

Regular article

Radical innovations: Between established knowledge and future research opportunities

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ABSTRACT

The fast growing body of radical innovation research is fragmented and difficult to overlook. We provide an overview of the most cited journals, authors, and publications and conduct a bibliographic coupling to structure the literature landscape. We identified the following research clusters: management of radical innovations, organizational learning and knowledge, financial aspects of radical innovation, radical innovation adoption and diffusion, radical industry innovations as challenges for incumbents, and radical innovation in specific industries. Based on an in-depth content analysis of these clusters, we identify the following future research opportunities: A systematic compilation of all intra- and extra-organizational management aspects, moderators, and mediators, extending radical innovation research's epistemological basis by adding strategic foresight, further research in individual, group (team), organizational, and inter-organizational capabilities required for radical innovation, a managerial perspective on adoption and diffusion of radical innovations, applying portfolio theory and real options theory to radical innovation research, stronger research efforts on coping strategies for firms faced with competitors' radical innovations, and intensifying both industry-specific and cross-industry research.

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Introduction

The smartphone as an example for a radical innovation unites the functions of common mobile phones, photo and video cameras, navigation systems, partially computers, and other devices. Additionally, installable apps allow for endless possible uses like instant messaging, fitness tracking, and mobile payment. Radical innovations, lacking a clear definition (Garcia & Calantone, 2002), differ from incremental ones in regard to the extend they add new value to customers (Souito, 2015), their novel knowledge intensity (Dewar & Dutton, 1986), and the required strategies and structures (Ettlie, Bridges, & O'Keefe, 1984). Firms engage in the development of radical innovations to pursue the opportunity to change or generate new markets, act as (temporary) monopolists, and significantly increase their profits (Rubera & Kirca, 2012; Slater, Mohr, & Sengupta, 2014). Especially due to current digitization trends, there is a high chance that radical innovations will still become more relevant (Kraus, Roig-Tierno, & Bouncken, 2019).

Over the years, the research landscape concerned with radical innovations has grown fast, leading to a fragmented research field which is difficult to overlook. To overcome this shortcoming, this research aims to systematize radical innovation research and to provide an overview of promising future research opportunities. More specifically, our bibliometric analyses comprise a temporal analysis of the productivity and impact of radical innovation research, performance analyses regarding the productivity and impact of journals and authors, and the impact of the most cited publications. Additionally, we conduct a bibliographic coupling to identify research themes within the field and to derive future research opportunities, based on an in-depth content analysis.

The paper is organized as follows. We explain the bibliometric methods we employed to gain insights. We present the results, discuss the findings, and derive future research opportunities. Our research contributes to research on radical innovation by providing a citation-based and therefore rather objective overview of the field and by stressing possible future research avenues.

Methodology

To structure the literature on radical innovation, we conducted a bibliometric analysis. This statistical approach uses

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article and citation numbers which are considered to objectively represent research productivity and impact (Kücher & Feldbauer-Durstmüller, 2019; Ramos-Rodríguez & Ruíz-Navarro, 2004; Zupic & Čater, 2015).

We retrieved our data set of 448 publications on 17 January 2020 from the *Web of Science* (WoS), which is regarded as a comprehensive database of scholarly literature (Gaviria-Marin, Merigó, & Baier-Fuentes, 2019; Norris & Oppenheim, 2007). We conducted a title rather than a topic search for 'radical innovation' to ensure that all publications in the data set focus on our topic rather than only deal with it marginally. We reduced the data set by selecting the WoS categories business, business finance, economics, management, multidisciplinary sciences, and operations research/management science. We also excluded publications from 2020 as the first days of the year would not have resulted in representative numbers in the temporal analysis. One article from 2020 which was still in the data set was removed manually. At the end, the data set comprised 339 articles.

Our bibliometric analyses can be separated into performance analyses focusing on productivity and impact and a bibliographic coupling as a science mapping which searches for research themes within the field (Noyons, Moed, & Luwel, 1999). Our performance analyses include a temporal analysis of the productivity and impact of radical innovation research which can locate the current state of research in the research lifecycle and answer the question if it is growing, stagnating, or declining. They also include an analysis of the productivity and impact of journals, the productivity and impact of authors, and the impact of the most cited articles. These productivity and impact analyses help to find the most relevant research.

Science mappings search for links between publications based on citation data. More specifically, we conducted a bibliographic coupling, for which we used *VOSViewer* to visually structure the bibliometric data (Van Eck & Waltman, 2014; Waltman, van Eck, & Noyons, 2010). We clustered the radical innovation literature based on strong links between citing and cited articles which are expected to deal with similar research questions (Zupic & Čater, 2015). We decided not to conduct a co-citation analysis which examines articles citing older articles (Small, 1973) and therefore is more suitable to capture the historic structure of the research field. Rather, we are interested in the structure of the *current* state of research and therefore employed the less common bibliographic coupling which examines younger publications that jointly cite older publications (Kessler, 1963). For this analysis, we further reduced the data set consisting of 339 documents to 266 by only including documents that were cited at least once. Of them, 252 were connected with 16,496 links.

Results

The temporal distribution of publications on radical innovations as depicted in Fig. 1 shows the development of the number of publications. The development can broadly be separated in three stages. The first period, from 1984 to 2005, produced a few, but several seminal publications. During the second period, from 2006 to 2013, the number of articles published per year gained momentum as it is more than five times the previous stage on average. The third period, from 2014 to 2019, displays the most productive timeline in radical innovation research so far, with an average of 33 publications per year. In 2016, with a total of 40 publications, the most contributions were published so far.

The development of citations the focal articles of our data set received is displayed in Fig. 2. Also three stages can be identified. Period one, from 1984 to 2004, displays the timespan with a low average number of citations. During the second period, 2005 to

2010, a significant increase in citations was measured. Citations passed 100 per year and reached almost 500. The last period, from 2011 to 2019, again displays a significant growth in citations, peaking at 1,661 in 2019. Since 2000, a constant growth in citations can be measured.

The analysis of the most influential journals reveals that the documents in our data set were published in 150 different journals. Table 1 shows the 20 top most cited journals in which 61 percent of articles of the data set were published. Therefore, these journals are also highly productive. Journals that rank highest in average citations per article are the *Journal of Marketing* (241 citations per article), *Academy of Management Review* (234 citations per article), and *Strategic Management Journal* (106 citations per article). The h-index refers to radical innovation articles only and does not display the overall h-index of the depicted journals. For example, the h-index of 19 held by the *Journal of Product Innovation Management* means that 19 articles on radical innovation published in that journal received at least 19 citations (Hirsch, 2005). The second and third highest h-index with 10 each belongs to the *Journal of Engineering and Technology Management* and *R & D Management*.

The analysis of the most influential authors in the radical innovation field selects the 20 most cited of 699 authors in the sample. In order to give an overview of the most influential ones, Table 2 indicates the 20 most cited ones. The ranking is led by Chandy who laid focus on larger organizations which struggle to facilitate and deal with radical innovations (Chandy & Tellis, 1998, 2000; Sorescu, Chandy, & Prabhu, 2003). Tellis co-authored several of Chandy's articles and also focused on the dynamics of technological change (Sood & Tellis, 2005). O'Connor, who also is the most productive author and has the highest h-index, predominantly added insights into the relationships between radical innovation and market learning (O'Connor, 1998) and the management of radical innovations (McDermott & O'Connor, 2002), especially in mature firms (Leifer, O'Connor, & Rice, 2001). The h-index, again, regards not the authors' overall publications but only those on radical innovation.

The 25 most cited and therefore most influential articles are listed in Table 3. Accordingly, the first places are occupied by older seminal articles. Dewar and Dutton (1986) was the most cited article in the sample. The authors empirically assessed whether there is a need for different theoretical models in the adaption of technological process innovation, regarding radical and incremental innovations. They suggested that, regarding adaption processes to technical process innovations, the investment in human capital in the form of technical specialists appeared to be a major facilitator. Ettlie et al. (1984) ranked second in citations. Similar to Dewar and Dutton (1986), the paper conceptualized the innovation typologies of radical and incremental innovations which today is the oldest and most consolidated innovation typology (Klarin, 2019). In contrast to Dewar and Dutton (1986), Ettlie et al. (1984) suggested that centralized decision-making has a strong impact on radical process innovation in organizations. The article ranking third in citations is Chandy and Tellis (1998). The paper proposed another view on the classification of radical and incremental innovations based on two dimensions. Innovations that had a high degree of novelty and a high degree of customer need fulfillment per currency unit, were considered to be radical innovations, while others ranking low in both dimensions were considered as incremental innovations. In addition, the authors propose the willingness to cannibalize as a strong indicator for organizations' innovation capabilities. Chandy and Tellis (2000), ranking fourth in citations, discuss that large incumbent firms rarely produce radical innovations and rely on incremental innovations instead. This is striking considering that they had the resources to invest in radical innovations. Additionally, US firms were less likely to be radically innovative than Japanese or Western European firms because the latter could make use of

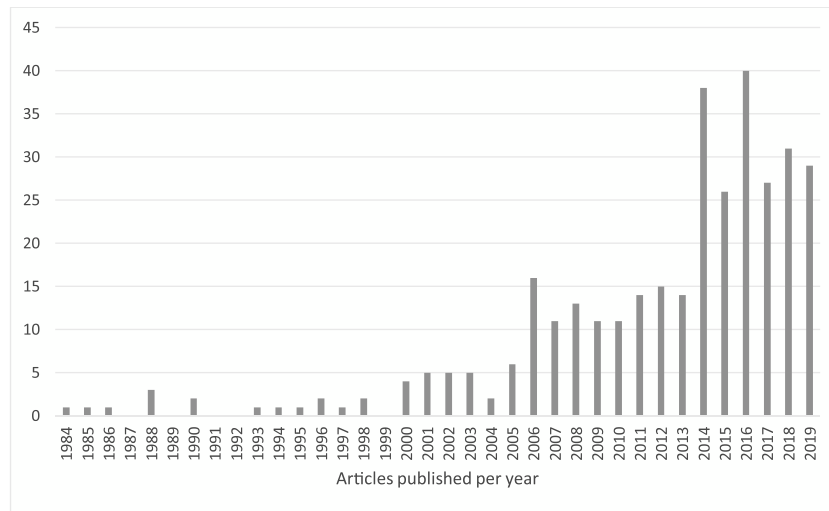


Fig. 1. Publications per year.

Source: Own elaboration.

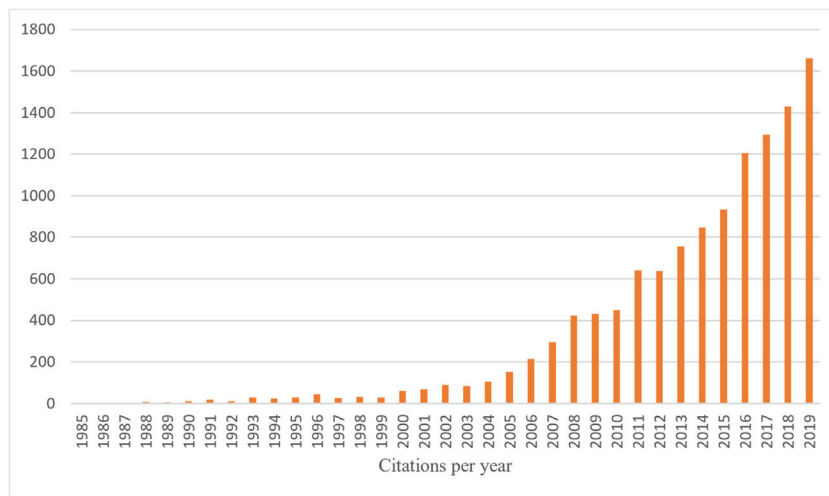


Fig. 2. Citations per year.

Source: Own elaboration.

Table 1
Most cited journals.

Rank	n	Journal	h-index	% of N	Overall citations	Citations within h-core	Avg. citations per article
1	34	Journal of Product Innovation Management	19	10.03%	2112	2034	62
2	2	Management Science	2	0.59%	1649	1649	825
3	6	Journal of Marketing	6	1.77%	1447	1447	241
4	13	R & D Management	10	3.83%	633	619	49
5	1	Journal of Marketing Research	1	0.29%	588	588	588
6	11	Journal of Engineering and Technology Management	10	3.24%	549	545	50
7	2	Academy of Management Review	2	0.59%	467	467	234
8	1	RAND Journal of Economics	1	0.29%	426	426	426
9	12	Research Policy	9	3.54%	400	394	33
10	18	Industrial Marketing Management	10	5.31%	359	325	20
11	10	Technovation	9	2.95%	320	320	32
12	3	Strategic Management Journal	3	0.88%	317	317	106
13	6	IEEE Transactions on Engineering Management	4	1.77%	303	303	51
14	11	Journal of Business Research	7	3.24%	293	283	27
15	13	Research-Technology Management	8	3.83%	257	241	20
16	2	MIS Quarterly	2	0.59%	227	227	114
17	14	International Journal of Technology Management	7	4.13%	166	154	12
18	10	Technology Analysis & Strategic Management	7	2.95%	141	135	14
19	1	Academy of Management Executive	1	0.29%	129	129	129
20	7	Technological Forecasting and Social Change	5	2.06%	97	93	14

Source: Own elaboration.

Note: n: number of articles; N = 339.

Table 2
Most cited authors.

Rank	Authors	Publications	H-index	Citations
1	Chandy, R. K.	6	6	1853
2	Tellis, G. J.	4	4	1665
3	O'Connor, G. C.	12	12	1128
4	Dewar, R. D.	1	1	1005
5	Dutton, J. E.	1	1	1005
6	Prabhu, J. C.	3	3	674
7	Ettlie, J. E.	1	1	644
8	Bridges, W. P.	1	1	644
9	Okeefe, R. D.	1	1	644
10	McDermott, C. M.	2	2	441
11	Henderson, R.	1	1	426
12	Hill, C. W. L.	1	1	418
13	Rothaermel, F. T.	1	1	418
14	Lettl, C.	4	4	415
15	Gerard, J.	1	1	347
16	Jaideep, C.	1	1	347
17	Verganti, R.	6	4	337
18	Ritala, P.	6	6	307
19	Zhou, K.	2	2	306
20	Gemuenden, H. G.	4	4	301

Source: Own elaboration.

less risky government subsidies whereas US firms had to rely on venture capital. The article ranking fifth in citations is [Henderson \(1993\)](#) who compares incumbents with new entrants and finds that incumbents underperform when they face new technology as their focus on incremental innovations reduced their capabilities to exploit radical innovations. Furthermore, the author connects radical innovations to greater performance features and significant impacts on existing markets. Other influential articles that shaped the field of radical innovation cover a variety of subjects including incumbent firm performance ([Hill & Rothaermel, 2003](#)), corporate culture ([Tellis, Prabhu, & Chandy, 2009](#)), strategy ([McDermott & O'Connor, 2002](#)), knowledge ([Zhou & Li, 2012](#)), and design and meanings ([Verganti, 2008](#)). [Table 3](#) also includes a row with the average annual citations which allow for a fairer comparison of the yearly impacts of publications as this indicator compensates for the amount of time a paper has been accessible. The highest annual citations on average (33.6) are attributed to [Zhou and Li \(2012\)](#) as well as [Tellis, Prabhu, and Chandy \(2009\)](#) who received an average of 31.5 citations per year. [Zhou and Li \(2012\)](#) explain how firms with different knowledge distributions should act to be able to develop radical product innovations. They argue that firms with wide cross-technological and cross-market knowledge benefit from internal knowledge sharing. On the contrary, they suggest that firms which have in-depth specialist knowledge regarding existing technologies and markets need to expand their knowledge scope by acquiring external market knowledge. [Tellis, Prabhu, and Chandy \(2009\)](#) analyze drivers of radical innovations across nations. Their findings imply that corporate culture was the strongest driver of radical innovations. In contrast, drivers usually considered as important such as government regulations or capital accessibility do not seem to be as relevant.

Bibliographic coupling

The bibliographic coupling analysis led to eight research clusters ([Fig. 3](#)). The statistical interconnections between publications do not guarantee that they are also dealing with the same topics. In that sense, one cluster did not show a common thread. Three clusters were very small, containing only one to three publications. Three clusters have a firm focus, two have a market focus, and two small clusters address specific industries. Against this background, the clusters can be described as follows.

Table 3
Most cited articles.

Rank	Article	Citations	Citations/year
1	Dewar & Dutton, 1986	1005	29.6
2	Ettlie, Bridges, & O'Keefe, 1984	644	17.9
3	Chandy & Tellis, 1998	588	26.7
4	Chandy & Tellis, 2000	548	27.4
5	Henderson (1993)	426	15.8
6	Hill & Rothaermel, 2003	418	24.6
7	Tellis, Prabhu, & Chandy, 2009	347	31.5
8	McDermott & O'Connor, 2002	334	18.6
9	Zhou & Li, 2012	269	33.6
10	Verganti (2008)	265	22.1
11	Sorescu, Chandy, & Prabhu, 2003	264	15.5
12	Lettl, Herstatt, & Gemuenden, 2006	203	4.5
13	Green, Gavin, & Aiman-Smith, 1995	199	8.0
14	O'Connor (1998)	186	12.1
15	Sood & Tellis, 2005	182	25.3
16	Ritala & Hurmelinna-Laukkanen, 2013	177	8.5
17	Malhotra, Majchrzak, Carman, & Lott, 2001	167	8.8
18	O'Connor & DeMartino, 2006	153	10.9
19	Slater, Mohr, & Sengupta, 2014	132	22.0
20	Leifer, O'Connor, & Rice, 2001	129	6.8

Source: Own elaboration.

Management of radical innovations: This large cluster comprises 68 publications which deal with various aspects in firms that should be managed to foster radical innovations. Several papers address organizational aspects such as organizational structure ([O'Connor & DeMartino, 2006](#)), teams ([Alexander & van Knippenberg, 2014](#)), organizational interconnectedness between radical innovation initiatives and the established organization ([Kelley, 2009](#)), organizational processes ([Hooge, Béjean, & Arnoux, 2016](#)), organizational culture ([McLaughlin, Bessant, & Smart, 2008](#)), institutional work ([Radaelli, Currie, Frattini, & Lettieri, 2017](#)), and trust ([Brattstrom, Lofsten, & Richtner, 2015](#)). Other articles deal with the integration of customers in the radical innovation process ([Lettl, Herstatt, & Gemuenden, 2006](#)), co-creation ([Perks, Gruber, & Edvardsson, 2012](#)), and open innovation ([Kennedy, Whiteman, & van den Ende, 2017](#)). Another sub-cluster concerns human resource issues such as human resource management practices ([Aagaard, 2017](#)), leadership ([Aronson, Reilly, & Lynn, 2008](#)), and employee motivation ([Pihlajamaa, 2017](#)).

Organizational learning and knowledge: With 67 publications, this cluster is similarly large and can be seen as a specific thematic subset of the prior one. Knowledge ([Zhou & Li, 2012](#)) and capabilities ([Chang, Chang, Chi, Chen, & Deng, 2012](#)) are regarded as key resources for radical innovations, and organizational learning, the corresponding process of changing the organizational knowledge and capability base, is therefore also considered as highly relevant ([Sheng & Chien, 2016](#)). Especially interorganizational learning ([Jean, Chiou, & Sinkovics, 2016](#)) and the corresponding absorptive capacity ([Ritala & Hurmelinna-Laukkanen, 2013](#)) are addressed as means to acquire external knowledge ([Flor, Cooper, & Oltra, 2018](#)) and use it commercially.

Financial aspects of radical innovations: This very small cluster with only two publications also addresses a specific organizational variable—financial resources. It concerns financing constraints and sources ([Caggese, 2019](#)) as well as financial consequences ([Sorescu, Chandy, & Prabhu, 2003](#)) of radical innovations.

Radical innovation adoption and diffusion: This cluster with 31 publications shifts the focus from the firm to the market as it stresses that the breakthrough success of radical innovations does not only rely on firms' innovativeness but also on customers to adopt them ([Dewar & Dutton, 1986](#)). For radical innovations to diffuse in the market, market barriers have to be overcome ([Sandberg & Aarikka-Stenroos, 2014](#)) and the right market entry ([Montaguti,](#)

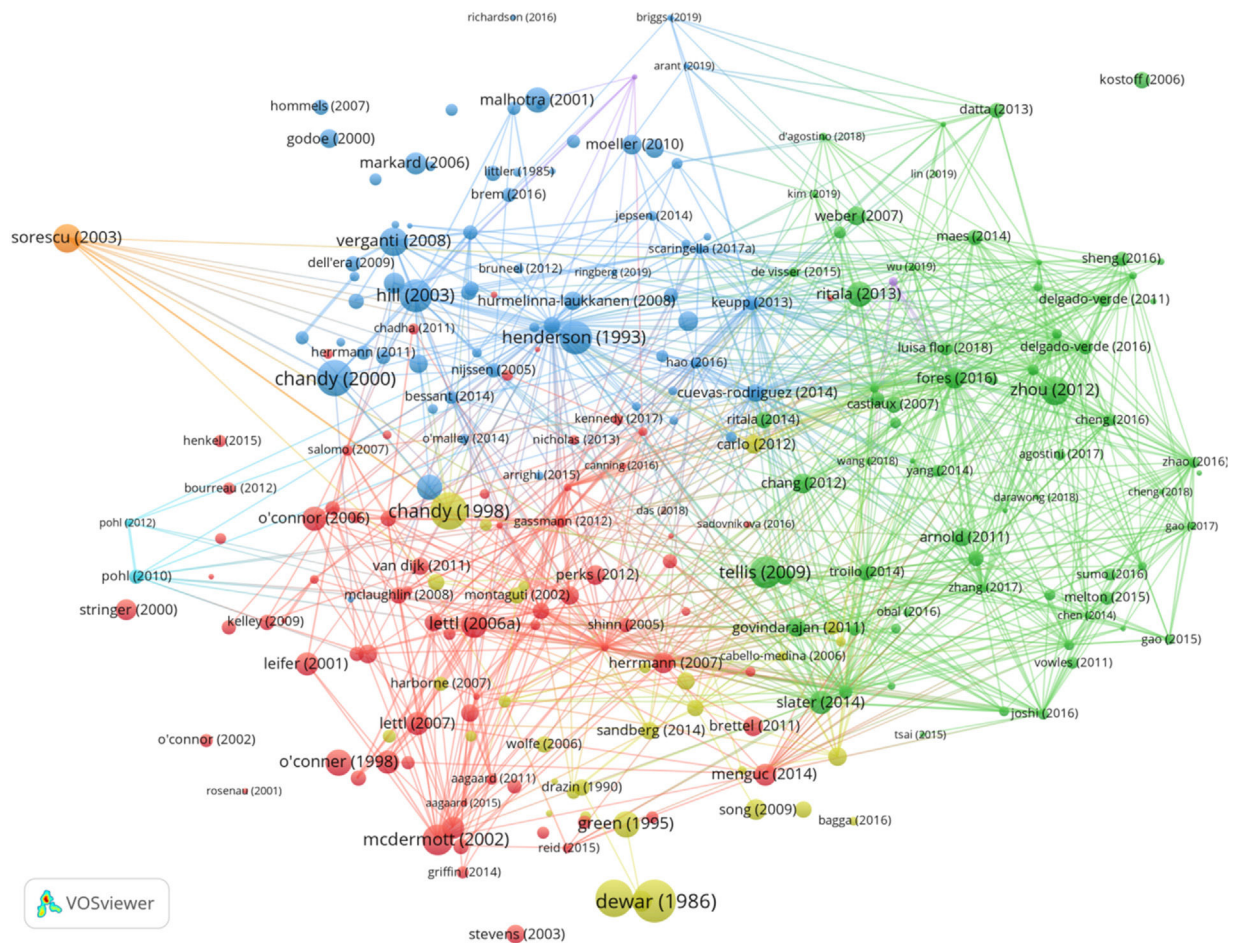


Fig. 3. Bibliographic coupling.

Source: Own elaboration based on VOSviewer

Kuester, & Robertson, 2002) and marketing strategy (Reinders, Frambach, & Schoormans, 2010) have to be pursued.

Radical industry innovations as challenges for incumbents: This cluster with 66 publications employs a market perspective. Here, firms are not seen as drivers but as potential victims of radical innovation. Incumbents previously dominating a market might be threatened by competitors or new entrants introducing radical innovations (Ansari & Krop, 2012; Hill & Rothaermel, 2003). In face of such crisis, incumbents might react with incompetence and underinvestment (Henderson, 1993) or, proactively, with an imitation strategy (Hurmelinna-Laukkanen, Sainio, & Jauhiainen, 2008) or business model innovation (Souto, 2015).

Radical innovations in specific industries: Two small clusters with one and three publications specifically address car manufacturers and financial service firms. However, in the other clusters, also several other industries, such as pharmaceuticals (Sorescu, Chandy, & Prabhu, 2003) etc., are used to generate propositions or test hypotheses regarding radical innovations.

Discussion

Performance of radical innovation research

The temporal distributions of both publications and citations clearly indicate that the research field is in a stage of growth and that the interest in radical innovation research has strongly increased over the last 20 years. It could have been expected that the financial crisis which also had consequences for the real

economy could have had an increasing effect on the research output, either because firms had to cut research and development costs or because generating radical innovations could have been a coping strategy. However, such an effect is not detectable. It is unclear what effect the current COVID-19 crisis might have on the innovation-related research output (Kraus, Clauß, Breier, Gast, Zardini, & Tiberius, 2020). We did not find any explanation for the two publication peaks in 2014 and 2016. Several publications were based on papers presented at conferences. However, none of them specifically focused on radical innovations, and the share of such papers was not higher than usually.

The analysis of the most influential journals shows that research on radical innovations is published in a wide variety of journals which focus on different topics. Interestingly, the *Journal of Product Innovation Management*, the most productive and most cited journal, and *Technovation* are the only two among the top 20 which specifically focus on innovation. Radical innovation research is also published in economic, general business, general management, marketing, operations research, R&D (research and development), strategic management, and technology management journals. This indicates that radical innovation, despite being a narrow topic itself, addresses all aspects in business.

The top author analysis shows that productivity and impact do not necessarily run concurrently. For example, Chandy is the overall most cited author, but the average number of citations per publication is 308.8, whereas Dewar and Dutton received 1,005 citations with just one article. However, even the least cited author on the top 20 list received an average of 75.3 citations per article, again

showing that research on radical innovations is regarded as highly relevant.

The closer look at the most cited individual publications, not surprisingly, find older articles on the first places. However, Dewar and Dutton's (1986) article also has a high average citation rate per year. The article not only analyzes whether incremental and radical innovations are adopted differently but also provides an interesting definition of the two innovation types which does not focus on the extent to which the market is disrupted but on the degree of new knowledge that is integrated in the innovation. The publication with the highest average annual citation rate and also the newest in the top 10 is by Zhou and Li (2012) who also focus on the role of knowledge in the radical innovation process. Both high scores demonstrate that the relationship between innovation and knowledge is considered highly relevant.

Current research state and future research opportunities

Based on the bibliographic coupling and the content analysis within the identified clusters, we propose the radical innovation research framework depicted in Fig. 4.

To generate a radical innovation (or enhance the likelihood of its emergence), firms have to implement a favorable setting in their organization and coordinate the radical innovation process (*Management of radical innovations*). As seen in the cluster description, the setting consists of various organizational variables such as structure, processes, culture, and many more. As previous research often analyzes relationships between specific organizational variables and partial radical innovation variables, innovation practitioners lack a systematic overview of all relevant aspects that should be subject to proper management of radical innovation. The scattered insights should be unified by future research. A radical innovation management “checklist” could name the intra- and extra-organizational aspects managers should pay attention to and how to best configure them. This overview would also help to identify research gaps as many organizational variables, such as agility (Brand, Tiberius, Bican, & Brem, 2019), internal idea contest designs (Hober, Schaarschmidt, & von Korfflesch, 2019), entrepreneurial orientation (Gupta, Mortal, & Yang, 2018), organizational innovation climate (Liu, Chow, Zhang, & Huang, 2019), organizational justice (Akram, Lei, Haider, & Hussain, 2020), or organizational wisdom practices (Akgün, Keskin, & Kirçovalı, 2019), as well as human resource variables, such as emotional intelligence (Açikgök & Latham, 2020), incentives (Ritala, Vanhala, & Järveläinen, 2020), individual innovation behavior (Strobl, Matzler, Nketia, & Veider, 2020), slack time (Medase, 2020), and top management teams (Sperber & Linder, 2018), and many more have been related to innovation performance but not yet been subject to in-depth analysis regarding specifically radical innovations. It would also be interesting to contrast findings about what radical innovation managers should do and what they really do (Maier & Brem, 2018).

At its core, the radical innovation process can be seen as a knowledge processing and learning process which feeds from internal and external sources (*Organizational learning and knowledge*). The role of the customer as a knowledge carrier and especially respondent of his or her own wants and needs has been stressed. External knowledge can also be assimilated through inter-organizational learning from suppliers and other partner firms. More generally, market learning also involves understanding technological trends and competitors' behavior. Apart from the knowledge that is directly relevant for the potential radical innovation, research also addresses radical innovation (dynamic) capabilities which can be seen as the applied procedural meta-knowledge or organizational metacognition regarding the radical innovation process. Future research might consider extending its epistemological foundation which is mainly based on the concept of “hard” knowledge which

can be assimilated and verified or falsified. As radical innovations are absolutely novel rather than based on existing predecessors, it makes sense not only to concentrate on “what is”, but also “what could be”. Apart from knowledge about current customer wants and needs, current structure of competition, and available technologies, strategic foresight (Fergnani, 2020; Iden, Methlie, & Christensen, 2017; Rohrbeck, Battistella, & Huizingh, 2015; Semke & Tiberius, 2020), and, more specifically, the use of the scenario technique (Tiberius, 2019; Tiberius, Siglow, & Sendra-García, 2020), could explore multiple future developments which do not represent factual knowledge but rather mental images. Rather than forecasting the most probable future state (Cuhls, 2003), the occupation with alternative possibilities might not only allow for a better future preparedness (Rohrbeck & Kum, 2018) but also increase creativity (Rohrbeck & Gemünden, 2011) as an antecedent of (radical) innovation (Anderson, Potočník, & Zhou, 2014). Also the conceptualization of capabilities can be enhanced (Saunila, 2019). Whereas current research often refers to the dynamic capabilities approach (Verona & Ravasi, 2003), the capabilities needed for radical innovation should be further specified on the individual, group (team), organizational, and inter-organizational level.

The success of radical innovations depends not only on firms' proper management but also on the market. The most ingenious innovation fails when market barriers are too high to overcome or customers do not want to buy it (*Radical innovation adoption and diffusion*). Whereas the questions of adoption and diffusion are well researched, explanations of their mechanics often take a market perspective rather than focusing on how to actively foster these processes and increase the likelihood of a radical innovation's market success. Future research could convey a managerial perspective more intensely.

If a radical innovation can be marketed successfully, the revenues and thus firm performance (Helm, Mauroner, & Pöhlmann, 2018) will significantly increase. In the ideal case, the firm has generated a new market and acts as a monopolist which would lead to massive growth. The small cluster *Financial aspects of radical innovations* but also publications scattered across other clusters address these financial outcomes of radical innovation. However, they also see financial resources not only as an output but also an input because radical innovations are considered to require sufficient liquid funds. That this cluster is so small and that hardly any other publication with a focus on financial aspects regarding radical innovations exists, is quite surprising and provides several future research opportunities. From a financial perspective, engaging in radical innovation is a highly risky investment. However, also the decision *not* to engage in radical innovation is a risky endeavor as competitors could come up with a radical innovation which could diminish or even destroy the focal firm's market position. Comparing such risks and providing an investment recommendation is financial studies' daily business which is rather unused so far. Interestingly, Paulson, O'Connor, and Robeson (2007) recommend evaluating the individual risks in a firm's portfolio of radical innovation projects. However, portfolio theory usually does not focus on high risk investments alone but tries to figure out the optimal diversification of securities regarding risk and return (Rubinstein, 2002). In that sense, *all* investment activities of a firm, i.e., also replacement and expansion investments as well as investments in incremental innovations, should be seen as part of a firm's investment portfolio which should be optimally diversified. The portfolio perspective can therefore assist with decision-making regarding whether or not to engage in specific radical innovation projects. Another attractive research opportunity is to apply real options strategy to radical innovation research. Real options apply the notion of financial options to real investments. A real option can be defined as the right but not the obligation to realize a business opportunity (Adner & Levinthal, 2004). A firm can make a compa-

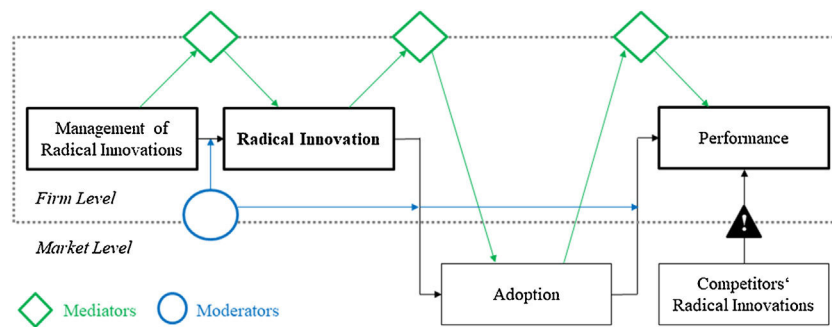


Fig. 4. Proposed research framework.

Source: Own elaboration.

ably small investment, the option price, to secure the possibility to engage in the business opportunity later. If the firm decides not to pursue the opportunity, the option price is lost, but not the whole investment amount that would have been required if the opportunity was implemented right away. This concept which already is applied to R&D projects (Huchzermeier & Loch, 2001), could also prove useful for radical investment projects, especially in an early stage when the firm has several ideas for radical innovations but it would be beneficial to wait until uncertainty diminishes.

Apart from the main identified variables relevant for radical innovation, the in-depth analysis of the clusters revealed that many publications address indirect variables – mediators and moderators – which also influence the overall success of radical innovation initiatives. Building on the idea of a radical innovation management checklist, a broader radical innovation checklist which also includes all variables which cannot be managed directly would prove helpful for practitioners involved in radical innovation initiatives. Future research should engage in building such a systematic overview which could be based on our suggested research framework (Fig. 4).

A firm's performance and even survival is at risk if a competitor or startup succeeds in generating and marketing a radical innovation which might diminish the focal firm's revenue and market share (*Radical industry innovations as challenges for incumbents*). If firms cannot engage in the development of radical innovations due to financial and human resource constraints, they have to find a suitable coping strategy in case a competitor's radical innovation emerges. Future research could more intensely and systematically immerse in such coping strategies as they could become imperative with the growing number of radical innovation initiatives. Additionally, coping strategies can be seen as alternative strategic options which complement the engagement in radical innovations themselves.

The cluster *Radical innovations in specific industries* and further publications across other clusters suggest that radical innovation is relevant in almost all industries. However, most research seems to analyze radical innovation in a specific industry exemplarily, possibly due to access to data, and then generalize the findings. Yet, both market structures and attributes of isomorphic firms (populations) might differ significantly from industry to industry. Therefore, future research should search for both generalizable findings which are valid across industries and industry specifics which differ in regards to radical innovation.

Limitations

Our bibliometric analysis is associated with several (potential) limitations. First, the quality of the analysis depends on the quality of the data set. The bibliometric data derived from the WoS might be incomplete and contain errors. Due to our conscientious handling of the data, we do not see problematic inadequacies. However, future

research could use additional databases. Second, bibliometrics are subject to the risk of the so-called Matthew effect which addresses the social reality that highly cited publications are only further cited due to their already high citations (García-Lillo, Úbeda-García, & Marco-Lajara, 2017). This effect increases over time and can cause that research is wrongly perceived as highly relevant. Third, and as already mentioned, clusters derived from science mappings usually do not provide accurately delimited categories as they are not content- but citation-based. The content analysis especially of rather blurry clusters is not as objective as bibliometrics usually suggest but resemble the methodology of qualitative research. Due to this subjectivity, other researchers might have labeled clusters differently. Fourth, future research opportunities, despite being based on the clustering and an in-depth content analysis, also involve a creative act and therefore have a subjective component. Researchers with different knowledge bases and associations might have come up with other suggestions.

Conclusion

In this study, we structured the large and fragmented literature on radical innovations using bibliometric analyses. The performance analyses revealed that radical innovation research has been growing fast in both annual publication numbers and citations, especially over the last 20 years, and it can be expected to gain further momentum. Articles are published in economic, general business, general management, innovation, marketing, operations research, R&D, strategic management, and technology management journals. The most cited authors are R. K. Chandy, G. J. Tellis, G. C. O'Connor, R. D. Dewar, and J. E. Dutton. The most cited articles are Dewar and Dutton (1986), Ettlie et al. (1984), Chandy and Tellis (1998), Chandy and Tellis (2000), and Henderson (1993). Zhou and Li (2012) is the paper with the highest average annual citation rate and also the most recent in the top 10.

The bibliographic coupling identified the following research clusters: Management of radical innovations, Organizational learning and knowledge, Financial aspects of radical innovations, Radical innovation adoption and diffusion, Radical industry innovations as challenges for incumbents, and Radical innovations in specific industries.

Based on an in-depth content analysis of these clusters, we recommend engaging in the following future research opportunities: A radical innovation management checklist should compile the intra- and extra-organizational phenomena innovation managers should focus on and give recommendations on how to best manage them. The radical innovation process should be conceptualized as an intra- and inter-organizational knowledge processing and learning process. However, radical innovation research should extend its epistemological basis. Apart from factual knowledge ("what is") it could also ask: "What could be?" Using strategic foresight might

enrich the knowledge base and increase creativity necessary for radical innovation. Further research in capabilities required for radical innovation should address individual, group (team), organizational, and inter-organizational characteristics. Rather than conveying a market view on the adoption and diffusion of radical innovations, future research might more intensely use a managerial perspective. The financial side of radical innovations needs more attention. We recommend applying portfolio theory and real options theory to radical innovation research. Building on the radical innovation management checklist, a broader radical innovation checklist could also address moderator and mediator variables and systematically present them to innovation practitioners. Stronger research efforts regarding coping strategies for firms which are faced with competitors' radical innovations would help top managers deal with such challenges. Industry-specific future research should not try to generalize its findings but elaborate on the industry specifics, whereas cross-industry research should identify knowledge that is applicable to a wide range of markets.

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