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Insights into relationships between disruptive technology/innovation and emerging technology: A bibliometric perspective

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ABSTRACT

"Disruptive technology & disruptive innovation" have been of scholarly interest for years, but there is still a need to better understand the nature of disruptions and their relationship to emerging technology processes. This paper pursues these issues by analyzing the interplay of technological emergence, disruption, and innovation. Applying bibliometric methods, the paper explores the conceptual foundations, themes, and research communities within these research domains. The results highlight the multiple theoretical foundations of research around technological change processes, disruption, and emergence. These differences among the domains invite conceptual cross-fertilization and consideration of interdisciplinary approaches to technological (and commercial) emergence.

1. Introduction

In traditional conceptual frameworks, disruptive innovation (DI) could occur in any established marketplace as a result of technological or non-technological factors (Christensen, 2003; Christensen and Leslie, 1997). If a certain technology plays a critical role in a disruptive innovation, it could be defined as "disruptive technology (DT)" (Bower and Christenson, 1995). Disruptiveness in innovation and technology is complex and not fully understood (Christensen et al., 2015; Danneels, 2004). The relationships between disruptive technology/innovation and emerging technology (ET) are seldom compared and discussed in prior literature. Those literatures have not extensively addressed possible differences between DT and DI and ET, and ambiguous usages for a specific technology (e.g. nanotechnology, big data, etc.) often occurred in past decades (Fan et al., 2015; Linton and Walsh, 2008). Understanding the complexity and theoretical foundations starts by reexamining the individual contemporary streams of academic literature. Understanding the academic perceptions of disruptions—through analyzing the relationships among technological emergence, disruption, and innovation processes—allows furthering the research agenda and clarifying the conceptual ambiguities. "Emerging technology," "disruptive innovation" and "disruptive technology" have evolved as frequently used concepts in scientific literature on management and Science, Technology & Innovation ("ST & I") policy analysis. In many contexts, including academic and professional literature, the "entangled" usage of these concepts may obfuscate their meaning to researchers and practitioners. A case in point is made by searching the Web of Science (WOS) to reflect how several timely technologies are presented as either emerging or disruptive—depending on the theoretical vantage points of the authors.

Table 1 raises interesting questions:

a) If each of these technologies can be addressed as emerging technology ("ET") or disruptive technology ("DT"),[1] do these terminologies have the same connotations?
b) Is there an evolving relation between ET and DT—i.e., a specific technology could become a DT, starting from an ET role, over a period of time, or vice versa?
c) Are there research communities that prefer using ET rather than DT, or vice versa, and why?
d) Based on the intellectual structures composed within each domain (ET and DT), are there any unveiled intersections, significant differences, or research blind-spots? Do differing intellectual structures convey important attributes of technological frontiers?

Although the terms have been used since the 1990's and widely

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[1] "For this discussion, we distinguish DT; later we combine to treat Disruptive Technology/Innovation."

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Table 1
Count of publications in selected emerging or disruptive technologies using either an emerging or disruptive technology framework.[a]

	Emerging technology	Disruptive technology
Nanotechnology	354	15
Big data	10	7
Internet of things	19	1
Electric vehicle	31	1
3D printing	13	6

[a] Indexes = SCI-EXPANDED, SSCI, A & HCI, ESCI; Timespan = 2006–2015.

adopted in the literature, exploration of the differences and relevance of the concepts of ET and DT is limited (Markides, 2006). Focusing on DT in particular, our theoretical understanding of the impact of new technology and when emergence turns to disruptions is scarce. This prompts questions: Which vantage point should we adopt to understand the terms? Are conceptual differences between these entities sufficient to consider them as separate topics?

This study uses a bibliometric approach to analyze ET and DT/DI concepts to clarify the conceptualizations and present possible implications for best treatment of emerging technology processes. Using co-citation analysis and bibliographical coupling, the study looks at Web of Science ("WOS") publication data on ET and DT/DI. The study finds clear, but weak, linkages between the concepts emanating from each domain. From a theoretical standpoint, the concepts remain mostly separate. As operational concepts ET and DT/DI have significant linkages.

2. Literature review

Since the 1990's, the concepts "emerging technology" and "disruptive technology" have become frequently used, but seldom analytically evaluated for possible overlaps. We suspect that casual usage of these concepts is frequent, especially in engineering and management literatures.

2.1. Disruptive technology

Disruptive technology can be defined as "*…a technology that changes the bases of competition by changing the performance metrics along which firms compete.*" (Bower and Christenson, 1995; Danneels, 2004). Yu and Hang (2010) review the concepts of DT tracing the origins of this mainstream theory from Schumpeter (1942), McKinsey and Foster (1986), and Henderson and Clark (1990) to the seminal work of Christensen (Bower and Christenson, 1995; Christensen and Leslie, 1997; Christensen and Overdorf, 2000). The concept of DT itself was introduced in the late 1990s, later modified by Christensen (2003) to disruptive innovation (DI) to more holistically include not only technological disruptions. Since then, DT seems to have been increasingly absorbed into the conceptualization of DI (Christensen et al., 2002, 2015; Christensen and Overdorf, 2000; Danneels, 2004). In the past three years, in Fig. 1, articles related to disruptive innovation (DI) have increased faster than articles related to DT. It is unclear if this is due to researchers just shifting terminology or if this is the result of true theoretical differences, such as can be identified between the innovation system and technological innovation system literatures (Suominen et al., 2016).

The terminological confusion highlights the conceptual ambidexterity and ongoing dialogue about the theory behind the DT and DI concepts (Yu and Hang, 2010, 2011). As noted by Markides (2006), there are different types of DI and disruptive technological innovation is only one manifestation of a disruption. Markides highlighted that to lump business-model, product and technological disruptions as one is probably a mistake. What is clear is that the literature struggles to distinguish between the concepts of DT and DI. For example, in the review by Yu and Hang (2010), DT and DI are used synonymously throughout the text. Due to this ambiguity, it seems unavoidable that any analysis of DT spills over to touch upon DI aspects. We are unsure if the terms should be regarded as segmental, hierarchical, or synonymous.

2.2. Emerging technology

The ET concept targets various characteristics, including the potentially dramatic impact a new technology has on the socio-economic system, significant uncertainties, and novel features (Boon and Moors, 2008; Martin, 1995; Porter et al., 2002; Small et al., 2014). In a literature review, Rotolo et al. (2015) integrated prior work from several authors to present a conceptual framework of emerging technology with the five characteristics of *radical novelty*, *relatively fast growth*, *coherence*, *prominent impact*, and *uncertainty & ambiguity*.

Actually, the relevant literature on ET is much more than the literature related to DT and DI, the time sequence of articles on ET is shown in Fig. 2, which depends on a similar topic search to that used in Fig. 1.

Basically, ET sounds more popular than DT and DI, and seems more frequently used in different disciplines. However, DT and DI are not equal to ET, and the differences of conceptual definitions between DT and ET seem significant; furthermore, the linkages between DT & DI and ET could be interesting and valuable. Rotolo et al. (2015) made an effort to synthesize from various definitions of ET and to highlight the multiple domains of research where the concept has been used. The authors found explicit definitions of ET applied in various different domains, such as science and technology policy, management, economics, and scientometrics. Partly due to the large number of domains that have adopted the concept, viewpoints are extensive. Hung and Chu (2006) and Porter et al. (2002) take a science policy view to emergence and focus on the economic influence and impact on competition brought on by novel technologies. Both Hung and Chu (2006) and Porter et al. (2002) look at impacts at a macro-level, linking to a broad base of literature, such as Martin (1995), who posited ET as technology with broad societal impacts.

Another viewpoint on ET emerges in the marketing and management literature, in which emergence is often observed from a technological adoption perspective. For example, Li (2005) accentuates the impacts of network externalities in emerging technology markets. A micro level view is offered by Riordan and Salant (1994) who look at the dynamics of companies in adopting new technologies into their portfolios. There is also extensive literature connecting emerging technologies to innovation management, such as Cozzens et al. (2010), who move the discussion more towards technology management. To a significant extent, literature uses ET as an operational concept rather than a theoretical one – i.e., how to identify and measure emergence? For example, the highly cited technological forecasting study by Daim et al. (2006) overlooks the definitional aspects of ET and limits its focus to an operational explanation of tracking technology pathways from invention to adoption. A similar operational view is also shared by Robinson et al. (2013) and Huang et al. (2014). Arguably, for much of the technology forecasting research, emergence remains a practical, operational concept.

2.3. Linkages between emergence and disruptions

Comparison of ET and DT is not prominent in the literature, although implicitly we understand the linkages of the concepts. Can a technology be disruptive but not emergent, or vice versa? Are ETs and DTs both reflections of radical change mechanisms? Do we require them to translate into innovations (practical applications)? Do we expect grand societal impacts of ETs and/or DTs? Intuitively, disruptions that are defined as technologies that shape how companies compete, and emergence, a technology with radical and prominent impact, seem

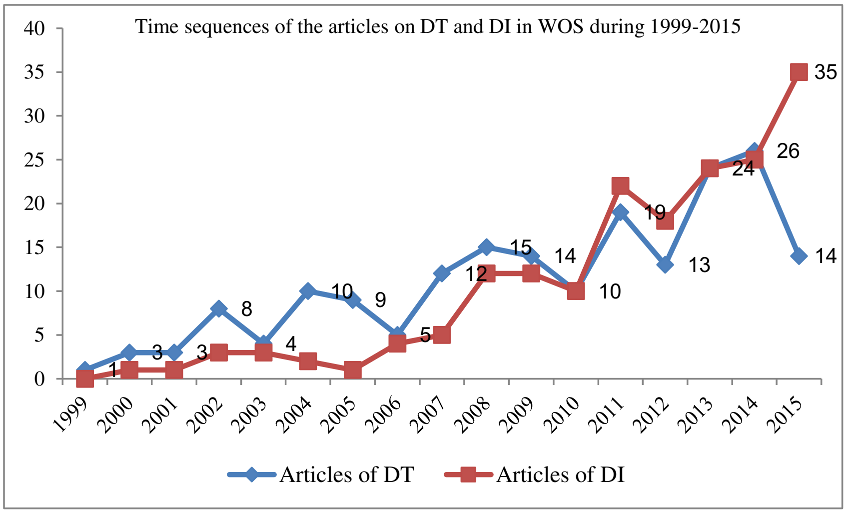

Fig. 1. Comparison between articles on DT and articles on DI. (The search strategy depends on the basic topic search of WOS. In addition, if a publication contains DI and DT, it can be included into the topic DI and DT simultaneously.).

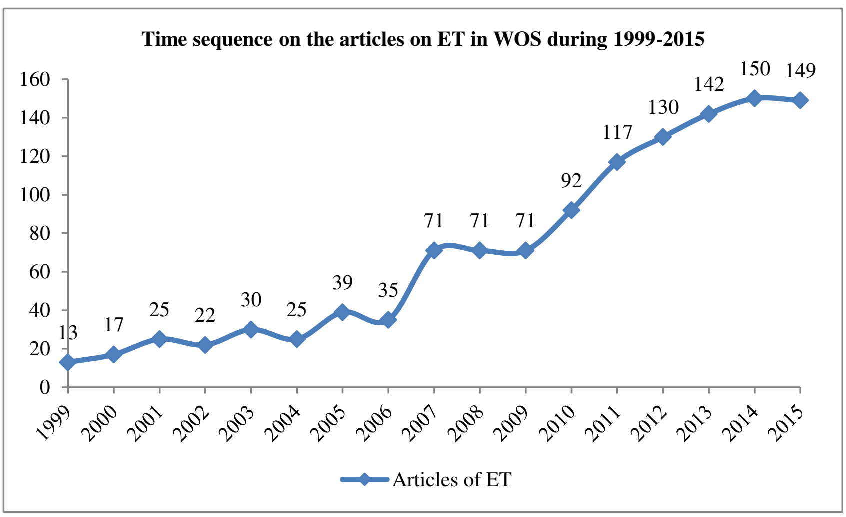

Fig. 2. Time sequence of articles on ET in WOS during 1999–2015.

to tell the same story with different words. To better understand the theoretical underpinnings of how technology plays a role in enabling global disruptive change, we should better understand key concepts. We argue these to be ET and DT.

Focusing on the linkages between the concepts, several stand forth. First, both concepts incorporate novelty. Novelty is clearly central to ET (Rotolo et al., 2015), but also in DT novelty is expected, even with technological improvement or invention in low-end or niche markets (Christensen et al., 2015). The assumption is that anything emergent or disruptive embeds a clear degree of novelty in the technology that sets it apart from the status quo. Second, literature suggests that both ET and DT portend impacts. Looking at the technological forecasting and foresight literatures, expecting societal impact is even more prevalent than the expectation of economic consequences. Similarly, with the innovation management literature, there is a clear setting where the incumbent (mature) technology is overthrown by the new technology causing a discontinuity in the market. But here, due to the conceptual distinction drawn between invention and innovation (Pavitt, 2006), the expectation of market potential is prominent. Finally, both ET and DT papers highlight the uncertainty relating to the new technology. The DT literature focuses on the capability to surpass the expectations of the user and create superior value. In the ET literature, much of the discussion focuses on uncertainty between technological options, rather than value propositions.

Both ET and DT are labels that convey a message to stakeholders of the introduction of a novelty, uncertainties related to it, and its possible future impacts. Making this statement alone is significant to create awareness of a novel technological option. ET literature could absorb some critical ideas from the traditional technology paradigm (cf., Dosi, 1982)—i.e., displace the old technology by providing superior performance or functionality. In contrast, DT focuses on market opportunity identification, competition, and adoption. In the managerial discourse, terminology is similarly ambidextrous. Innovation based on technology development is basically a dynamic process over time, and neither a low-cost nor a high-end market can fully delimit the essence of product evolution. This could be an explanation of why the definitional challenges concerning the DT concept have been so central to the research agenda of disruptions (Danneels, 2004; Markides, 2006). Central to the terminological discussion is the relationship between the terms. Literature of technological development focuses on a point of disruption or discontinuity that begins an era of ferment (Anderson and Tushman, 1990), but how does emergence relate to this? Is the point of disruption also the point of emergence or something that precedes it?

Going from a conceptual to an operational level, ET indicators can be used to detect or probe the occurrence or degree of emergence (Daim et al., 2006; Porter et al., 2002; Rotolo et al., 2015; Small et al., 2014). However, a key question remains as to whether we can forecast "*disruption*" (Hüsig et al., 2005; Paap and Katz, 2004) based on degree of emergence? Several studies have made an effort to link the concepts at an operational level, for example through roadmaps (Kostoff et al.,

Table 2
Search strategy to retrieve emerging and disruptive technology papers[a].

No	Search rule	Results
Rule 1	(TS = ("emerging technolog*") NOT TS = ("disruptive technolog*")) AND DOCUMENT TYPES: (Article or Review)	1231
Rule 2	(TS = ("disruptive technolog*") NOT TS = ("emerging technolog*")) AND DOCUMENT TYPES: (Article or Review)	192
Rule 3	(TS = ("disruptive innovation*") NOT TS = ("emerging technolog*" AND "disruptive technolog*")) AND DOCUMENT TYPES: (Article or Review)	183
Rule 4	(TS = ("emerging technolog*" AND "disruptive technolog*" AND "disruptive innovation*") AND DOCUMENT TYPES: (Article or Review)	1

Indexes: SSCI, A & HC.
[a] Timespan: 1996–2015.

2004; Walsh, 2004) or R & D strategies (Yu and Hang, 2011).

3. Analytical methods and data collection

This study uses bibliometric methods, namely co-citation and bibliographic coupling, to analyze the relationship of emerging and disruptive technology concepts. The study is based on data retrieved from the Web of Science (WOS), limiting search to the Social Science Citation Index (SSCI) and Arts & Humanity Citation Index (A & HCI). The search strategy is shown in Table 2. The search strings used are implemented in the WOS Topic (TS) field, which searches for the terms in the title, abstract, author keywords, or the Keywords Plus® fields.

Rule 1, in Table 2, searches for articles relating to ET. Rule 2 retrieves articles on DT. Rule 3 excludes ET and DT, focusing on isolating DI. We then use co-citation analysis (Small, 1973) to highlight the shared publications between ET, DT, and DI. Co-citation clustering is utilized to present the relevance between different research topics (Zhang and Guan, 2016). In co-citation analysis, two documents are co-cited if there exist one or more documents that cite both articles. Co-citation can be treated as dichotomous—only considering the existence or absence of a link. But, co-citation can be weighted based on the count of articles that co-cite the two documents. The result of the co-citation approach is a network of cited documents, highlighting shared origins of the concepts (Youtie et al., 2013).

Bibliographic coupling is used to study the shared intellectual background of the publications (Kessler, 1963). At the core of this analysis is the assumption that the more references two documents share, the stronger their shared intellectual foundation. The results of bibliographic coupling serve as a "contemporaneous representation of knowledge" (Li, 2017; Youtie et al., 2013). Bibliographic coupling analysis also facilitates visualization of research frontiers for a specific topic (Boyack and Klavans, 2010; Gazni and Didegah, 2016; Li et al., 2017).

The research process used in this study is depicted schematically in Fig. 3. At first, data are retrieved from WOS. Calculations are done using *CiteSpace* software (Chen, 2006). The analysis is divided into two streams—a backward focused co-citation analysis and a contemporaneous bibliographical coupling analysis. For the co-citation analysis data are first analyzed as a whole, drawing out if the ET, DT and DI literatures share intellectual background. This is followed by an analysis of ET and DT, embedded with DI, separately, to uncover research fields within the concepts. A forward looking analysis is done on the ET and DT data separately, in an effort to highlight research frontiers in each, looking at possible commonalities in research agenda.

We analyzed results using the visual mapping created by *CiteSpace* and data provided for clusters and documents. Silhouette value is used to evaluate the clustering results. As most of the clustering algorithms are unsupervised, indicators are utilized to evaluate the clustering effectiveness and convergence. The silhouette coefficient is a popular indicator (Rousseeuw, 1987) to help evaluate clustering results; see Eq. (1).

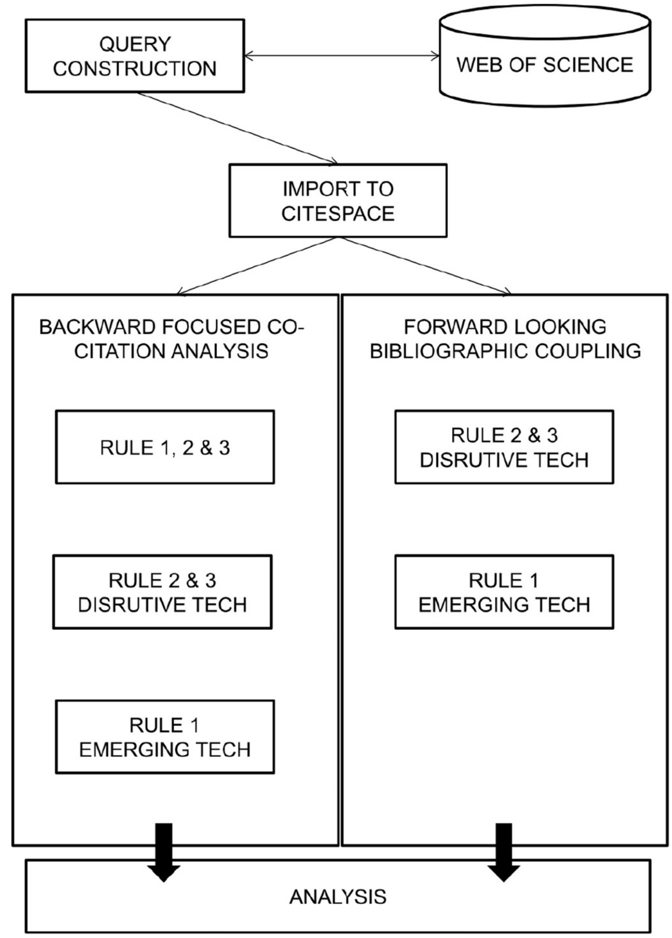

Fig. 3. General process of bibliometric analysis based on *CiteSpace*.

$$S(i) = \begin{cases} 1 - a(i)/b(i), & if \;\; a(i) < (i), \\ 0, & if \;\; a(i) = b(i), \\ b(i)/a(i) - 1, & if \;\; a(i) > b(i) \end{cases} \tag{1}$$

In Eq. (1), ***s(i)*** is the *silhouette coefficient* that needs to be computed; for each ***i*** (e.g., a publication) in the dataset ***DS (e.g., publication set)***, ***a(i)*** is the average distance of ***i*** from all other data points within the same cluster (or group), ***b(i)*** is the lowest average distance of ***i*** to any other cluster, in which ***i*** is not a member. The value of ***s(i)*** should locate in the range [− 1, 1], as shown in Eq. (2).

$$-1 \leq s(i) \leq 1 \tag{2}$$

At a document level, the importance of each document is analyzed using a *betweenness centrality* value. In network analysis, *betweenness centrality* calculates how many times a node (publication) is a bridge along the shortest path between two nodes. This gives an importance measure of a publication in a cluster. Finally, for bibliographic coupling, citation count of a publication is used as an indicator of importance of a publication to the research front – helping to discern the key research agendas for each of ET and DT.

4. Analyzing the relevance between emerging technology and disruptive technology

4.1. An historical analysis based on author co-citation networks

To clarify the research communities addressing ET and DT, we performed co-citation analysis based on authors. Results of the analysis appear in Fig. 4 and Table 3.

The co-citation network of the authors is based on all of the articles

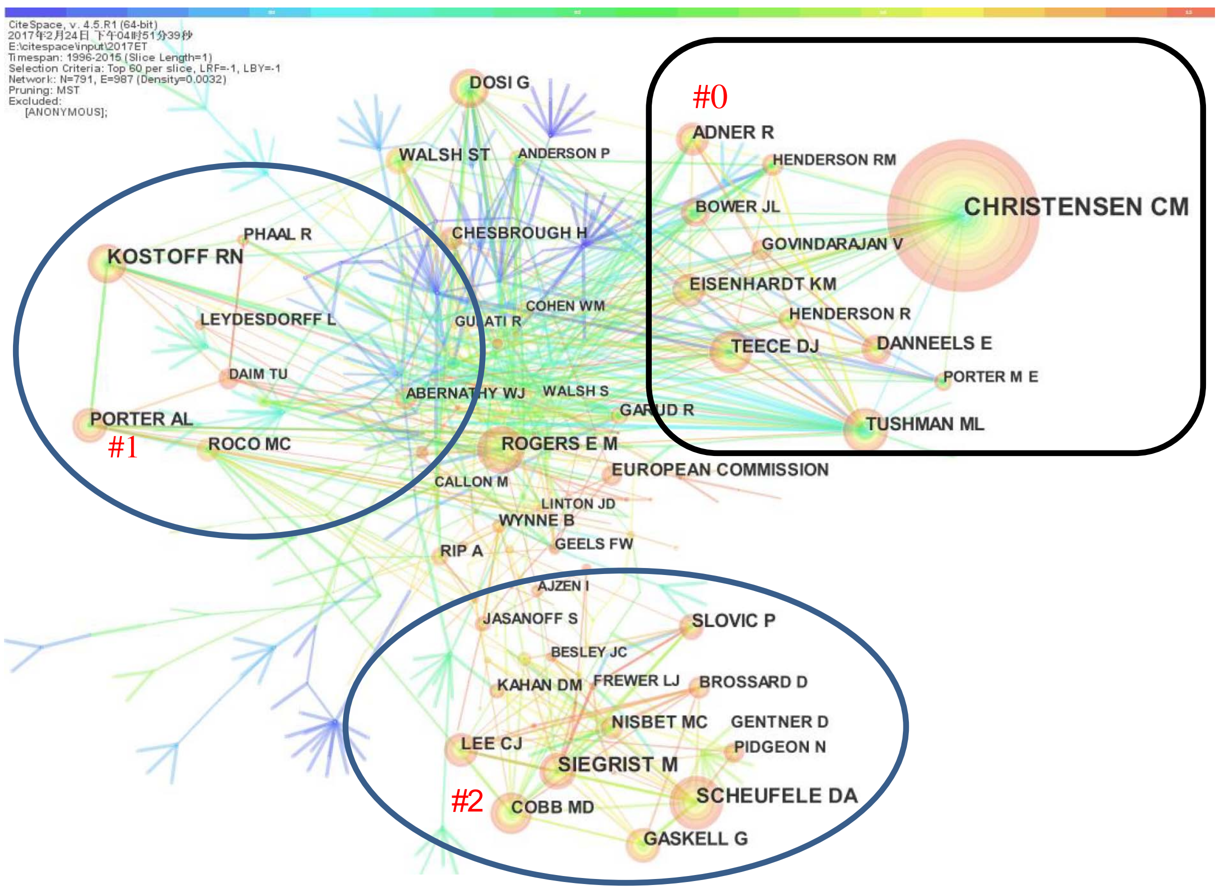

Fig. 4. Results of co-citation analysis of the authors based on *CiteSpace*.

Table 3
Top three clusters of co-citation clustering based on *CiteSpace*.

ID	Size	Silhouette	Mean (year)	Top terms (Log-Likelihood Ratio, p-value)
#0	87	0.686	2004	Disruptive innovation (47,770.38, 1.0E − 4); disruptive technologies (30,386.38, 1.0E − 4)
#1	61	0.839	2009	Emerging technologies (32,224.41, 1.0E − 4); public attitude (21,374.64, 1.0E − 4);
#2	41	0.905	2002	Human side (11,283.33, 1.0E − 4); biological need (3410.95, 1.0E-4);

for ET, DT, and DI, using the search described in Table 2. This analysis highlights research communities using clustering, and visualizes connections between these different communities.

Three primary clusters (research communities) are detected. Cluster #0 includes authors such as Christensen, Tushman, and Teece, authoring seminal work on DT and innovation (Christensen and Leslie, 1997; Teece, 1986; Tushman and Anderson, 1986). Cluster #1 involves research in technology forecasting, S & T policy and technology opportunity analysis, central authors being Kostoff, Porter, and Daim (Porter and Detampel, 1995; Daim et al., 2006). Cluster #2 contains such scholars as Scheufele, Siegrist, and Gaskell, who are researchers in the fields of social communication and risk governance (Gaskell et al., 2005; Scheufele and Lewenstein, 2005; Siegrist et al., 2007).

The three clusters have few direct connections in the co-citation mapping. There is almost no direct mediator to connect the cluster #0 and the #1 cluster and only a few mediating authors in the network as a whole. These are, for example, Dosi focusing on technological paradigm and technical change, and Cohen focusing on competitive strategies. Although links between clusters are present, there is significant isolation among the foundations of the three clusters. This is highlighted in Table 3, which describes the clusters.

Cluster #0, associated with DI and DT, draws from the business and management research community. This cluster is the largest of the clusters. Cluster #1, labeled as ET and public attitude, involves emerging technologies, social communication and a multidisciplinary social science research community. This cluster raises societal aspects of ET, for example aspects of nanotechnologies' impact on society. Cluster #2 belongs to the research communities on such aspects as impact of ET on humans, biological needs, and risk perception about ET. Cluster #2, which is earliest based on mean year of publication, appears as playing a mediating role among the three research communities, as very few articles in Cluster #1 directly cite the literature in Cluster #0. The authors at the center of the cluster focus on the use of scientometric and text mining methods in operationalizing technological pathways. The top-terms in the cluster remain detached from the author profiles central to the cluster.

Focusing the co-citation analysis on DT and DI literature we further analyze the combined dataset of 363 distinct records, the union of search Rule 2 and Rule 3 (Table 2). The resulting co-citation clustering is shown in Fig. 5 and Table 4.

With the possible exception of Cluster #1 (Table 4; Fig. 5), whose silhouette value is less than 0.8, the clusters have sufficient silhouette values to be considered as coherent clusters. Focusing on the top terms, DI and DT are dominant. Cluster #0 deals with DT and differentiating market strategies. Cluster #1 is labeled by DI and "new market (segment)". Christensen (2003) expanded the definition of DT to DI;

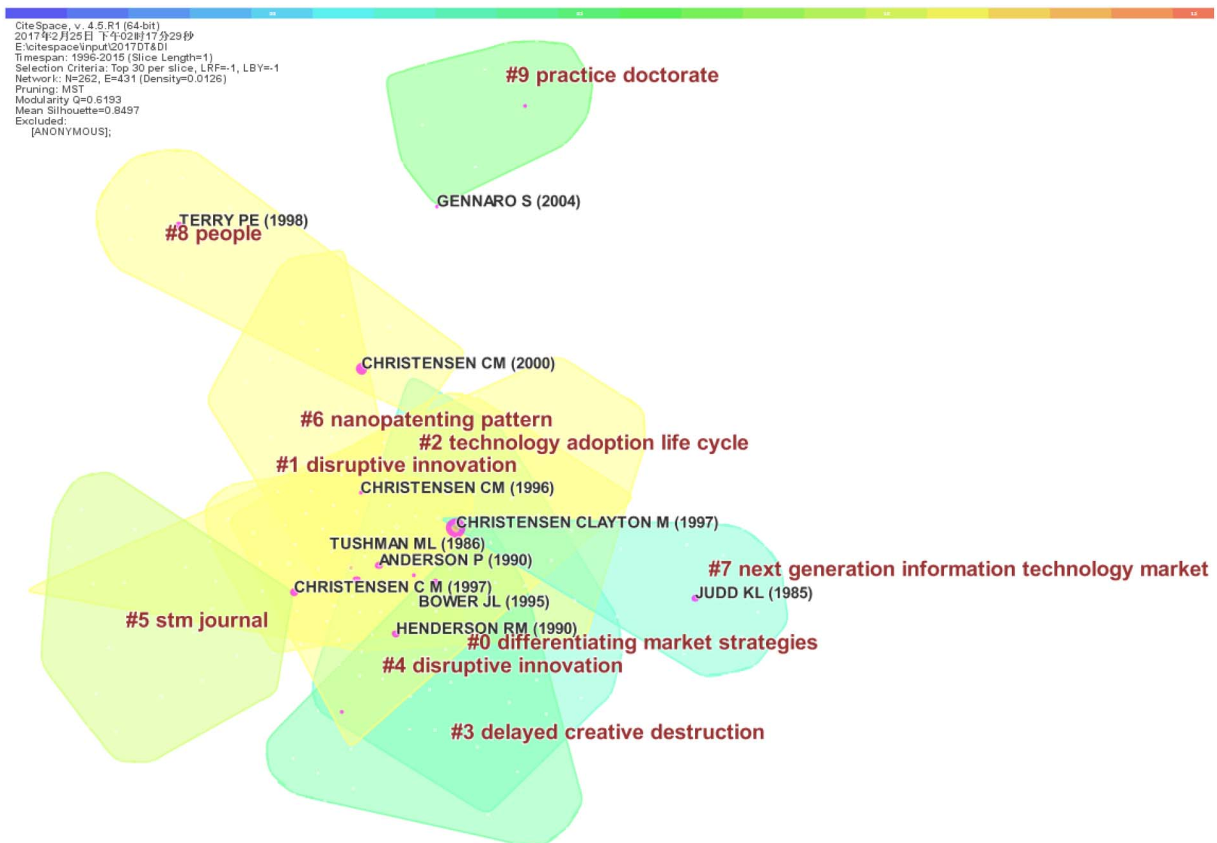

Fig. 5. Clustering map of co-citation based on the literature of DT and DI.

Table 4
Top 5 clusters in Fig. 5.

ID	Size	Silhouette	Top terms (Log-Likelihood Ratio, p-value)
#0	36	0.917	Disruptive technologies (13,691.17, 1.0E − 4); differentiating market strategies (13,598.2, 1.0E − 4); sustaining technologies (12,771.51, 1.0E − 4);
#1	33	0.773	Disruptive innovation (12,673.48, 1.0E − 4); new market (3871.14, 1.0E − 4); existing market (3871.14, 1.0E − 4);
#2	30	0.837	next generation information technology market (16,157.76, 1.0E − 4); explaining entry (16,157.76, 1.0E − 4); research report (16,157.76, 1.0E − 4);
#3	29	0.904	stm journal (6499.71, 1.0E − 4); managing innovation (5535.97, 1.0E − 4); technology adoption life cycle (3923.8, 1.0E − 4);
#4	28	0.814	Technological change (4216.26, 1.0E − 4); technology intelligence process (3559.16, 1.0E − 4); disruptive technological change hyper-learning (3419.46, 1.0E − 4);

Table 5
Top 10 references by betweenness centrality in top 5 clusters presented in Fig. 5.

Betweenness centrality	References	Cluster
0.544	Christensen CM. (1997). INNOVATOR'S DILEMMA. Boston: Harvard Business School Press	3
0.41	Christensen CM., Bohmer R., Kenagy J. (2000). Will disruptive innovations cure health care?. Harvard business review, 78(5), 102–112.	3
0.32	Bower JL., Christensen CM. (1995). Disruptive technologies: catching the wave. Harvard Business Review, 73(1), 43–53.	2
0.29	Tushman ML., & Anderson, P. (1986). Technological discontinuities and organizational environments. Administrative Science Quarterly, 31(3), 439–465.	4
0.26	Anderson P., Tushman, M. L. (1990). Technological discontinuities and dominant designs: a cyclical model of technological change. Administrative Science Quarterly, 35(4), 198–210.	0
0.26	Kamien MI., Schwartz NL. (1982). Market structure and innovation. Cambridge University Press.	2
0.13	Veryzer RW. (1998). Discontinuous innovation and the new product development process. Journal of product innovation management, 15(4), 304–321.	0
0.11	Christensen CM., Bower JL. (1996). Customer power, strategic investment, and the failure of leading firms. Strategic management journal, 197–218.	1
0.09	Rogers EM. (1995). Diffusion of innovations. The Free.	4
0.09	Markides, C. (2006). Disruptive innovation: In need of better theory. Journal of product innovation management, 23(1), 19–25.	1

Markides (2006), somewhat critically, noted that other than technological disruption exists. Central to this stream of literature is also the role of established firms, and the failure of these to adopt disruptive technologies. Cluster #3 focuses on the life-cycle of innovations and managing innovation. Cluster #4 looks at technological change and its operationalization through the intelligence process,

The core set of literature within DT concerns market dynamics. It focuses on understanding the importance of discontinuities and

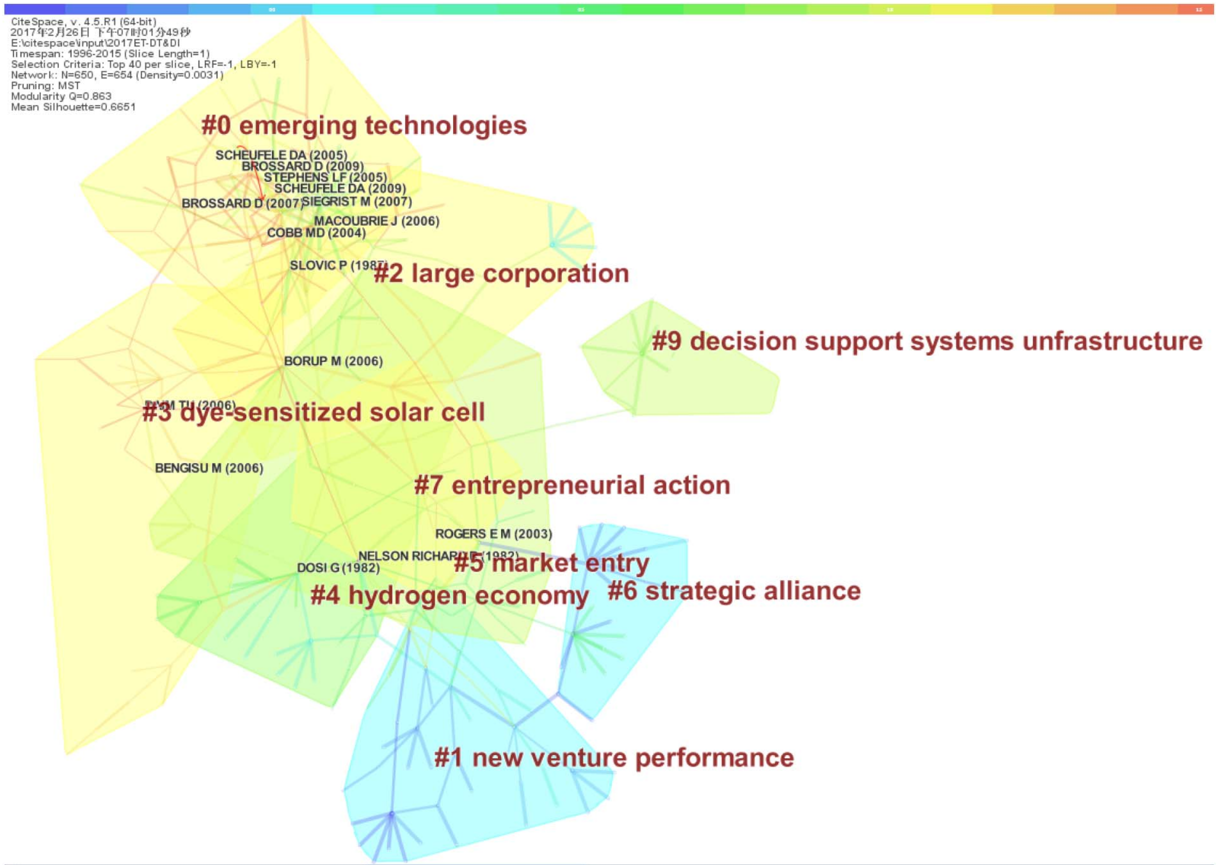

Fig. 6. Co-citation clustering of references based on the literature of emerging technology.
[Using the data retrieved by Rule 1 in Table 2].

Table 6
Top 5 clusters in Fig. 6.

ID	Size	Silhouette	Top terms (tf-idf weighting)	Top terms (Log-Likelihood Ratio, p-value)
#0	80	0.894	Group voice | nanotechnology concern	**Emerging technologies** (26,556.56, 1.0E − 4); nanotechnology hazard (22,701.78, 1.0E − 4); experts perception (22,701.78, 1.0E − 4);
#1	42	0.949	New technology forecasting algorithm | case	**New venture performance** (4388.3, 1.0E − 4); technology strategy (4166.57, 1.0E − 4); independent biotechnology venture (4166.57, 1.0E − 4);
#2	37	0.926	AHP rating | case	Large corporation (7833.28, 1.0E − 4); established firm (7833.28, 1.0E − 4); breakthrough invention (7833.28, 1.0E − 4);
#3	36	0.871	Netherlands | case	Dye-sensitized solar cell (6201.94, 1.0E − 4); innovation journey (6156.79, 1.0E − 4); current discourse (5092.13, 1.0E − 4);
#4	33	0.934	Corporate organizations | genomic technologies	Hydrogen economy (4421.34, 1.0E − 4); hydrogen futures literature (4421.34, 1.0E − 4); Korean firm (1669.03, 1.0E − 4);

Note: TF-IDF stands for Term Frequency, Inverse Document Frequency that offers a tool to help distinguish relative term specificity.

dynamics among firms in adopting these. Fig. 5 points to the separation of the DT and DI discussions from the ET literature, and this is further emphasized by Table 5, clearly showing the microeconomic base of this stream of literature.

For ET, the results show a qualitatively different emphasis. Fig. 6, Tables 6 and 7 offer perspectives. The co-citation analysis reveals 116 clusters; the five largest are shown in Table 6.

Based on Fig. 6 and Table 6, the research articles concerning ET appear more diversified than the research on DT and DI, extending far from microeconomics, but also including aspects of it. Already established in Fig. 5, ET literature clearly has distinct social and operational streams. This is also shown in the deeper analysis of ET publications indicating strong streams of literature focusing on the social aspects of new technology, but also addressing microeconomic issues. Striking is that the clustering seen in Fig. 6 is more heavily based on case study topics than on ET theory building. This further emphasizes that with ET, literature is more directed towards it being an operational construct rather than a theoretical discourse.

In the past two decades, with the development of nanotechnology, more social science researchers are evaluating the perceived risks of ET. However, except for technology opportunity analysis, articles addressing technology roadmapping, the relevant research on corporate strategy including R & D, innovation pathway studies, organizational evolution, and knowledge management seem much less than we would anticipate. The top 10 references in the five largest clusters, ordered by their centrality in Fig. 6, are shown in Table 7.

As seen in Table 7, the core literature central to the clusters focuses on social aspects and public attitudes towards new technologies (e.g., nanotechnology, dye-sensitized solar cell and hydrogen energy), macro-level technological paradigm analysis, and micro-level competition analysis. The micro-level studies on competitiveness and on a resource-based view of the firm link to Cluster #1 on the new technology based

Table 7
Top 10 references ordered by the centrality in the largest clusters presented in Table 6.

Betweenness centrality	Reference	Cluster
0.14	Nelson RR., Winter S. (1982). An Evolutionary Theory of Economic Change. Cambridge, MA.	4#
0.1	Drexler KE. (2003). Nanotechnlogy: Drexler and Smalley make the case for and against 'molecular assemblers'. Chemical & Engineering News, 81(48), 37–42.	4#
0.09	Sims Bainbridge, W. (2002). Public attitudes towards nanotechnology. Journal of Nanoparticle Research, 4(6), 561–570.	0#
0.08	Arora, A., & Gambardella, A. (1990). Complementarity and external linkages: the strategies of the large firms in biotechnology. The Journal of Industrial Economics, 361–379.	1#
0.07	Cobb, M. D., & Macoubrie, J. (2004). Public perceptions about nanotechnology: risks, benefits and trust. Journal of Nanoparticle Research, 6(6), 395–405.	0#
0.06	Dosi, G. (1982). Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. Research policy, 11(3), 147–162.	4#
0.05	Macoubrie, J. (2006). Nanotechnology: public concerns, reasoning and trust in government. Public Understanding of Science, 15(2), 221–241.	0#
0.05	Gaskell, G. (2005). Imagining nanotechnology: cultural support for technological innovation in Europe and the united states. Public Understanding of Science, 14(1), 81–90.	0#
0.05	Mads Borup, Nik Brown, Kornelia Konrad, & Harro Van Lente. (2006). The sociology of expectations in science and technology. Technology Analysis & Strategic Management, 18(3–4), 285–298.	3#
0.05	Walsh, S. T. (2004). Roadmapping a disruptive technology: A case study: The emerging microsystems and top-down nanosystems industry. Technological Forecasting and Social Change, 71(1), 161–185.	2#
0.05	Nikulainen, T., & Palmberg, C. (2010). Transferring science-based technologies to industry—does nanotechnology make a difference?. Technovation, 30(1), 3–11.	2#
0.05	Townsend, E., & Campbell, S. (2004). Psychological determinants of willingness to taste and purchase genetically modified food. Risk Analysis, 24(5), 1385–1393.	0#

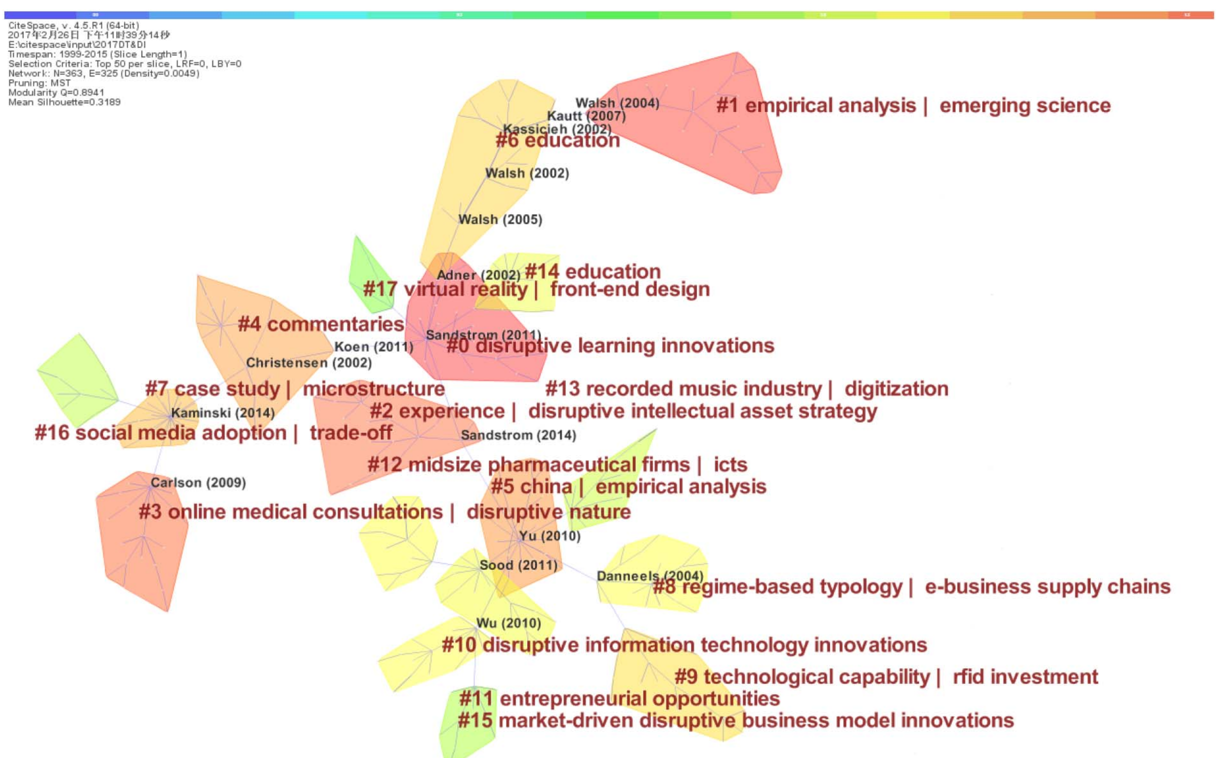

Fig. 7. Bibliographic coupling of the literature related to disruptive technology and disruptive innovation based on the merging dataset of Rule 2 and Rule 3 in the Table 2.

firm. Excluding this cluster, the other major clusters focus on a macro-level analysis of societal impact and large-scale adoption.

Table 7 provides an interpretation of the diversification of the related research on ET and traditional theories on innovation, technology development strategy, communication, and public perception of risk, which are important components of the intellectual base of ET. In contrast, the intellectual base of DT and DI presented in Fig. 5, Tables 4 and 5 is much more simplified and focused on such aspects as: corporate technology strategy, organization change for technology discontinuity. Most of the DT and DI high centrality articles are published in several top management journals – i.e., *Administrative Science Quarterly*, *Journal of Product Innovation Management*, *and Strategic Management Journal*.

4.2. A contemporaneous representation of knowledge

Based on bibliographic coupling, a contemporaneous view on the subject, the literature related to DT and DI focuses on organization theory of enterprises, business model innovation, comparisons between disruptive technology/innovation, sustaining technology/innovation, disruptive innovation, and radical innovation. Fig. 7 and Table 8 describe the results of the bibliographic coupling of the literature related

Table 8
Top 10 clusters presented in Fig. 7.

ID	Size	Silhouette	Top terms (tf*idf weighting)	Top terms (Log-Likelihood Ratio, p-value)
#0	25	0.977	Disruptive learning innovations	South Africa (111.25, 1.0E − 4); disruptive learning innovation (111.25, 1.0E − 4); ODL environment (111.25, 1.0E − 4);
#1	24	0.957	Empirical analysis | emerging science	Successive generation (118.7, 1.0E − 4); generalized cost performance curve (118.7, 1.0E − 4); graphic information (118.7, 1.0E − 4);
#2	23	0.965	Experience | disruptive intellectual asset strategy	Financial chapter (135.55, 1.0E − 4); alternative perspective (129.61, 1.0E − 4); engineering education (129.61, 1.0E − 4);
#3	23	0.987	Online medical consultations | disruptive nature	Retail clinics (114.89, 1.0E − 4); therapeutic technologies (114.89, 1.0E − 4); stem cell (114.89, 1.0E − 4);
#4	23	0.956	Commentaries	Northern California perspective (125.64, 1.0E − 4); RDBMS industry (125.64, 1.0E − 4); Australian educational publishing (120.14, 1.0E − 4);
#5	22	0.986	China | empirical analysis	Disruptive innovation (114.28, 1.0E − 4); industrial district (114.08, 1.0E − 4); leveraging exaptation (114.08, 1.0E − 4);
#6	22	0.944	Education	Managing intellectual property (117.44, 1.0E − 4); using patent pool (117.44, 1.0E − 4); optical disc industry (117.44, 1.0E − 4);
#7	21	0.987	Case study | microstructure	Human body (110.04, 1.0E − 4); technological enhancement (110.04, 1.0E − 4); legal practice (103.89, 1.0E − 4);
#8	19	0.966	Regime-based typology | e-business supply chains	Industry characteristics (109.7, 1.0E − 4); dynamic product differentiation strategies (109.7, 1.0E − 4); technological paradigm theory (103.56, 1.0E − 4);
#9	17	0.97	Technological capability | RFID investment	Mediating role (104.63, 1.0E − 4); supply chain integration (104.63, 1.0E − 4); operational performance (104.63, 1.0E − 4);

to DT and DI. Note that there are almost no direct arguments connecting ET, DT, and DI, within articles with a high number of citations or centrality in Fig. 7.

To further present the information in Fig. 7, the 10 largest clusters covering over 60% of the records are listed in Table 8. For different tools or algorithms, the top terms could appear different, even somewhat ambiguous. Therefore, the labeled results in Table 8 could be inspiring as well as controversial.

Bibliographic coupling enables us to understand the research fronts in a field (Kessler, 1963; Li et al., 2017). Focusing attention on the highly cited publications in Fig. 7 and Table 8, we can understand the bibliographic coupling results in more depth. There is a stream of literature focusing on continuing the theoretical discussion on the concepts of DT and DI (Adner, 2002; Danneels, 2004). The DT concept arises as influential in several domain-specific fields, such as health care (Christensen and Overdorf, 2000), nanotechnology (Walsh, 2004), 3D-printing (Berman, 2012), and even pedagogics (Conole et al., 2008). The research front in DT also incorporates a literature stream on technology roadmapping, focusing on uncovering technological pathways and disruptions (Kostoff et al., 2004; Phaal et al., 2004; Walsh, 2004). These publications operate mostly in the microeconomics frame, rather than with a broader societal vantage point that appears more prominent in the ET literature. Finally, one of the research frontiers takes an organizational and business model view. This would include the work of O'Reilly and Tushman (2004), Christensen and Overdorf (2000), Adner (2002) and Johnson et al. (2008).

Similar analysis of bibliographic coupling of the literature related to ET is presented in Fig. 8 and Table 9. This shows scattered research fronts, high in domain-specific case studies and low in theoretical development of the emergence concept. [This is the case despite our limiting the dataset to social science and humanities in WOS.] Looking at Fig. 8, none of the cluster labels suggests developing ET theory, with a possible exception of technology roadmapping.

Table 9 provides the largest ten clusters, which could reveal the research fronts on ET over the past two decades. The main finding in Fig. 8 and Table 9 is the link between ET and DT, which has been lacking from prior findings. Ahuja and Lampert (2001), implicitly, and Veryzer (1998), explicitly, refer to disruptions of discontinuities. In the work of Ahuja and Lampert (2001) the authors focus on breakthrough invention, arguing that experimentation with technologies that emerge offers a tool to create breakthrough inventions. The authors subsequently connect such inventions with literature on discontinuities (within their references). Veryzer (1998) draws from the broad literature on new product development and focuses on highlighting the necessity of formal processes in managing discontinuities in the new product development process and handling of, what the author names, emerging technologies.

Besides the significant differences in such clustered themes and high centrality nodes, the results of bibliographic coupling on ET are much more diversified than those for DT and DI, and more concrete technologies (e.g. *Nanomedicine*, *pervasive computing, synthetic biology* and *solar photovoltaic* etc.) are mentioned by the relevant literature. Meanwhile, such issues as risk assessment, anticipatory governance, and sustainable governance also differ from the research fronts of DT and DI. Of course, some common interest or methodology also can be found between ET and DT & DI, for example, human/consumer behavior, case study and empirical analysis are favorite issues or methods of all these domains.

5. Discussion and limitations

Disruptiveness in technological development and the creation of successful innovation are complex phenomena (Danneels, 2004). Re-examining the contemporary streams of literature in the domain, we gain an in-depth view on the scholarly perception of disruptions together with emergence. Our literature review highlights the overlap

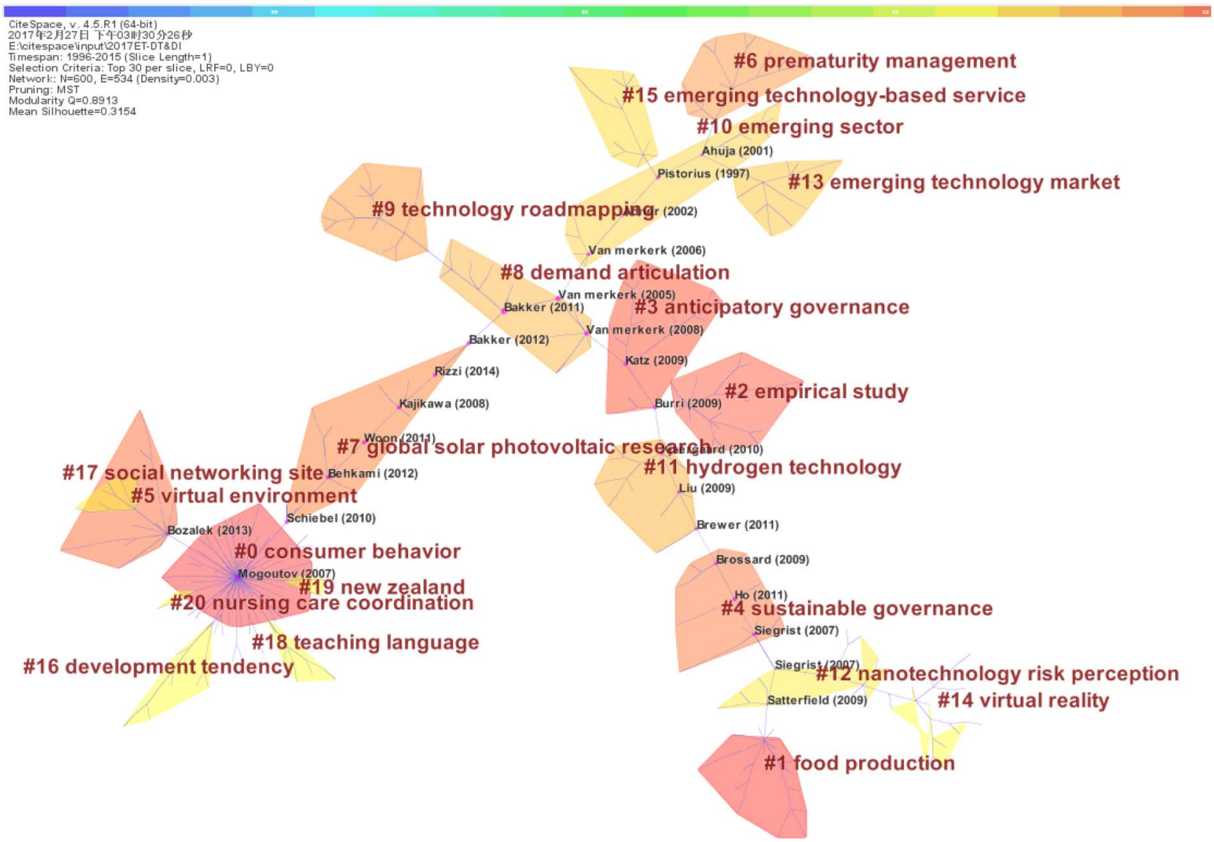

Fig. 8. Bibliographic coupling of the literature related to emerging technology retrieved by the Rule 1 in the Table 2.

between the concepts, such as novelty, defining both disruption and emergence. This emphasizes the need to understand ET, DT, and DI, specifically as we see emergence being, by volume of articles, dominant and the concept of disruption relatively late-coming.

Markides (2006) pointed towards the conceptual ambiguity and possibly inaccurate use of DT. Our findings on ET highlight the lack of theoretical orientation in research concerning technological emergence. The findings in this study contribute on several aspects to our current understanding. First, the ambidextrous usages of ET and DT in the academic literature are significant and almost any new technology could be called emerging and/or disruptive, especially in the engineering areas. Even in social science, business, or management, a given technology can be defined both as emerging and disruptive in different articles during the same time-period. This probably stems from the promotional value of labeling something emerging, disruptive or both.

First, in regards to terminology, our study offers several findings. DT is highly relevant in the management literature and it has corporate strategy implications, but seems more suitable for the retrospective studies or case studies—i.e., treating a disruption that has already occurred. DT is increasingly absorbed into the framework of disruptive innovation (Christensen et al., 2015; Christensen and Overdorf, 2000), emphasizing the target disruption's capability to create monetary gains. ET, on the other hand, is often utilized to depict the possibility of a dramatic change and impact on socio-economic systems (Rotolo et al., 2015). An ET could fail over time, or become a generalized technology, or even a disruptive technology. It is clear that there exists an evolving relationship between ET and DT. Our results suggest that in regard to terminology the conceptual difference is driven by disciplinary focuses rather than thematic emphases.

Second, in mapping the contemporaneous literature, the study found a few direct links between the academic communities related to ET and DT. For example, the theory of innovation economics (e.g., Nelson, Dosi, etc.) connects the research on ET and S & T policy with the community writing about DT and DI. We can also envision the community of social communication through risk analysis of ET or the development of a specific ET (e.g., nanotechnology) linking it to DT. However, the results of our analysis did not suggest a theory-based link between the concepts, rather a separation where DT focuses on microeconomics and ET incorporates a strong presence of social aspects.

Third, through co-citation analysis, the intellectual base of ET appears to be more interdisciplinary than the related topics of DT and DI. ET involves links to topics such as business, economics, public policy, and communication. From a more topical perspective, bibliographic coupling depicts a similar phenomenon. This similarly emphasizes that the ET concept is more focused on depicting societal challenges with a flare of literature focusing on microeconomics.

Finally, the strong emphasis in the DT research front on theory building, and the lack of similar discussion in ET, suggests that these concepts should be approached differently. DT and DI emerge with relatively rigorous theoretical constructs, with active scientific dialogue concerning conceptual issues. Conceptual emphases seem largely lacking in the ET literature, suggesting it to be an operational, rather than a theoretical arena. This argument is supported by the plethora of case study work and the lack of theory building in the ET literature as we decompose it via co-citation and bibliographic coupling analyses.

Our work draws both theoretical and practical implications. Theoretical implications focus on a call for further research on the frameworks and interconnections of DI, DT and ET. We argue that existing literature shows multiple overlaps between the concepts, but literature seldom draws from similar origins. Albeit that the concept of ET is still in need of significant theory formulation (Suominen and Newman, 2017), while the theory of DI is much more evolved, research should look towards a framework integrating the concept of emergence and disruptions. As a research agenda, future studies should look towards conceptual interpretation, going beyond operationalization

Table 9
Top 10 largest clusters in Fig. 8.

ID	Size	Silhouette	Top terms (tf*idf weighting)	Top terms (Log-Likelihood Ratio, p-value)
#0	89	0.992	Modeling | functions	Consumer behavior (258.96, 1.0E − 4); health technology assessment (219.38, 1.0E − 4); private payers coverage (219.38, 1.0E − 4);
#1	29	0.991	Competitiveness | risk assessment	Food production (318.51, 1.0E − 4); nanotechnology concern (191.76, 1.0E − 4); emerging Nano medicine (185.11, 1.0E − 4);
#2	28	0.994	Case | nanoproducts	Empirical study (190.48, 1.0E − 4); critical theory (177.44, 1.0E − 4); funding success (171.07, 1.0E − 4);
#3	28	0.936	Personalisation behavior | critical assessment	anticipatory governance (358.2, 1.0E − 4); synthetic biology (344.8, 1.0E − 4); fourth amendment (271.31, 1.0E − 4);
#4	26	0.959	Benefit perceptions	Sustainable governance (192.18, 1.0E − 4); public eye (172.2, 1.0E − 4); developing country (172.2, 1.0E − 4);
#5	26	0.985	Pervasive computing | education	Virtual environment (189.99, 1.0E − 4); second life (189.99, 1.0E − 4); clinical skill competency (164.55, 1.0E − s4);
#6	25	0.96	Antecedents | exploring health information technology innovativeness	Prematurity management (163.99, 1.0E − 4); parental perception (163.99, 1.0E − 4); Canadian hospital (157.4, 1.0E − 4);
#7	25	0.95	Citation network analysis	Global solar photovoltaic research (169.75, 1.0E − 4); non-silicon material (169.75, 1.0E − 4); using patent (162.93, 1.0E − 4);
#8	25	0.931	Emerging technologies | risk assessment	Demand articulation (174.03, 1.0E − 4); technological pedagogical content knowledge (161.08, 1.0E − 4); technology integration self-efficacy (161.08, 1.0E − 4);
#9	25	0.971	German	Technology roadmapping (179.16, 1.0E − 4); international collaboration (159.88, 1.0E − 4); developing nanomedicine (159.88, 1.0E − 4);

interests, within the ET community, to explore fit to frameworks of disruptive potential of an innovation. This would have clear implications in the strategy driven DT and DI community. On the other hand, literature on disruptive innovation could gain from departing from the management orientation to embed societal factors. As a case in point, literature on ET risk perception and governance, which is an important issue of social communication and anticipatory governance, but also could be integrated into entrepreneurship theory and practice, or technological opportunities analysis for established industries and enterprises.

As practical implications, our work strives to focus the attention of managers talking about disruptions and policy makers focusing on emergence to find common ground at the intersection of the concepts. A case in point could be 3D printing technology, considered as a typical ET due to its radical impact on the traditional manufacturing process. The derived ecosystem of its relevant products has been gradually emerging, (e.g., nanomaterial for 3D printing, specific software and hardware, training and consultant programs) (Bruck et al., 2016; Laplume et al., 2016). However, the mode for personal or family production could be a typical low-end market, compared to traditional mass production, and 3D printing could be considered a DT or a critical technological factor of DI (Berman, 2012; Delvenne and Vigneron, 2015). Complex technologies such as this have potential for significant societal and microeconomic implications, calling for broad-based studies on their capability of disruption beyond the corporate world.

We acknowledge that this article has limitations. The retrieval rules used to create the dataset have been created through a trial-and-error process and it is certainly possible that the search string omits relevant literature. However, tests with different search terms suggest that this is not severe and that the data represent the fields of ET and DT adequately. The clustering algorithm treats phrases extracted from the titles of article references and within the sample articles by Natural Language Processing. This creates an automated labeling system and we can question if these labels agree with human classification. The authors have made efforts to manually inspect core documents and labels of clusters and check the machine created labels. In addition, the *CiteSpace* software is widely adopted in the field of bibliometrics, supporting its use as an analytical tool. Finally, the interpretive steps taken following the bibliometric analysis are subjective in nature. If done by someone else, these could yield different results. We trust that provision of the clustering visualizations along with complementary details in the tables allow the reader to assess whether our interpretations appear valid.

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