE TEM* IEEE Transactions on Engineering Management, *OMEGA* Omega - International Journal of Management Science, *LRP* Long Range Planning, *FUTURES* Futures, *SMJ* Strategic Management Journal, *RTM* Research-Technology Management, *MS* Management Science, *ICC* Industrial and Corporate Change

▲ indicates that the periodical rose in the ranking when compared to the previous period, or came to appear in the list of the top 10; ▼ indicates that the periodical fell in the ranking when compared to the previous period. The absence of a symbol indicates that there was no change in ranking compared to the previous period. CV: Represents the Citation Value calculated as the ratio of "number of individual citations" by "total citation received", for each specified period

[a]Values referring to the total number of publications in the database (33.182)

innovation area (see Table 1), going from 176 publications in the first period to 27.153 (+ 15,328%), and the increase in the number of journals from 39 to 660 (+ 1592%) in the 4th period. In this context, many journals that were prominent among the most cited and with the largest volume of publications in the innovation area, such as the American Economic Review, Quarterly Journal of Economics and Business Horizons that were among the most influential and cited journals during the first period (1956–1970), which were supplanted by other journals already in the second period, as was the case of Research Management, which took the lead in the second period (1971–1985), when Research Policy emerged and, from this second period emerged as the most influential and relevant periodical of the innovation area, maintaining the leadership to the present day. Other journals are notable for their fluctuations during the three following periods, such as the Technological Forecast and Social Change, the International Journal of Technology

Management and the Journal of Product Innovation Management, which fluctuate from the 2nd period and are included in the overall ranking of the most cited journals in the innovation area, demonstrating the effort required to establish in a certain area of knowledge. It is important to note that the overwhelming majority of journals were unable to remain stable in more than one of the periods of this study, reflecting the lack of focus or excessive reach of the editorial scope.

Therefore, it seems reasonable to suppose that the high reputation and the broad thematic focus of the periodicals that compose the general ranking favored their leadership positions. In this context, it is important to highlight that five journals have emerged with a CV exceeding 2.0% of the last two periods to the present (last 30 years), such as Research Policy (4.9%), Technical Forecast and Social Change (2.7%), the Journal of Product Innovation Management (2.3%) and Technovation[6] (2.1%) which exerted a greater influence on the construction of knowledge in the innovation area. Despite the percentage reduction in journal entries in the volume of citations received, it is possible to assume that this reduction is due to the high volume of publications and the appearance of many journals that contributed to this process.

Thirdly, the most cited references are of fundamental importance to identify the authors and their respective works that served as a basis for the structuring and generation of knowledge in each period of the time analyzed, in addition to highlighting the works of each period which are most cited nowadays indicating the perpetuity and vitality of publications and their influences in the present day.

Tables 4 and 5 provide the list of the 20 publications in the database that were most cited in each of the four periods of this study, and it is possible to observe the relevance of some authors such as Mansfield who were influential during the first period of analysis, with three works of his own (Mansfield 1962, 1963a, b) among the 20 most cited. Another interesting feature to be observed about Mansfield is to figure as sole author in most of his works, which reinforces the idea of prevalence of the individual researcher in the first period and that has been changing over time for greater collaboration between authors in the fourth period, which was responsible for the increase in average authors per article as mentioned above. Another highlight is the author Abernathy, who in the second period compose two publications that appear among the most cited (Utterback and Abernathy 1975; Abernathy and Clark 1985). Already in the third and fourth periods, the main highlight is Levinthal, who in the third period appears with three works, two in co-authorship with Cohen (Cohen and Levinthal 1989, 1990; Levinthal and March 1993), besides Grant who figures individually in two works still in this same third period (Grant 1996a, b). And in the fourth period, where the volume of publications is much higher, the highlight is Venkatesh et al. (2003) who, having only one work among the 20 most cited, has 93% more citations than the second most cited. Such a difference in the volume of citations, which also occurs with Cohen and Levinthal (1990) demonstrates the great relevance of these two studies, being able to generate a significant theoretical framework for the innovation area, more specifically introducing concepts such as "absorptive capacity in the context of innovation" (Cohen and Levinthal 1990) and the "user acceptance of information technology" (Venkatesh et al. 2003).

Fourth, the characteristics of key-references including the identification of the most cited publications of each period reveals the most prominent authors and the key issues that

[6] The journal Technovation was created in 1981, within the second period under analysis, when it released its first volume. However, it emerged among the twenty best periodicals in the innovation area in the 4th period, occupying the 4th position in the ranking with a CV of 2.2%.

Table 4 Ranking of the top 20 papers most cited[a] currently (first and second periods) *Source*: Research data

1st period [1956–1970]				2nd period [1971–1985]			
Rank	Paper's author (year)	Cit.	CV (%)	Rank	Paper's author (year)	Cit.	CV (%)
1	Mansfield (1962)	312	8.85	1	Farrell and Saloner (1985)	758	3.55
2	Griliches (1958)	294	8.34	2	Kimberly and Evanisko (1981)	697	3.26
3	Thompson (1965)	234	6.64	3	Utterback and Abernathy (1975)	674	3.16
4	Modigliani et al. (1966)	232	6.58	4	Abernathy and Clark (1985)	658	3.08
5	Barzel (1968)	172	4.88	5	Kirton (1976)	612	2.87
6	Kennedy (1964)	164	4.65	6	Nelson and Winter (1977)	610	2.86
7	Knight (1967)	154	4.37	7	Miller and Friesen (1982)	512	2.40
8	Lancaster (1966)	111	3.15	8	Tushman (1977)	474	2.22
9	Samuelson (1965)	99	2.81	9	Ettlie et al. (1984)	438	2.05
10	Leibenstein (1969)	86	2.44	10	Gort and Klepper (1982)	434	2.03
11	Engel et al. (1969)	74	2.10	11	Damanpour and Evan (1984)	373	1.75
12	Robertson (1967)	72	2.04	12	Dasgupta and Stiglitz (1980)	355	1.66
13	Mansfield (1963b)	71	2.01	13	Daft (1978)	353	1.65
14	Rosner (1968)	67	1.90	14	Loury (1979)	349	1.63
15	Shepard (1967)	61	1.73	15	Downs and Mohr (1976)	348	1.63
16	Becker and Whisler (1967)	57	1.62	16	Hirschman (1980)	322	1.51
16	Mansfield (1963a)	57	1.62	17	Midgley and Dowling (1978)	306	1.43
18	Robertson and Myers (1969)	56	1.59	18	Krugman (1979)	284	1.33
18	Evan and Black (1967)	56	1.59	19	Reinganum (1983)	267	1.25
20	Roberts (1968)	55	1.56	20	Hage and Dewar (1973)	259	1.21
	Total citations/period	3.524			Total citations/period	21.356	

List of the most cited papers, among the 33.182 works that compose the collected database for this work. For each study, the number of citations is presented in the column (Citation) and the Citation Value (CV) representing the calculated value as the ratio of "number of individual citations" by "total citations received", for each specified period

[a]The citation number presented corresponding to the number of citations received by each paper at the moment of the gathering data. The last line shows the total number of citations received by all publications of the period that are within the database, indicated in Table 1

most drive the innovation area at different points in time. In Tables 6 and 7 the main publications coming from the citation analysis are listed. It is important to clarify that the 803.907 references analyzed from the 33.182 articles in the database resulted in this list of tables below, indicating that the articles presented in this list are the most cited articles together. To exemplify, we take the author Rogers (1962), who during the first period of analysis was cited ten times among the articles of the database published in the period and among these articles he appears in the references of 44 publications simultaneously, this being the number of co-citation. Already in the second period, this same work is cited 66 times and it appears simultaneously, in the references of 579 works. Thus, among the publications that emerged as classics that served as a base of support for the generation of scientific knowledge in the innovation area, we can highlight some prominent and prolific authors that became a reference over time. However, no author was able to maintain a single work among the top 20 references in the four analyzed periods. Nevertheless, few

Table 5 Ranking of the Top 20 papers most cited[a] currently (third and fourth periods) *Source*: Research data

3rd period [1986–2000]				4th period [2001–2016]			
Rank	Paper's author (year)	Cit.	CV (%)	Rank	Paper's author (year)	Cit.	CV (%)
1	Cohen and Levinthal (1990)	7.549	2.34	1	Venkatesh et al. (2003)	3.424	0.75
2	Nonaka (1994)	3.592	1.11	2	Zahra and George (2002)	1.768	0.39
3	Kogut and Zander (1992)	3.427	1.06	3	Dimasi et al. (2003)	1.571	0.34
4	Grant (1996b)	3.324	1.03	4	Zollo and Winter (2002)	1.324	0.29
5	Eisenhardt and Martin (2000)	2.605	0.81	5	M. E. Porter and Kramer (2006)	935	0.20
6	Powell et al. (1996)	2.414	0.75	6	Boschma (2005)	910	0.20
7	Teece (1986)	2.361	0.73	7	Tsai (2001)	903	0.20
8	Szulanski (1996)	2.173	0.67	8	Laursen and Salter (2006)	864	0.19
9	Henderson and Clark (1990)	2.156	0.67	9	Reagans and McEvily (2003)	794	0.17
10	Brown and Duguid (1991)	1.978	0.61	10	Amit and Zott (2001)	737	0.16
11	Cohen and Levinthal (1989)	1.909	0.59	11	Carlile (2002)	716	0.16
12	Levinthal and March (1993)	1.848	0.57	12	Katila and Ahuja (2002)	679	0.15
13	Williamson (1991)	1.715	0.53	13	De Dreu and Weingart (2003)	654	0.14
14	Leonard-Barton (1992)	1.713	0.53	14	R. Martin and Sunley (2003)	652	0.14
15	Hansen (1999)	1.641	0.51	15	Kostova and Roth (2002)	621	0.14
16	Damanpour (1991)	1.595	0.49	16	Rosenkopf and Nerkar (2001)	618	0.14
17	Taylor and Todd (1995)	1.559	0.48	17	Greenwood et al. (2002)	616	0.13
18	Aghion and Howitt (1992)	1.521	0.47	18	He and Wong (2004)	611	0.13
19	Griliches (1990)	1.516	0.47	19	Bresnahan et al. (2002)	593	0.13
20	Grant (1996a)	1.501	0.47	20	Garcia and Calantone (2002)	591	0.13
	Total citations/period	322.635			Total citations/period	457.274	

List of the most cited papers, among the 33.182 works that compose the collected database for this work. For each study, the number of citations is presented in the column (Cit.) and the Citation Value (CV) representing the calculated value as the ratio of "number of individual citations" by "total citations received", for each specified period

[a]The citation number presented corresponding to the number of citations received by each paper at the moment of the gathering data. The last line shows the total number of citations received by all publications of the period that are within the database indicated in Table 1

authors were able to appear in three of the four analyzed periods, such as James G. March (Cyert and March 1963; March 1991; March and Simon 1958) appearing in the 1st, 2nd and 4th periods, and that generated relevant contributions in the area of organizational management serving as support for a number of studies that would later explore the innovation area. Another author who appears in the first three periods is Everett Rogers (Rogers 1962, 1983; Rogers and Shoemaker 1971) who established a milestone in the studies about the innovation diffusion process. In addition, the studies by Richard R. Nelson (Nelson 1959; Nelson and Winter 1982) have brought, in the first period of study, relevant contributions to the pioneerism in the study of the economic perspective of innovation, happening in the two last periods of the study and highlighted by the theoretical framework established in his work on the evolutionary theory of economic changes.

When analyzing the works that appear in two of the periods studied, we highlight Edwin Mansfield study (Mansfield 1961) about technological changes and imitation rate, establishing parameters for the process of new product development; Zvi Griliches (Griliches

Table 6 Ranking of the top 20 key-references[a] (first and second periods) *Source*: Research data

1st period [1956–1970]				2nd period [1971–1985]			
Rank	Key-reference (author/year)	Cit.	CoCit.	Rank	Key-reference (author/year)	Cit.	CoCit.
1	Mansfield (1961)	11	83	1	Rogers and Shoemaker (1971)	66	579
2	Rogers (1962)	10	44	2	Rogers (1962)	52	289
3	Jewkes (1958)	7	66	3	Mansfield (1968)	39	246
4	Mansfield (1963c)	6	40	4	Zaltman et al. (1973)	33	374
5	Solow (1957)	5	36	5	March and Simon (1958)▲	26	280
6	Griliches (1957)	4	30	6	Burns and Stalker (1961)	24	246
7	Maclaurin and Harman (1949)	4	33	7	Schmookler (1966)	20	104
8	March and Simon (1958)	4	23	8	Utterback and Abernathy (1975)	19	153
9	Nelson (1959)	4	6	9	Langrish (1972)	19	113
10	Carter and Williams (1958)	3	17	10	Hage and Aiken (1970)	17	222
11	Coleman et al. (1957)	3	6	11	Mansfield (1961)▼	17	139
12	Cyert and March (1963)	3	34	12	Mohr (1969)	16	251
13	Enos (1962)	3	46	13	Griliches (1957)▼	15	131
14	Galbraith (1967)	3	7	14	Robertson (1971)	15	110
15	Habakkuk (1962)	3	13	15	Downs and Mohr (1976)	14	200
16	Hicks (1932)	3	4	16	Utterback (1974)	14	176
17	Katz (1961)	3	14	17	Freeman and Soete (1974)	14	101
18	Knight (1963)	3	23	18	Tilton (1971)	14	95
19	Mansfield (1963a)	3	31	19	Schon (1967)	14	76
20	Salter (1960)	3	42	20	Arrow (1962)	14	65

Papers list (authors/year) that were most used as key-reference by the most cited papers in the innovation field in each period. All complete references are available at the end of this work

▲ Indicates that the paper rose in the ranking when compared to the previous period; ▼ indicates that the paper fell in the ranking when compared to the previous period

[a]Key-reference is measured by the frequency with which two papers are cited together by other papers (Co-cited), representing the most important and influent papers that were used as the base by the most cited papers by each period (see Tables 4 and 5)

1957) who brought relevant empirical contributions to the theory of technological change, making evident their contributions in the first two studied periods. In the two intermediate studied periods (2nd and 3rd periods), the work of Gerald Zaltman (Zaltman et al. 1973) brings contributions to organizations about the nature of innovation and its characteristics, and Tom E. Burns (Burns and Stalker 1961) who advanced innovation management by analyzing the different ways organizations react to change and analyzing the impact of technical innovation.

In the last two periods (3rd and 4th), a greater number of works can be highlighted, such as the work of Rebbeca M. Henderson (Henderson and Clark 1990) who analyzes the architecture of innovation, investigating the reconfiguration of existing products, the errors and correctness of the process of innovation in organizations; David Teece (Teece 1986) who advanced by questioning profitability through technological innovation, advancing the debate for the generation of public policies; Joseph Alois Schumpeter (Schumpeter 1934) who is considered the "father of innovation", revolutionized influencing a whole generation of researchers by considering technological innovation as the engine of capitalist economic development; and Wesley M. Cohen (Cohen and Levinthal 1990) who generated

Table 7 Ranking of the Top 20 key-references[a] (third and fourth periods) *Source*: Research data

3rd period [1986–2000]				4th period [2001–2016]			
Rank	Key-reference (author/year)	Cit.	CoCit.	Rank	Key-reference (author/year)	Cit.	CoCit.
1	Nelson and Winter (1982)	427	5.678	1	Cohen and Levinthal (1990)▲	2.993	49.125
2	Rogers (1983)	256	2.469	2	Nelson and Winter (1982)▼	1.893	28.835
3	Cohen and Levinthal (1990)	255	3.427	3	Barney (1991)	1.602	25.431
4	M. E. Porter (1980)	243	2.941	4	March (1991)	1.417	27.432
5	Von Hippel (1988)	207	2.328	5	Teece et al. (1997)	1.384	24.224
6	Tushman and Anderson (1986)	202	3.220	6	Eisenhardt (1989)	1.258	13.540
7	Henderson and Clark (1990)	184	2.727	7	Fornell and Larcker (1981)	1.123	16.772
8	Teece (1986)	183	2.244	8	Kogut and Zander (1992)	1.093	22.820
9	Porter (1990)	176	1.552	9	Podsakoff et al. (2003)	1.042	15.430
10	Williamson (1975)	169	2.043	10	Teece (1986)▼	1.032	15.929
11	Burns and Stalker (1961)▼	155	2.287	11	Powell et al. (1996)	1.019	18.905
12	Schumpeter (1934)	152	1.760	12	Nonaka and Takeuchi (1995)	981	13.841
13	Dosi (1988)	145	1.723	13	Henderson and Clark (1990)▼	951	16.114
14	Cohen and Levinthal (1989)	142	1.682	14	Cohen and Levinthal (1989)	929	11.514
15	Porter and Millar (1985)	142	1.497	15	Schumpeter (1934)▼	839	10.956
16	Clark and Fujimoto (1991)	138	1.772	16	Grant (1996b)	831	16.041
17	Williamson (1985)	133	1.440	17	Chesbrough (2003)	806	11.204
18	Thompson (1967)	131	1.898	18	Jaffe et al. (1993)	783	11.631
19	Zaltman et al. (1973)▼	127	1.764	19	Eisenhardt and Martin (2000)	754	14.564
20	Rosenberg (1982)	126	1.441	20	Zahra and George (2002)	752	14.404

Papers list (authors/year) that were most used as key-reference by the most cited papers in the innovation field in each period. All complete references are available at the end of this work

[a]Key-reference is measured by the frequency with which two papers are cited together by other papers (Co-cited), representing the most important and influent papers that were used as the base by the most cited papers by each period (see Tables 4 and 5)

▲ Indicates that the paper rose in the ranking when compared to the previous period; ▼ indicates that the paper fell in the ranking when compared to the previous period

a great impact with his work on the absorptive capacities required for organizational learning in order to enable the generation of innovation, which among all published works in the field of innovation, certainly is the most cited, indicating the great influence and contribution to the construction of knowledge in the innovation area.

Although the result of the analysis did not indicate authors with a work that was able to remain in the list of the 20 main works throughout the four periods of study, certainly some authors deserve to be highlighted because they emerged with two or more works in the same studied period, as was Edwin Mansfield who figured among the top 20 with 4 different works (Mansfield 1961, 1963a, c, 1968) generating contributions by assessing the speed of response of organizations to new technologies, as well as analyzing the size of organizations, their market and its relationship with the innovation process. With three different works in the same period (3rd) Michael Porter stands out (Porter 1980, 1990, 1985) with models and advances in the area of organizational strategy. Other authors that stand out for having two works in the list of the most relevant ones within the same period of analysis are James Utterback (Utterback 1974; Utterback and Abernathy 1975), Everett

Rogers (Rogers 1962; Rogers and Shoemaker 1971), Wesley M. Cohen (Cohen and Levinthal 1990, 1989), Oliver E. Williamson (Williamson 1975, 1985), David Teece (Teece 1986; Teece et al. 1997) and Kathleen M. Eisenhardt (Eisenhardt 1989; Eisenhardt and Martin 2000) who certainly contributed to the formation of the pillars of knowledge in the innovation area. In general, despite the fluctuations between the different time periods studied, the result is very instructive and allows the generation of insights. In contrast to the great classics pointed out in the results analyzed so far, the most recent works were published 13 years ago (Chesbrough 2003; Podsakoff et al. 2003), which indicates the reduction of the production capacity of new classical works. This analysis of the key-references provided evidence of a shift in the focus of the subject, as is evident in the view of the theory of organizations serving as support for the generation of innovation studies, such as the strategic process of technological and organizational change, development of new products, communication and diffusion of technology to the most current themes present in the last period studied, such as learning, dynamic and absorbing capacities, knowledge management and the development of studies based on innovation resources.

Results of the co-citation analysis

The analysis of co-citations reveals the main research fronts within the innovation area. This section begins with an overview of the size and composition of emerging research networks of citation and co-citation relationships among the most cited authors in each period. Then the co-citation network is presented for each of the four-time periods under study with the clusters described according to their structure and content. When comparing the networks within the four periods, the co-citation analysis answers the question about how knowledge in innovation evolved and was developed over time.

Size and composition of the research networks

As indicated in the co-citation maps, the networks show that from the first to the fourth period under analysis, the number of authors co-cited within the network of each period grows steadily. This development correlates with the growth of the discipline and indicates the expansion of the knowledge base of the innovation area. The great increase in connectivity over the periods also suggests the strongest interrelationships between researchers and their subjects of interest in later periods. The evaluation of the composition and structure of the identified networks are based on three measures: size, links and peers that are frequently used in social network analysis (De Nooy et al. 2011). The numbers calculated for each of the authors (including isolated) within the network characterize the role and position that a focus researcher represents. The summary value for the various authors in each of the periods can be calculated as follows: size is the number of other authors with whom the author in focus has a co-citation relation. They form their ego network (Wasserman and Faust 1994). The derived research networks then consist of a series of ego networks, in which the links is the number of actual links and the peers is the number of contingency links across all the authors (with whom the author in focus was in an ego network) (Backhaus et al. 2011). The first-cycle citation network (Fig. 1) is characterized by authors with relatively few relationships of co-citation (size) and ego networks with only a few links, so the isolated authors only co-cited with each other, and the co-citation chains (e.g. co-citation strings with no significant crosslinks) are likely to occur many

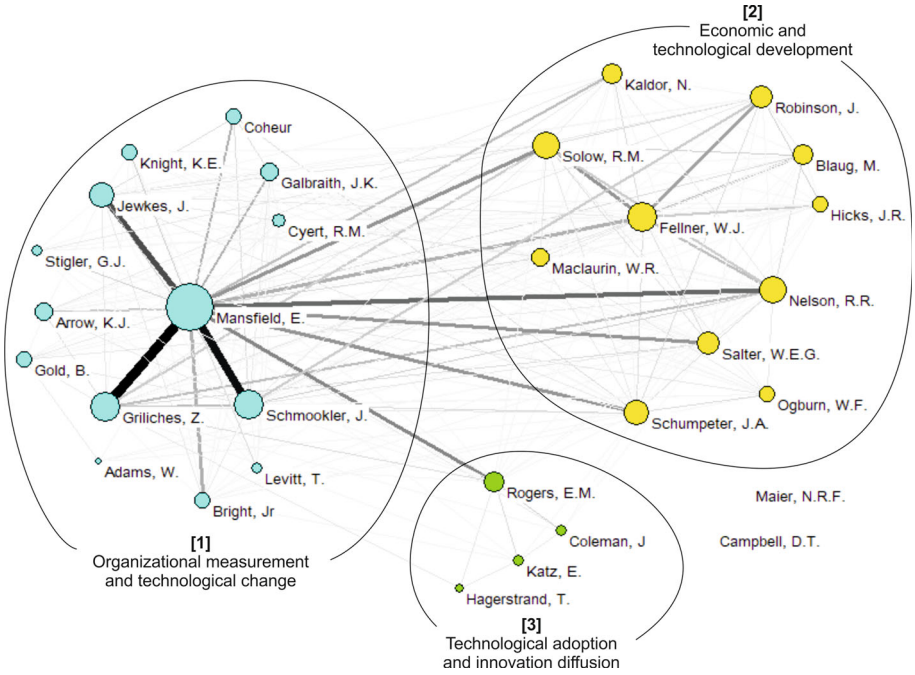

Fig. 1 Authors' co-citation networks 1956–1970

times in this period, implying a smaller concentration or interrelated search field (Gmür 2003). Because of these isolated authors the links are irrelevant according to the requirements for the formation of clusters and are then eliminated, which explains the eliminations in this first period.

In the first two periods, the high peer measure value suggests several linked ego networks, which results in fairly large clusters or multiple cited co-author connections. Generally, the size of a cluster is measured by the number of authors, indicating the importance of the corresponding search domain. Their density, or the ratio of the number of actual and possible links between authors shows the authors' proximity and cluster coherence (Gmür 2003). In the co-citation maps of the four periods, the relative size of the nodes (or vertices) indicates the central role of each respective author, increasing in accordance with the number of other authors who are co-cited with the author in question. A large node also indicates that the author's works play an important role for the topical orientation of the cluster. Thus, the node often serves as a starting point for the detection of thematic points that are in focus by the cluster and that can be better analyzed together with the basic references of the other authors of the cluster. The lines between authors represent the co-citation relationships, based on the CoCit score. The thicker lines indicate higher CoCit scores, which also indicates a closer relationship between the cited co-authors.

Co-citation network 1956–1970

The first network of co-citations comprises 31 of the 316 most cited authors of the period, which is the one with the fewest authors among all the periods analyzed. It consists of three clusters and two isolated authors, both disconnected. Group 1 is considerably larger in size

than the other groups, with 14 authors. Although it has a low density it has a topic in focus: Organizational measurement and technological change. The dominant authors in this group are Mansfield, Griliches, Schmookler and Jewkes (Griliches 1990; Mansfield 1962, 1963b, 1961, 1963a, 1968, 1963c; Griliches 1958, 1957; Schmookler 1966). The size of the cluster and the finding that all central authors also appear among the twenty most cited publications in this period (Table 4) reflects the great importance of this sub-theme for researchers in the innovation area from 1956 to 1970.

Group 2 is somewhat smaller than group 1, having 11 authors of the 32 displayed on the network. Its main focus is the economic perspective of technological change and economic development. Its main representatives are Schumpeter, Fellner, Solow, Nelson and Salter (Nelson 1959; Schumpeter 1934, 1939, 1942; Fellner 1961, 1966, 1956; Salter 1960; Solow 1957). In group 3, there are only four authors, having as central theme the technological adoption and innovation diffusion, represented by Rogers, Katz, Colema and Hagerstrand (Rogers 1976, 1962; Coleman et al. 1957).

Co-citation network 1971–1985

Compared with the previous network, there are more authors and clusters in this second analyzed period (Fig. 2), in line with the general growth of research activities in the innovation area in the 70s. With a larger and differentiated network, in the second period, the network of co-citations corresponds to 42 of the 332 most cited authors, distributed in 6 groups and only one author alone. The three groups formed from the previous network are also presented, however it is important to highlight that the targeting of the first group was altered if adjusted with the third group from the previous period. Thus, part of the group that had a focus on Organizational Measurement and Technological Change followed the direction of the Economic and Technological Development group (Group 2), occurring also the transition of some authors like Schmookler, Griliches, Jewkes that happened to appear in this second period in the group

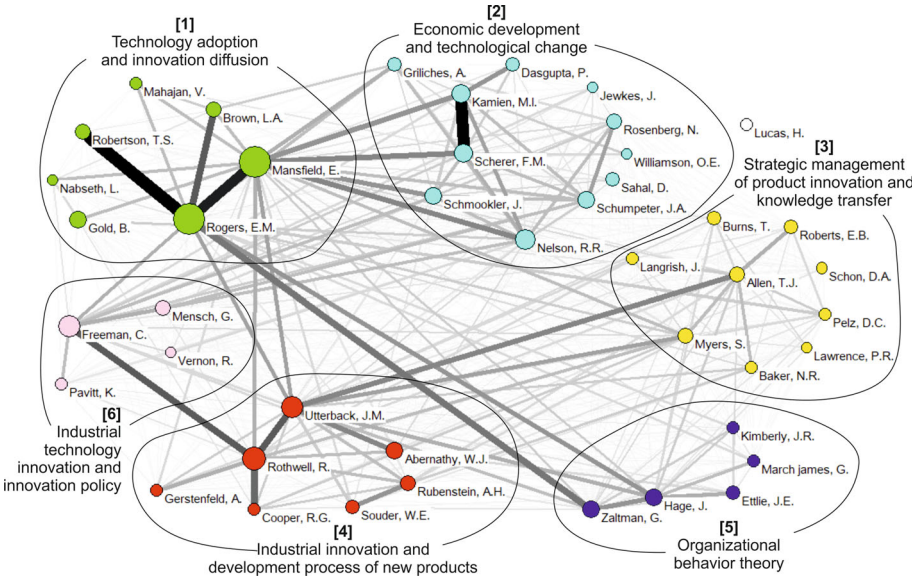

Fig. 2 Authors' co-citation networks 1971–1985

focusing on Economic Development and Technological Change. The same did not occur with Mansfield who directed his efforts in the following period in the same sense as Rogers acting with the Technological adoption and innovation diffusion.

Despite the transition of some authors between the groups, the changes reflect the research efforts reflected in the publications made during the period, showing that the areas of research were still insipient and that the bases for the formation of the areas that would constitute the foundations of innovation were still being structured. In this second period some new areas emerged, such as the area of strategic management of product innovation and knowledge transfer (Cluster 3), especially Myers, Roberts and Burns (Robertson and Myers 1969; Burns and Stalker 1961; Roberts 1968); Industrial innovation and development process of new products (Cluster 4), with emphasis on Utterback, Abernathy and Rothwell (Rothwell and Zegveld 1985, 1981); Organizational behaviour theory (Cluster 4), with emphasis on Ettlie, March, Hage and Zaltman (Zaltman et al. 1973; March and Simon 1958; Hage and Aiken 1970; Hage and Dewar 1973; Ettlie 1980; Ettlie et al. 1984); and the Industrial technology innovation and the generation of innovation policies (Cluster 6), especially Freeman and Pavitt (Pavitt 1984, 1969; Pavitt et al. 1989; Freeman 1963; Freeman et al. 1982, 1965; Freeman and Soete 1974). Although some themes or areas of investigation may have been initiated by certain authors, the change of the area of some authors suggests that newer research areas or themes have been developed by even younger researchers, who have replaced the previous dominant authors. Such variation also reflects the dynamics of the research over this period, which has led to a shift in the research goals of particular researchers, making them invest more in certain directions than others.

Co-citation network 1986–2000

The co-citation network shown in Fig. 3 is significantly larger, with 89 authors of the 309 selected, many of whom did not appear on the maps of previous periods. Because of a large

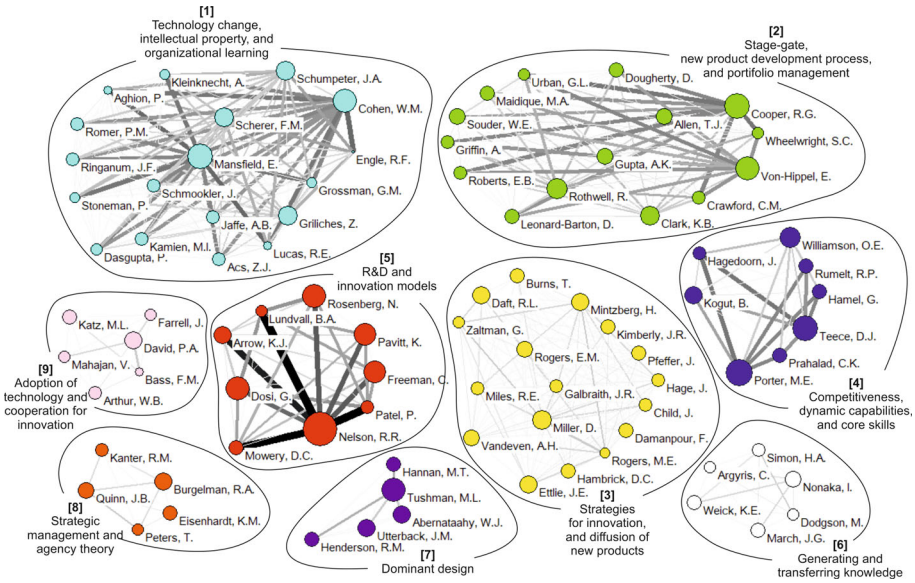

Fig. 3 Authors' co-citation networks 1986–2000

number of new researchers who emerged in the scientific research scenario in this period, it is reasonable to assume that many of them needed to deal with new tracks of research that were still in formation at the time. So, the topical structure of the period in focus changed considerably, increasing the number of clusters from 6 to 9 and increasing the thematic complexity when compared to previous periods. Several other areas emerged as well (nine clusters), representing different fronts of research that contribute to the generation of knowledge in innovation. The first cluster reunited some authors who directed their research in this period, investigating technological change, intellectual property and the process of organizational learning. In the second cluster, the authors discuss themes related to the stage-gate theories used in the new products development process, as well as theories for portfolio management. With this third cluster, dedicated to the strategy for innovation and diffusion of new products, the three major clusters are formed in this third period.

The other clusters bring together fewer researchers, but they form relevant research fronts to support the formation of the innovation area, such as: (4) competitiveness, dynamic capabilities and the essential competencies of organizations, (5) Research & Development and innovation models (6) the process of organizational knowledge generation and transfer, (7) dominant design theories, (8) strategic management and agency theory, and (9) the process of adoption new technologies and the cooperation for innovation generation. In order to obtain a cleaner look and better identification of the clusters, the connections between the clusters (which connect one cluster to the other through the co-citation lines) were removed, remaining only the lines that connect the authors internally, within the cluster where is found.

Co-citation network 2001–2016

In this last period, among the analyzed ones, it is possible to observe that both the level of authors that grew in the network and the number of clusters grew, reaching 14, emerging new research areas and completing the evolutionary trajectory over time. In this network, 121 authors of the 308 selected ones are presented. In all, there are 14 clusters, the first being the largest, with 23 authors and is a continuation of this same cluster of the previous period, but added more authors and expanded its scope, developing themes such as stage-gate and the new products development process and portfolio management. A cluster that emerged with a group of 16 authors and who has been working on relevant topics such as Social Innovation and innovation strategies with a focus on emerging markets, reverse knowledge transfer and the creative economy is cluster 2. Likewise, cluster 3 also has 16 authors and stands out for his work in themes related to Spillovers, R&D, intellectual property, patents and organizational learning (see Fig. 4).

The other clusters reveal in detail the structure of the knowledge that was developed and the topics of greater relevance for the researchers, covering research areas such as Triple-Helix and innovation systems (Cluster 4); Disruptive innovation, dominant design, patents and ambidexterity (Cluster 5); Competitive strategy (Cluster 6); Transaction costs theory, resource-based view and dynamic capabilities (Cluster 7); Organizational behavior and absorptive capacity (Cluster 8); Global innovation for multinational enterprises (Cluster 9); Generation and transfer of knowledge (Cluster 10); Open innovation and the democratization of innovation (Cluster 11); Entrepreneurship and economic development (Cluster 12); Research methods (Cluster 13) and finally studies on the construction of dynamic capacities, exploration and exploitation.

In the four periods under analysis, the analysis of co-citations brings the main areas of research that contribute to the formation of knowledge in innovation, however some

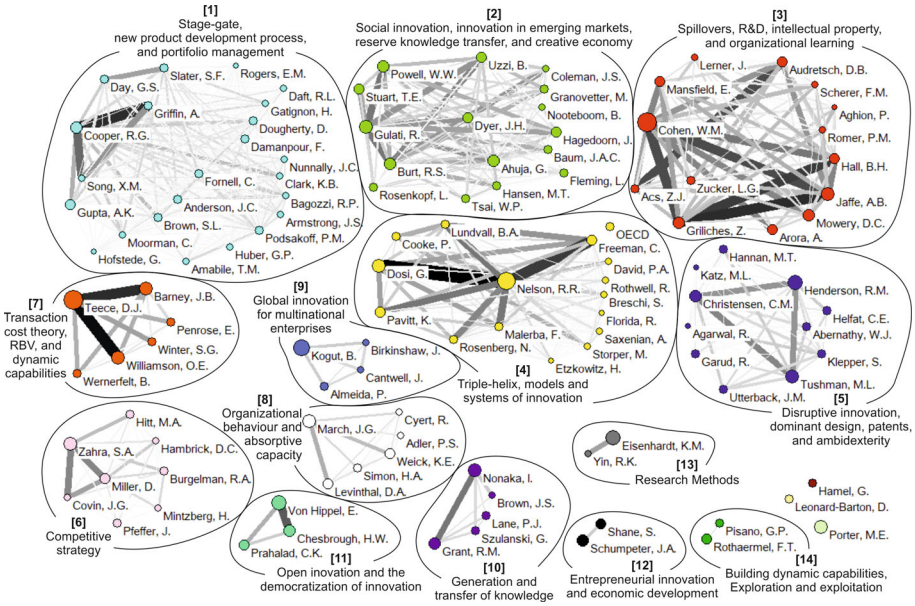

Fig. 4 Authors' co-citation networks 2001–2016

clusters may not have the adequate amount of collaborators to develop the theme, suggesting that the research activity in this topic is in decline compared to other areas of innovation or may indicate an emerging theme still at an early stage of development, indicating the direction for future researchers who can direct their efforts in promising and poorly designed areas. The key results for this last network include the increase in the number of links between the research sub-areas, the emergence of a large number of authors and the formation of the first cluster of methodological aspect.

First, clusters formed with links from the current network, directly or indirectly, form a coherent set, revealing some subgroups without interconnections, providing for future researchers some ideas for further research that combine different schools of thought to generate works and new areas. Second, only a set of researchers have been able to appear on the maps over time, indicating the relevance and consistency of the research areas where these authors work. The continuity of the themes and the permanence of some clusters over time also indicate a variation in the topical orientation and composition of clusters, which may indicate a slowdown in the dynamism of the research for some classic themes of the innovation area, which shows consistency with the results of the citation analysis. Second, the continuity of some authors over the four periods of time and consequently, most of the identified research areas continue to focus on themes that emerged from the second time analyzed period, indicating the consistency of these areas and the solid conceptual framework that gives support to the works and authors of each area, despite the small changes in the direction of some authors in relation to their research areas. The authorship of the authors Yin and Eisenhardt in a specific cluster representing the use of research methods, such as the application of the case study methodologies, indicate the increasing importance of the use of these methods in the innovation area but is important to keep sight for use of new research methods in innovation, opening new avenues for future studies. Finally, it should be noted that in this last network of the fourth

analysis period, the clusters increased, as well as the volume of authors involved, revealing the growing influence of the network approach for the analysis of citations and co-citations, indicating the importance of social network analysis for a better understanding of science and the advance of knowledge, as in the case of the innovation area.

Conclusions

According to Cronin (1998), the citations are like "frozen footprints in the landscape of academic achievement" that reveal patterns of interaction between researchers, and consequently, evidence of the structure of a discipline (Üsdiken and Pasadeos 1995). Some studies have already been carried out to investigate the state and evolution of innovation, but none focused on the innovation area as a whole, associating the use of social network analysis methodology, and did so with such a wide range or volume of data as performed by the present study. Moreover, with this study, we have contributed to complement some previous studies (e.g. Cancino et al. 2017; Merigó et al. 2016; Shafique 2013) providing a wide range of analysis with a good volume of data. In order to reinforce the studies and to evaluate the intellectual structure of the innovation area from a different perspective, this article used bibliometric methods and techniques for the first time in this field of research, associating bibliometrics with social network analysis, carrying out a longitudinal study with a sixty-year span of publications.

Regarding the first research question, the results of the citation analysis reveal a framework in the innovation area characterized by a continuous and accelerated growth in the number of publications and authors mentioned, especially from the third period analyzed in this study, revealing the great openness and potential of the area for new publications. In addition, the low age of the cited references and the marked fluctuation in the ranking of the most cited articles in each period portrays a highly dynamic field with short research cycles in the first two periods of analysis. Among the most cited publications, Mansfield (1961); Rogers and Shoemaker (1971); Nelson and Winter (1982) and Cohen and Levinthal (1990) emerge as classics that provide the basis for the field of innovation. Over time, citations tend to decrease as the differentiation of themes that make up the innovation area advances, appearing in new areas, becoming universally accepted (Ramos-Rodríguez and Ruíz-Navarro 2004). The increasing maturity of the references occurs precisely because of the dynamism of the research area since the most cited articles in the last two periods. An example is the greater volume of citations received by articles listed in the third period than the articles listed in the fourth period.

The same with the average age, that the references have in the fourth period indicating the tendency of the recent research in resorting to the classic publications with average age equal or superior to 6 years after published. The analysis of citations carried out and presented by the maps of each period was summarized in Fig. 5, which indicates the evolution of the innovation area after tracing and comparing the different areas of research detected. The size of the labels represents the size of the clusters in the co-citation networks. In this context, the four main conclusions emerge. First, the increasing number of authors and clusters over time until the last period reflects the growth and diversification of the discipline. Second, the dynamism of the area of research in innovation that was detected by the citation analysis is further confirmed by the increasing variation of cluster members and themes within networks over time. Third, the increasing interaction of innovation subfields over time suggests the convergence of subfields within the core of the

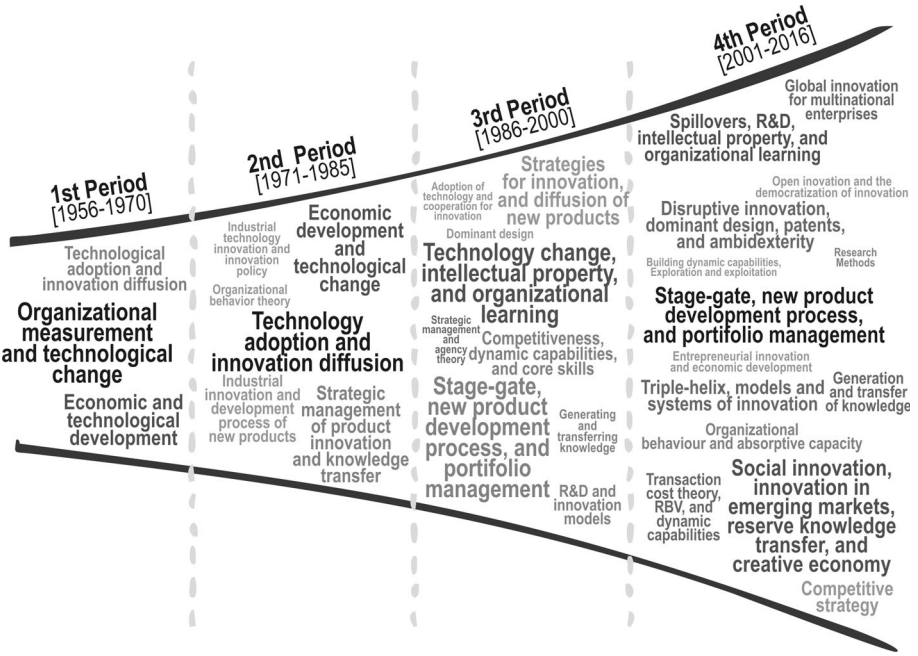

Fig. 5 Summary of the evolution of the innovation field

innovation area, resulting in the creation of a common knowledge base. Isolated approaches, therefore, have been increasingly replaced by jointly developed research projects. Joint efforts to develop research towards the core areas could allow the joint application of different schools of thought to issues by future researchers answering current research questions. Fourthly, considering the breadth of research themes in the innovation area, it is promising to develop innovation types targeted at emerging markets and to confront the economic crisis situations faced by these developing economy countries.

Research limitations

Inevitably, the results of this study are limited by certain caveats that deserve to be mentioned. The main limitations are the design of the research and the dataset, as well as the bibliometric methods used. In relation to the dataset, the main disadvantage is the multi-authorship, as was previously observed, since the databases only contain the data of the first author of the articles referenced by each publication available in the database. And even if all the authors were available, the volume of data to be treated and analyzed considering all the authors in question would require computational resources that would render such resources unviable. In addition, despite the analysis, filtering, corrections and normalizations performed in the databases, there is always the possibility of failures, mainly due to errors in spelling, incoherence, homonyms, that is, different authors with the same name (Smith 1981). The data collection was carried out covering all articles within the indicated parameters until February 17, 2016, which indicates that the most recent articles published certainly did not have enough time to be cited and appear in the networks of citations and co-citations.

Directions for futures studies

With this, we believe to provide findings able to help scholars, researchers, and Ph.D. students in future research, as well managers and practitioners to understand the theoretical basis of innovation research in the business context, and how its pillars are sustained.

Futures studies could exploit those clusters presented in Fig. 4, deepening the comprehension of the themes, authors, and their relationships. New methods of innovation research, and how these methods may contribute to the innovation research field could be exploited, helping to highlight new avenues for future studies. We stand out the relevance to develop studies to able to help understand how these new methodologies such as big data, artificial intelligence, machine learning, statistical modeling, bayesian networks, experiments, among others, are changing these emerging themes in innovation research such as innovation services, knowledge intensive business services, industry 4.0, sustainability, frugal innovation, social innovation, innovation in emerging economies, innovativeness consumption, among others.

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