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Discerning the Research Paths on Disruptive Technologies: A Bibliometric Approach

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Abstract – **Emergent, disruptiveness, radicalness or discontinuity are concepts typically associated with those technologies capable of defying and overcoming the status-quo. As such, it is said that such technologies, translated into appropriate innovations, can significantly contribute to the competitive advantage of firms. Therefore, this topic has typically attracted considerable attention within the 'Technology and Innovation Management' (TIM) community.**

In particular, this paper presents an attempt to discern the research paths chosen in prior studies on emerging technologies. With that purpose in mind, a bibliometric analysis targeting some of the most important TIM-related journals was conducted. In this regard, this study goes beyond the typical outcomes of a bibliometric analysis by attempting to define a taxonomy of the type of approaches taken for the study of emerging technologies. Here, this approach focused on aspects such as the (a) level of analysis, (b) sources of empirical information, (c) research methods and tools, and (d) research topics and their interrelations.

Index Terms – **Disruptive, Emergent, Discontinuous, Bibliometric Analysis, TIM, Technology**

1. INTRODUCTION

Emerging, disruptive, radical, nascent, revolutionary, discontinuous, breakthrough, among others are terms used to describe those technologies and innovations with a potential to defy and significantly overthrow the status-quo. For the sake of simplicity – and despite their slightly different meanings – the rest of this paper will group those concepts into a single one: *disruptive technologies and innovations*. Due to its long tradition within the Technology and Innovation Management (TIM) field, it may be incorrectly inferred that the study of disruptive technologies and innovations has reached a maturity stage. In contrast, this paper will show that this topic has attracted and is still attracting the interest of the TIM research community, which, as will be seen, has eagerly approached this topic from a diversity of perspectives.

In this regard, two sets of questions are worth exploring. First, how has the field of disruptive technologies and innovation been able to remain a regular topic in the research agenda of the TIM community? Here, it is known that the very nature of those technologies and innovation – disruptiveness, breakthrough-capability, radicalness, etc. – make them critical for the future viability of technology-intensive firms [1],[2]; the growth and the creation of entirely new industries [3]; the transformation of existing patterns of technical development [4]; as well as a key driver for long-term competitiveness and economic growth [5]. Furthermore, TIM-research on disruptive technologies and innovations – theoretical concepts, frameworks, empirical research, etc. – plays a critical role in channeling, along the appropriate 'wealth-generating conduits', the breakthrough-capability of such technologies and innovations, whose potential, if not properly handled, may not be fully exploited or, in the worst case, can be detrimental for the firm. Second, the following set of questions deal with the way the field of disruptive technologies and innovation has been approached so far; specifically, which topics have been typically emphasized? Which ones overlooked? Which industrial fields or segments have been prioritized? Which research methods have been usually come to be used? Which topics seem most promising for future research? As may be inferred, an answer to the latter questions is not straightforward; thus, the conduction of a formal method of analysis is necessary. Here, the present paper is an attempt to answer these open questions.

Specifically, the interest of this paper lies on discerning and characterizing the different paths selected in previous research efforts on disruptive technologies and innovation; thus this study will attempt to shed light on the *'how'* driving the research of this important topic. With that purpose in mind, we decided to conduct a bibliometric analysis of literature related with radical, disruptive, emerging, discontinuous, and nascent technologies and innovations based on five of the top ten TIM journals (plus two additional journals), as defined by Linton and Thongpapanl [6]. Here, it is believed that such literature sources comprise a representative sample of critical studies on disruptive technologies/innovation within the TIM-field.

Finally, this paper is divided into five sections. Section 2 provides the theoretical background on which this research is based. Following, section 3 presents a short description of the methodology of analysis used in this paper. Next, section 4 provides the main outcomes of this research. Finally, section 5 ends with a series of concluding remarks, as well as some paths for future research.

2. SOME THEORETICAL BACKGROUND

This section will attempt to provide an overview of the variety of concepts encompassing the field of disruptive technologies and innovations through a brief explanation of the technological change process for disruptive technologies and innovations.

An established technology is characterized by the existence of a technological trajectory which defines the rate and direction of multi-dimensional trade-offs among critical technological variables [7]. Such a technological trajectory is

initially contained within a technological paradigm – a pattern of solution embodying the prescriptions on the directions of change to pursue/neglect [7]. As the paradigm is further legitimized, it can then be visualized as a technological regime [8], which embraces a wider range of actors and involves higher levels of cognition, such rules and institutions. Here, not only technology changes, but even 'stiff' structures as regimes may change as one or more of its core or constitutive rules change, as defined by Poel [4]. As a technological paradigm/regime may contain one or more technological trajectories, the performance of a technological trajectory may also be driven by a group of 'aligned' and diverse technologies, not solely technical, but also organizational, market-related, business model-related, among others. Morever, a situation with an established technology is characterized by gradual changes along/within a specific technological trajectory-paradigm- regime set, as well as by the presence of established firms – mostly large firms embedded in a formalized industrial sector – with well-developed external networks, and a set of resources, capabilities, competences, and routines more or less aligned to the nature of incremental technologies and innovations.

Once a discontinuity emerges due to the creation of a new market, a new technology, de-regulation, among many other sources of discontinuity [9], a new technology emerges along a different trajectory and contained within a different paradigm/regime set. Typically, for a period of time the new technology may underperform the old technology; however, after a certain time the new technology may catch-up and even overcome the old technology [10, 11]. In response, the old technology may attempt to improve its performance; phenomenon labeled as the 'sailing effect', as defined by Pistorius and Utterback [12]. Once the new technology establishes itself, the traditional three-stage pattern of technological change settles in: fluid stage, transitional stage and maturity, as suggested by Anderson and Tushman, and Utterback [13, 14].

As may be inferred, the existence of the new and old trajectory/paradigm/regime set is not mutually exclusive, rather old technologies may persist and even interact and co-exist with the new technologies, particularly in complex systems; the same applies to old and new paradigms/regimes [12,15-17]. In this regard, the new technological trajectory-paradigm-regime set is characterized by being typically populated by a set of heterogeneous newly entrant firms, such as SMEs (small- and medium-enterprises), start-ups, spin-offs, among others.

Despite the imminent changing environment, some of the established companies remain 'stuck' to their technologies, or they are simply a victim of the organizational inertia, sunk costs, lock-in effects, cumulativeness and path dependency, customer path-dependencies, as well as functional aspects such as 'learning-by-using', 'learning-by-practice', network externalities, complementary assets, among others [3,18] which hinder them to switch or 'jump' to the new trajectory/paradigm/regime set. Moreover, other established firms may seem reluctant to change until the technology has been proven [19]. Nevertheless, established firms particularly those possessing critical complementary assets for the commercialization of the innovation may be capable of jumping – breaking-out – to the new trajectory/paradigm/regime-set; here, through the establishment of collaboration schemes with SMEs or explorative organizations, [20-23]. Along the same line, McKelvey [16] has suggested that external relations may contribute to improve the capabilities of firms to "jump" to the new technology. In this regard, SME are not immune to failure [24]; here, various authors have studied those factors that may increase their chances of survival [25].

Furthermore, in order for both established and entrant firms to be to be able to convert ideas/knowledge into wealth-generating innovations, including those of a disruptive nature, they should be endowed with appropriate routines, such as technology intelligence, technological scanning and technological foresight, resource allocation; learning, knowledge, skills, transformative capacity / absorptive capacity; explorative / exploitative; capabilities / competencies (integration, market, technological), dynamic capabilities, complementary assets; appropriate organizational forms, among others [26-29]

In this regard, products may also play a crucial role as sources of disruptive improvement, as defined by [30] in his analysis of the incremental improvement of components as a source of discontinuities in systems (consideration of the product structure); technological configuration for complex products [31].

Finally, as said at the beginning of this sub-section, technological change per-se is futile without the conversion of those technologies, ideas, or knowledge into social and wealth-generating innovations. The latter involves the successful commercialization of those products, processes, models, etc. into the market [19], among many other authors.

3. METHODOLOGY OF ANALYSIS

Before getting into the description of the outcomes of this analysis, this section shortly describes the methodology of analysis used in this study. As recommended by Porter and Cunningham [32], this report visualizes *'bibliometric analyses'* as a problem-solving cycle comprising a series of stages. For the purpose of this study, a general methodology of analysis composed of nine steps was defined.

After the appropriate planning and preparation activities were conducted, the sample of data was drawn from different databases based on the selected search string. In this regard, Table 1 presents the characteristics of the search conducted for this study: search query, journals analyzed, time period, fields searched, and databases used. The next step consisted in filtering out irrelevant sources by skim-reading title, abstract, and keywords. Following, the remaining sources were gathered in a database. In total, the database consisted of ~166 journal papers. Subsequently, a random selection of papers was drawn in order to define the structure of the classification matrix. Once the classification matrix was more or less defined, the next step consisted in a detailed examination of the abstract, introduction, research method, and conclusion sections of those papers and skim-reading the rest of the contents in order to classify the paper according to the structure of the matrix. After that, a series of descriptive statistics were calculated through the use of a spreadsheet software, as well as a series of analyses conducted through the use of a tech-mining software. Finally, a series of conclusions were drawn *(see Section V)*.

search query	"emergent technolog*" OR "emergent innovati*" OR "emerging innovati*" OR "emerging technolog*" OR "disruptive technolog*" OR "disruptive innovati*" OR "radical technolog*" OR "radical innovati*" OR "nascent technolog*" OR "discontinu*"
journals searched	Research Policy; Technological Forecasting and Social Change; Technovation; IEEE Transactions on Engineering Management; Journal of Engineering and Technology Management; Technology in Society; Journal of Evolutionary Economics
time period	1995 - 2009
type of information	journal papers, in English
fields searched	title, word, and abstract
databases	sciencedirect.com, ISI World of Knowledge, EconLit

Table 1. Description of the search query

4. RESULTS

This section presents the outcomes of the bibliometric analysis. These results will be described in several sub-sections.

4.1 Distribution of papers by journal

From the seven TIM-related journals analyzed, three of them make up 80% of the total of publications gathered in this study; namely, Technological Forecasting and Social Change (TFSC), Research Policy (RP), and Technovation (T). As shown in Figure 1, the total of disruptive technology/ innovation-related publications over the years has followed a more or less increasing trend. Moreover, Figure 1 also shows that the distribution of publications by each journal over the years exhibits no special patterns, with the exception of the more or less positive and continuous tendency in the number of publication for TFSC and RP.

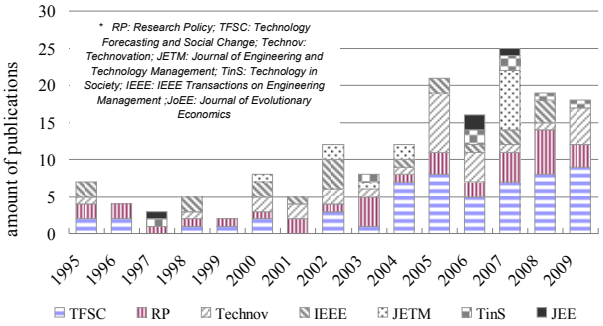

Fig.1. Number of publications over time

4.2 Prolific authors and country-affiliation of institutions

In this section, prolificacy was measured by the total number of publications assigned to an author, regardless of his/her position in the paper *(e.g. first author, second author, etc.)*. Furthermore, country-affiliation was assumed to be that of the first author.

Table 2 provides a list of the most prolific authors, as well as their institutions and their country-affiliation.

researcher name	institution	country	count
Walsh, S.T.	University of New Mexico	USA	6
Geels, F.W.	Einhoven University of Tech	NET	4
Porter, A.L.	Georgia Institute of Tech.	USA	3
Rothaermel, F.T.	Michigan State University	USA	3
Dismukes, J.P.	University of Toledo	USA	3
Kajikawa, Y.	University of Tokyo	JPN	3
Takeda, Y.	University of Tokyo	JPN	3

Table 2. Prolific authors, institutions and country affiliation

Table 2 provides only a glimpse of the list of prolific authors, since a total of 29 more authors were listed with two publications. Based on the full list of authors with more than one publication, American and European authors (and/or institutions) appear to be driving the research on the field of disruptive technologies and innovations.

A similar situation is portrayed in Figure 2, which presents the distribution of the country affiliation for the total of papers. However, for the case of the EU-countries research is dominated by two countries: the Netherlands and the United Kingdom.

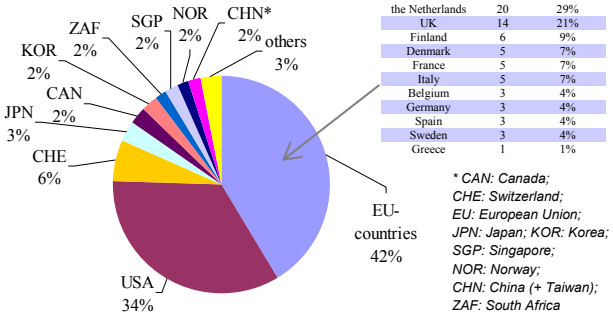

Fig.2. Distribution of the country affiliation

The next sub-section will attempt to describe four aspects of the collected publications: the level of analysis used in their analysis, the industrial sector(s) and the geographical area(s) analyzed, as well as the type of research methods and tools employed.

4.3 Level of analysis

As shown in Figure 3, the majority of the analyses approached disruptive technologies/innovation at a meso- and macro-level, according to the definitions used. Particularly, the analysis of horizontally- and vertically-arranged firms within a country, technology-based analysis within a country, and country comparisons were emphasized. In contrast, analyses focusing on a single firm and those targeting a group of horizontally-related firms in different countries were less frequent.

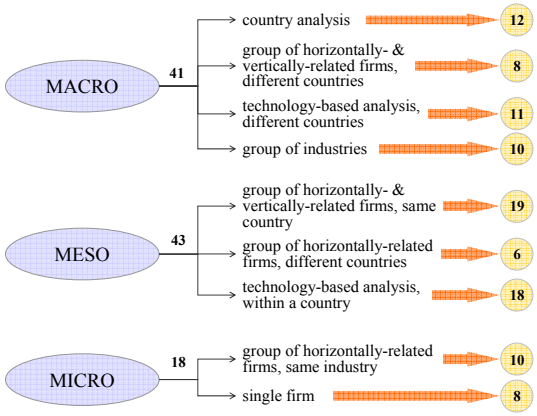

Fig.3.Evaluation of the levels of analysis

The results shown in Figure 3 were based on about two-thirds of the collected publications, for the the remaining papers were theoretical in nature; and thus, they made no use of a specific level of analysis.

4.4 Targeted industrial sector and geographical area

Regarding the industrial sector and the geographical area, there is a clear trend towards the conduction of global studies; that is, studies embracing more than one industrial sector *(~ 20% of the papers)* or including more than one country in their analysis *(< 40% of the papers)*. Here, the specific composition of those global studies was not further analyzed.

Nevertheless, the following discussion deals with such papers focusing on a single industrial sector or a specific country. As expected, studies on current emerging technologies such as sustainability/energy, ICT and telecommunications, biotechnology and pharmaceuticals, and nanotechnology were more frequent. Moreover, fewer studies focus on other advanced industrial sectors such as aerospace, advanced materials and biomedicine. Interestingly, more traditional sectors such as mechanical manufacturing, service sectors such as publishing and government, among others were also addressed, as shown in Figure 4.

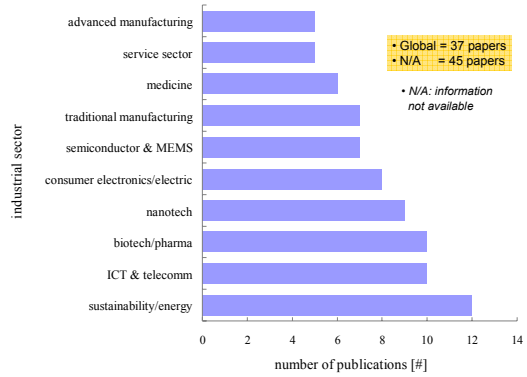

Fig.4. Distribution of papers by industrial sector analyzed

About the geographical areas analyzed by those papers, little less than half of the papers concentrated their analysis on a specific geographical. Here, USA and European countries dominated by more or less equal proportions – about 25% each. The contribution from other countries was not significant.

4.5 Research methods and tools

Next, this sub-section will touch upon the characteristics of the research methods and tools employed by the collected papers. Before delving into those aspects, the sources of information used by the collected studies will be briefly described. Here, besides publications and historical sources of information, interviews, surveys, and patents were the sources of information most frequently used. Interestingly, nearly half of the collected papers made use of a combination of information sources. The latter reflects the need to support the studies on disruptive technologies/innovation on different sources of information in order to embrace as many perspectives as possible, and thus gain a clearer view of the complexity behind those processes.

Regarding the research methods and tools employed, the use of a large variety of approaches of analysis for the study of disruptive technologies/innovation was observed. Furthermore, the collected studies presented more or less equal proportions of theoretical and empirical methods. Here, the importance of the case-study method in the study of disruptive technologies and innovations should be highlighted. Moreover, depending on the nature of the studies – theoretical or empirical – a different set of tools and methods came to be used. Figure 5 shows the distribution in the application of a series of research tools and methods.

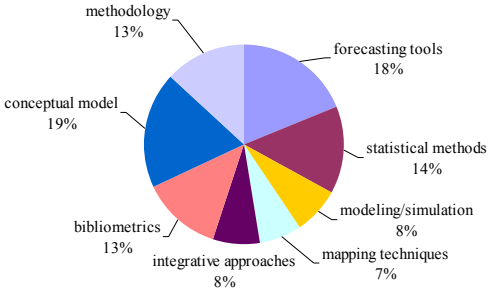

Fig.5. Distribution of research methods and tools

In this regard, two important points should be emphasized. First, this study observed a tendency to integrate or combine different research tools or methods *(integrative approaches)* under the same framework of analysis. Of course, some research tools and methods may have a higher affinity with some specific tool and methods; however, the attempt to tackle disruptive technologies/innovation-related studies 'from different fronts' was observed. The latter may be in line with the need for more comprehensive studies capable of analyzing disruptiveness from different perspectives.
Second, as shown in Figure 5, preferred research tools and methods were forecasting tools *(scenario analysis, roadmapping, among others)*, statistical methods *(mainly hypothesis testing and correlation analysis)*, the development of conceptual models and methodologies, as well as the use of bibliometric techniques. Besides those research tools and methods, others such as TEN (techno-economic networks), RTA (revealed technological advantage), complex system theory, ANT (agent network theory), conjoint analysis, among others were also employed by the studies. In this regard, under such an abundance of research tools and methods, a key competence for researchers is the selection of the appropriate tool or combination of tools of analysis, according to the characteristics and framework of their studies.

4.6 Research Topics

Figure 6 presents an overview of the research topics tackled by the collected papers. Specifically, this figure shows the accumulated number of records for the research topics dealt with in the collected papers. As may be inferred, one paper can be allocated to more than one topic. Due to space limitations, it is not possible to explain in detail the contents of this figure. Therefore, this section will limit to the description of some key aspects.

As seen in Figure 6, the research approaches on this field are characterized by encompassing the whole knowledge-to-innovation conversion chain. Furthermore, figure 6 also shows those research topics that were more frequently addressed by the collected publications. Basically, most frequently addressed research topics are those related with the *dynamic nature of technology and innovation*, such as technological dynamism (interactions between technologies, technological trajectories, etc.), industrial dynamics, patterns of innovation, among others. Besides, *forecasting approaches* were also strongly represented including

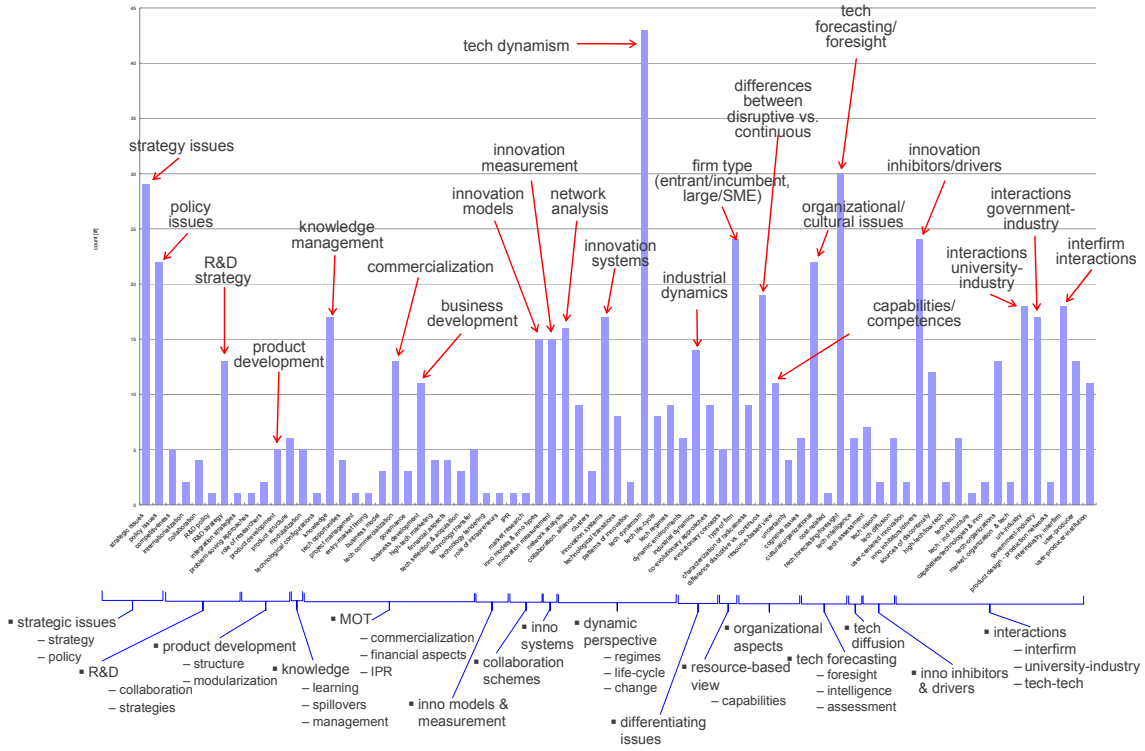

Fig. 6. Publications by research topic

technological forecasting, foresight, intelligence, and assessment. Moreover, a good number of studies analyzed the contrasting differences among firms (large vs. small, incumbent vs. entrant, etc.) along several aspects. Additionally, other studies targeted the analysis of those factors inhibiting and fostering disruptive innovation, as well as those sources inducing discontinuities.

Also, organization and cultural issues turned out to play an important role in the studies of disruptive technologies and innovations; here, issues such as coordination, organization, role of management, human resources, personality, etc. were analyzed. Another interesting topic frequently researched was the attempt to define the meaning of disruptiveness; that is, what is what changes, how much it changes, and from which perspective the change is new.

Further important topics were the use of the resource-based perspective, particularly through the use of the concept of dynamic capabilities and competences in general; studies dealing with innovation models, approaches for the measurement of innovation, and those related with innovation systems; topics related with interactions and interlinkages among actors (university, government, firms, etc.); strategy and policy issues; knowledge management-related concepts; entrepreneurship and business development issues regarding disruptive technologies/ innovation; and, commercialization aspects, particularly those differentiating the commercialization between disruptive and sustaining technologies/innovation.

In contrast, research topics such as technological marketing, financing, intellectual property rights, transfer and selection strategies, among others were weakly approached by the journals examined. In this regard, it may be possible that the specific disciplinary focus / field specialty of the evaluated journals weaken the analysis of those topics.

5. CONCLUSIONS AND IMPLICATIONS

This paper has described an attempt to characterize and discern the research paths taken by previous studies in the field of disruptive technologies and innovations. With that purpose in mind, an exhaustive bibliometric analysis was conducted on five journals belonging to the top-ten journals, as defined by Linton and Thongpapanl [6].

Based on the results presented in this paper, it can be said that the field of disruptive technologies and innovations is still attracting the interest of the TIM research community, which has eagerly approached this field from a myriad of perspectives. Such diversity and heterogeneity is not only present in the variety of research topics addressed, but also in the research tools and methods used, the sectors and geographical areas analyzed, the multitude of researchers engaged in the field, among others.

Furthermore, the use of integrative approaches (a) combining the strengths of diverse research tools and methods, theoretical concepts and methodologies, as well as (b) allowing the possibility to embrace the unit of analysis from different perspectives appear to be a promising area in the research of disruptive technologies and innovations. In this regard, it is believed that such integrated approaches comprise robust methods well-aligned to the uncertainty and complexity characterizing disruptive technologies and innovations.

However, as previously said, the effective use of such integrated approaches will demand strong competences on the side of researchers in the selection of the appropriate tool, concepts, methodologies, etc. or a combination of them, according to the characteristics and framework of their studies.

Moreover, interesting approaches seem to be slowly coming up, such as the use of the transitions approach, functional approaches for measuring the performance of innovation systems, methodological approaches for the evaluation of innovation systems, as well as the use of integrated methodologies combining the strengths and perspectives of each of their component methodologies. Such methods are regarded as very promising, particularly for their application in the analysis of the emergence of disruptive innovations / system innovations, as defined by Geels [33].

Finally, future work will target two fronts: (1) to complement the present study with further analyses, such as keyword-correlation networks, clustering maps, co-citation trees, collaboration networks, among others; and (2) to include all ten journals from the top-ten TIM-ranking in order to embrace as much as possible the variety of approaches used in the analysis of disruptive technologies and innovations.

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