PhD Doctorate in "Economics, Management and Statistics"

XXXIII Cycle

University of Messina

Knowledge recombination, external collaborations and firms' innovative capabilities

PhD Candidate:
Alessia Donato

Tutor:
Prof. Fabrizio Cesaroni

Cotutor:
Prof. Daniela Baglieri

Academic Year 2019/2020

to Vittorio Morello.
Poet, writer, music critic, lawyer, grandfather.
14 December 1921 - 21 August 2020.

Acknowledgments

I wish to thank:

Professor F. Cesaroni, for guiding me on this long journey.
Professor F. P. Appio, for sharing his experience in the field with me.
Professor D. Baglieri and the entire management section of the University of Messina, for the interesting meetings organized periodically.
The scientific staff and the participants of the *R&D Management Conference 2019* for the advice on my work.
Two anonymous referees of *Strategic Management Journal*, for contributing to the substantial improvement of my research.
Professor D. Carfì, for the interesting discussions.
Two anonymous referees for the suggestions in reviewing my thesis.

Contents

Chapter 0

Preface

The technological field of silica aerogel has caught the attention, in the last years, of many firms, which have, therefore, invested in the development and application of this nanotechnology. In our study, we examine this field of research - which has seen a drastic increase in the number of published patents - with a patents analysis. Because patents are correlated with the innovation activity they can indicate innovations. The main goal is the search of characteristics of innovations that can increase the possibility of determining success and creating value for the firms. We consider specifically the possibility of creating successful innovations through the recombination of different knowledge.

0.1 Structure of the thesis

In the first chapter, we propose an examination of the current literature on innovation, taking into account, specifically, the concept of knowledge diversity and knowledge recombination. The analysis of recent trends tend to consider the value of innovations related to the ability of creating novelty in the combination of knowledge. This novelty could be developed by the firm itself, "exploiting untapped knowledge synergies" (Karim and Kaul, 2015) through the structural recombination of business units within the firm or exploring external knowledge and integrating it with in-house knowledge, or could be the product of an integrated collaboration networks.

The second chapter is the corner stone of the entire thesis and it contains all our theoretical premises that allow us to answer our research questions and to apply and verify our assumptions. In other terms, in chapter 2 we introduce the fundamental theoretical and methodological architectures of all our scientific research that could be synthesized as:

- consideration of set of patents in technological areas;
- consideration of possibility to recombine different knowledge;
- existence of indexes that measure the recombination of different knowledge and the novelty in the recombination;
- understand if the introduction of scientific knowledge brings in the arena innovations that reveal successful.

In the third chapter, we analyze if the quality of an innovation and its market value is positively associated to the firm' ability of creating innovations through recombination of knowledges and how the value of innovations changes in case of firm' collaboration with other partners. We explicitly distinguish collaborations between firms and scientific partners, firms that operate in the same sector and firms that operate in different technological sectors.

In the fourth chapter we analyze the effect, in the relationship between the firms' technological diversification and the innovation performance outcomes, of the use of scientific knowledge in the development of patented inventions. This analysis has been, therefore, conducted at firm level.

In the fifth chapter we propose the conclusions of the thesis, with an analysis of the contribution to the existing literature and of possible practical implications.

Finally, we propose an Appendix 1 with the original algorithms written for deriving some technological characteristics of the sample in thesis' chapter 2 and the Appendix 2 with all the patents analyzed in chapter 2, in order to assess reference for future studies.

Chapter 1

The search of new knowledge in the firm's innovation process: a literature review

Abstract. We propose an examination of the current literature on innovation, taking into account, specifically, the concept of knowledge diversity and knowledge recombination. We analyze bibliometric data using the software VOSviewer and we derive indications on the principle analyzed research fields, where they come from and in what directions they are going.

Keywords: co-citation analysis, keywords co-occurrence analysis, citation analysis, knowledge recombination, knowledge creation.

1.1 Introduction

Innovation is essential for the survival, economic growth and success of a firm. Moreover, according to the knowledge-based theory, successful firms are those that continuously create new knowledge thanks to which they are able to produce new technologies and products and continuously innovate, obtaining competitive advantages on the market. The search of new knowledge is, therefore, an activity strongly sought by the firms.

In this chapter, we provide a review of the existing literature on innovation, taking into account specifically the recent concept of "knowledge recombination". This literature review is needed because the field of innovation and management of knowledge is very large and requires an analysis of different concepts that should be considered together in order to find all the possible connections and evolutions between the different research areas. At this aim, the bibliometric analysis with the Vosviewer software allows to analyze a lot of bibliometric data providing results of easy interpretation, thanks to the creation of visualization maps, without the need to possess a deep knowledge of clustering techniques.

Particularly, based on a co-citation analysis - at the level of cited references - we will enumerate the principal managerial theories that represent the scientific background from which our examination starts. Based on a co-occurrence analysis - at the level of keywords - we will determine the principal fields of research and how they are connected. Finally, based on a citation analysis - at the level of documents - we will suggest the future research directions on the search of new knowledge in the firms' innovation process.

1.2 Methodology

In this chapter, we propose three different analysis and we present the maps created by the software VOSviewer (version 1.6.15 – see Van Eck & Waltman, 2010), displayed in different ways according to the different aspects we want to emphasize. Specifically, we present a keyword co-occurrence map, a co-citation map, and a citation-map.

The first map shows connections between keywords that appear together in the same document, the co-citation map shows connections between references that are both cited by the same document while the citation map shows connections between documents.

Bibliometric data have been extracted from the *Web of Science Core Collection* [1]. We search for terms such as 'knowledge recombination', 'technological diversification', 'scientific diversification', 'knowledge diversification' or 'breakthrough inventions' in documents' title, abstract or keywords, considering no restriction on the years of publication. The results of the search contain 674 documents (articles, conference proceedings, book chapters and book). Figure 1.1 shows the total of the publications grouped by year and figure 1.2 show the sum of times the publications have been cited per year.

[1] The search of documents could be replicated using the command line TOPIC: ("breakthrough inventio∗" OR "knowledge recombination" OR "knowledge divers∗" OR "scien∗ divers∗" OR "technological divers∗") Refined by: DOCUMENT TYPES: (ARTICLE OR PROCEEDINGS PAPER OR BOOK CHAPTER) Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI. Data have been extracted on September 12, 2020.

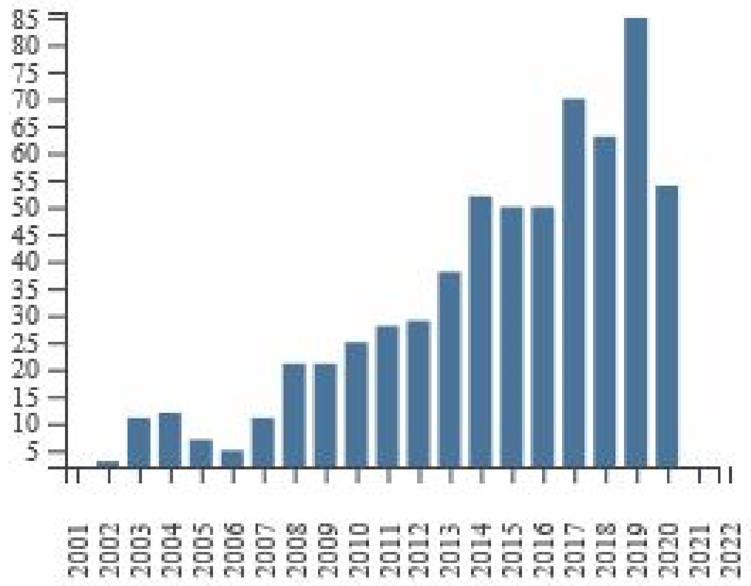

Figure 1.1: Total publication by year

1.3 Results

1.3.1 Clustered and chronological analysis of keyword co-occurrence

In the first analysis, items are keywords, related with co-occurrence links. The *strength* of each link indicates the number of publications in which two keywords occur together. The *weight* of a keyword represents its importance and keywords with a higher weight are shown more prominently than others. The distance between two keywords indicates their relatedness in terms of co-occurrence links. Every keyword may belong to only one cluster and every cluster is represented by a different color.

We here present two types of different visualization of the analysis based on keywords co-occurrence, that are the network visualization

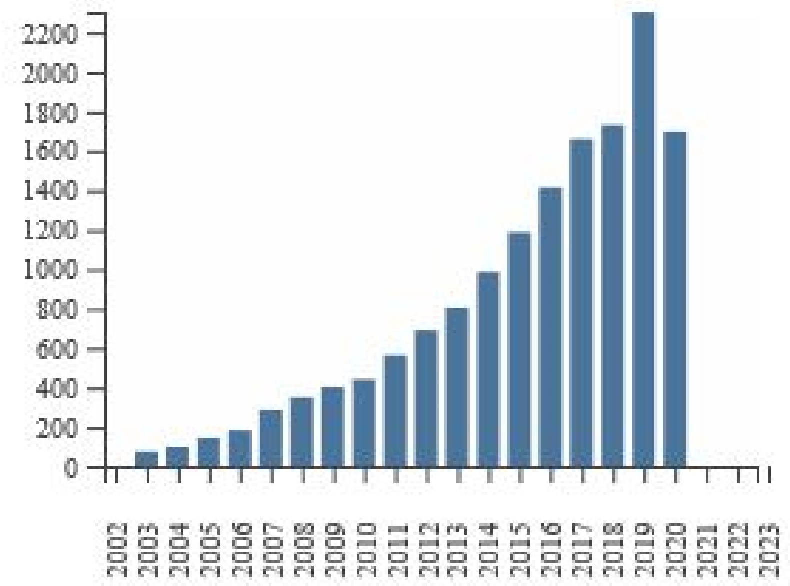

Figure 1.2: Sum of times cited by year

and the overlay visualization. As we can see in figures 1.3 and 1.4, the two visualization are identical except that keywords are colored in a different way. In the network visualization keywords are grouped in clusters of different colors, while in the overlay visualization keywords are colored based on the average publication year of the document in which a keyword occurs. The shape of the network can give us some indications. Generally, items are displayed in the map showing clearly separated and distant areas. Here, instead, the distribution is much more concentrated, with the principal items of different clusters very close to each other, indicating the strong relation between the research topics.

Nevertheless, based on the keyword co-occurrence network visualization, we can distinguish three clusters. We display only keywords with a minimum number of occurrences of 10 times, that are 82 and we have excluded the keyword 'diversity' because of too general meaning.

The most important keywords of the first cluster (in red) are *performance* and *knowledge diversity.* This group includes WoS scientific works that relate the innovation performance of a firm with the *diversity*, understood as *knowledge diversity.* We speak also of *knowledge creation, knowledge transfer, collaboration, networks* and *science* indicating that diversity of knowledge can be obtained through collaborations with external bodies or between subunits of the same firm or through the acquisition of scientific knowledge. This diversity of knowledge can lead to the creation of new knowledge and *impact* for the company.

The most important keywords of the second cluster (in green) are *technological diversification, innovation* and *knowledge.* It contains works that study the technological diversification of *firms* in relation to innovation and *growth*, determining suggestions on the type of strategy that a company should adopt (*specialization* or *diversification*). Moreover, it is studied the role of *knowledge recombination* and *relatedness* - i.e diversify across related technological fields (see Breschi et al., 2003). This type of study analyzes *patents*, mainly *patent citations* and determines development of technological *indicators.*

The most important keywords of the third cluster (in blue) are *absorptive capacity, R&D, exploration, capabilities* and *performance.* It includes works that link firm's *innovation performance* with absorptive capacity and that defined characteristics that influence this capacity (*R&D* activity, *exploration, exploitation, technological diversity, strategic alliances*).

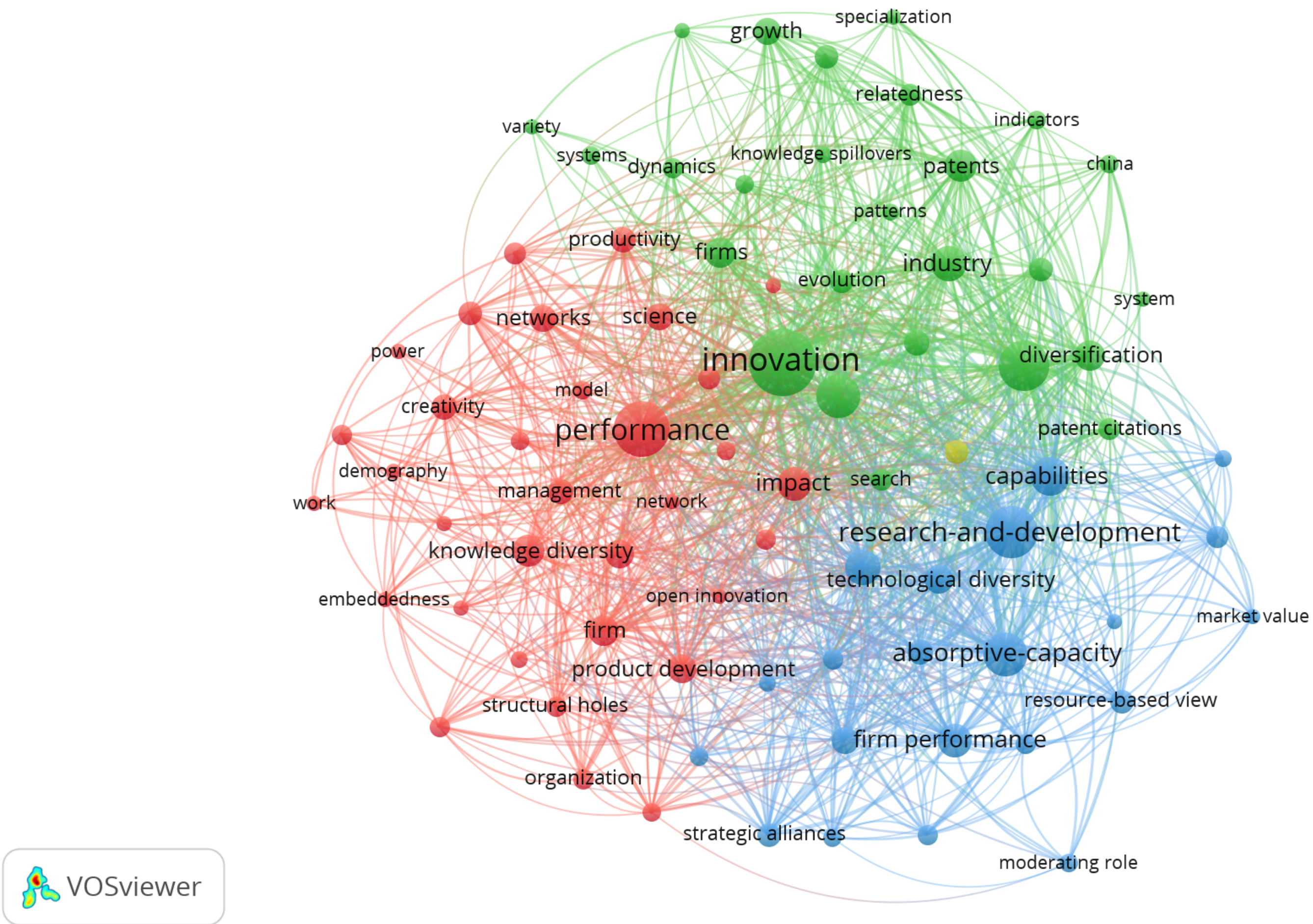

Figure 1.3: Keyword network clustering results

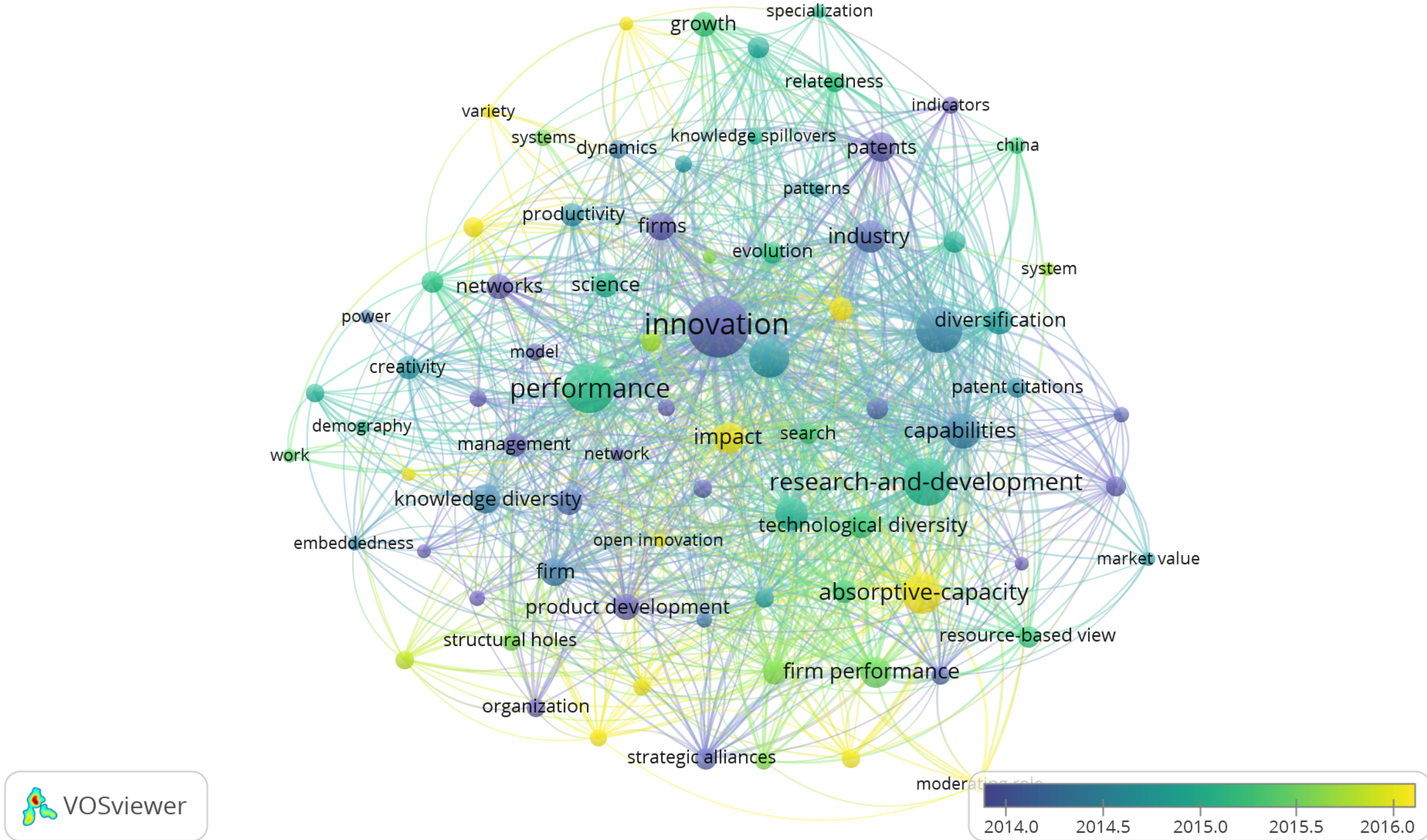

Figure 1.4: Overlay visualization for chronological analysis of keywords

So, we can distinguish three very related fields: ‘knowledge diversity’, ‘technological diversification’ and ‘absorptive capacity’.

An analysis of the overlay visualization, that shows keywords differently colored according to the average year of keyword occurrence, suggests that the more recent branch of research tends to consider *innovation performance* as influenced by *collaboration networks, absorptive capacity* and *knowledge recombination* ability (see figure 1.5).

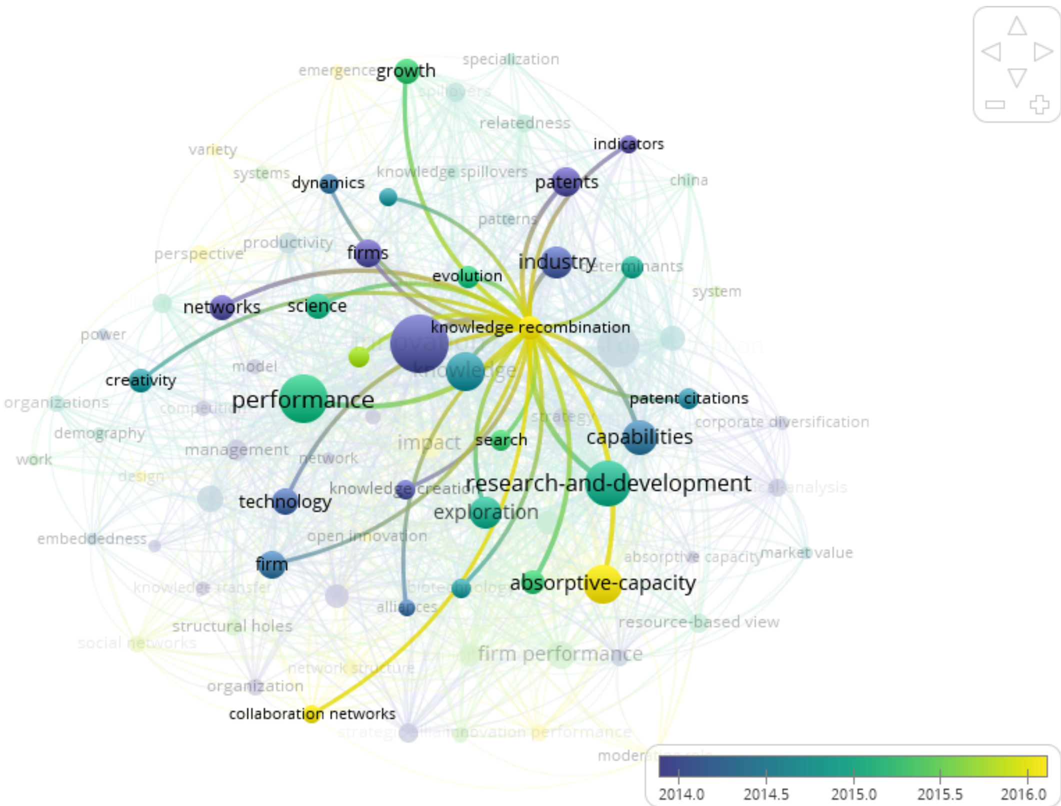

Figure 1.5: Particular of the overlay visualization

Indeed, networking is central to the innovation process, then the ability to network, i.e. making use of external knowledge, using partners to access complementary assets and managing the producer/user relations, is a crucial capability.

So, key competencies are necessary, as well as competencies in reorienting them, transforming them and integrating them with external complementary resources and assets.

1.3.2 Clustered analysis of references co-citation

In the second analysis, we construct a co-citation map at the level of cited references. Items are references, related with co-citation links that indicate connections with other references cited by the same document. Also in this case, we present the network visualization (fig. 1.6), where the cited references are grouped in clusters[2].

The bigger items in the map, representing the more cited references, give indications on the principal managerial theories used as theoretical background.

We can observe two clusters near each other (red and green) and a distant cluster (blue). The red cluster refers to literature such as Cohen and Levinthal (1990), Kogut and Zander (1992), and Zahra and George (2002), the green cluster refers to literature such as Nelson and Winter (1982), March (1991), Fleming (2001), Rosenkopf and Nerkar (2001), Ahuja and Lampert (2001) and the blue cluster refers to literature such as Granstrand (1998), Gambardella and Torrisi (1998), Breschi et al. (2003), Garcia-Vega and (2006), Leten et al. (2007).

It is easy to associate the first cluster (red) with the cluster that refers to the 'absorptive capacity' in the precedent keyword clustered

[2]For reasons of replicability, we report the setting parameters to generate the network visualization in VOSviewer: *Normalization method*: Association strength; *Layout values (Attraction vs Repulsion)*: default attraction and repulsion values; *Clustering values*: Resolution = 1.00, Minimum cluster size = 1.

analysis. Indeed, in 1990, Cohen and Levinthal introduce for the first time the concept of absorptive capacity (*"a firm's ability to recognize the value of new, external information, assimilate it, and apply it to commercial ends"*), considering this ability as fundamental for the firm innovation activity.

Later, Zahra and George (2002) distinguish 'potential' absorptive capacity and 'realized' absorptive capacity, suggesting that both together are essential for the development of firm's competitive advantage in the market.

The green cluster can be associated with the 'knowledge diversity' concept and refers to the *knowledge-based theory*.

According to the *knowledge-based theory of the firm*, the *knowledge* reveals the most strategically significant resource of a firm. Successful firms are those that continuously create new knowledge, by which they are able to produce new technologies and products. The "knowledge-creating" firm has the sole purpose of continuous innovation.

Katila and Ahuja (2002) argue that firm creates new knowledge in two ways: reusing its existing knowledge and exploring new knowledge. Also March (1991) considers the relation between the "exploration of new possibilities and the exploitation of old certainties in organizational learning".

Some recent studies show an increasingly difficult for firms to create and exploit technological capabilities on their own and becomes increasingly common for firms and organizations to acquire and use external sources of knowledge and technology. Indeed, Rosenkopf and

Nerkar (2001) affirm that *"to move beyond local search requires that exploration span some boundary"*.

There exist also some difficulties and uncertainties in the firms search for new knowledge. For instance, the dependence upon the initial capabilities of the company, when a process of creating new knowledge is triggered. Indeed *"the existing capabilities of the firm will likely dictate the direction in which the firm moves"* (Kogut and Zander, 1992).

And, also, the technological uncertainty that derives when *"inventors' search processes with unfamiliar components and component combinations"* (Fleming, 2001). Indeed, it is not so clear to understand how different knowledges deriving from external search could be integrated for develop success.

Nevertheless, experimenting with *novel, emerging and pioneering* technologies can help to improve the probability of creating breakthrough inventions (Ahuja and Lampert, 2001).

The blue cluster can be associated with the 'technological diversification' concept and refers to the theory of *technology-based firm.*

This theory was born in 1998 with Granstrand's article "Towards a theory of the technology-based firm", where he explored the phenomenon of firm-level technological diversification finding the positive relation with business diversification. The same result was confirmed by Gambardella and Torrisi (1998) in their analysis on electronics firms.

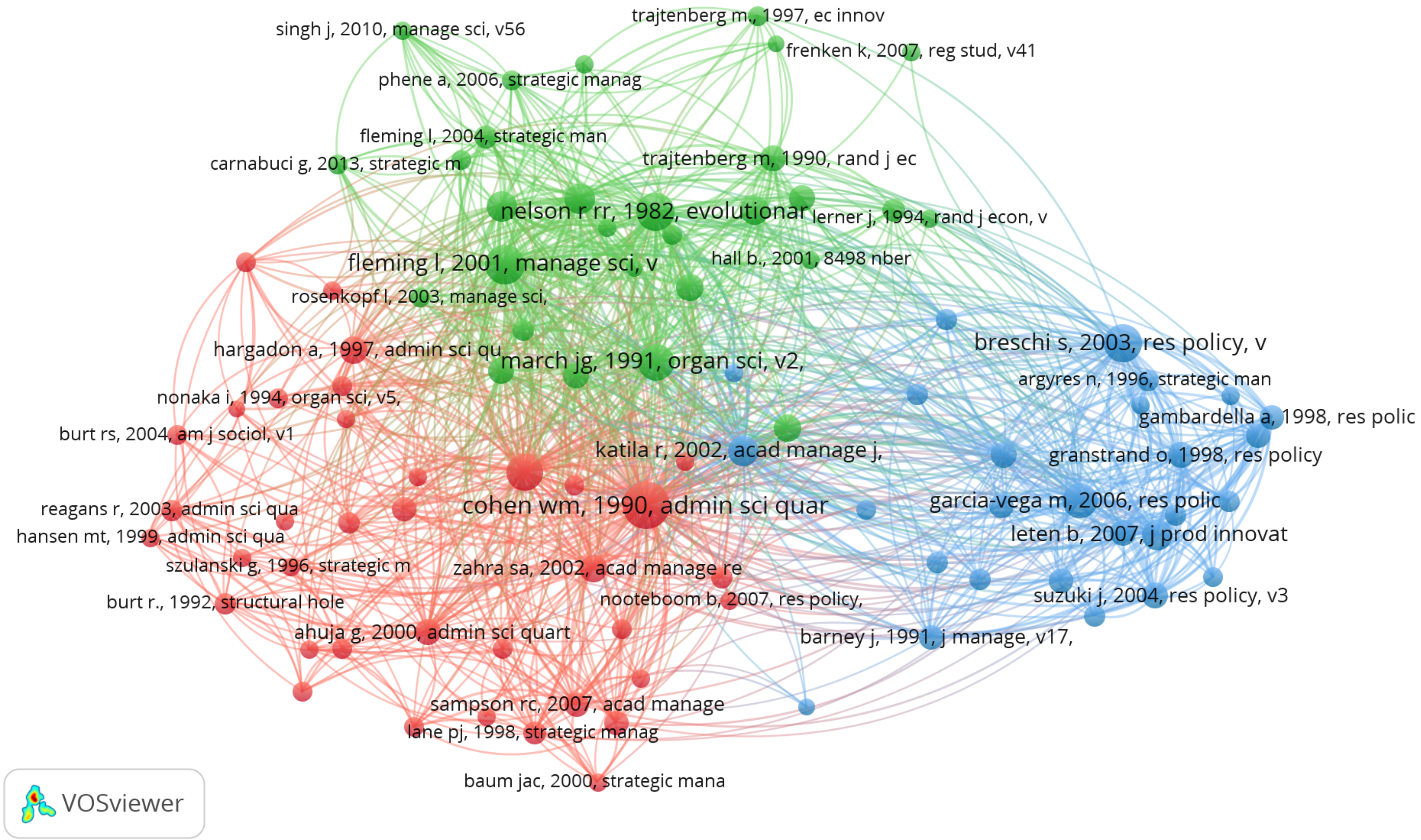

Figure 1.6: Co-citation network clustering result

Then several authors explored the impact of technological diversification on financial performance (Miller, 2006) or on innovative activity (Garcia-Vega, 2006; Leten et al., 2007), suggesting that diversification is essential for a survival of technology-based firms (Suzuki and Kodama, 2004) and the positive impact of diversification across fields with common knowledge base (knowledge relatedness) in the firm's innovation activity (Breschi et al. 2003). Moreover, technological diversity may *"mitigate core rigidities and path dependencies by enhancing novel solutions"* (Quintana-Garcia and Benavides-Velasco, 2008).

Despite this evidence, a high level of diversification *"may yield few marginal benefits"* (Leten 2007).

1.3.3 Chronological analysis of the document's citations

In the third analysis, we construct a citation map at the level of documents. Items are documents, related with connections of citations between documents. In this case, we present the overlay visualization (fig. 1.7), where the documents are colored according to their year of publication. We display only documents with a minimum number of 20 citations and that are related at least with one other document, that are 75.

Thanks to this type of analysis, we can visualize the new research directions, represented by the yellow items in the map (fig. 1.7) and that we discuss in the following section.

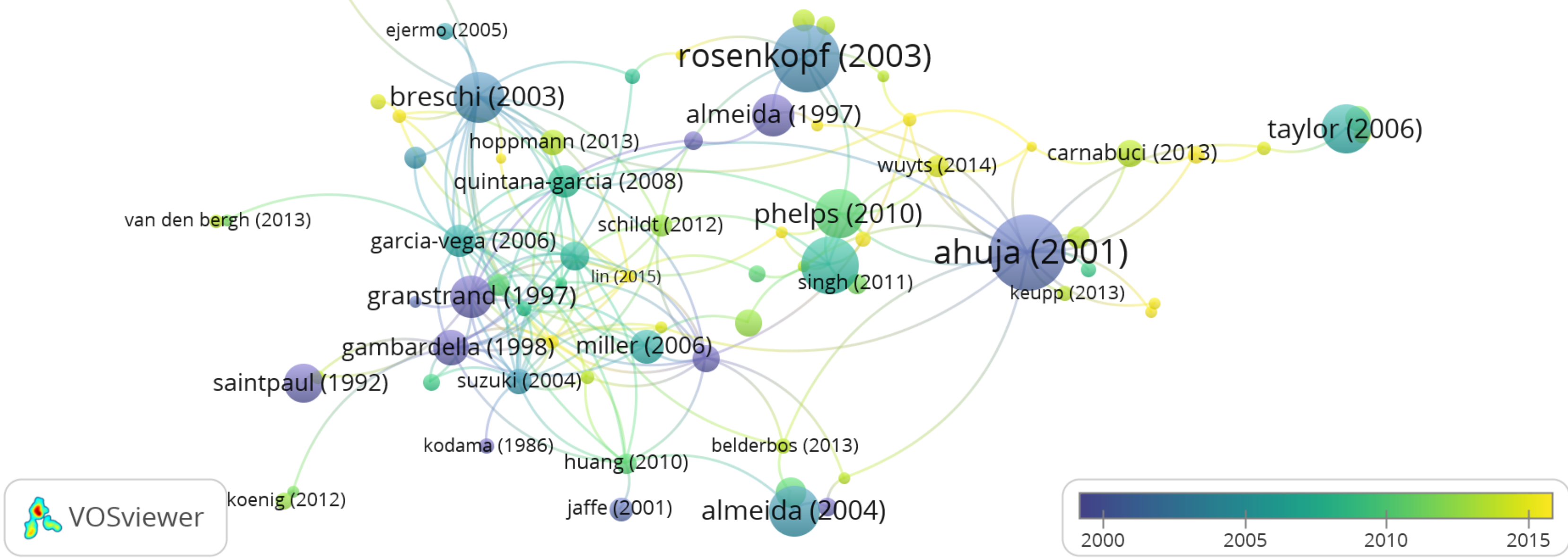

Figure 1.7: Overlay visualization for chronological analysis of documents

1.4 Discussion: new research directions

The first direction investigates the innovation among emerging market firms based on the knowledge recombination view. Corredoira and McDermott (2014) explored the important role of organizational and institutional networks in helping local firms to integrate imported advanced knowledge with local knowledge, while Xie and Li (2018) examined the moderating role of institutional development of a firm's home region.

Another direction starts from the concept of firm' *recombinant creation* ability – that is the ability to create technological combinations new to the firm (Carnabuci and Operti, 2013) - and evolved with its extension to the level of single invention instead of firm.

Indeed, it is now common consider an invention as 'novel' if it develops a new combination of technological knowledge respect to all the precedent inventions. Arts and Veugelers (2015), according to this view, found that recombine *familiar* components in unprecedent ways increase the probability to create useful and breakthrough inventions.

Finally, Jung and Jeongsik (2016) consider the direction of the exploration of external knowledge, finding that successful inventions are generated more frequently when firms search original knowledge and incorporate it into internal R&D.

1.5 Conclusions

In this chapter, we have provided a review of the existing literature on innovation, taking into account specifically the recent concept of "knowledge recombination".

Based on a co-occurrence analysis - at the level of keywords - we determined the principal fields of research and how they are connected. Specifically, we have distinguished three very related fields: the 'knowledge diversity', the 'technological diversification' and the 'absorptive capacity'. The shape of the network shows a very concentrated distribution, with the principal items of different clusters very close to each other, indicating the strong relation between the research topics.

Based on a co-citation analysis - at the level of cited references - we enumerated the principal managerial theories that represent the scientific background from which our examination have started. In particular, the 'knowledge diversity' concept refers to the *knowledge-based theory*, the 'technological diversification' concept refers to the theory of *technology-based firm* and the 'absorptive capacity' concept arises from its definition in the work of Cohen and Levinthal (1990).

Finally, based on a citation analysis - at the level of documents - we analyzed the future research directions on the search of new knowledge in the firms' innovation process. The recent trends tend to consider the value of innovations related to the ability of create novelty in the combination of knowledge. This novelty could be developed by the firm itself, "exploiting untapped knowledge synergies" (Karim and Kaul, 2015) through the structural recombination of business units within the firm or exploring external knowledge and integrating it with in-house knowledge, or could be the product of an integrated collaboration networks.

1.6 Appendix: Terms per cluster & Cited references per cluster

1.6.1 Terms per cluster

Cluster 1 (33 items): collaboration; collaboration networks; competition; creativity; demography; design; economics; embeddedness; firm; heterogeneity; impact; information; integration; knowledge creation; knowledge diversity; knowledge transfer; management; model network; networks; open innovation; organization; organizations; performance; perspective; power; product development; productivity; science; social networks; structural holes; technology; work.

Cluster 2 (26 items): china; determinants; diversification; dynamics; emergence; entrepreneurship; evolution; firms; growth; indicators; industry; innovation; knowlegde; knowledge recombination; knowledge spillovers; patent citations; patents; patterns; relatedness; search; specialization; spillovers; system; systems; technological diversification; variety.

Cluster 3 (21 items): absorptive capacity; absorptive-capacity; alliances; biotechnology; capabilities; competitive advantage; corporate diversification; dynamic capabilities; empirical-analysis; exploitation; exploration; firm performance; innovation performance; local search; market value; moderating role; network structure; research-and-development; resource-based view; strategic alliances; technological diversity.

1.6.2 Cited references per cluster

Cluster 1 (37 items):

1. ”ahuja g, 2000, admin sci quart, v45, p425, doi 10.2307/2667105”

2. ”ahuja g, 2001, strategic manage j, v22, p197, doi 10.1002/smj.157”

3. ”baum jac, 2000, strategic manage j, v21, p267, doi 10.1002/(sici)1097-0266(200003)21:3¡267::aid-smj89¿3.0.co;2-8”

4. ”burt r., 1992, structural holes soc”

5. ”burt rs, 2004, am j sociol, v110, p349, doi 10.1086/421787”

6. ”cassiman b, 2006, manage sci, v52, p68, doi 10.1287/mnsc.1050.0470”

7. ”chesbrough h.w., 2003, open innovation new”

8. ”cohen wm, 1990, admin sci quart, v35, p128, doi 10.2307/2393553”

9. ”dyer jh, 1998, acad manage rev, v23, p660, doi 10.2307/259056”

10. ”fleming l, 2007, admin sci quart, v52, p443, doi 10.2189/asqu.52.3.443”

11. ”galunic dc, 1998, strategic manage j, v19, p1193, doi 10.1002/(sici)1097-0266(1998120)19:12¡1193::aid-smj5¿3.3.co;2-6”

12. ”granovetter ms, 1973, am j sociol, v78, p1360, doi 10.1086/225469”

13. ”grant rm, 1996, organ sci, v7, p375, doi 10.1287/orsc.7.4.375”

14. ”grant rm, 1996, strategic manage j, v17, p109, doi 10.1002/smj.4250171110”

15. ”hansen mt, 1999, admin sci quart, v44, p82, doi 10.2307/2667032”

16. ”hargadon a, 1997, admin sci quart, v42, p716, doi 10.2307/2393655”

17. ”henderson r, 1994, strategic manage j, v15, p63, doi 10.1002/smj.4250150906”

18. ”kogut b, 1992, organ sci, v3, p383, doi 10.1287/orsc.3.3.383”

19. ”lane pj, 1998, strategic manage j, v19, p461, doi 10.1002/(sici)1097-0266(199805)19:5¡461::aid-smj953¿3.0.co;2-l”

20. ”laursen k, 2006, strategic manage j, v27, p131, doi 10.1002/smj.507”

21. ”levitt b, 1988, annu rev sociol, v14, p319, doi 10.1146/annurev.so.14.080188.001535”

22. ”mowery dc, 1996, strategic manage j, v17, p77, doi 10.1002/smj.4250171108”

23. ”nahapiet j, 1998, acad manage rev, v23, p242, doi 10.2307/259373”

24. ”nerkar a, 2005, manage sci, v51, p771,
doi 10.1287/mnsc.1040.0354”

25. ”nonaka i, 1994, organ sci, v5, p14,
doi 10.1287/orsc.5.1.14”

26. ”nooteboom b, 2007, res policy, v36, p1016,
doi 10.1016/j.respol.2007.04.003”

27. ”phelps cc, 2010, acad manage j, v53, p890,
doi 10.5465/amj.2010.52814627”

28. ”powell ww, 1996, admin sci quart, v41, p116,
doi 10.2307/2393988”

29. ”reagans r, 2003, admin sci quart, v48, p240,
doi 10.2307/3556658”

30. ”rodan s, 2004, strategic manage j, v25, p541,
doi 10.1002/smj.398”

31. ”sampson rc, 2007, acad manage j, v50, p364”

32. ”schilling ma, 2007, manage sci, v53, p1113,
doi 10.1287/mnsc.1060.0624”

33. ”stuart te, 2000, strategic manage j, v21, p791,
doi 10.1002/1097-0266(200008)21:8¡791::aid-smj121¿3.0.co;2-k”

34. ”szulanski g, 1996, strategic manage j, v17, p27,
doi 10.1002/smj.4250171105”

35. ”tsai wp, 2001, acad manage j, v44, p996,
doi 10.2307/3069443”

36. ”yayavaram s, 2008, admin sci quart, v53, p333, doi 10.2189/asqu.53.2.333”

37. ”zahra sa, 2002, acad manage rev, v27, p185, doi 10.2307/4134351”

Cluster 2 (29 items):

1. ”ahuja g, 2001, strategic manage j, v22, p521, doi 10.1002/smj.176”

2. ”carnabuci g, 2013, strategic manage j, v34, p1591, doi 10.1002/smj.2084”

3. ”dosi g, 1982, res policy, v11, p147, doi 10.1016/0048-7333(82)90016-6”

4. ”fleming l, 2001, manage sci, v47, p117, doi 10.1287/mnsc.47.1.117.10671”

5. ”fleming l, 2001, res policy, v30, p1019, doi 10.1016/s0048-7333(00)00135-9”

6. ”fleming l, 2004, strategic manage j, v25, p909, doi 10.1002/smj.384”

7. ”frenken k, 2007, reg stud, v41, p685, doi 10.1080/00343400601120296”

8. ”griliches z, 1990, j econ lit, v28, p1661, doi 10.3386/w3301”

9. ”hall b., 2001, 8498 nber”

10. ”hall bh, 2005, rand j econ, v36, p16”

11. ”harhoff d, 1999, rev econ stat, v81, p511, doi 10.1162/003465399558265”

12. ”henderson rm, 1990, admin sci quart, v35, p9, doi 10.2307/2393549”

13. ”jaffe ab, 1986, am econ rev, v76, p984”

14. ”jaffe ab, 1993, q j econ, v108, p577, doi 10.2307/2118401”

15. ”kaplan s, 2015, strategic manage j, v36, p1435, doi 10.1002/smj.2294”

16. ”lerner j, 1994, rand j econ, v25, p319, doi 10.2307/2555833”

17. ”levinthal da, 1993, strategic manage j, v14, p95, doi 10.1002/smj.4250141009”

18. ”march jg, 1991, organ sci, v2, p71, doi 10.1287/orsc.2.1.71”

19. ”miller dj, 2007, acad manage j, v50, p308, doi 10.2307/20159856”

20. ”nelson r rr, 1982, evolutionary theory”

21. ”phene a, 2006, strategic manage j, v27, p369, doi 10.1002/smj.522”

22. ”rosenkopf l, 2001, strategic manage j, v22, p287, doi 10.1002/smj.160”

23. ”rosenkopf l, 2003, manage sci, v49, p751, doi 10.1287/mnsc.49.6.751.16026”

24. ”singh j, 2010, manage sci, v56, p41, doi 10.1287/mnsc.1090.1072”

25. ”sorensen jb, 2000, admin sci quart, v45, p81, doi 10.2307/2666980”

26. ”stuart te, 1996, strategic manage j, v17, p21”

27. ”trajtenberg m, 1990, rand j econ, v21, p172, doi 10.2307/2555502”

28. ”trajtenberg m., 1997, ec innovation new te, v5, p19, doi 10.1080/10438599700000006”

29. ”tushman ml, 1986, admin sci quart, v31, p439, doi 10.2307/2392832”

Cluster 3 (27 items):

1. ”argyres n, 1996, strategic manage j, v17, p395, doi 10.1002/(sici)1097-0266(199605)17:5¡395::aid-smj826¿3.0.co;2-e”

2. ”barney j, 1991, j manage, v17, p99, doi 10.1177/014920639101700108”

3. ”breschi s, 2003, res policy, v32, p69, doi 10.1016/s0048-7333(02)00004-5”

4. ”cantwell j, 2000, ind corp change, v9, p21, doi 10.1093/icc/9.1.21”

5. ”chiu yc, 2008, technol forecast soc, v75, p875, doi 10.1016/j.techfore.2007.07.003”

6. ”cohen wm, 1989, econ j, v99, p569,
doi 10.2307/2233763”

7. ”cyert r.m., 1963, behav theory firm”

8. ”gambardella a, 1998, res policy, v27, p445,
doi 10.1016/s0048-7333(98)00062-6”

9. ”garcia-vega m, 2006, res policy, v35, p230,
doi 10.1016/j.respol.2005.09.006”

10. ”granstrand o, 1994, ieee t eng manage, v41, p355,
doi 10.1109/17.364559”

11. ”granstrand o, 1997, calif manage rev, v39, p8,
doi 10.2307/41165908”

12. ”granstrand o, 1998, res policy, v27, p465,
doi 10.1016/s0048-7333(98)00067-5”

13. ”henderson r, 1996, rand j econ, v27, p32,
doi 10.2307/2555791”

14. ”huang yf, 2010, technovation, v30, p420,
doi 10.1016/j.technovation.2010.01.004”

15. ”katila r, 2002, acad manage j, v45, p1183,
doi 10.2307/3069433”

16. ”leonardbarton d, 1992, strategic manage j, v13, p111,
doi 10.1002/smj.4250131009”

17. ”leten b, 2007, j prod innovat manag, v24, p567,
doi 10.1111/j.1540-5885.2007.00272.x”

18. ”lin bw, 2006, ieee t eng manage, v53, p17, doi 10.1109/tem.2005.861813”

19. ”miller dj, 2006, strategic manage j, v27, p601, doi 10.1002/smj.533”

20. ”palepu k, 1985, strategic manage j, v6, p239, doi 10.1002/smj.4250060305”

21. ”patel p, 1997, res policy, v26, p141, doi 10.1016/s0048-7333(97)00005-x”

22. ”penros e et, 1959, theory growth firm”

23. ”quintana-garcia c, 2008, res policy, v37, p492, doi 10.1016/j.respol.2007.12.002”

24. ”rothaermel ft, 2004, strategic manage j, v25, p201, doi 10.1002/smj.376”

25. ”suzuki j, 2004, res policy, v33, p531, doi 10.1016/j.respol.2003.10.005”

26. ”teece dj, 1986, res policy, v15, p285, doi 10.1016/0048-7333(86)90027-2”

27. ”teece dj, 1997, strategic manage j, v18, p509, doi 10.1002/(sici)1097-0266(199708)18:7¡509::aid-smj882¿3.0.co;2-z”

1.7 References

1. G. Ahuja, C. M. Lampert, 2001. Entrepreneurship in the large corporation: a longitudinal study of how established firms create

breakthrough inventions. Strateg. Manag. J. 22(6-7): 521–543. DOI: 10.1002/smj.176

2. S. Arts, R. Veugelers, 2015. Technology familiarity, recombinant novelty, and breakthrough invention. Industrial and Corporate Change, 24(6): 1215-1246. DOI: 10.1093/icc/dtu029

3. S. Breschi, F. Lissoni, F. Malerba, 2003. Knowledge relatedness in firm technological diversification. Research Policy, 32, pp. 69–87.

4. G. Carnabuci, E. Operti, 2013. Where do firms' recombinant capabilities come from? Intraorganizational networks, knowledge, and firms' ability to innovate through technological recombination. Strat. Mgmt. J. 34: 1591–1613. DOI: 10.1002/smj.2084

5. W. Cohen, D. Levinthal, 1990. Absorptive capacity: a new perspective on learning and innovation, Administrative Science Quarterly, 35, No. 1, pp.128–152.

6. R. A. Corredoira, G. A. McDermott, 2014. Adaptation, bridging and firm upgrading: How non-market institutions and MNCs facilitate knowledge recombination in emerging markets. Journal of International Business Studies, 45(6): 699-722.

7. L. Fleming, 2001. Recombinant uncertainty in technological search. Management Science 47(1): 117-132.

8. A. Gambardella, S. Torrisi, 1998. Does technological convergence imply convergence in markets? Evidence from the electronics industry. Research Policy 27(5): 445-463.

9. M. Garcia-Vega, 2006. Does technological diversification promote innovation? Research Policy, 35, pp. 230–246.

10. O. Granstrand, 1998. Towards a theory of the technologybased firm. Research Policy, 27, pp. 465–489.

11. H. J. Jung, L. Jeongsik, 2016. The quest for originality: A new typology of knowledge search and breakthrough inventions. Acad. Management J. 59(5):1725–1753.

12. S. Karim, A. Kaul, 2015. Structural Recombination and Innovation: Unlocking Intraorganizational Knowledge Synergy Through Structural Change. Organization Science, 26(2): 439-455.

13. R. Katila, G. Ahuja, 2002. Something old, something new: A longitudinal study of search behavior and new product introduction. Academy of Management Journal, 45(6), 1183–1194

14. B. Kogut, U. Zander, 1992. Knowledge of the firm, combinative capabilities, and the replication of technology. Organization Science 3(3): 383-397.

15. B. Leten, R. Belderbos, B. Van Looy, 2007. Technological diversification, coherence, and performance of firms. Journal of Product Innovation Management, 24, pp. 567–579.

16. J.G March, 1991. Exploration and Exploitation in Organizational Learning. Organization Science, 2(1), DOI 10.1287/orsc.2.1.71

17. D.J. Miller, 2006. Technological diversity, related diversification, and firm performance. Strategic Management Journal, 27, pp. 601–619.

18. R. R. Nelson, S.G. Winter, 1982. An Evolutionary Theory of Economic Change. Cambridge, MA: Belknap Press.

19. C. Quintana-Garcìa, C. A. Benavides-Velasco, 2008. Innovative competence, exploration and exploitation: The influence of technological diversification. Research Policy, 37, pp. 492–507.

20. L. Rosenkopf, A. Nerkar, 2001. Beyond local search: Boundary-spanning, exploration, and impact in the optical disk industry. Strategic Management Journal, 22: 287-306.

21. J. Suzuki, F. Kodama, 2004. Technological diversity of persistent innovators in Japan. Research Policy, 33, pp. 531–549.

22. N. J. Van Eck, L. Waltman, 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics, 84(2), 523–538.

23. Z. Xie, J. Li, 2018. Exporting and innovating among emerging market firms: The moderating role of institutional development. Journal of International Business Studies, 49(2): 222-245.

24. S. Zahra, G. George, 2002. Absorptive capacity: a review, reconceptualization, and extension, Academy of Management Review, 27(2): 185–203.

Chapter 2

Are technological novel inventions successful? A patent analysis in the silica aerogel sector

Abstract. The technological field of silica aerogel has caught the attention, in the last years, of many firms, which have, therefore, invested in the development and application of this nanotechnology. In our study, we examine this field of research - which has seen a drastic increase in the number of published patents - analyzing all the patents from 2006 to 2018. We here propose an *ex-ante* measure of scientific diversification of a patent indicating the diversity of scientific knowledge sources used as background in the construction of a patent. The empirical findings of this study provide new evidence that the use of different scientific knowledge helps in the generation of novel inventions and improves the ability of create successful inventions. At the same time, as consequence, helps mitigate the risks associated to radical innovation projects that are related to the uncertainty in

obtaining success in the recombination of knowledge across domains. A discussion of managerial implications and drawbacks ends the study.

Keywords: knowledge recombination, technological novelty, scientific diversification, patent analysis.

2.1 Introduction

In the modern economy, innovation is essential for the survival, economic growth and success of a firm; however, in the road to achieve innovation, firms should take in account that uncertainty always exists.

Particularly, accomplishing a radical innovation is a very risky activity, in which earnings can be large but very uncertain. Despite this, many firms invest in trying to develop radical innovations to achieve and maintain competitive advantage.

Radical innovation projects differ from incremental innovation ones mainly in terms of time frame, since the cycles are longer and more unpredictable, with greater uncertainty about resources, while incremental innovations tend to be realized over a shorter time period. Furthermore, they differ in the outcome they want to achieve, in terms of the impact of the new technology/product on the market and the expected benefits.

One of the risks linked to radical innovations (see Keizer and Halman, 2007) is represented by the uncertainty outcome, which is associated with the gap between available and required skills, knowledge and experience.

Usually, some firms focus on core technology and search for innovation following established paths, with less risks thanks to the exploration of fields close to the field of the existing business activities. On the contrary, other firms tend to explore external fields and acquire knowledge from outside in order to develop new and successful products, going to meet greater risks.

It is easy to conject that recombination across domains is in fact the source of the uncertainty because it is unclear whether knowledge from distinct domains can be successfully integrated (see for instance Fleming, 2001).

In this respect, in this work, we desire to show how the increase in the pool of scientific knowledge of a patent's inventors increases the probability of creating successful innovations when recombining knowledges across domains and, therefore, helps mitigate the risks associated to radical innovations.

To do this, we consider a sample of patents concerning a new nanomaterial applied in several technological fields and that would seem to be promising for the development of successful innovations.

Our contribution to the extant literature regards a more comprehensive understanding of the features of patents that may influence the generation of successful inventions.

2.1.1 Theory and background

In trajectories theory, Christensen and others define a radical change as an invention that "launches a new direction in the technology"

(Christensen and Rosenbloom, 1995) and "disrupts or redefines a performance trajectory" (Christensen and Bower, 1996), while an incremental invention "makes progress along established path" (Christensen and Rosenbloom, 1995).

Rosenberg and Nekar (2001, p. 290) argue that a "'radical' exploration builds upon distant technology that resides outside of the firm. The technological subunit utilizes knowledge from a different technological domain and does not obtain that knowledge from other subunits with the firm."

So, in order to get radical innovations, a firm (or, more precisely, a team of inventors) should possess the ability to take knowledge from the outside and use and recombine that knowledge with internal knowledges for create new discoveries. In this respect, some studies associate the characteristic of technological novelty - that is novelty in the recombination of technological domains - to radical innovations (Arthur, 2007; Verhoeven et al, 2016) even though not all technologically novel inventions will result in successful innovations (Fleming, 2001).

Literature shows that by exploring and recombining across technological domains, firms increase the possibility of generating breakthrough inventions (Ahuja and Lampert 2001; Katila and Ahuja 2002).

2.1.2 Motivation and gap

Recently, Jung (2019) suggests that not only recombination across boundary but also sources of recombined technologies may affect the outcomes of firm's exploration. He finds, in a nanotechnology sector, that recombining university-developed technology increases the likelihood of generating a breakthrough invention, while recombining firms-developed technology decreases this likelihood. The motivation is that technologies developed by university reflect the focus on basic science coming from university research.

It seems reasonable to think that the use of knowledge coming from basic science may take to a better recombination of technological knowledge and may positively influences the generation of successful inventions (highly valuable inventive outcomes), especially if knowledge comes from different scientific fields.

In particular, also if it is not demonstrated in the literature a direct relation between use of scientific source of knowledge and development of successful inventions, cited scientific references has been considered as an important source of background information and inspiration for the inventors (Callaert et al., 2014).

Gruber et al. (2012) examine how individual-level characteristics of inventors affect the breadth of their technological recombinations suggesting that a thorough understanding of science may help inventors in identifying and assimilating knowledge elements in more distant technology domains.

The gap we find in literature is associated to the missing accurate analysis concerning the incidence of the use of different scientific knowledge in the value of an innovation, while many empirical studies have analyzed only the effect of the recombination across technological domains, at patent level (Gosh et al., 2009; Moaniba et al., 2018) or at firm level (Gambardella and Torrisi, 1998).

2.1.3 Contribution to existing literature

A core interest in the literature on innovation is understanding how firms may tap into new technological domains in order to achieve successful innovations. Literature on innovation strategy has increasingly highlighted the vital role of cross-disciplinary knowledge and knowledge recombination across different domains in the development of important inventions.

However, the majority of the studies rely only on technological knowledge dimension. For instance Moaniba et al. (2018) analyze the cross-disciplinary knowledge only considering a technological point of view, finding a strong positive relationship of recombination of technologically diverse knowledge with the technological value of an invention. Rosenzweig (2016) finds that diversified technology knowledge and diversified country knowledge are both positively associated with the impact of technological innovation.

Our contribution to the extant literature on innovation regards the analysis of both scientific and technological dimension together when a firm recombine knowledge across distinct domains. So we analyze the effect of simultaneously relying on technological and scientific diversification in the development of successful and novel inventions.

At the same time, we contribute also to the scientific debate about the topic of the assessing the novelty of radical innovations, developing an ex-ante patent indicator of diversification of scientific knowledge that we will find to be strongly linked to the technological novelty of an invention.

2.1.4 Research questions

Following the precedent literature, our preferred conceptualization of 'radicality' picks up novelty, but theoretical discussions mainly revolves around innovations with an exceptional value to firms.

In this regard, it is important to distinguish between the novelty of an innovation and its value. These two dimensions represent different concepts and often do not go to the same direction: incremental inventions that tend to have large value and novel inventions that fail to create any value.

It seems to be interesting to specifically analyze how relying on diverse knowledge sources correlates to novelty, value and value conditional on novelty. The latter would reflect whether novel solutions – plausibly brought on by relying on diverse knowledge – are successful.

Our purpose is testing the idea that diverse scientific knowledge improves the quality of search. The hypothesis is that relying on diverse scientific knowledge would increase the probability of obtaining valuable inventions, which in turn decreases the risk implied by novel recombination.

From that follows the research questions.

1. Does the diversification of scientific knowledge sources influence the technological novelty of an invention?

2. Does diversification of scientific knowledge sources have positive effect on the value of an invention?

3. Do technological novel inventions tend to be successful?

To test these claims, we explicitly distinguish, in patented inventions, between the dimension of novelty and impact and verify if novel inventions tend to create value. Another possible way, that will be considered in further research, would be to explicitly analyze the variance of the value distribution implied by certain characteristics of an invention (see Fleming, 2001).

2.2 Methodology

2.2.1 Patent analysis and innovation indicators

In the past 30 years, a common way for evaluate the effect of different technological characteristics on product or firm success (Reitzig, 2003) has been represented by the analysis of patents portfolio. Patents are correlated with the innovation activity (Acs et al., 2002), so they can indicate innovations. Patents have become an important metric in the innovation literature thanks to the easy availability of patent citations. Citations on patents arise from rigorous procedures to ensure that appropriate citations are issued and a focal patent cites previous patent only when there is a legitimate reason to cite the previous patent's intellectual property; accordingly, many scholars have carried out empirical investigations on patents to determine technological characteristics of innovations (Arts et al., 2013; Arts and Fleming, 2018; Arts and Veugelers, 2014; Verhoeven et al, 2016; Veugelers and Wang, 2019).

A review on innovation indicators is provided in Dziallas and Blind (2019) and Adams et al. (2006).

To obtain indicators of the quality of an invention the number of forward citations has been used, i.e. the number of times a patent is cited by other patents. This number indicates the impact a patent has had in an industry (Albert et al., 1991) and the value of an invention (Trajtenberg, 1990), but provide no idea of whether the impact is due to the invention's technical content being radical. Incremental inventions, indeed, could receive many forward citations.

Katila (2000) found that short citation lags may not properly capture the value of innovations, and that radical innovations tend to be cited later than incremental. The use of forward citations, so, needs to consider a large enough time period after the publication of the patent for an *ex-post* innovation assessment.

For what concerns the radicality of an invention, Rosenkopf and Nerkar (2001) measure the degree of radicality showing how incremental patents are often more narrowly cited within a certain domain of patents and radical patents are often cited by multiple domains of patents.

Moreover, they claim that radical inventions will be more likely to cite patents from other patent classes than from the class to which the radical invention belongs. Accordingly, Shane (2001) measures the radicality of a focal patent as the number of three-digit patent classes its cited patents belong to, excluding its classes (based on the International Patent Classification). This analysis is faced using the backward citations to patent references, that are patents cited by the focal patent.

This measure implies that patents that do not cite previous patents possess zero radicality, which is at odds with Ahuja and Lampert

(2001) that think that radical inventions are properly those that arise from no previous technology.

A recent method for assessing the radical nature of an innovation consists in measuring the novelty, obtained by the focal patent, in the recombination of technological knowledge with respect to previous innovations. In this regard, Verhoeven and co-authors propose an indicator that considers novelty in recombination of knowledge as *ex-ante* measure of technological novelty with "the potential to drive radical technological change" (Verhoeven et al., 2016).

2.2.2 Analysis

In our work, the analysis unit is not the firm but the single invention. Moreover, the analysis is not restricted to firms, but all the existing patents of firms and universities and research centers that develop or use the same chosen nanotechnology in a certain reference period are considered.

We conduct three different analysis. Firstly, we analyze whether the diversification of scientific knowledge sources used to build the single patent influences the probability of obtaining technological novelty in the combinations of knowledge. This novelty is a feature of radical innovations, which are a goal strongly sought by companies to obtain large gains and positions of competitive advantage in the market. Secondly, we analyze if such scientific diversification - together with the technological diversification - influences the value of the invention. Finally, we evaluate if novel inventions tend to be successful.

This analysis could lead to better understand the features of patents that may drive the generation of value.

Specifically, in our study, to evaluate the value of an invention the forward citations are counted, to evaluate the novelty in the combinations of knowledge, the pairs of subclasses and sub-groups according to the IPC classification assigned to the single patent are compared, while the backward citations are analyzed to assess the diversification of the knowledge considered in constructing the patent. These citations refer to the patents and scientific literature used to build the focal patent and therefore represent both technological and scientific knowledge.

Technological novelty

In 2016, Verhoeven and co-authors proposed an indicator as ex-ante measure of technological novelty with "the potential to drive radical technological change" (Verhoeven et al., 2016).

Based on Verhoeven et al. (2016) new concept of novelty in the combination of technological knowledge as radicality measure, in our study, we examine the pairwise combinations of technological subclasses and sub-groups (according to the IPC-codes assigned to every patent) and, we calculate the novelty as a count of the new pairs of technological knowledge with respect to all the pairs ever combined by all previous patents which focus in the new technology of silica aerogel. We consider, compared to Verhoeven et al. (2016), also a more fine-grained level for the evaluation of technological novelty that is the sub-group level, which seems also appropriate given the fact that a rather narrow technological field is studied.

This procedure requires that a patent belong to at least two different technological subclasses or sub-groups in order to obtain at least a couple of different technological domains.

Diversity index

This study measures the diversity of used technological and scientific knowledge sources through an entropy-based measure (Palepu,1985), that is the Shannon-Wiener diversity index (Magurran and McGill, 2011).

Entropy-based indicators have been largely used in literature as indicators for technological diversity. Carnabuci et al. (2013), for instance, measure inventor's knowledge diversity using Teachman's entropy index and Appio et al. (2019) measure patent portfolio diversity using Shannon-Wiener entropy index.

A diversity index is a mathematical measure of species diversity in a community. The diversity indices don't simply count the number of different species but take in account the relative abundances of different species.

We determine two diversification indices for each patent analyzed, showing the diversification of the sources of knowledge with which the patent has been built.

Specifically, we distinguish two main knowledge bases, the one linked to technological knowledge (assessed through patent references, PRs), and the other linked to scientific knowledge (assessed through non-patent references, NPRs) (Callaert et al., 2006).

The Shannon index is calculated using the following equation:

$$H' = -\sum_i p_i \ln(p_i) \tag{2.1}$$

where p_i represents the proportion of the i-th species and is defined as

$$p_i = n_i/N$$

where

- n_i represents the number of times the i-th species appears in the references cited by the patent for which H' is calculated;
- N represents the number of times all the species appear in the references cited by the patent for which H' is calculated.

The diversity measure is summed across all the different species in equation (2.1). In our study, the species are the categories of the WoS[1] core collection for the evaluation of diversification of non-patent references, and the sub-classes and sub-groups of the IPC [2] classification for the evaluation of diversification of patent references.

Variables of the analysis

Dependent variables. We calculate the novelty in the recombination of knowledges as the number of pairwise sub-class and sub-group combinations of a patent that appear for the first time in the group of patents that refer to the field of silica aerogel (our sample). To do so,

[1]ISI Web of Science database covers a large share of the scientific journal literature in many scientific disciplines. Every journal and book covered by *Web of Science* core collection is assigned to at least one of the 258 subject categories (`https://images.webofknowledge.com/images/help/WOS/hp\_subject\_category\_terms\_tasca.html`).

[2]The IPC has a systematic and hierarchical structure. Classification becomes more detailed with every further (sub)division. In order we have classification for section, class, subclass, group and subgroup (see `https://www.wipo.int/classifications/ipc/en/`).

each pairwise combination of sub-classes and sub-groups is compared with all pairwise combinations of all prior patents in the field. We have proposed the comparison with the prior patents in this specific field of nanotechnology and not a comparison with all prior patents in all fields of technologies (Fleming et al., 2007; Jung and Jeongsik, 2016, Verhoeven et al., 2016) because we are analyzing a new nanomaterial. So, a new combination of technological domains created in producing or applying the specific new nanomaterial represents itself a good measure of novelty in an invention. Furthermore, in this way, we can find a greater percentage of patents with at least one new pair of technological knowledge and this is useful for the analysis, since the number of patents considered in the study is not very large due to the recent interest in patent publications on this nanomaterial.

Moreover, we calculate the patent value by forward citations as the number of times a patent is cited by other, later, patents. We distinguish between non-self and self forward citations, evaluating if the citations received come only from other assignees/applicants or also from the same assignee/applicant that have developed the patent. Forward citations are positively related to the economic value of a patent and the impact of an invention and indicate whether an invention has been successful (in terms of satisfaction of market demand or possibility to develop competitive advantage). The number of non-self forward citations, particularly, allow to understand the importance of a patent for the competitors in the market.

Independent variables. For each focal patent, we calculate:

- the diversification of cited patent references as an index H'_{PR1}, based on an entropy measure of diversity, that reflect the degree of diversification of the cited patents, at level of sub-groups, based on the International Patent Classification.

- the diversification of cited patent references as an index H'_{PR2}, based on an entropy measure of diversity, that reflect the degree of diversification of the cited patents, at level of sub-classes, based on the International Patent Classification.

- the diversification of cited non-patent references as an index H'_{NPR}, based on an entropy measure of diversity, that reflect the degree of diversification of scientific area of knowledge of the cited scientific literature [3].

Control variables. In implementing the empirical analysis to test the idea, we try to control for many potential covariates of novel recombination and value of an invention at various levels (inventors, technology field, time, firm/assignee and claims).

Inventors. Because scientific diversification might correlate to characteristics of inventors that also affect the novelty, we added the number of inventors.

Technological field. To control for the effects, in novelty and value, of various technological fields of application of the specific nanotechnology, we included the main section variable (accordingly to the IPC classification).

Year. When using the number of forward citations as a measure of value, it is important to consider a 'citation window' to make patents

[3]The classification is based on the WoS core collection and the scientific documents considered in the evaluation of scientifically knowledge source are based on Callaert (2006) identification of scientific literature, based on which journal articles, conference proceedings, books, and reference books/databases can be considered 'science at large', while industry-related and patent-related documents can be seen as technology at large.

across years comparable. This citation window is, in literature, recognized to be as 5 years after the publication of a patent. Otherwise, the number of citations received will strongly correlate to the 'age' of the patent. Our sample presents inventions patented in the temporal range 2006-2018. As it is not possible to respect, for recent patents, the time frame foreseen, we included the variable year to control the temporal effects of the age of the patents.

At the same time, the age of the patent might relate also to the novelty, because, as the technology has emerged during the time period considered, we would expect that the 'novelty' evolved relatively more in the early years.

Assignee. We included the firm dummy variables to account for heterogeneity in technological recombination capabilities. This variable assumes the value 0 if the assignee is a firm or 1 if the assignee is not a firm (i.e. universities, research centers).

Claims. To control for the effect of patent claims on the novelty and the value of an invention, we added the number of claims. Claims of a patent define which subject-matter is protected by the patent and we expect that this number should be related with our dependent variables.

For a robustness check analysis, we consider, also, the following variables:

- the patent backward citations as the number of patents cited by the focal patent, and
- the non-patent backward citations as the number of scientific documents cited by the focal patent.

The above values of number of citations are also used in the measurement of quality of innovations and represent different concepts respect to the diversity indices. They only count the number of citations to previous references but does not consider whether these citations belong to the same or different technological or scientific area of knowledge. The index of diversification, instead, implicitly is related to the number of cited references, but assumes the maximum value when the focal patent cites patents that all belong to different domains and decreases when the domains of the cited patents are similar.

In Table 2.1 we present the summary of the variables.

2.3 Material

We want to explain, now, why we consider, in our study, nanotechnology and why, specifically, the silica aerogel technology. Nanotechnology is considered an "emerging general-purpose technology that promises mass applications in many sectors" (e.g., Roco 2011, Jung 2019). Given the application in many technological fields and in many sectors, it is reasonable to think that many new combinations of technological knowledge will be developed.

In addition, the field of nanotechnology generally produces many successful (highly cited) innovations. This circumstance is important for our analysis, as many patents usually receive little or no citation.

We study silica aerogel because it is an emerging nanotechnology and we expect that, like similar nanomaterials in the past (i.e. graphene and carbon nanotubes), could generate successful inventions.

Table 2.1: Summary Statistics

Variable	Description	Mean	Std. Dev.	Min.	Max.
Patent value (self)	n. of times a patent is cited by other patents	1.44	3.55	0	25
Patent value (no-self)	n. of times a patent is cited by other patents excluding self-citations	1.11	2.77	0	17
Novelty (sub-class)	n. of pairwise subclass combinations of a patent	1.40	6.70	0	65
Novelty (sub-group)	n. of pairwise sub-group combinations of a patent	6.27	35.83	0	350
Diversification of cited patent at sub-classes level	index of diversification of the cited patents based on the IPC	0.82	0.88	0	2.97
Diversification of cited patent at sub-groups level	index of diversification of cited patents based on the IPC	1.54	1.48	0	5.05
Diversification of cited non-patent	index of diversification of the cited scientific references based on the WoS	0.32	0.70	0	2.49
Backward cit. patents	Number of patents cited by the focal patent	4.10	8.54	0	56
Back cit. non-patents	Number of scientific documents cited by the focal patent	3.08	11.78	0	75
Claims	Number of claims of the focal patent	12.81	10.71	0	76
Inventors	Number of inventors of the focal patent	3.05	1.74	1	9

Aerogel is a nano-porous super-insulating material, that consists of a foam-like network of molecules that is 99.8% air. Silica aerogel possesses excellent physical and thermal insulating properties: it is the lightest solid material known with high temperature stability, very low dielectric constant and high surface area. This nanostructured material is aimed at the markets of oil and gas sector, thermal and acoustic insulation industry, construction sector, healthcare industry and aerospace industry.

Silica aerogel tech has seen an incredible increase in number of published patents and that demonstrate the growing interest of firms and universities in such an investment, also because a material with all these excellent properties may be applied in the innovation of many technological sectors.

Our sample is composed by 97 focal patents, grouped to the level of patent families. Patents are selected to be part of the 'silica aerogel technology' by searching for keywords silica aerogel/silica aerogels in patent's title and abstract, using the QPat database. All patents with publication date between 2006 and 2018 have been considered, not restricted to firms as assignee. The principle assignees are L'Oreal, LG Chem, Aspen Aerogel, Panasonic, IBM, MIT, NASA.

The patents in the sample belong to 115 different sub-groups and 40 different sub-classes of technological domains, according to the IPC, with a basin of 697 backwards citations between technology and science. Particularly, patent references are 398 and belong to 857 different sub-groups and 99 different sub-classes of technological domains, while non-patent references are 299 and belong to 32 different area of scientific knowledge, according to the WoS classification.

2.4 Results

In Table 2.2 is presented the correlation matrix, where we show the correlation between the diversification index of patent references (classified at sub-classes H_{PR1} and sub-groups H_{PR2} level), the diversification index of non-patent references H_{NPR}, the number of cited patents, the number of cited non-patents, the novelty (classified at sub-classes and sub-groups level) and the patent value (with and without self-citations).. We can see that the novelty (classified at sub-classes and sub-groups level) is very correlated to the value of the patent. This indicates that, in our sample, technological novelty of an invention, that is the novelty in the recombination of knowledge, is positively associated to the possibility of obtaining gains and acquiring value (from the sale of the new product or technology in the market or for the intellectual rights of the invention).

The independent variables of our analysis will not be analyzed all simultaneously but in different regressions in order to obtain different considerations.

We used the negative binomial regression for a non-negative counting outcome both for the technological novelty and the value of a single invention. Because the dependent variables exhibit overdispersion, we prefer the negative binomial regression respect to the Poisson regression. Moreover, the assumption of independence of event counts is respected.

Errors have been clustered by patent main technological field of application (at section level), given the great influence of a field in the possibility of creating novelty and/or technological impact.

Table 2.2: Correlation matrix.

	H_{PR1}	H_{PR2}	H_{NPR}	Back.	Back. non-pat.	Novelty (sub-class)	Novelty (sub-group)	Value (self)	Value (non-self)
H_{PR1} (sub-class)	1.0000								
H_{PR2} (sub-group)	0.8884	1.0000							
H_{NPR}	0.4722	0.4420	1.0000						
Back. Cit. pat.	0.5943	0.6453	0.3467	1.0000					
Back. Cit. non-pat.	0.3632	0.3164	0.6922	0.3510	1.0000				
Novelty (sub-class)	0.2863	0.2633	0.3427	0.4919	0.3392	1.0000			
Novelty (sub-group)	0.2470	0.2318	0.3055	0.4702	0.3204	0.9923	1.0000		
Value (self)	0.3462	0.3445	0.3031	0.4017	0.4630	0.6878	0.6767	1.0000	
Value (non-self)	0.3512	0.2689	0.3272	0.3382	0.4800	0.6050	0.5886	0.9203	1.0000

In Table 2.3 and 2.4, we present the regressions with the novelty as dependent variable.

In regression (1) we consider only control variables, then we add technological diversification at two levels (regressions (2) and (3)). Both are significant and positively associated to the technological novelty but technological diversification at sub-class level has a greater effect (0.73 instead of 0.37).

It is possible to think that the second level of diversification gives information on technological diversification that is too specific and less contributes to technological novelty.

When we add the scientific diversification (regression (4)), we find that scientific diversification strongly and significantly contributes to the dependent variable, much more than technological diversification. Moreover, scientific diversification remains significant and with high coefficient when we consider scientific and technological diversification together (regressions (5) and (6)), while technological diversification is not significant. The year very little contributes in technological novelty and seems, also with low significance, that firms produces less technological novelty than universities and research centers.

Similar results come from the analysis, when technological novelty at sub-groups level is considered, with the exception that the number of inventors always appears very significant and positively associated to the new recombination of knowledge.

Table 2.3: Regression with the novelty at sub-class level as dependent variable. Robust standard errors in parentheses, clustered by technological domain. $^{+}p < 0.1; ^{*}p < 0.05; ^{**}p < 0.01; ^{***}p < 0.001$.

	(1)	(2)	(3)	(4)	(5)	(6)
H_{PR1}		0.7318***			0.2915	
		(0.1235)			(0.2853)	
H_{PR2}			0.3738**			0.0494
			(0.1074)			(0.2110)
H_{NPR}				0.9339***	0.7268***	0.8775***
				(0.1672)	(0.1807)	(0.1289)
Claims	0.0460	0.0070	0.0101	0.0070	0.0014	0.0053
	(0.0447)	(0.0397)	(0.0360)	(0.0180)	(0.0172)	(0.0123)
Inventors	0.0572	0.1267	0.1174	0.0738	0.0977	0.0813
	(0.1123)	(0.0899)	(0.0874)	(0.1014)	(0.0829)	(0.0698)
Assignee	0.6175+	0.7854**	0.7024+	0.2577	0.3912	0.2856
	(0.3682)	(0.2629)	(0.3628)	(0.2768)	(0.3204)	(0.2970)
Year	-0.0723	0.0116	-0.0103	-0.0850+	-0.0521	-0.0764
	(0.0678)	(0.0746)	(0.0743)	(0.0509)	(0.0830)	(0.0799)
Constant	-0.9841	-2.5444*	-2.125+	-0.4342	-1.1468	-0.6182
	(1.3797)	(1.1698)	(1.2776)	(0.9370)	(1.4343)	(1.2746)
Log pseudo-likelihood	-112.83	-109.28	-110.52	-107.62	-107.22	-107.58
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 2.4: Regression with the novelty at sub-group level as dependent variable. Robust standard errors in parentheses, clustered by technological domain. $^{+}p < 0.1; ^{*}p < 0.05; ^{**}p < 0.01; ^{***}p < 0.001$.

	(7)	(8)	(9)	(10)	(11)	(12)
H_{PR1}		0.5522*			0.0531	
		(0.2331)			(0.4335)	
H_{PR2}			0.2497*			-0.0718
			(0.1208)			(0.2172)
H_{NPR}				0.8247**	0.7797**	0.9236***
				(0.2821)	(0.2899)	(0.1719)
Claims	0.05814	0.0253	0.0310	0.01564	0.0152	0.0169
	(0.0414)	(0.0295)	(0.0322)	(0.01520)	(0.0132)	(0.0128)
Inventors	0.1940**	0.2478***	0.2357***	0.2055***	0.2105***	0.1942***
	(0.0745)	(0.0571)	(0.0658)	(0.0512)	(0.0549)	(0.0469)
Assignee	0.7234	0.9245+	0.8548	0.4928	0.5226	0.4329
	(0.5945)	(0.5451)	(0.6424)	(0.4940)	(0.3782)	(0.2970)
Year	-0.0011	0.0724	0.0478	-0.0104	-0.0029	-0.0262
	(0.0536)	(0.0552)	(0.0470)	(0.0332)	(0.0761)	(0.0548)
Constant	-1.0244	-2.3158*	-1.8979+	-0.5113	-0.6674	-0.1788
	(1.4233)	0.9208	(1.1009)	(1.1183)	(1.4322)	(1.0068)
Log pseudo-likelihood	-178.24	-176.65	-177.36	-175.38	-175.37	-175.52
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

For answer to the second research question, we regress putting patent value as dependent variable, both including and excluding the self-citations. In Table 2.5 and 2.6, we present the results. We can see that the scientific diversification strongly influences the patent value, measured by counting the number of forward citations, both including and excluding the self-citations (regressions (4-6), (10-12)). Its effect even exceeds that given by technological diversification and, in the second case, the significance of its coefficient is very high. The technological diversification at sub-groups level, also as in the novelty, affects less than technological diversification at sub-class level.

These results show that the scientific diversification is a good predictor not only of the probability of creating technological novelty in the combination of knowledge but also of the impact obtained ex-post by the innovation.

In all the regressions, we can see that the publication date has a significant impact on forward citations and, as expected, the forward citations decrease from 2006 to 2018. The number of claims is significantly and negatively related to the value when we exclude self-citations. This circumstance could be explained by the less interest of the competitors in the development of a technology/product with many claims.

Appears evident a difference between firms and non-firms when we include or exclude the self-citations in the counting of patent value. Firms tend to possess, in average, more citations respect to non-firms when we include the self-citations (+0.65 instead of +0.09), as we show in regressions (1) and (7) with only control variables.

Table 2.5: Regression with the value, evaluated considering the self-citations received by the patent, as dependent variable. Robust standard errors in parentheses, clustered by technological domain. $^{+}p < 0.1;^{*} p < 0.05;^{**} p < 0.01;^{***} p < 0.001$.

	(1)	(2)	(3)	(4)	(5)	(6)
H_{PR1}		0.5997***			0.3471*	
		(0.1520)			(0.1606)	
H_{PR2}			0.4790***			0.3496***
			(0.0954)			(0.0888)
H_{NPR}				0.6488***	0.4242*	0.3753*
				(0.1481)	(0.1651)	(0.1649)
Claims	0.0212	-0.0005	-0.0148	0.0013	-0.0049	-0.0184
	(0.0203)	(0.0276)	(0.0180)	(0.0259)	(0.0297)	(0.0214)
Inventors	0.1866*	0.1641	0.2117	0.2429+	0.2092	0.2370
	(0.0895)	(0.1264)	(0.1422)	(0.1246)	(0.1441)	(0.1519)
Assignee	-0.6505+	-0.6981*	-0.4095**	-1.2512***	-1.0661***	-0.8173***
	(0.3689)	(0.2973)	(0.1383)	(0.1738)	(0.2852)	(0.1237)
Year	-0.5900***	-0.5579***	-0.5076***	-0.5861***	-0.5708***	-0.5332***
	(0.0890)	(0.0977)	(0.0664)	(0.0772)	(0.0927)	(0.0642)
Constant	4.9781***	4.3893***	3.2592***	5.5332***	5.0245***	4.1099***
	(0.2788)	(0.9543)	(0.6389)	(0.5291)	(0.8257)	(0.4991)
Log pseudo-likelihood	-103.91	-101.37	-100.58	-101.24	-100.69	-99.94
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 2.6: Regression with the value, evaluated excluding the self-citations received by the patent, as dependent variable. Robust standard errors in parentheses, clustered by technological domain. $^{+}p < 0.1; ^{*}p < 0.05; ^{**}p < 0.01; ^{***}p < 0.001$.

	(7)	(8)	(9)	(10)	(11)	(12)
H_{PR1}		0.7534***			0.4663***	
		(0.1662)			(0.1330)	
H_{PR2}			0.4105**			0.1968+
			(0.1271)			(0.1118)
H_{NPR}				0.8176***	0.5361***	0.6623***
				(0.1519)	(0.1321)	(0.0866)
Claims	0.0064	-0.0233**	-0.0235***	-0.0256**	-0.0343***	-0.03585***
	(0.0114)	(0.0087)	(0.0046)	(0.0093)	(0.0087)	(0.0049)
Inventors	0.2308+	0.2340	0.2740	0.3224+	0.2901	0.3262+
	(0.1198)	(0.1644)	(0.1783)	(0.1678)	(0.1774)	(0.1896)
Assignee	-0.0992	0.0516	-0.0572	-0.6959***	-0.3889*	-0.5092**
	(0.5062)	(0.1448)	(0.2985)	(0.1980)	(0.1573)	(0.1817)
Year	-0.4950***	-0.4405***	-0.4477***	-0.4911***	-0.4625***	-0.4773***
	(0.0830)	(0.0304)	(0.0500)	(0.0391)	(0.0279)	(0.0377)
Constant	3.1903**	1.9318*	1.9110+	3.6476***	2.7641**	3.0401**
	(1.0968)	(0.9229)	(1.1522)	(0.8233)	(0.8429)	(0.9855)
Log pseudo-likelihood	-93.18	-88.94	-90.38	-88.82	-87.67	-88.32
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Moreover, it is important to underline that, for equal scientific diversification adopted in the creation of patents, firms receive on average more forward citations than non-firms. This result could lead, especially for firms, to a greater use of scientific knowledge that will directly or indirectly influence the creation of valuable patents.

In Table 2.7 and 2.8, we analyze if novelty positively affects the value of an invention and so if novel inventions tend to be successful. We propose the analysis with the novelty measured at sub-class level, but similar results come from the sub-group level. Regressions (1) and (7) shows the significant and positive relation between novelty and value (both including and excluding self-citations). The results of other regressions are very similar to these reported in Table 2.5 and 2.6. We show, moreover, that patent value, conditional on novelty, is correlated with the diversification of both technological and scientific knowledge.

We want to underline that all the coefficients of novelty in Table 2.7 and 2.8 indicate the influence on the patent value when the novelty increase of 1 unit, that is if one new pair of technological knowledge is created. Even if these coefficients could appear small respect to those of the diversity, the variables are not homogeneous and so not comparable. In order to compare their effects, they should be normalized respect to their maximum value.

2.4.1 Robustness check

We want to consider an additional analysis with the number of backward citations to patent and non-patent references instead of the diversification indices.

Table 2.7: Regression with the value, evaluated considering the self-citations received by the patent, as dependent variable conditional on novelty. Robust standard errors in parentheses, clustered by technological domain. $^{+}p < 0.1; ^{*}p < 0.05; ^{**}p < 0.01; ^{***}p < 0.001$.

	(1)	(2)	(3)	(4)	(5)	(6)
H_{PR1}		0.4612***			0.2617*	
		(0.1242)			(0.1292)	
H_{PR2}			0.3940***			0.2965*
			(0.1071)			(0.1168)
H_{NPR}				0.5175***	0.3665*	0.3226*
				(0.1354)	(0.1564)	(0.1635)
Novelty	0.0374***	0.0256***	0.0236*	0.0270**	0.0235**	0.0212*
	(0.0091)	(0.0071)	(0.0071)	(0.0100)	(0.0083)	(0.0101)
Claims	-0.0019	-0.0096	-0.0215	-0.0122	-0.0140	-0.0248
	(0.0171)	(0.0238)	(0.0152)	(0.0265)	(0.0278)	(0.0202)
Inventors	0.1548+	0.1488	0.1905	0.2174+	0.1939	0.2181
	(0.0928)	(0.1199)	(0.1386)	(0.1251)	(0.1405)	(0.1498)
Assignee	-0.7756*	-0.7796**	-0.5406***	-1.2607***	-1.1145***	-0.8925***
	(0.3253)	(0.2849)	(0.1461)	(0.1787)	(0.2580)	(0.1100)
Year	-0.5453***	-0.5351***	-0.4965***	-0.5608***	-0.5511***	-0.5209***
	(0.0884)	(0.0963)	(0.0683)	(0.0806)	(0.0921)	(0.0653)
Constant	5.0861***	4.5903***	3.6412***	5.5905***	5.1712***	4.3534 ***
	(0.3510)	(0.8754)	(0.5549)	(0.4750)	(0.7256)	(0.4500)
Log pseudo-likelihood	-102.07	-100.63	-99.94	-100.41	-100.08	-99.43
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 2.8: Regression with the value, evaluated excluding the self-citations received by the patent, as dependent variable conditional on novelty. Robust standard errors in parentheses, clustered by technological domain. $^{+}p < 0.1; ^{*}p < 0.05; ^{**}p < 0.01; ^{***}p < 0.001$.

	(7)	(8)	(9)	(10)	(11)	(12)
H_{PR1}		0.6243***			0.3685**	
		(0.1511)			(0.1242)	
H_{PR2}			0.3114**			0.1261
			(0.1162)			(0.1006)
H_{NPR}				0.6993***	0.5028***	0.6162***
				(0.1345)	(0.1263)	(0.0894)
Novelty	0.0387***	0.0234***	0.0269***	0.0275***	0.0221***	0.0245***
	(0.0038)	(0.0029)	(0.0056)	(0.0035)	(0.0031)	(0.0051)
Claims	-0.0180*	-0.0315***	-0.0319***	-0.0399***	-0.0427***	-0.0441***
	(0.0082)	(0.0062)	(0.0085)	(0.0104)	(0.0084)	(0.0104)
Inventors	0.2059+	0.2213	0.2505	0.3032+	0.2808	0.3082+
	(0.1180)	(0.1567)	(0.1672)	(0.1656)	(0.1739)	(0.1820)
Assignee	-0.1652	0.0378	-0.0491	-0.6992***	-0.4609**	-0.5852**
	(0.4149)	(0.1531)	(0.2765)	(0.1886)	(0.1710)	(0.1932)
Year	-0.4528***	-0.4255***	-0.4335***	-0.4721***	-0.4513***	-0.4650***
	(0.0627)	(0.0282)	(0.0488)	(0.0377)	(0.0286)	(0.0370)
Constant	3.2126***	2.1840**	2.2761*	3.7239***	2.9891***	3.3222***
	(0.8652)	(0.8124)	(0.9678)	(0.7080)	(0.7663)	(0.8919)
Log pseudo-likelihood	-91.04	-88.22	-89.52	-87.76	-87.01	-87.54
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Citations to prior art have been used in literature as a measure of technology search and the process of transfer of knowledge from science to technology, respectively. Particularly, citations to non-patent references have been found indirectly linked to the value, being considered as an important source of background information for the inventors (Callaert et al.,2014).

Table 2.9: Robustness check. Robust standard errors in parentheses, clustered by technological domain. $^{+}p < 0.1; ^{*}p < 0.05; ^{**}p < 0.01; ^{***}p < 0.001$.

	Novelty (sub-class)	Novelty (sub-group)	Value (no-self)	(Value) (self)
	(1)	(2)	(3)	(4)
Backward	0.0610*	0.0621+	0.0291*	0.0334
cit. pat.	(0.0262)	(0.0364)	(0.0132)	(0.0258)
Backward	0.0107	0.0046	0.0283***	0.0249**
cit. non-pat.	(0.0177)	(0.0324)	(0.0070)	(0.0072)
Claims	-0.0119	-0.0063	-0.0263***	-0.0101
	(0.0222)	(0.0169)	(0.0064)	(0.0277)
Inventors	0.0352	0.1787***	0.2894	0.2186
	(0.0766)	(0.0462)	(0.1802)	(0.1426)
Assignee	0.4797+	0.8237	-0.4809*	-1.0770***
	(0.2698)	(0.5515)	(0.2430)	(0.1843)
Year	-0.0445	0.0241	-0.4326***	-0.5166***
	(0.0693)	(0.0335)	(0.0254)	(0.0642)
Constant	-0.7077	-0.9704	3.0485**	4.8895***
	(1.040)	(0.8590)	(0.9360)	(0.5974)
Log pseudolik.	-107.43	-174.39	-88.67	-100.11
Prob > chi2	0.0000	0.0000	0.0000	0.0000

As we can see in Table 2.9, while the citations to non-patent references are significant and positive related to the patent value (regressions (3) and (4)), we could say nothing about their influence in the novelty (regressions (1) and (2)). The scientific diversification, instead, influences both the novelty and the value of a patent.

2.5 Discussion

We propose a discussion of the results, following the previous research questions. In particular, we have specifically analyzed how relying on diverse knowledge sources correlates to novelty, value and value conditional on novelty. The hypothesis is that relying on diverse scientific knowledge would increase the probability of obtaining valuable inventions, which in turn decreases the risk implied by novel recombination.

From the first analysis, we find that the diversification of scientific knowledge sources strongly and significantly influence the technological novelty of an invention, while the technological diversification is not significant. This result indicates that our proposed ex-ante patent indicator of diversification of scientific knowledge results strongly linked to the technological novelty of an invention. This indicator can be used to assess the novelty of radical innovations and we can so contribute to the scientific debate about this timely topic.

From the second analysis, we find that the scientific diversification strongly influences the patent value, measured by counting the number of forward citations, both including and excluding the self-citations. Our results, on one side, confirm that of Moaniba et al. (2018) or Rosenzweig (2016) when they find a strong positive relationship of recombination of technologically diverse knowledge with the technological value of an invention, but, on the other side, surpass their, when we find that the effect of the recombination of scientifically diverse knowledge in the value of an invention even exceeds that given by technological diversification. In effect, studies suggested that a thorough understanding of science may help inventors in identifying and assimilating knowledge elements in more distant technology domains and affect the breadth of their technological recombinations (Gruber et al. 2012). Also here we find that the scientific diversification is a good indicator not only of the probability of creating technological novelty in the combination of knowledge but also of the impact obtained ex-post by the innovation.

From the third analysis, we find the significant and positive relation between novelty and value (both including and excluding self-citations).Therefore, novel inventions (brought on by relying on diverse scientific knowledge) tend to be successful. This result allows to reduce the risk implied by novel recombination when a firm search success exploring distant knowledges.

In conclusion, the results of the analysis imply that the use of different scientific knowledge as background in the construction of a patent helps in the ability of generate novel and successful inventions, when inventors recombine knowledge between different technological domains and, at the same time, helps mitigate the risks associated to radical innovations.

2.6 Conclusions

In our chapter, we have tried to understand more comprehensively the features of patents that may influence the generation of successful inventions. The empirical findings of this study provide new evidence that successful inventions involve the use of different scientific knowledge when inventors recombining knowledge across different technological domains.

For this purpose, we have analyzed a research field that has seen a strong increase in the publication of patents in the last years, that is the silica aerogel nanotechnology. Therefore, we have *ex-ante* evaluated the *technological novelty* of the innovations and we have found that this measure is strongly influenced by the diversification of scientific knowledge used in the creation of patents.

We have then analyzed characteristics of patents that could affect the probability of obtaining successful inventions showing that diversification of scientific knowledge together with diversification of technological knowledge facilitate the development of successful inventions.

Moreover, we have found the positive correlation between novelty and value of inventions, indicating that novel inventions tend to be successful.

The results of the analysis imply that the use of different scientific knowledge as background in the construction of a patent helps in the ability of generate novel and successful inventions, when inventors recombine knowledge between different technological domains and, at the same time, helps mitigate the risks associated to radical innovations.

We could draw, also, the conclusion that the *ex-ante* proposed measures of scientific and technological diversification could be considered as good predictors of value; that could lead to using them for patent measures. However, the performance of the model in predicting outcomes is not tested in our analysis.

2.6.1 Theoretical implications

A core interest in the literature on innovation is understanding how firms may tap into new technological domains in order to achieve successful innovations. Literature on innovation strategy has increasingly highlighted the vital role of cross-disciplinary knowledge or knowledge recombination across different domains in the development of important inventions.

However, the majority of the studies rely only on technological knowledge dimension. For instance Moaniba et al. 2018 analyze the cross-disciplinary knowledge only considering a technological point of view, finding a strong positive relationship of recombination of technologically diverse knowledge with the technological value of an invention. Rosenzweig (2016) finds that diversified technology knowledge and diversified country knowledge are both positively associated with the impact of technological innovation.

Our contribution to the extant literature on innovation regards the analysis of both scientific and technological dimension together when a firm recombine knowledge across distinct domains. So we analyze the effect of simultaneously relying on technological and scientific diversification in the development of successful and novel inventions.

At the same time, we contribute also to the scientific debate about the topic of the assessing the novelty of radical innovations, developing an ex-ante patent indicator of diversification of scientific knowledge that we found to be strongly linked to the technological novelty of an invention.

2.6.2 Practical implications

Possible implications for firms regard the learning of how to manage uncertainties and risks present in radical innovation projects. Those risks and uncertainties could determine several financial losses within the patent portfolio investment. The proposed solution is to increase the basin of scientific knowledge of the inventors in order to increase the ability of recombining different knowledge in a novel and successful way.

The scientific knowledge could be improved, for instance, increasing the investments in R&D projects or developing collaborations of scientific exchange with other economic subjects (mainly universities and research centers).

Moreover, the evaluation of the scientific diversification of the patents of a firm could help the manager of a firm to understand which patents will probably obtain value and so in which patents it is worth investing in and which patents should be renewed.

2.6.3 Drawbacks

A limitation of the analysis is related to the extension of the results. In fact, by selecting a successful sub-domain of nanotechnology, a hindsight bias is introduced. Indeed, conditional on the fact that a lot of value was created in a certain sub-domain, certain characteristics predict value. However, this is by no means generalizable to patents in fields for which it is not clear whether they were successful.

We could expect that the results could be extended to the field of nanotechnology because it generally produces many successful innovations, but not to other fields.

Another drawback is referred to the core independent variable, the scientific diversification. At this aim, practices vary widely across organizations as to the propensity to include non-patent references and unlike patent references, there is no specific guideline or requirement for citing non-patent references. So, the results could be influenced by this factor.

Another drawback is that the patent classes are determined by the patent office and are reclassified or added or altered with varying frequency, and this could not allow to the patent to be comparable in time. But at a level of sub-classes this problem is reduced.

The last drawback is that the sample of analyzed patents is not very large due to the recent development in patent publications on this nanomaterial.

2.7 References

1. Z.J. Acs, L. Anselin, A. Varga, 2002. Patents and innovation counts as measures of regional production of new knowledge. Research Policy 31(7): 1069–1085

2. R. Adams, J. Bessant, R. Phelps, 2006. Innovation management measurement: a review. Int. J. Manag. Rev., 8 (1): 21-47.

3. G. Ahuja, C. M. Lampert, 2001. Entrepreneurship in the large corporation: a longitudinal study of how established firms create breakthrough inventions. Strateg. Manag. J. 22(6-7): 521–543. DOI: 10.1002/smj.176

4. M. B. Albert, D. Avery, F. Narin, P. McAllister, 1991. Direct validation of citation counts as indicators of industrially important patents. Research Policy, 20(3): 251–259.

5. F. P. Appio, L. M. De Luca, R. Morgan, A. Martini, 2019. Patent portfolio diversity and firm profitability: A question of specialization or diversification? Journal of Business Research 101, 255-267.

6. S. Arts, F. P. Appio, B. Van Looy, 2013. Inventions shaping technological trajectories: do existing patent indicators provide a comprehensive picture? Scientometrics. DOI: 10.1007/s11192-013-1045-1

7. S. Arts, L. Fleming, 2018. Paradise of Novelty - Or Loss of Human Capital? Exploring New Fields and Inventive Output. Organization Science. Articles in Advance, pp. 1-19.

8. S. Arts, R. Veugelers, 2014. Technology familiarity, recombinant novelty, and breakthrough invention. Industrial and Corporate Change, pp. 1-32. DOI: 10.1093/icc/dtu029

9. W.B. Arthur, 2007. The structure of invention. Research Policy 36: 274–287.

10. J. Callaert, B. Van Looy, A. Verbeek, K. Debackere, B. Thijs, 2006. Traces of prior art: An analysis of nonpatent references found in patent documents. Scientometrics 69(1): 3-20.

11. J. Callaert, M. Pellens, B. Van Looy, 2014. Sources of inspiration? Making sense of scientific references in patents. Scientometrics 98: 1617-1629.

12. G. Carnabuci, E. Operti, 2013. Where do firms' recombinant capabilities come from? Intraorganizational networks, knowledge, and firms' ability to innovate through technological recombination. Strat. Mgmt. J. 34: 1591–1613. DOI: 10.1002/smj.2084

13. C. M. Christensen, J.L. Bower, 1996. Customer power, strategic investment, and the failure of leading firms. Strateg. Manag. J. 17: 197–218.

14. C. M. Christensen, R.S. Rosenbloom, 1995. Explaining the attacker's advantage: Technological paradigms, organizational dynamics, and the value network. Research Policy, 24(2): 233-257.

15. K. Dahlin, D. Behrens, 2005. When is an invention really radical? Defining and operationalizing technological radicalness. Research Policy 34(5):717-737.

16. M. Dziallas, K. Blind, 2019. Innovation indicators throughout the innovation process: An extensive literature analysis, Technoinnovation 80-81: 3-29.

17. L. Fleming, 2001. Recombinant uncertainty in technological search. Management Science 47(1): 117-132.

18. L. Fleming, S. Mingo, D. Chen, 2007. Collaborative brokerage, generative creativity, and creative success. Admin. Sci. Quart. 52(3):443–475.

19. A.Gambardella, S. Torrisi, 1998. Does technological convergence imply convergence in markets? Evidence from the electronics industry. Research Policy 27(5): 445-463.

20. Ghosh, X. Martin, J. M Pennings, F. C. Wezel, 2009. Recombination Experience: A Study of Organizational Learning and Its

Innovation Impact. SMS 29th Annual Conference Submission.

21. M. Gruber, D. Harhoff , K. Hoisl (2012). Knowledge Recombination across Technological Boundaries: Scientists versus Engineers. Management Science, 59(4).

22. R. Henderson, 1993. Underinvestment and incompetence as responses to radical innovation – evidence from the photolithographic alignment equipment industry. RAND J. Econ. 24: 248–270.

23. H.J. Jung, L. Jeongsik, 2016. The quest for originality: A new typology of knowledge search and breakthrough inventions. Acad. Management J. 59(5):1725–1753.

24. H.J. Jung, 2019. Recombination sources and breakthrough inventions: university developed technology versus firm developed technology. The Journal of Technology Transfer. DOI: 10.1007/s10961-019-09741-0.

25. R. Katila, 2000. Measuring innovation performance. International Journal of Business Performance Measurement, 2: 180-193.

26. R. Katila, G. Ahuja, 2002. Something old, something new: A longitudinal study of search behavior and new product introduction. Academy of Management Journal, 45(6), 1183–1194

27. J.A. Keizer, J.I.M. Halman, 2007. Diagnosing Risk in Radical Innovation Projects. Research Technology Management 50(5): 30-37.

28. A.E. Magurran, B.J. McGill, 2011. Biological diversity: Frontiers in measurement and assessment. New York: Oxford Uni-

versity Press.

29. M. Moaniba, H. Su, P. Lee, 2018. Knowledge recombination and technological innovation: the important role of cross-disciplinary knowledge. Innovation, Organization & Management, 20 (4): 326-352.

30. K. Palepu, 1985. Diversification strategy, profit performance and the entropy measure. Strategic Management Journal, 6(3): 239-255.

31. M. Reitzig, 2003. What determines patent value? Insights from the semiconductor industry. Research Policy, 32: 13-26.

32. Roco, M. (2011). The long view of nanotechnology development: The National Nanotechnology Initiative at 10 years. Journal of Nanoparticle Research, 13, 427–445.

33. L. Rosenkopf, A. Nerkar, 2001. Beyond local search: Boundary-spanning, exploration, and impact in the optical disk industry. Strategic Management Journal, 22: 287-306.

34. Rosenzweig, S. (2016). The effects of diversified technology and country knowledge on the impact of technological innovation. J Technol Transf. DOI 10.1007/s10961-016-9492-5.

35. S. Shane, 2001. Technological Opportunities and New Firm Creation. Management Science 47(2): 205-220.

36. M. Trajtenberg, 1990. A penny for your quotes: patent citations and the value of innovations. RAND Journal of Economics, 21(1): 172–187.

37. D. Verhoeven, J. Bakker, R. Veugelers, 2016. Measuring technological novelty with patent-based indicators. Research Policy, 45: 707-723.

38. R. Veugelers, J. Wang, 2019. Scientific novelty and technological impact. Research Policy, 48(6): 1362-1372.

Chapter 3

The Recombination of knowledge: incidence of external collaborations in the quality of firm's innovation outcomes

Abstract. In this chapter, we analyze if the quality of an innovation (understood as technological impact) and its market value is positively associated to the firm' ability of recombining knowledge and how the value of innovations changes in case of firm' collaboration with other partners. We explicitly distinguish collaborations between firms and scientific partners, firms that operate in the same sector and firms that operate in different technological sectors. To do that, we use patents' information in an emerging nanotechnology sector. The analysis is conducted at level of patents, because information coming from this type of intellectual property rights (secondary data) are easily available and allow a study at micro level, more detailed respect to a common analysis of the potential recombination ability conducted at the level of firms. The findings suggest the positive influence of the use and recombination of many knowledges, both technological and scientific, in the quality and market value of the innovations. Collaborations with subjects that provide different knowledge than that of the firm are favorable, both scientific (universities and research centers) and technological (firms that possess knowledge in different sectors). Finally, innovations resulting from the collaboration of many partners specialized on the same sector do not increase their value, but on the contrary reduce it.

Keywords: external collaborations, scientific collaborations, similar firms, diverse firms, patent value.

3.1 Introduction

It is true that successful innovations could born from no existing technologies (Ahuja and Lampert, 2001) but, generally, innovations arise from the recombination or transformation of existing knowledges in an unprecedent way.

What are the characteristics that a firm should possess in order to be able to recombine knowledges?

A firm should possess a lot of knowledge, often also in different sectors, and should also be able to continuously increase (improve) the knowledge pool, exploring new sources and acquiring from the outside or creating collaborations; in that way, the probability to create new connections and new developments increases. All these capabilities and competences seem related to the firm internal R&D activity. Indeed, having previous knowledge improves the inventor's ability to learn more and better assimilate his surroundings. This allows for better ability to use all knowledge in new settings (King and Lakhani, 2011).

Moreover, the possession of a large knowledge stock should facilitate external collaborations with different types of partners. It is essential to consider alliances when evaluating the ability to create new knowledge, because if it is true that having a large pool of knowledge allows firms to generate innovations with more ease, certainly the presence of collaborating subjects, which shared their own pool of knowledge and skills, increases this probability. For instance, a common strategy that a firm - in science-based industries – could adopt for acquiring scientific knowledge and skills lies in research collaborations with universities.

3.1.1 Novelty of the study

Often firm's abilities to create innovation has been assessed considering the percentage of investments in R&D or the number of external collaborations, but this information indicates the 'potential' of a firm, that is how much the firm is potentially able to generate innovations. But if we go specifically, how much of the knowledge possessed by firms has actually been used to create each innovation? And all this knowledge (internal, acquired, shared), recombined and transformed, influence the creation of value for the firm?

In our study we want to conduct an analysis at the level of a single innovation. Our sample contains all the patents (published by firms) in a certain technological sector and contains, so, products of firm's internal R&D activity. Every patent will be associated to its value in the market measured by the received forward citations. Then the analysis will be clustered at level of firm because we consider the *ability of using and combining knowledges* as a firm's capability.

The analysis at patent level allows to evaluate information that in a firm-level analysis would be lost. We, here, find a correspondence between characteristics of every patent and the associated value in the market. For example, it can be evaluated the specific sources of knowledges adopted for building up every patent and, therefore, from how many different precedent discoveries every invention takes place or how many technological or scientific knowledges have been really integrated to develop every invention.

Moreover, it is possible to evaluate if collaborations with a specific company is better than another company in terms of quality of the innovation outcomes or if collaborations with other types of partners has a greater impact.

3.2 Theoretical framework

3.2.1 The incidence of recombination capacity in the value of an innovation

The development of innovations and the ability to capture value from them is a goal strongly sought by firms to obtain and maintain competitive advantage on the market. Recently, a common method used by firms in order to develop innovations lies in the exploration of external technological domains. Such external search increases the probability of creating new recombination of knowledges and, so, of creating innovations but requires a good firm's capacity of acquisition and exploitation. The innovation literature suggests that a firm's absorptive capacity helps improve the quality and frequency of innovation outcomes (Lane et al., 2006; Volberda et al., 2010), and therefore the development of successful innovations.

Cohen et al. 1990 define absorptive capacity as *"the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends"*.

This capacity allows firm to assimilate knowledge, combine it with existing in-house knowledge and exploit it in internal R&D activities (for instance patents, trademarks, copyrights, etc.).

Zahra and George (2002) consider absorptive capacity as a dynamic capacity and distinguish 'potential' absorptive capacity and 'realized' absorptive capacity, suggesting that both together are essential for the development of firm's competitive advantage in the market.

All the characteristics of absorptive capacity (Martín-de Castro, 2015) are possessed by firms that are capable to identify and acquire external knowledge and, also, to assimilate them and combine with internal knowledges for the creation of novel ideas.

Certainly, this ability requires *in primis* the capacity to identify and value external knowledge (Zahra and George, 2002). Generally, firms that invests in internal R&D activities are more prepared to recognize and absorb external sources of knowledge (Cassiman and Veugelers, 2006; Li, 2011), since they possess in-house the right knowledge that would permit absorption of knowledge from different domains (Cohen et al. 1990). In fact, the identification and acquisition of external knowledge seems related to the internal investment in R&D (Arora and Gambardella, 1994; Cohen and Levinthal, 1989; Cassiman and Veugelers, 2006).

Many authors have analyzed the relationship between internal R&D and external knowledge (for instance Cassiman and Veugelers, 2006; Cohen and Levinthal, 1990; Katz and Allen, 1982; Pisano, 1990). Karim and Mitchell (2004) suggest that internal development and acquisitions contribute in the creation of value. Arora et al. (2014) explore the interplay between R&D, external knowledge and organizational structure suggesting that the three elements of a firm's innovation strategy should be aligned to support each other for a good performance of the firms.

However, the analysis of the relation between internal R&D activity or absorptive capacity (defined as a byproduct of internal R&D) and value of innovation have been conducted principally at firm-level (Huang et al. 2015) and, more rarely, has been considered the scientists' absorptive capacity in an analysis at inventor-level.

Nevertheless, when we evaluate the incidence of the recombination ability in the innovation quality, and so when we evaluate if the knowledges (internal, acquired, shared) actually used in the creation of each innovation, recombined and transformed, generate value for the firm, we need an analysis at patent level.

At this aim, we have to recall that it is not so clear to understand how different knowledges deriving from external search could be integrated for develop success (Fleming 2001). Recently, Arts and

Fleming (2018) found that, in the exploration of new fields, the effect on value increases when the inventors collaborate with experts or use scientific literature in the new field.

We, so, explore the research question:

In a patent-level analysis, does the ability to recombine a lot of knowledge positively influence the value of innovation?

3.2.2 The incidence of network team (R&D alliances) in the value of an innovation

Many authors recognize the positive incidence of R&D alliances in the quality and efficiency of innovations.

Certainly, the discovery of new product/process through internal R&D activity is a good way to obtain success but even external collaborations can generate earnings for the firm. In fact, the firms cannot possess in-house knowledges in many technological fields and, in searching external and unknown technological knowledge, they can obtain more benefits by cooperating with external experts than by investing for the employees' acquisition of the required knowledge. Moreover, the time-to-market could be reduced and the access to new markets facilitated (Narula, 2001).

In addition, in the collaboration with other subjects, the risks of economic losses are reduced because they are shared between the two partners. Sure, there are some risks in the collaboration, due to the possibility that the partner takes advantage from the acquired knowledge and become a competitor (Alcácer and Oxley, 2014). In addition, it can be difficult to create alliances because it is not always easy to make explicit knowledges that are tacit.

Martínez-Noya and Narula (2018) explain that firms could try to protect their knowledge through contracts or making alliances with familiar partners, at the expense of innovation performance.

Hurtado-Ayala and Gonzalez-Campo (2015) exhibit a summary framework in which they show that company networks activity, in literature, has been measured by the number of partners/affiliates, alliances with research institutes and use of scientific journals/attending events. For instance, Vega-Jurado et al. (2008) use the number of R&D alliance members to capture the firm's external knowledge.

In conclusion, alliances – or, at least, some types of alliances - are expected to increase the value of the product that comes from the collaboration. Therefore, it would be interesting to analyze if the value of an innovation is positively influenced by the presence of collaboration with other partners.

Nieto et al. (2007) analyzes the role of different types of collaborative networks for the novelty of product innovation and find that collaboration with suppliers, clients and research organizations have a positive impact on the novelty of innovation, while collaboration with competitors has a negative impact.

Dong et al. (2015), analyzing a relation between inter-firm collaborations and technological value of their outputs, find the positive incidence of the variety of technological knowledge of the partners profile but the negative incidence when partnering firms are distant in term of their technological profile.

Pereira and Leitao (2016), instead, find that coopetition (that is collaboration with competitors) positively impacts the product innovation, in a sample of Italian and Portuguese manufacturing firms.

From this literature we explore the research question:

Do firms that exploit R&D alliances with other partners improve their ability of creating successful innovations? What is the incidence of different types of partners in the value of innovations?

3.3 Methodology

We use a quantitative analysis based on patent information.

Patents are common examples of firm's innovation outputs and represent products of the exploitation of new knowledges through internal R&D activities.

In our study, we want to evaluate if the firm's capacity of creating innovations through recombination of knowledges is positively linked to the value of its innovations, with an analysis at patent level

.

In particular, we consider the ability to use and combine or transform different knowledges. These knowledges could be acquired externally or by sub-units of the same firm through internal collaboration or could be made available by external partners. The measure of this ability is indicated by how many sources of knowledge (external and/or internal, technological and/or scientific) each patent has been able to use and combine or transform.

3.3.1 Measures

The creation of a new discovery is the last step of a process that starts from acquisition and assimilation and is followed by recombination or transformation of knowledges. Information coming from the backward citations of a patent represent the knowledges that have been acquired and, above all, used. The cited technological and scientific sources, in a patent, both if these knowledges are developed or not by firm's employee, represent technological and scientific knowledge that are used in the creation of a new discovery.

So, to measure the use of knowledges and the ability to combine/-transform them, we consider cited sources of knowledge, both technological and scientific.

Unlike an analysis of the ability in the external search that is measured by counting how much the firm cites external patents (Argyres and Silverman, 2004), when we count how much knowledge has actually been used and transformed for the creation of a single discovery, we also consider the technological knowledge possessed within the firm itself, which certainly have been used differently for the creation of an invention.

Specifically, we evaluate if, for the creation of a new product/process, many sources of technical knowledge are used. This aspect notes the capacity of the inventors or employee not only to have understood and acquired technological information deriving from different products compared to what it is going to realize but also know how to apply them in order to develop innovations.

The number of cited patents indicates the quantity of technological knowledge acquired and used to create the product. The used technological knowledge can be developed outside the firm (in this case are non self patent citations) or inside to the firm in precedent inventions (self-citations). We expect that all the used inventions appear in the citations of focal patent because it exists a rigorous procedure that guaranties that appropriate citations to all the precedent discoveries are made.

Then, we measure the use of scientific knowledge. The scientific knowledge is essential to understand general aspects of the phenomena, improves the firm's acquisition skill and in general, companies with internal R&D programs are able to use better the science that comes from outside (Gambardella, 1992).Furthermore, citations to scientific sources of knowledge in a patent have been associated with the novelty of the innovation (Callaert et al. 2006).

It seems correct to think that if new or important scientific knowledges have been used as sources of inspiration in the creation of a patent, they would be included in the scientific citations (citations to non-patent references).

Finally, the capacity to develop R&D alliances is also synonymous of the ability to absorb knowledge and develop it in a new way.

The creation of an invention in collaboration with other entities (firms or universities or research institutes or autonomous inventors etc.) denotes the capability of having used in a favorable way more large technological knowledges, with the aim of a specific application.

3.3.2 Data collection

In our analysis, we evaluate the technological impact and value of the innovations in relation to some abilities that influence the creation of new knowledge. We concentrate in one of the sectors that generally spend the most in financing the R&D activity, that is the technology sector.

In particular, the nanotechnology sector seems suitable for our purpose, because this emerging technology promises applications in many sectors (Roco, 2011) and, so, determine high possibility of developing new inventions from the recombination and transformation of different knowledges.

In addition, we study the field of silica aerogel, a nanomaterial that have seen a drastic increase in the number of published patents in the last years, because we expect that, like similar nanomaterials in the past (i.e. graphene and carbon nanotubes), its application could generate many successful inventions. This aspect is essential in our analysis because many patents usually receive little or no citation.

All patents in the silica aerogel technology have been considered. We use QPat database, a worldwide patent database that cover over 60 million documents, and search citations, legal status of every single patent or patents in a family. Patents are grouped at family level. The total number of published patents until 2018 is 8042. We distinguish between patents owned by firms and by other subjects such as universities, scientific academies, research institute etc. (see Fig. 3.1 and 3.2) and refer to the first group of data in our examination because we search implications for the firms activity.

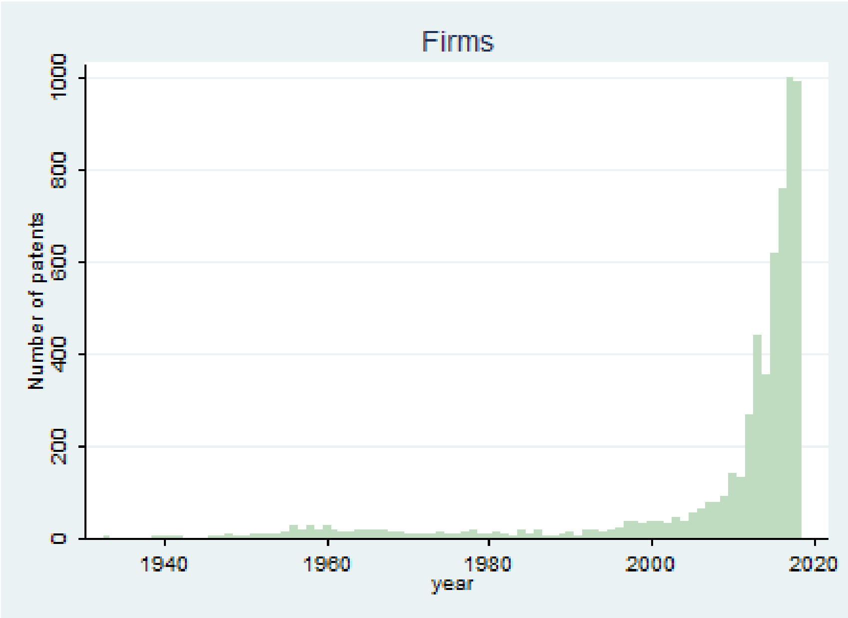

Figure 3.1: Patents of firms on silica aerogel technology until the year 2018

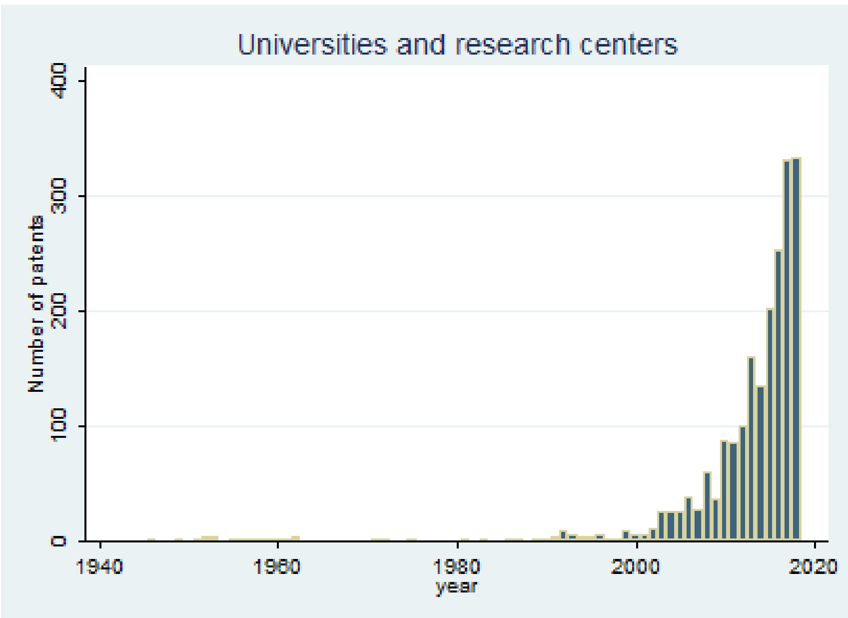

Figure 3.2: Other patents on silica aerogel technology until the year 2018

We choose to analyze the last five years, where the number of published patents is always increasing and where we can control for the influence of the year in the number of received forward citations.

3.3.3 Variables

To assess the *quality* of an innovation, we use the number of forward citations that are the citations received by other later patents. In order to make different patents comparable in time we include the year of publication and we control for the effect of the year of publication on the received citations.

To assess the use of *technological knowledge sources*, we count the cited patents. Also patents developed by the same assignee must be included because they give information on already possessed technological knowledges, but developed in a different way.

To assess the use of *scientific knowledge sources*, we evaluate if scientific research have been cited and so we use a dummy variable with the value of 1 if a patent presents backward citations to scientific literature and 0 otherwise.

To assess the *R&D alliances*, we evaluate the presence of external collaborations, creating a dummy variable with the value of 1 if collaborations are made, 0 otherwise.

Moreover, in the case of collaborations, we create dummy variables explaining the type of collaboration, so we consider *scientific alliance* if the collaboration is created with universities and/or research institutes and *firm alliance* if the collaboration is created with other firms. More specifically, *diverse firm* if exist the presence of at least one firm specialized in different type of products or sectors, *similar firm* if exist the presence of at least one firm specialized in the same type of products or sectors and probably that can compete in the market.

Moreover, we create a variable *type of alliance* indicating the partner diversity and we assign 0 if do not exist alliances with other partners, 1 if the alliance is developed only with firms or only with scientific research centers and universities, 2 if the alliance is developed together with the two types of partners.

We count the *number of assignees* for evaluating the number of subjects that collaborate in the patent creation and its incidence in the patent value.

We control for the technological sector of the focal patent because this aspect could influence the dependent variable. We, so, associate to every patent the main sector, using the assigned main international sector according to the international patent classification at section level.

Finally, we control for the influence of specific characteristics of every firm, clustering all the data at firm level.

We recap all the variables in Table 3.1.

3.4 Results

We present in Table 3.2 the correlation between the variables.

Table 3.1: Summary Statistics

Variable	Description	Mean	Std. Dev.	Min.	Max.
Quality	n. of times a patent is cited by other patents	0.78	2.32	0	43
Techn. know. sources	n. of patents cited by the focal patent	2.85	5.37	0	124
Scient. know. sources	1 if the focal patent presents backward cit. to scientific literature, 0 otherwise	0.05	0.23	0	1
R&D alliances	1 if collaborations are made, 0 otherwise	0.07	0.26	0	1
Type of alliance	0 if do not exist alliances, 1 if exist alliance with one type of partner, 2 if exist alliance with both the two types of partners	0.0777	0.2805	0	2
Alliance with firms	1 if the collaboration is created with firms, 0 otherwise	0.04	0.19	0	1
Diverse firm	1 if the collaboration is created with firm/firms specialized only in different type of products, 0 otherwise	0.01	0.12	0	1
Similar firm	1 if the collaboration is created with firm/firms specialized in the same type of products, 0 otherwise	0.02	0.15	0	1
Scientific alliance	1 if the collaboration is created with universities and/or research institutes 0 otherwise	0.04	0.0	0	1
Assignee	number of assignees	1.10	0.52	1	22

Table 3.2: Correlation matrix

	qual.	tech. know.	scient. know.	R&D all.	type of all.	alliance firm	div. firm	sim. firm	scient. all.	assig.
quality	1.00									
tech. know. sources	0.33	1.00								
scient. know. sources	0.09	0.17	1.00							
R&D alliances	0.03	0.02	0.008	1.00						
type of alliance	0.03	0.02	0.005	0.98	1.00					
alliance with firm	0.003	0.002	-0.01	0.70	0.72	1.00				
diverse firm	0.014	-0.001	0.02	0.42	0.47	0.61	1.00			
similar firm	-0.01	-0.001	-0.03	0.56	0.55	0.80	0.05	1.00		
scient. alliance	0.04	0.02	0.02	0.72	0.73	0.05	0.08	0.01	1.00	
assignees	0.009	0.059	0.02	0.63	0.64	0.51	0.36	0.40	0.42	1.00

Going to analyze the correlation of the considered variables with the dependent variable, that is the quality of the patent, we see that the values are all positive with the exception of the *similar firm* variable. This already leads to think that the presence of a collaboration between firms of the same sector or producing the same product will result in a reduction in the value of the patent compared to companies that work without collaborating with firms of the same type. However, all the correlation coefficients are very low and only the *technological knowledge sources*, which indicates the number of citations to existing patents, is very related to the value of the patent. A certain correlation is also noted in the variable *scientific alliance* which indicates alliance with a purely scientific entity (such as universities, academic centers, research institutes) and in the variable *scientific knowledge sources*, which indicates the citation of scientific literature.

The correlation between the other variables is low, proving the fact that there are no problems of collinearity. Naturally, the presence of alliances (*R&D alliances*) and different *types of alliance* are very related, but they are not to be considered simultaneously in the regressions.

We use the negative binomial regression because the dependent variable is a non-negative counting variable that exhibit overdispersion. The assumption of independence of event counts is respected.

In Table 3.3 we show the results of our regressions.

Table 3.3: Regression with quality as dependent variable. Robust standard errors in parentheses, clustered at firm level. $^{+}p < 0.1; ^{*}p < 0.05; ^{**}p < 0.01; ^{***}p < 0.001$.

	(1)	(2)	(3).	(4)	(5)	(6)
tech.		0.0693***	0.0698***	0.0704***	0.0705***	0.0708***
sources		(0.0184)	(0.0183)	(0.0184)	(0.0185)	(0.0185)
scient.		0.4971+	0.4922+	0.4972*	0.4957+	0.4914+
sources		(0.2675)	(0.2669)	(0.2658)	(0.2652)	(0.2657)
assignees			-0.2741**	-0.3588***	-0.3518***	-0.3592***
			(0.0860)	(0.0681)	(0.0673)	(0.0711)
R&D			0.3298*			
alliances			(0.1569)			
type of				0.4364**		
alliance				(0.1263)		
alliance					0.3522+	
with firm					(0.1884)	
diverse						0.5285+
firm						(0.2904)
similar						0.1785
firm						(0.2120)
scient.					0.4867**	0.4799**
alliance					(0.1558)	(0.1558)

	(1)	(2)	(3).	(4)	(5)	(6)
Year						
2015	-0.8241***	-0.7481***	-0.7477***	-0.7544***	-0.7534***	-0.7478***
	(0.0975)	(0.1048)	(0.1049)	(0.1050)	(0.1055)	(0.1055)
2016	-1.6767***	-1.6489***	-1.6527***	-1.6542***	-1.6555***	-1.6521***
	(0.1391)	(0.1110)	(0.1108)	(0.1107)	(0.1105)	(0.1102)
2017	-3.0019***	-2.8176***	-2.8180***	-2.8196***	-2.8170***	-2.8087***
	(0.1794)	(0.1755)	(0.1752)	(0.1751)	(0.1757)	(0.1756)
2018	-4.5366***	-4.3089***	-4.3080***	-4.3086***	-4.3070***	-4.3043***
	(0.6572)	(0.5748)	(0.5748)	(0.5742)	(0.5746)	(0.5756)
Section						
B	-0.1141	-0.2237	-0.2315	-0.2313	-0.2320	-0.2267
	(0.2838)	(0.1790)	(0.1801)	(0.1797)	(0.1799)	(0.1797)
C	-0.2931	-0.1769	-0.1792	-0.1791	-0.1795	-0.1792
	(0.2073)	(0.1824)	(0.1847)	(0.1842)	(0.1842)	(0.1839)
D	-0.1900	-0.2102	-0.2072	-0.2036	-0.2032	-0.2023
	(0.3019)	(0.2433)	(0.2437)	(0.2437)	(0.2439)	(0.2438)

	(1)	(2)	(3).	(4)	(5)	(6)
Section						
E	-0.5426	-0.3554	-0.3588	-0.3566	-0.3574	-0.3607
	(0.2773)	(0.2336)	(0.2342)	(0.2337)	(0.2336)	(0.2333)
F	0.1484	0.1017	0.1032	0.1074	0.1075	0.1061
	(0.2636)	(0.2294)	(0.2293)	(0.2296)	(0.2296)	(0.2296)
G	-0.1218	-0.0284	0.0346	-0.0084	-0.0070	-0.0180
	(0.3047)	(0.2997)	(0.3007)	(0.2969)	(0.2976)	(0.2954)
H	-0.4054	-0.3983+	-0.3879	-0.3749	-0.3709+	-0.3695+
	(0.2594)	(0.2252)	(0.2233)	(0.2232)	(0.2231)	(0.2228)
Constant	1.4893***	0.9837***	1.2582***	1.3393***	1.3315***	1.3355***
	(0.1919)	(0.2242)	(0.2123)	(0.1887)	(0.1908)	(0.1894)
Numb. of obs	3717	3717	3717	3717	3717	3717
Wald chi2	410.01	913.63	934.61	939.19	938.34	939.66
Log pseud.	-3344.12	-3258.85	-3256.35	-3255.00	-3254.85	-3254.65
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Regression (1) presents only the control variables *year* and *section*, that have been included with the aim of controlling for the effects of time and technological sector in the quality of the patents.

The variable *technological knowledge sources* is very significant in all the regressions (2)-(6), showing the high influence of the number of cited patents in the quality of the invention. As expected, the use of many sources of technological knowledge, and implicitly the ability of having recombined them, contributes in the creation of valuable inventions. The citation of *scientific knowledge sources*, as explained, is not directly linked to the value of an invention but its presence increases the scientific background of the inventors, allowing a better ability of acquisition and recombination of knowledge in a new way, also improving the novelty (Callaert et al., 2006). In regressions (2)-(6), we show that this variable presents coefficient +0.49 with a level of significance $p < 0.1$. From regression (2), we can say that the use of technological and scientific knowledge positively influences the value of an innovation. So, patents that arise from the use and combination of many technological knowledge and the use of scientific sources are more likely to obtain value and success.

In regressions (3)-(6), we analyze the incidence of the collaborations in the value.

From regression (3), we deduce that the *number of assignees* is negatively linked to the value of the patent with coefficient -0.27, while the presence of an *R&D alliance* (of any kind) is positively linked with coefficient 0.33. The two effects seem almost to cancel out if it exists an alliance with a single partner and they become negative as the number of partners increases.

When we consider the variable *type of alliance*, in regression (4), we find that the presence of alliances with different type of partners increases the value of the patent of a coefficient 0.43 for every different type of alliance while the *number of assignees* reduces the patent value of a coefficient -0.35 for every assignee.

Finally, in regressions (5) and (6) we consider, in a more detailed way, the specific type of alliance and, so, we distinguish *alliance with firms* and *scientific alliance*. We find that the presence of scientific alliances increases the technological value of the patent with a positive and significant coefficient of +0.48. The alliance with *diverse firms* is positively associated, with a level of significance $p < 0.1$, to the quality with coefficient +0.52, while the alliance with *similar firms* is not significant and presents a coefficient of 0.19.

Also in this case the *number of assignees* negatively influence the patent value with a coefficient of -0.36, leading to a total negative influence in case of more than two partners.

From the difference between the coefficient of alliance with similar firm and that of the number of assignees it is deduced that collaboration even with a single company of the same type leads to negative value with respect to a situation of no collaboration.

Alliances with scientific entities and with diverse firm increase the quality of the innovation, but as the number of partners of the same type increases, the value of the patent decreases.

3.5 Discussion

We recap the relevance of the results in the light of existing literature. As explained in the theoretical background section, many authors have considered the firm's ability to create a networks activity, counting for instance the number of partners/affiliates, the number of alliances with research institutes and the use of scientific journals/attending events (Hurtado-Ayala and Gonzalez-Campo, 2015). Other authors used the number of R&D alliance members to capture the firm's external knowledge (Vega-Jurado et al., 2008).

However, all these types of analysis consider the firm as unit of analysis and search for the effect of external collaborations in the firm performance outcomes. Our analysis, instead, is conducted at the level of the single invention. Only Nieto et al. (2007) have conducted an analysis at patent level, however examining the role of different types of collaborative networks for the novelty of product innovation.

We contribute to the existing literature analyzing if the value and success of an innovation is positively influenced by the presence of collaboration with other partners. The results are interesting and novel, especially when it comes to linking the types of collaboration variables to the patent's value and success.

Moreover, our research fits into the open innovation paradigm, for which firms must rely on an innovation model that not only takes into account internal ideas and resources, but also knowledge and skills from outside, in particular from startups, universities, research institutes and non-competing firms.

Our results confirm this paradigm, showing that alliances with scientific entities and with firms specialized in different types of products increase the value of an innovation. We, therefore, suggest the importance of the dependent variable patent value - not yet considered before - in open innovation studies.

3.6 Conclusions

In this chapter, we have analyzed if the quality of an innovation (understood as its technological impact and value) is positively associated to the firm's ability of recombining knowledge and how the value changes in case of firm' collaboration with other partners.

We have considered all patents owned by firms in the silica aerogel technology in the time period 2014-2018.

From the analysis of our sample, we can affirm that:

1. the use of technological and scientific knowledge positively influences the value of an innovation. So, patents that arise from the use and combination of more technological knowledges and the use of scientific knowledge sources are more likely to obtain value and success.

2. the number of different types of collaborations increases the value of a patent but as the number of partners of the same type increases, the value of the patent decreases.

As expected, so, the use of many sources of technological knowledge contributes in the creation of successful inventions. The citation of *scientific knowledge sources* is fundamental in the procedure of integration of many knowledges, mainly when external knowledges are explored, and contribute to the quality of the innovation.

For what concerns the collaborations, not always they increase the patent value with respect to a situation of no collaboration.

From the difference between the coefficient of alliance with similar firm and that of the number of assignees it is deduced that collaboration even with a single company of the same type leads to negative values, that is, it would suit not to collaborate or, at least, not to collaborate if the intent is to develop value and money from the discovery.

Alliances with scientific entities (coefficient + 0.48) and with diverse firms (coefficient +0.52), on the contrary, increase the quality of the innovation, but as the number of partners of the same type increases, the value of the patent decreases.

3.6.1 Implications

The results of the study determine implications for firms that fear economic losses when they trying to expand their technological knowledge domain, suggesting the positive influence of the use and recombination of many knowledges in the quality and market value of the innovations.

Internal knowledge can be increased with the exploration of new fields, supported by the acquisition of scientific knowledge, and with collaborations with other partners. Specifically, collaborations with subjects that provide different knowledge than that of the company are favorable, both scientific (universities and research centers) and technological (firms that possess knowledge in different sectors).

Finally, the study suggests that innovations resulting from the collaboration of many partners for each type do not increase their value, but on the contrary reduce it. Therefore, it is possible to think that when many subjects collaborate, the aim is not to create value for their firm but to find new ideas and acquire new knowledge that can be then developed individually.

3.7 References

1. Ahuja, G., Lampert, C. M., 2001. Entrepreneurship in the large corporation: a longitudinal study of how established firms create breakthrough inventions. Strateg. Manag. J. 22(6-7): 521–543.

2. Alcácer, J., Oxley, J., 2014. Learning by supplying. Strateg. Manag.J. 35 (2), 204-223.

3. Argyres, N. Silverman, B., 2004. R&D, organization structure, and the development of corporate technological knowledge, Strategic Management Journal, 25: 929–958.

4. Arora, A., Belenzon, S. and Rios, L. (2014). Make, Buy, Organize: The Interplay Between Research, External Knowledge, And Firm Structure. Strategic Management Journal, 35(3), 317-337.

5. Arora, A. and Gambardella, A. (1994) 'Evaluating technological information and utilizing it: scientific knowledge, technological capability, and external linkages in biotechnology', Journal of Economic Behavior and Organization, Vol. 24, No. 1, pp.91–114.

6. Arts, S., Fleming, L., 2018. Paradise of Novelty—Or Loss of Human Capital? Exploring New Fields and Inventive Output. Organization Science

7. Callaert, J., Van Looy, B., Verbeek, A., Debackere, K., Thijs, B., 2006. Traces of prior art: An analysis of nonpatent references found in patent documents. Scientometrics 69(1): 3-20.

8. Cassiman, B. and Veugelers, R. (2006) 'In search of complementarity in the innovation strategy: internal R&D and external

knowledge acquisition', Management Science, Vol. 52, No. 1, pp.68–82.

9. Cohen, W. and Levinthal, D. (1989) 'Innovation and learning: the two faces of R&D', Economic Journal, Vol. 99, No. 397, pp.569–596.

10. Cohen, W. and Levinthal, D. (1990) 'Absorptive capacity: a new perspective on learning and innovation', Administrative Science Quarterly, Vol. 35, No. 1, pp.128–152.

11. Huang, K., Lin, K., Wu, L., Yu, P., 2015. Absorptive capacity and autonomous R&D climate roles in firm innovation, Journal of Business Research, Vol. 68, No. 1, pp. 87-94.

12. Huo, D. and Motohashi, K. (2015) 'Understanding Two Types of Technological Diversity and their Effects on the Technological Value of Outcomes from Bilateral Inter-firm R&D Alliances', RIETI Discussion Paper Series 15-E-064

13. Fleming, L., 2001. Recombinant uncertainty in technological search. Management Science 47(1): 117-132.

14. Gambardella, A. (1992) 'Competitive advantages from in-house basic research', Research Policy, Vol. 21, No. 5, pp.391–407.

15. Hurtado-Ayala, A. and Gonzalez-Campo, C. H. (2015) 'Measurement of knowledge absorptive capacity: An estimated indicator for the manufacturing and service sector in Colombia', Globalization, Competitiveness & Governability Georgetown University, Vol. 9, No. 2, pp. 16-42.

16. Karim and Mitchell,W. (2004). Innovating through acquisition and internal development: A quarter century of boundary evo-

lution at Johnson & Johnson. Long Range Planning, 37(6), 525-547.

17. Katz, R., & Allen, T. 1982. Investigating the not invented here (nih) syndrome: A look at the performance, tenure, and communication patterns of 50 r&d projects. R&D Management, 12: 7-19.

18. King, A. and Lakhani, K. (2011) The Contingent Effect of Absorptive Capacity: An Open Innovation analysis, Harvard Business School, Working Paper, pp.11–102.

19. Lane, P., Balaji, R. and Pathak, S. (2006) 'The reification of absorptive capacity: a critical review and rejuvenation of the construct', Academy of Management Review, Vol. 31, No. 4, pp.863–883

20. Li, X. (2011) 'Sources of external technology, absorptive capacity, and innovation capability in Chinese state-owned high-tech enterprises', World Development, Vol. 39, No. 7, pp.1240–1248

21. Martín-de Castro, G. (2015) 'Knowledge management and innovation in knowledge-based and high-tech industrial markets: the role of openness and absorptive capacity', Industrial Marketing Management, May 2015, Vol. 47, pp.143–146.

22. Martínez-Noya, A and Narula, R. (2018) 'What more can we learn from R&D alliances? A review and research agenda' Business Research Quarterly (2018) 21, 195-212

23. Narula, R., 2001. Choosing between internal and non-internal R&D activities: some technological and economic factors. Technol.Anal. Strateg. Manag. 13, 365-388.

24. Nieto, M.J., Santamaría, L., 2007. The importance of diverse collaborative networks for the novelty of product innovation. Technovation 27 (6), 367-377.

25. Pereira, D. and Leitao, J. (2016) 'Absorptive capacity, coopetition and generation of product innovation: contrasting Italian and Portuguese manufacturing firms', Int. J. Technology Management, Vol 71, No. 1-2.

26. Pisano, G. P. 1990. "The R&D Boundaries of the Firm: An Empirical Analysis." Administrative Science Quarterly 35(1): 153–176.

27. Roco, M. (2011). The long view of nanotechnology development: The National Nanotechnology Initiative at 10 years. Journal of Nanoparticle Research, 13, 427–445.

28. Vega-Jurado, J., Gutiérrez-Gracia, A., and Fernández-de-Lucio, I. (2008) Analyzing the determinants of firm's absorptive capacity: beyond R&D. R&D Management, 38 (4), 392-405.

29. Volberda, H., Foss, N. and Lyles, M. (2010) 'Absorbing the concept of absorptive capacity: how to realize its potential in the organization field', Organization Science, Vol. 21, No. 4, pp.931–951.

30. Zahra, S. and George, G. (2002) 'Absorptive capacity: a review, reconceptualization, and extension', Academy of Management Review, Vol. 27, No. 2, pp.185–203.

Chapter 4

Effect of science in the relation between firms' technological diversification and innovation performance

Abstract.[1] Several studies have analyzed the relationship between the firms' technological diversification and the innovation performance outcomes. We use information coming from patents portfolio of a sample of firms that operate in a nanotechnology sector and analyze the effect, in this relationship, of the use of scientific knowledge in the development of patented inventions. We find, firstly, that the trend of the quality of innovation with the technological diversification of a firm appears similar to a Gaussian with positive asymmetry. Secondly, we find that with the increase in the percentage of the used science

[1]This chapter has been accepted for publication in *Journal of Mathematical Economics and Finance*.

by year, in one side, firms appear to obtain the maximum impact of the innovation, in average, with a less technological diversification in the patent's portfolio and, in the other side, innovations with more impact are obtained in average.

Keywords: Technological diversification, patent analysis, scientific knowledge, Gaussian relation, nanotechnology.

4.1 Introduction

Several studies have analyzed the relationship between the firms' technological diversification and the innovation performance outcomes. A complete review on this topic can be found in Ceipek et al. (2019). The main results show an inverted U-shaped link between technological diversification and innovation quantity (Leten et al. 2007), suggesting that over a certain level of technological diversification the quantity of innovation decreases. Other studies find a linear positive relationship between the innovation quality (in terms of impactful and originality of the innovation) and the technological diversification obtained recombining knowledge in diversified technological portfolios (Lee et al. 2012, Corradini and De Propris 2017).

On the contrary, the focused technological diversification appears negatively linked to the quality of innovation for small size firms (Corradini et al. 2016) and negatively linked to the quantity of intellectual property (Lin and Chen 2005). Mariani (2004) suggests a dependence on the considered technological sector. Recently, the moderator effects of some features have been studied (Kim et al. 2009, 2016), principally the resource and portfolio characteristics (the firm's size, R&D

expenditures, patent portfolio size) and inter-firm collaborations.

4.1.1 Motivation and literature gap

Use of basic research, fundamental for firms that operate in sectors guided by science, allows to gain necessary knowledge for subsequent applications in various technological fields. We adopt, as a factor that could affect the relation between firm's technological diversification and quality outcomes, more precise information with respect to the amount of R&D expenditures, such as the actual basic research that has been used as prior art in the development of every new invention of firm's patent portfolio.

4.1.2 Research question

Scientific sources of knowledge used in building up patents, in a firm's portfolio, should determine positive effect in quality of innovation performance, both for diversified and specialized firms. So, we ask the following research question.

Do investments in basic research impact on the relationship between firms' technological diversification and innovation performance?

4.1.3 Fitness

The aim is to provide guidance, mainly to science-based firms, on how to manage knowledge bases and how to organize the patent portfolio in order to obtain value from innovations.

4.2 Methodology

We use a quantitative analysis based on patent information. To assess the technological diversification of firm's patent portfolio, we use the Shannon-Wiener entropy measure at the subclass level (according to the IPC classification), and we group the patents by firms and also by year (since a firm's innovation quality is time-dependent). To assess the quality of innovation, we use the average number of forward citations received. Finally, to evaluate if basic research has been used and cited, we assign 1 if backward citations to scientific literature are present, 0 otherwise. Then we create the variable science as the average of the use of basic research.

4.2.1 Index of technological diversification

For evaluating the diversity of species, we use the Shannon-Wiener index, that is calculated using the following equation:

$$H' = -\sum_i p_i \ln(p_i) \tag{4.1}$$

where

- $p_i = n_i/N$;
- n_i = the abundance of the i^{th} species and
- N = the total abundance

Then, we apply the jackknife technique that is a general method that reduces the bias of an estimate. Here it is used to improve the estimate of diversity statistics. In this research, the species are the sub-classes of the IPC[2] classification for the evaluation of diversification of technological fields.

4.3 Empirical material

Companies in different sectors and industries conduct R&D in its two steps: basic research and applied research; pharmaceuticals, semiconductor, and technology companies generally spend the most. Our analysis would study the effect of scientific basic research in the relation between technological diversification and innovation performance, so we examine a sample of firms that operate in a sector guided by science. Specifically, we consider a nanotechnology sector and we study the impact of technological diversification on qualitative aspects of innovation, through a patent analysis. Patents have become an important metric in the innovation literature due to an easy and open trail of patent citations.

We use QPat database, a worldwide patent database that cover over 60 million documents, and search citations, legal status of every single patent or patents in a family.

All patents in the field of *silica aerogel* nanotechnology have been considered and the sample analyzed contains the inventions of the top ten assignee in the sector.

We searched for keywords *silica AND aerogel OR silica AND aerogels* in patent's *Title OR Claims*. The patents selected are 2530, distinguished in legal status alive (1998) and dead (532). The classification

[2]The IPC has a systematic and hierarchical structure. Classification becomes more detailed with every further (sub)division. In order we have classification for section, class, subclass, group and subgroup (see `https://www.wipo.int/classifications/ipc/en/`).

according to the year of the first application is:

- after 2015 (600)
- 2011-2015 (982)
- 2006-2010 (440)
- 2001-2005 (381)
- before 2001 (127).

The top ten assignee are L'Oreal (240), Aspen Aerogel (154), Cabot (134), LG Chem (78), Basf (53), Wyeth (42), Hyundai Motor (37), Life Tech (32), W L Gore & Ass. (32), Dow Global Tech. (30).

We show in Table 4.1 a recap of some statistics grouped by firm.

Table 4.1: Statistics

FIRM	n. pat.	n. forw (aver.)	n. backw (aver.)	science %	Tech. sub-clas	H'_{JSC}
Aspen Aerogels	154	3,74	5,805	0,195	23	2,503
Basf	53	1,11	5,83	0,17	12	1,7767
Cabot	134	6,64	8,5	0,21	29	2,571
Dow global	30	1	4,13	0,2	16	2,416
Hyundai	37	0,32	4,78	0,216	20	2,442
LG chem	78	0,705	3,85	0,29	19	2,084
Life tech	32	9,94	23,31	0,625	9	1,717
L'Oreal	240	0,89	7,025	0,49	6	0,480
WL Gore	32	7,56	9,28	0,28	12	1,617
Wyeth	42	0,81	1,71	0,095	3	0,397

We show in Table 4.2 the variables of the analysis grouped by firm and year and we calculate the diversification index, corrected with the jackknife technique, at sub-class level of technological diversification.

Table 4.2: Variables

	year	patents	H'_{JSC}	forward	science (%)
Aspen	2014	9	2,002	1,222	0,111
	2013	1	1,012	5,000	0,000
	2012	10	1,891	4,500	0,200
	2011	1	1,536	1,000	0,000
	2010	3	1,860	13,333	0,000
	2009	2	0,000	0,000	0,000
	2008	3	1,520	5,667	0,000
	2007	14	2,454	8,571	0,214
	2006	14	2,272	1,857	0,286
	2005	16	2,267	17,625	0,375
	2004	4	1,397	18,500	0,250
	2003	2	1,009	13,500	0,000
Basf	2014	3	0,856	0,000	0,333
	2013	4	1,035	1,500	0,500
	2012	14	0,834	2,214	0,214
	2011	2	0,000	0,000	0,000
	2010	6	0,000	3,500	0,333
Cabot	2014	2	1,805	0,000	0,000
	2013	1	0,000	0,000	0,000
	2012	11	1,946	5,000	0,182
	2011	3	2,110	0,667	0,333
	2010	9	2,355	4,111	0,111
	2009	7	1,422	6,143	0,286
	2008	10	1,262	5,800	0,300
	2007	9	2,278	2,333	0,000
	2006	11	1,416	5,545	0,182
	2005	10	2,449	10,100	0,400
	2004	7	1,333	18,286	0,143
	2003	6	1,977	8,833	0,333
	2002	15	0,969	5,400	0,400
	2001	14	1,774	12,571	0,143
	2000	8	1,428	7,250	0,250
	1999	6	0,912	2,500	0,000

	year	patents	H'_{JSC}	forward	science (%)
Dow Global	2014	10	1,976	0,800	0,100
	2013	2	1,771	7,500	0,500
	2003	2	0,627	0,000	0,000
	2001	1	0,627	0,000	1,000
Hyundai	2015	17	1,890	0,412	0,176
Lg Chem	2016	9	1,332	1,556	0,444
	2015	6	0,513	5,667	0,500
Life Tech	2015	2	0,777	1,000	0,500
	2014	3	1,209	2,333	0,667
	2013	5	0,930	0,200	0,600
	2012	2	0,964	1,500	1,000
	2011	1	0,389	4,000	1,000
	2010	3	1,522	2,000	0,667
	2009	3	1,383	3,333	0,333
	2008	5	1,368	27,200	1,000
	2007	3	1,302	49,667	0,667
L'Oreal	2015	76	0,417	0,421	0,329
	2014	11	0,300	2,455	0,545
	2013	78	0,486	1,372	0,885
	2012	7	0,303	6,429	0,571
WL Gore	2015	3	0,905	1,000	0,000
	2013	3	1,622	0,667	0,667
	2012	1	1,186	0,000	0,000
	2008	2	1,324	13,000	0,500
	2007	1	0,955	7,000	1,000
	2006	5	1,269	6,800	0,600
	2005	5	1,475	34,000	0,400

	year	patents	H'_{JSC}	forward	science (%)
Wyeth	2014	2	0,187	0,500	0,000
	2013	1	0,000	0,000	0,000
	2011	1	0,000	0,000	0,000
	2010	1	0,000	0,000	0,000
	2009	2	0,000	0,000	0,000
	2008	12	0,350	0,250	0,083
	2007	16	0,406	1,063	0,125
	2006	7	0,422	1,857	0,143

4.4 Results

We firstly propose, in figure 4.1, a linear relationship between the firm's technological diversification and the quality of innovations, showing a bad adaptation to data (R^2=0.07).

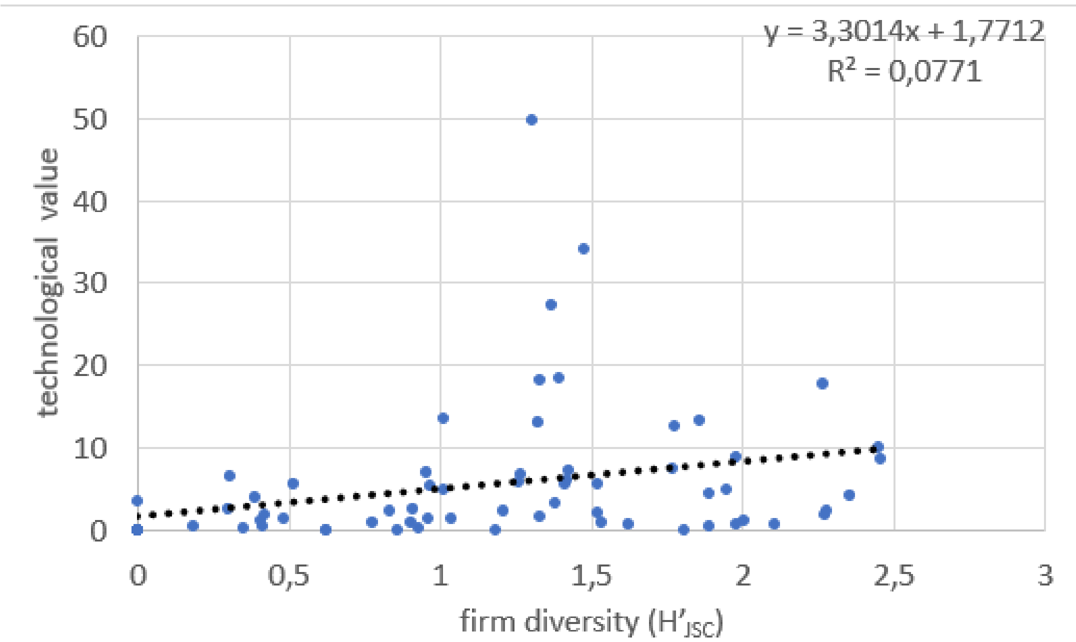

Figure 4.1: Linear equation: $y = b_0 + b_1 x$

Then we propose, in figure 4.2, a quadratic relationship (supported by the existing literature), showing a better adaptation to data respect to a linear relationship, but with coefficient R^2 very low (R^2=0.12).

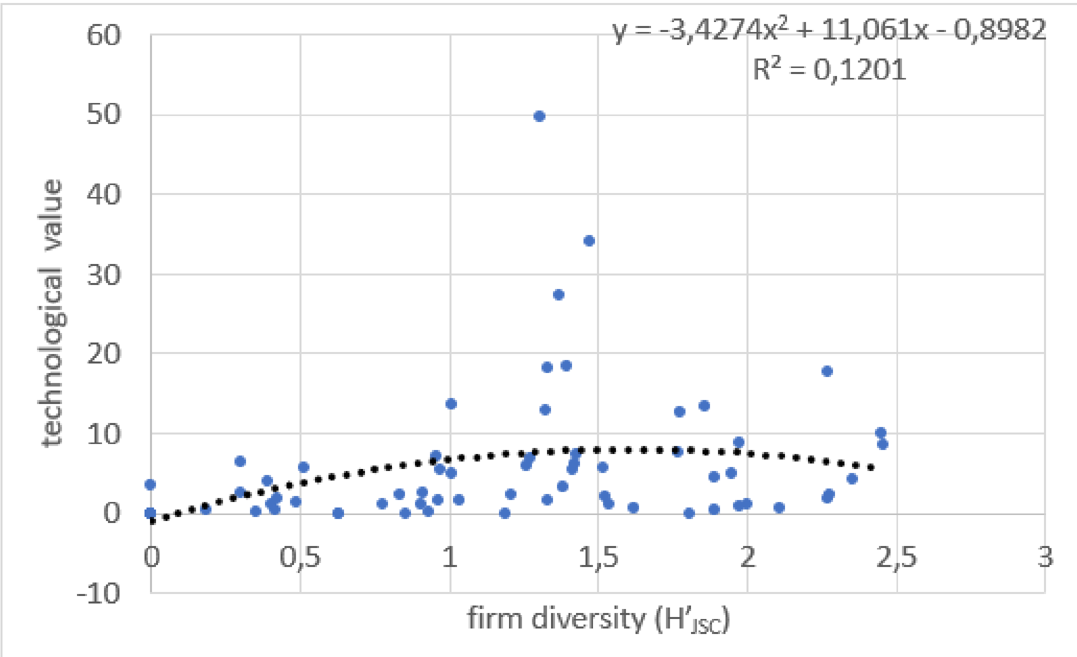

Figure 4.2: Quadratic equation: $y = b_0 + b_1x + b_2x^2$

Therefore, looking at the trend of the graph, we suggest a Gaussian relationship of the type

$$y = b_0 * exp(-(x - b_2)^2/(b_1)^2)$$

where

- b_0 represents the ordinate of the peak,
- b_1 represents the standard deviation
- b_2 represents the mean.

This type of relation fits the data much better than the previous ones (R^2=0.42).

4.4.1 Effect of science

If we want to consider the effect of the science in this relation, we could analyze how the coefficients b_0, b_1 and b_2 vary when we regress a subset of the sample with specific characteristics of science. For instance, if the percentage of science is less than 30%, the coefficients of the non-linear regression change as follows in table 4.3, regression (2) compared to (1).

Table 4.3: Results of the regressions. Robust standard errors in parentheses ($^{*}p < 0.05;^{**} p < 0.01;^{***} p < 0.001$).

	(1)	(2)	(3)
b_0	12.0835***	8.4566**	13.2742**
	(3.2439)	(2.2391)	(4.3397)
b_1	0.4665***	0.6414***	0.1437*
	(0.0808)	(0.1443)	(0.0572)
b_2	1.4187***	1.4245***	1.3583***
	(0.0707)	(0.1102)	(0.0537)
b_3			7.1582***
			(1.7352)
R^2	0.4223	0.5671	0.4794
n. obs	68	37	68

For evaluating the incidence of the science, we regress

$$nforward = b_0 * \exp(-(H_{JSC} - b_2)^2/(b_1)^2) + b_3 * science$$

showing the results in regression (3) of table 4.3.

We show in figure 4.3 and 4.4 the Gaussian curves with the coefficients determined in table 4.3, regressions (1) and (2).

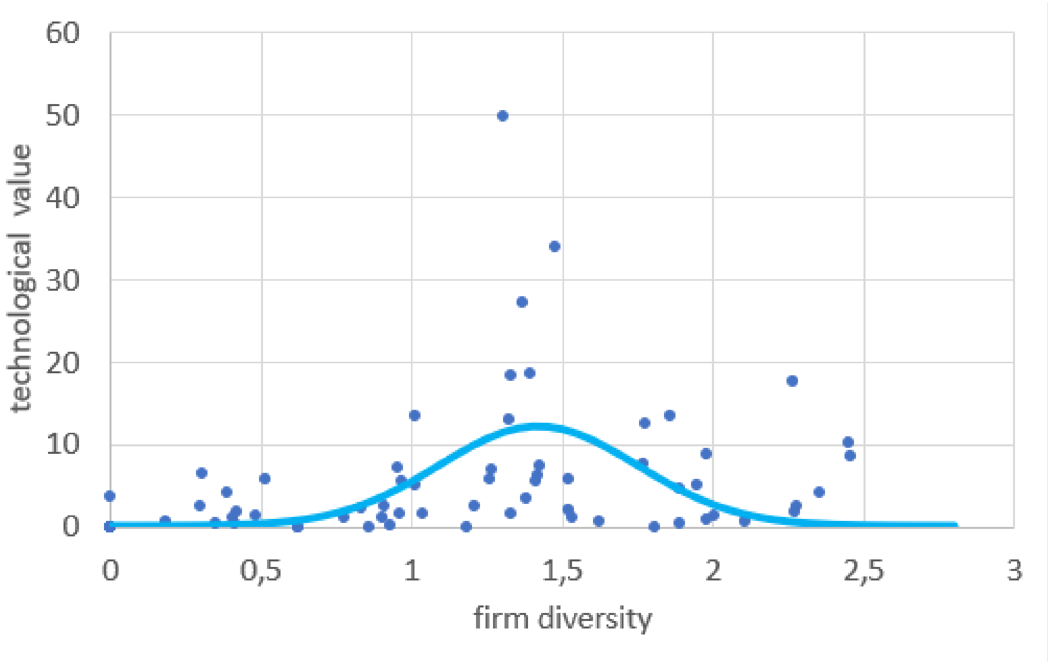

Figure 4.3: Gaussian equation: $y = b_0 * exp(-(x - b_2)^2/(b_1)^2)$

4.5 Discussion and conclusions

First evidence shows that the trend of the quality of innovation with the technological diversification of a firm appears similar to a Gaussian with positive asymmetry. The positive linear relation is significant but with low adaptation to data (R^2=0.07). The non-linear relation in the form of a Gaussian, instead, is very significant for robust standard errors with the p-value of all the coefficients less than 0.0001 and presents a better adaptation to data (R^2=0.42).

The effect of the use of sources of scientific knowledge in the creation of patents is very relevant: it is able to move the Gaussian peak

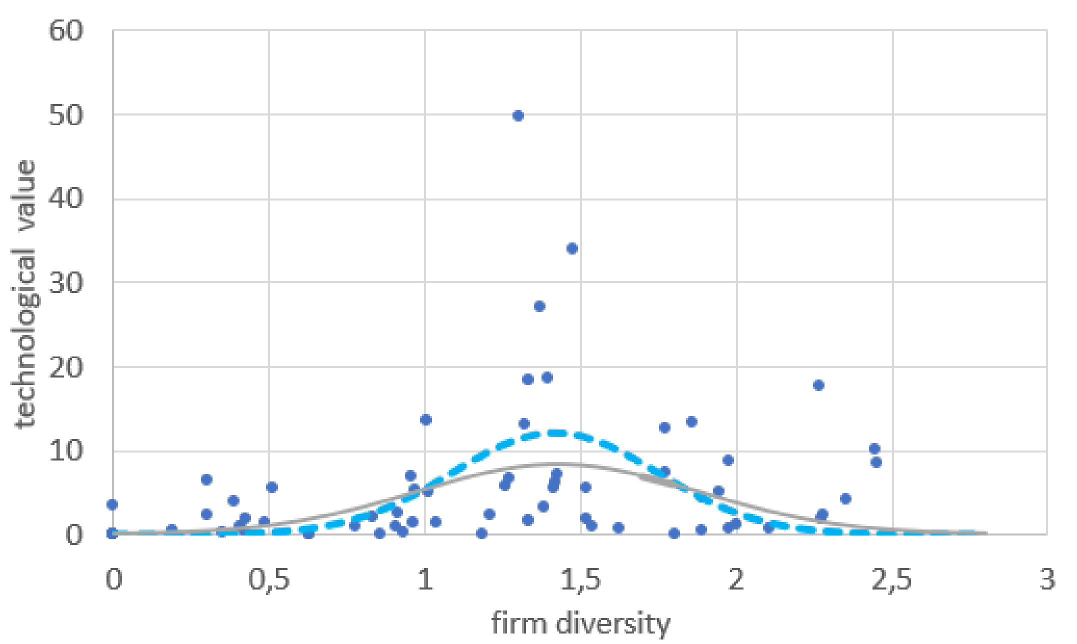

Figure 4.4: Gaussian equation: $y = b_0 * exp(-(x - b_2)^2/(b_1)^2))$ if % science $< 0,30$

to the left and raise it, in a diversification-innovation graph. This circumstance implies that, with the increase in the percentage of the used science, in one side, firms appear to obtain the maximum impact of the innovation, in average, with less technological diversification in the patent's portfolio and, in the other side, innovations with more impact are obtained in average.

Further analysis will study the firm collaboration effects (with other firms or universities) and the firm's size effect.

4.5.1 Contribution to theory

This research contributes for the study of the relation between technological diversification and innovation performance in a sample of science-based firms (firms that operate in sectors guided by science: i.e. pharmaceutical, biotechnology, nanotechnology). The effect of basic research in this relation is also analyzed. The positive effect of the use of basic research as source of knowledge for the development of patents with impact (highly cited) is easy explained. The basic research, indeed, allows inventors to gain scientific knowledge that is necessary for subsequent applications in various technological fields. If the exploration and combination of different technological knowledge appears associated with an increase of the patent value (Gosh et al. 2009), the use of scientific knowledge itself, in the same way, allows a better understanding of all the phenomenon and could facilitate the ability to find new connections between technological areas and new discoveries.

4.5.2 Contribution to practice

The positive impact of the basic research in the qualitative performance of innovation demonstrate the advantage of investing in R&D activities, both for firms that focus on core technology and search innovation exploring fields close to the field of the existing business activities and for diversified firms. Mostly for diversified firms is necessary a good balance of science and technology because excessive technological diversification, not supported by high basic research, could nullify the benefits of a portfolio.

4.6 References

1. R. Ceipek, J. Hautz, M. C.J. Mayer, K. Matzler (2019). Technological Diversification: A Systematic Review of Antecedents, Outcomes and Moderating Effects. International Journal of Management Reviews, 21, 466-497.

2. Corradini, C., Demirel, P. and Battisti, G. (2016). Technolog-

ical diversification within UK's small serial innovators. Small Business Economics, 47, pp. 163–177.

3. Corradini, C. and De Propris, L. (2017). Beyond local search: Bridging platforms and inter-sectoral technological integration. Research Policy, 46, pp. 196–206.

4. Donato, A., Appio, F. P., Baglieri, D., Cesaroni, F. (2019). Where do radical innovations come from? The case of nanotech. Conference Proceedings, R&D Management Conference 2019, Ecole Polytecnique, Paris, France.

5. Ghosh, A., Martin, X., Pennings, J. M. and Wezel, F. C. (2009). Recombination Experience: A Study of Organizational Learning and Its Innovation Impact. SMS 29th Annual Conference Submission.

6. Kim, J., Lee, C.-Y. and Cho, Y. (2016). Technological diversification, core-technology competence, and firm growth. Research Policy, 45, pp. 113–124.

7. Kim, H., Lim, H. and Park, Y. (2009). How should firms carry out technological diversification to improve their performance? An analysis of patenting of Korean firms. Economics of Innovation and New Technology, 18, pp. 757–770.

8. Lee, W.-L., Chiang, J.-C., Wu, Y.-H. and Liu, C.-H. (2012). How knowledge exploration distance influences the quality of innovation. Total Quality Management & Business Excellence, 23, pp. 1045–1059.

9. Leten, B., Belderbos, R. and Van Looy, B. (2007). Technological diversification, coherence, and performance of firms. Journal of Product Innovation Management, 24, pp. 567–579.

10. Lin, B.-W. and Chen, J.-S. (2005). Corporate technology portfolios and R&D performance measures: A study of technology intensive firms. R&D Management, 35, pp. 157–170.

11. Mariani, M. (2004). What determines technological hits? Research Policy, 33, pp. 1565–1582.

Chapter 5

Conclusions

5.1 Contribution to existing literature

A core interest in the literature on innovation is understanding how firms may tap into new technological domains in order to achieve successful innovations. Literature on innovation strategy has increasingly highlighted the vital role of cross-disciplinary knowledge or knowledge recombination across different domains in the development of important inventions.

However, the majority of the studies rely only on technological knowledge dimension. For instance Moaniba et al. 2018 analyze the cross-disciplinary knowledge only considering a technological point of view, finding a strong positive relationship of recombination of technologically diverse knowledge with the technological value of an invention.

Our contribution to the extant literature on innovation regards the analysis of both scientific and technological dimension together when a firm recombine knowledge across distinct domains. So we analyze the effect of simultaneously relying on technological and scientific diversification in the development of successful and novel inventions.

Our findings prove that recombining domains in different scientific together with technological fields - based on cited references and patents - increases the probability of developing successful inventions. Moreover, the technological novelty of an invention results strongly linked to our proposed ex-ante patent indicator of diversification of scientific knowledge, so we contribute also to the scientific debate about the timely topic of the assessing the novelty of radical innovations.

Moreover, starting from the relevant result about the importance of increasing and acquiring scientific knowledge (together with technological knowledge), we examine the relationship between the value of an innovation, the knowledge recombination, and the firms' collaborative efforts with external partners. We study, in particular, how different types of collaboration with external partners influence the patent's value and success, contributing to the literature on open innovation through a study at patent analysis. The results are interesting and novel, especially when it comes to linking the types of collaboration variables to the patent's value and success.

Based on the open innovation paradigm, firms must rely on an innovation model that not only takes into account internal ideas and resources, but also knowledge and skills from outside, in particular from startups, universities, research institutes and non-competing firms. Our results follow the open innovation paradigm, showing that alliances with scientific entities and with firms specialized in different types of products increase the value of an innovation, but as the number of partners of the same type increases, the value of the patent decreases.

5.2 Theoretical implications

Our thesis suggests how to understand more comprehensively the features of patents that may influence the generation of successful inventions. The empirical findings of this study provide new evidence that successful inventions involve the use of different scientific knowledge when inventors recombining knowledge across different technological domains.

Moreover, we have found the positive correlation between novelty and value of inventions, indicating that novel inventions tend to be successful. This result is not trivial, indeed often incremental inventions tend to have large value and novel inventions fail to create any value. However, the results of the analysis imply that the use of different scientific knowledge as background in the construction of a patent helps in the ability of generating novel and successful inventions, when inventors recombine between different technological domains and, at the same time, helps mitigate the risks associated to radical innovations.

We could draw, also, the conclusion that the *ex-ante* proposed measure of scientific diversification could be considered as good predictors of technological novelty; that could lead to using it for patent measure.

When we consider how the value of an innovation changes in case of firm' collaboration with other partners, we find that the number of different types of collaborations increases the value of a patent but as the number of partners of the same type increases, the value of the patent decreases, so the collaborations not always increase the patent value with respect to a situation of no collaboration.

From the difference between the coefficient of alliance with similar firm and that of the number of assignees it is deduced that collaboration even with a single company of the same type leads to negative values, that is, it would suit not to collaborate or, at least, not to collaborate if the intent is to develop value and money from the discovery.

Alliances with scientific entities and with diverse firms, on the contrary, increase the value of the innovation, but as the number of partners of the same type increases, the value of the patent decreases.

Finally, our research contributes to the study of the relation between technological diversification and innovation performance in a sample of science-based firms (firms that operate in sectors guided by science: i.e. pharmaceutical, biotechnology, nanotechnology). The effect of basic research in this relation is also analyzed. The positive effect of the use of basic research as a source of knowledge for the development of patents with impact is easily explained. The basic research, indeed, allows inventors to gain scientific knowledge that is necessary for subsequent applications in various technological fields. If the exploration and combination of different technological knowledge appears associated with an increase of the patent value (Gosh et al. 2009), the use of scientific knowledge itself, in the same way, allows a better understanding of all the phenomenon and could facilitate the ability to find new connections between technological areas and new discoveries.

The trend of the quality (in term of technological impact and value) of innovation with the technological diversification of a firm appears similar to a Gaussian with positive asymmetry. The effect of the use of sources of scientific knowledge in the creation of patents is very relevant: it is able to move the Gaussian peak to the left and raise it, in a diversification-innovation graph. This circumstance implies that, with the increase in the percentage of the used science, in one side, firms appear to obtain the maximum impact of the innovation, in average, with less technological diversification in the patent's portfolio and, in the other side, innovations with more impact are obtained in average.

5.3 Practical implications

Possible implications of our thesis for firms regard the learning of how to manage uncertainties and risks present in radical innovation projects. Those risks and uncertainties could determine several financial losses within the patent portfolio investment. The proposed solution is to increase the basin of scientific knowledge of the inventors in order to increase the ability of recombining different knowledge in a novel and successful way.

The scientific knowledge could be improved, for instance, increasing the investments in R&D projects or developing collaborations of scientific exchange with other economic subjects (mainly universities and research centers).

Moreover, the evaluation of the scientific diversification of the patents of a firm could help the manager of a firm to understand which patents will probably obtain value and so in which patents it is worth investing in and which patents should be renewed.

Internal knowledge can be increased with the exploration of new fields, supported by the acquisition of scientific knowledge, and with collaborations with other partners. Specifically, collaborations with subjects that provide different knowledge than that of the company are favorable, both scientific (universities and research centers) and technological (firms that possess knowledge in different sectors).

The study suggests that innovations resulting from the collaboration of many partners for each type do not increase their value, but on the contrary reduce it. Therefore, it is possible to think that when many subjects collaborate, the aim is not to create value for their firm but to find new ideas and acquire new knowledge that can be then developed individually.

Finallly, the positive impact of the basic research in the qualitative performance of firm' innovation demonstrates the advantage of investing in R&D activities, both for firms that focus on core technology and search innovation exploring fields close to the field of the existing business activities and for diversified firms. Mostly for diversified firms is necessary a good balance of science and technology because excessive technological diversification, not supported by high basic research, could nullify the benefits of a portfolio.

Chapter 6

Appendix 1: Using Matlab for developing originals algorithms that evaluate patent's technological characteristics

We, here, propose the original algorithms written for deriving some technological characteristics of the sample in thesis' chapter 2. Therefore, the sources of technological and scientific literature represents the backward citations of the sample of patents studied in chapter 2. Also the technological sub-class assigned to every patent refers to the sample of patents studied in chapter 2. Nevertheless, the procedure can be applied to any different sample changing these values.

6.1 Evaluation of technological diversity index at sub-group level

We propose the original Matlab algorithm used for the evaluation of the technological diversity index at sub-group level of a patent of the sample.

```
%all the cited patents expressed as a vector of
   the IPC components at subgroup level
ATE193980=[]
AU2006231371=[B01J1300 C01B3312 C01B33152 C01B3316
    C01B3346]
BR200607020=[B01J1300 C01B3312 C01B33152 C01B3316
   C01B3318 C01B3346 C08G77442 C08J412]
BR9406431BRPI9406431=[B01J1300 C01B3316]
CN101372337CN101372337B=[C01B3314]
CN101503195CN101503195B=[C01B3314]
CN101671029CN101671029B=[C01B3314]
CN101671030CN101671030B=[C01B3314]
CN101698584CN101698584B=[C04B1438 C04B2800]
CN101791881CN101791881B=[A41D3102 B32B2732 B32B516
   ]
CN102179230CN102179230B=[B01J2010 B01J2028
   B01J2030]
CN102557577CN102557577B=[C04B3002]
CN102602944CN102602944B=[B09B300 C01B3316]
CN102712487CN102712487B=[C01B3316]
CN102795826CN102795826B=[C04B2824]
CN102964107=[C04B2826]
CN102976783=[C04B3800]
```

CN103102135CN103102135B=[C04B1606 C04B2824]
CN103118979CN103118979B=[C01B3316]
CN103301787CN103301787B=[B01J1300]
CN103435055=[C01B3316]
CN104851965=[H01L3516 H01L3534]
CN1127631=[A61K800 A61K804 A61K818 A61K825 A61K829 A61K831 A61K855 A61K858 A61K872 A61K889 A61K8891 A61K8894 A61K8895 A61K8897 A61K8898 A61K892 A61Q100 A61Q102 A61Q104 A61Q106 A61Q108 A61Q110 A61Q1704 A61Q1900 C08L8304]
CN1214319=[C01B3314 F16L5902]
CN1668372CN1331588=[B01J1300 B61D1718 C08J932 C08L10114 E04F1300 E04F1318]
DE102006049179=[D01F200 D01F202 D01F916]
DE102009042526=[F16L5900]
DE102009053784=[C01B3316]
DE19939836=[A61K800 A61K802 A61K804 A61K806 A61K819 A61K825 A61K826 A61K827 A61K829 A61K830 A61K837 A61K892 A61Q100 A61Q102 A61Q104 A61Q106 A61Q112 A61Q1500 A61Q1704 A61Q1900]
DE2330956=[A45D700 A45D704 A61K800 A61K844 A61K872 A61K873 A61K881 A61K886 A61K891 A61Q504 A61Q506 C08F1600 C08F1638 C08F1808 C08F200 C08F244 C08F21804 C08F28300 C08F28306 C08F29106 C08F844 C08L3906]
DE69424995=[B01J1300 C01B3316]
EP68671=[C04B2442 C04B4149 C04B4164 C08K505 C08K554 C08L8300 C08L8304 C08L8308 C09D18304]
EP122483=[C08G5900 C08G5914 C08G5918 C08G5930 C08G5940 C08G5968 C08K505 C08K55435 C08L6300

C08L8300 C08L8304 C08L8306 C09D18304 C09D18310 C09J16300 C09J18300]

EP171722=[A23J306 A23L1760 B01D1102 B01J1300 B01J3700 C01B3314 C01B33158 C01B3332 C01B3906]

EP396076=[C01B33158 C04B1406 C04B3000 F16L5902 F16L5908]

EP412704=[A61K800 A61K804 A61K834 A61K837 A61K840 A61K846 A61K889 A61K8891 A61K8895 A61K8897 A61K891 A61Q500 A61Q502 A61Q504 A61Q506 A61Q512 A61Q700 C08L8304]

EP412707=[A61K800 A61K834 A61K837 A61K840 A61K846 A61K889 A61K8891 A61K8895 A61Q500 A61Q502 A61Q504 A61Q506 A61Q512 A61Q700 C07F718 C08L8308 C11D182 C11D300 C11D700]

EP582152=[A61K8899 A61Q506 A61Q512 C08F28312]

EP619111=[A61K800 A61K831 A61K834 A61K835 A61K841 A61K844 A61K887 A61Q506 C08G1808 C08G1865]

EP637600=[A61K887 A61Q110 A61Q302 A61Q506 C08G1808 C08G1842 C08G63685]

EP640105=[A61K800 A61K834 A61K841 A61K889 A61K8891 A61K8893 A61K8895 A61K891 A61Q1900 A61Q500 A61Q502 A61Q504 A61Q506 A61Q700 C08F29000 C08F29006 C08F29908 C08L8310 C09J15500 C09J15700 C09J18300 C09J18310 C09J406]

EP648485=[A61K800 A61K819 A61K825 A61K870 A61K872 A61K873 A61K884 A61K885 A61K887 A61K892 A61Q302]

EP656021=[A61K800 A61K834 A61K836 A61K8365 A61K837 A61K840 A61K841 A61K846 A61K887 A61K920 A61K928 A61K932 A61Q506 C08G1800 C08G1808 C08G1830 C08G1842 C08G1865 C08G1866 C08L7504 C09J17506]

EP707518=[B01J1300 C01B3316]
EP751162=[A61K800 A61K806 A61K872 A61K887 A61K889 A61K8891 A61K8896 A61K8898 A61K890 A61K891 A61Q100 A61Q110 A61Q302 A61Q502 A61Q506 C08G1808 C08G1861 C08G7742 C08G77452 C08G77458 C08L8308]
EP1412415=[C08G7744 C08K322 C08K336 C08K554 C08K5541 C08K55415 C08L8304 C08L8306 C09D18310]
EP1457472=[C01B3136 C04B35571 C04B35575 C04B3580]
EP1879690=[B01J1300 C01B3312 C01B33152 C01B3316 C01B3346]
EP2501653=[C01B33158 C01B3316]
FR1222944=[C08F28306]
FR1400366=[A61K881 A61Q506 C08F22400 C08F800 C08F830 C08F832]
FR1564110=[A61K881 A61Q506 C08F21808 C08F22006]
FR1580545=[A61K881 A61Q504 A61Q506 C08F1612 C08F202 C08F2062 C08F21808]
FR2077143=[A61K881 A61Q506 C08F22034 C08F22610 C08F2606 C08F800]
FR2198719=[A47J2721 H01H3748 H01H3752 H05B306]
FR2265781=[A61K800 A61K836 A61K837 A61K881 A61Q506 C08F2062 C08F21804]
FR2265782=[A61K800 A61K836 A61K837 A61K881 A61Q506 C08F1800 C08F1802 C08F2062 C08F21808 C08F22000 C08F22004]
FR2350384=[C09D500 C09D502 C09D700]
FR2357241=[A61K881 A61Q506]
FR2393573=[A61K800 A61K804 A61K841 A61K881 A61Q500 A61Q502 A61Q506 A61Q512]

FR2439798=[A61K800 A61K834 A61K872 A61K881 A61Q500 A61Q502 A61Q504 A61Q506 C08F1600 C08F1614 C08F1800 C08F1802 C08F21614 C08F21800 C08F21802 C08F21808 C08F21810 C08F21812 C08F22004]
FR2743297=[A61K800 A61K831 A61K834 A61K835 A61K837 A61K839 A61K872 A61K887 A61K889 A61K8891 A61K8896 A61K8898 A61K890 A61Q100 A61Q110 A61Q1900 A61Q302 A61Q500 A61Q506 C08G1808 C08G1861 C08L7504 C08L8310]
FR2851915=[A61K837 A61K881 A61Q102 A61Q106 A61Q108 A61Q1900 A61Q302]
FR2986422=[A61K806 A61K825 A61K849 A61K892 A61Q1704]
FR2986424=[A61K858 A61Q1700]
GB814740=[B01J1300 C08G7700]
GB839805=[A61K804 A61K881 A61Q506 C08J309]
GB1350661=[E04B180 E04C216 F16L5902]
JP03063218=[H04R722 H04R902 H04R904]
JP07202439=[H05K103 H05K346]
JP07257918JP3854645=[C01B33154 C01B3316 C04B3000 C04B3800]
JP07505330JP3507492=[A61K9127 A61K950 B01J1302 B01J1306]
JP08504674JP2840881=[B01J1300 C01B3316]
JP09508055=[A61K800 A61K802 A61K820 A61K823 A61K826 A61K827 A61K828 A61K833 A61K836 A61K849 A61Q1500 B01D900 B01J1300 B01J200 C01F700 C01F748 C01F756 C01G2500]
JP11335115=[C01B33158 C01B3316]

JP2001316474=[C08G77442 C09D13302 C09D14304 C09D18302 C09D18304]

JP2001524439JP4643823=[C01B33158 C01B3316]

JP2002173534=[C08F22606 C08F23008 C08G77442]

JP2002509069JP4331894=[B01J1300 C01B33154 C01B33155 C01B3316]

JP2003027035=[C09J17908 C09J20100 C09J700 H05K346]

JP2003183529JP3901534=[B65D8586 C08J500 C08K324 C08K509 C08L10100 C08L10114 C08L5100 C08L5104 C08L7102]

JP2003212999JP4128363=[C01B33159 C08G7702 C09K300 C09K500]

JP2005050860=[C08G7310 H05K103 H05K111 H05K346]

JP2005116660=[H05K346]

JP2005145812JP5103707=[C01B3314]

JP2006219446=[A61K31727 A61K3822 A61K4706 A61K4722 A61K4730 A61K4742 A61K914 A61P4300 B01J1300]

JP2008222527JP4912190=[C01B33152 C03B802]

JP2008537570JP4994360=[C01B3312 C01B33152 C01B3316 C01B3318 C01B3346 C08G77442 C08J312]

JP2010167685JP5354266=[B32B2700 B32B708 F16L5902]

JP2011136859=[C01B3316 C04B3800 C04B3808 D06M15643 D06M10100 D06M10140]

JP2012091943JP5528296=[B32B702 C01B33158 C01B33159 C03C2706]

JP2012144428JP5456089=[B01J1300 B01J2010 B01J20281 B01J20291 B01J2032 C01B33154 C01B33155 C01B33159 C01B3316 C01B3318]

JP2013203804JP6042085=[C01B33193 C09C100 C09C128 C09C312 C09D1700 C09D20100 C09D712]

JP2013511461=[C01B3316]
JP62169392=[]
JP63175636=[]
KR101155503=[E04B188 E04C226]
KR101171711=[B32B1514 E04B180 E04C2296]
KR101454233=[A47G902 D04H1413 D04H1488 D04H1498]
KR19967001693KR100158053=[]
KR20000057244KR100566390=[B01J1300 B01J2010 B01J20281 B01J20291 B01J2032 C01B33154 C01B33155 C01B3316 C01B3318]
KR20050084503=[A61F703 A61F708 A61L1544 C09K518 F24V3000]
KR20090097747KR100940618=[C04B1404 C04B1410 C04B1606 C04B2424]
KR20100002232=[C04B1404 C04B1410 C04B1432 C04B2424]
KR20100083543KR101072287=[B32B516 B32B712 E04C224]
KR20100092683KR101064869=[C01B33141 C01B33157 C01B33158]
KR20100098905KR101124383=[D06B304 D06M1177]
KR20110082379KR101193987=[C01B3314 C01B33158 D06M1159 D06M1177]
KR20120091788=[B29C6306 B32B518 F16L5900 F16L5910]
KR20120102711KR101466455=[C01B3314 C01B33146 C01B3316]
KR20120113469KR101292796=[E04B194 E04F1510]
KR20130022163KR101287805=[B32B528 C03C2524 C08J524 C08L102]
KR20130066582=[E04B176 E04B180 F16L59065]
KR20140046222=[B63B2902 B63B900 E04B180 F16L5902]

KR20160100082KR101789371=[C01B33158 F16L5902]
LU75370=[A61K881 A61Q506 C08F22054 C08F22238]
LU75371 =[A61K872 A61K873 A61K881 A61Q302 A61Q506 C08F22054 C08F22238]
PT103257=[C01B3312 C01B33152 C01B3316 C01B3346]
US20010034375US7470725=[B01J1300 B01J2010 B01J20281 B01J20291 B01J2032 C01B33154 C01B33155 C01B3316 C01B3318]
US20020005145US6653356=[B01J1300 B01J2106 B01J3500 C01G23053 C09C136]
US20020028385US6500401=[C01B32384 C04B3000 C04B3800 C08K304 H01G900 H01G9155 H01M458 H01M4583 H01M462 H01M496]
US20020094426US7078359=[B01J1300 B32B526 C04B1406 C04B3002 D04H100 D04H1300 D06M1179 E04B176 E04B178 H05K900 D06M10140]
US20020104599US6986818=[C01B1332 C01F1700 C01F734 C01G102 C01G1500 C01G1902 C01G2502 C01G2702 C01G3300 C01G37033 C01G4100 C01G4301 C01G4902 C06B2100 C06B3300 C06B4700]
US20020161114US6858680=[A61L2700 A61L2718 A61L2726 A61L2750 A61L2904 A61L2906 A61L2914 A61L3100 A61L3104 A61L3106 A61L3114 C08G1838 C08G1848 C08G1861 C08G1866 C08J500 C08L10100 C08L7500 C08L7504]
US20030007987US6562322=[A61K800 A61K804 A61K818 A61K825 A61K829 A61K831 A61K855 A61K858 A61K872 A61K889 A61K8891 A61K8894 A61K8895 A61K8897 A61K8898 A61K892 A61Q100 A61Q102 A61Q104 A61Q106 A61Q108 A61Q110 A61Q1704 A61Q1900 C08L8304]

US20030055198US6720402=[A61L2700 B29C6100 C08F29904 C08G8100 C08L10100 C08L10116]
US20030060519US6620458=[C01F744 C04B35111 C04B35624 C04B3800]
US20030077438US6887563=[C04B2612 C04B2826 C04B3002]
US20030147931US6780422=[A61K800 A61K804 A61K818 A61K825 A61K829 A61K831 A61K855 A61K858 A61K872 A61K889 A61K8891 A61K8894 A61K8895 A61K8897 A61K8898 A61K892 A61Q100 A61Q102 A61Q104 A61Q106 A61Q108 A61Q110 A61Q1704 A61Q1900 C08L8304]
US20030176277US6809060=[B01J2118 B01J2340 B01J2346 B01J3708 H01M486 H01M488 H01M492 B01J3718 H01M810]
US20030203635US6767476=[B24B3700 C09G102 C09K1304 C09K1520 C09K314 C23F300 H01L21304 H01L21306 H01L21321]
US20040029982US7378450=[B01J2118 B01J2340 B01J3510 B01J3702 B01J3703 B01J3708 C04B1434 C04B2000 C04B3000 C04B3800 C04B4150 H01M488 H01M490 H01M492]
US20040058808US7005401=[B01J2370 B01J3708 H01M488 H01M490 B01J2106 B01J2118 B01J3702 H01M81018]
US20040065619US6843919=[B01D5304 B01D5334 B01J2006 B01J2020 B01J2032 C01B1314 C01F514 C09C102 C09C306 C02F128 C02F150]
US20040109986US6919122=[A21B148 A21C1302 B29C3914 B29C3918 B29C7050 B29D2906 B32B2504 B32B316 B32B3700 B65G1534 B65G1542 D06N304 D06N312 F16G108 F16G116 B29C5904]

US20040118748US7087156=[C10G2503 C10G4502 C10G6706 B01J2106 B01J3703]
US20040118749US7160438=[C10G2500 C10G6706]
US20040120876US7402293=[C01B3312 C01B33158 C01B33159 C09C130]
US20040132845US7074880=[B01J1300 C08G7310 C08J928 H01M490]
US20040175345US7005134=[A61K800 A61K804 A61K818 A61K825 A61K829 A61K831 A61K855 A61K858 A61K872 A61K889 A61K8891 A61K8894 A61K8895 A61K8897 A61K8898 A61K892 A61Q100 A61Q102 A61Q104 A61Q106 A61Q108 A61Q110 A61Q1704 A61Q1900 C08L8304]
US20040176643US6927309=[A01N2522 A01N3108 A01N3114 A01N3736 A01N4102 A01N4104 A01N4110 C07C30986 C07C31714 C07C32126 C07C32128 C07C32360 C08G5940 C11B900]
US20040202602US7390474=[B01J2118 B01J2342 B01J3703 B01J3708 B01J3734 C01B3100 C04B3800 C25B1103 C25B1112 H01M486 H01M492]
US20050046086US7399439=[B01J1300 B06B102 B29B1512 B29C3508 B29C3914 B29C3916 B29C3918 F16L5902 E04B]
US20050064279US6906003=[C01B300 F17C1100]
US20050066574US7410718=[C04B35524 C04B35624 C04B3583 C10L544 C10L546 C10L548 H01M458 H01M496 H01M800 H01M814]
US20050103990US7799726=[B01D5388 B01D5394 B01J2118 B01J2346 B01J2374 B01J3506 B01J3510 B01J37025 C01B3102 C01B3120 C06D504 H01M486 H01M496 B01J23745 B01J23755 B01J3702 B01J3708 B64G140

H01M490]
US20050131163US7071287=[B01J1300 C08G7310 C08J928 H01M490]
US20050167891US6989123=[B01J1300 B06B102 B29B1512 B29C3508 B29C3914 B29C3916 B29C3918 F16L5902 E04B]
US20050192366=[C01B33158 C04B1406 C04B2440 C04B3000 C08J928 G04B]
US20050192367US7691912=[C01B3300 C01B33158 C08J928 D04H142]
US20050215068US7256147=[B01J2106 B01J2342 B01J3504 B01J3700 B01J3708 C04B3546 C04B35524 C04B35624 C04B3800 H01G920 H01M806]
US20060036045=[B32B2740 C08G1800 C08L7500]
US20060054487US7238261=[B01J1912 C01B3100]
US20060078719=[D04H300]
US20060088562US7160550=[A61K800 A61K804 A61K818 A61K825 A61K829 A61K831 A61K855 A61K858 A61K872 A61K889 A61K8891 A61K8894 A61K8895 A61K8897 A61K8898 A61K892 A61Q100 A61Q102 A61Q104 A61Q106 A61Q108 A61Q110 A61Q1704 A61Q1900 C08L8304]
US20060093808US7270851=[B32B2700]
US20060099139US7282466=[C01B1700 C01B3100 C01B3102]
US20060116433US7691911=[B29C4434]
US20060154195=[A61C300]
US20060155376US7780875=[A61F228]
US20060199455US7504346=[B01J1300 B32B1702 B32B502 B32B526 C03C300 C04B1406 C04B3002 D04H100 D04H1300 D06M1179 E04B176 E04B178 H05K900

D06M10140]
US20060229374US8461223=[B29C4434]
US20060246027=[A61K819 A61K889]
US20060281828US8029871=[B29C7104]
US20060293434=[C08K304]
US20070092468=[A61K800 A61K804 A61K818 A61K825 A61K829 A61K831 A61K855 A61K858 A61K872 A61K889 A61K8891 A61K8894 A61K8895 A61K8897 A61K8898 A61K892 A61Q100 A61Q102 A61Q104 A61Q106 A61Q108 A61Q110 A61Q1704 A61Q1900 C08L8304]
US20070134488US7858188=[B32B2720 B32B516 C08K304]
US20070142222=[B01J2108 B01J2118 B01J2340 B01J3510 B01J3702 B01J3703 B01J3708 C04B1434 C04B2000 C04B3000 C04B3800 C04B4150 H01M488 H01M490 H01M492]
US20070152363=[B29C6500]
US20070154698=[B32B1302 B32B904]
US20070166222US7691909=[C01B3102 C01B3104]
US20070173157=[B32B2712]
US20070222116US7560062=[B29C4302 B29C4322 B29C5902]
US20070231576=[B32B2736]
US20070292732US7816413=[B01J1300 C08J302 H01M810]
US20080093016US7780890=[B01J1300 B06B102 B28B114 B29B1512 B29C3508 B29C3914 B29C3916 B29C3918 B32B2704 F16L5902 E04B]
US20080188575US7737189=[C01B3312 C01B33152 C01B33155 C01B3316 C01B3346]
US20080200432=[A61K31695 A61P4300 C07F704]
US20080229704=[E04C202 E04C254]

US20080261116US8828481=[B05D512 H01M404 H01M413 H01M4139 H01M458 H01M4587 H01M10052 H01M1036]
US20080307737US7947354=[E04B162]
US20090018232=[C08F246]
US20090087665US7931940=[B05D302 B32B1706 B32B2732 B32B2736 G02B111 G02B1111 G02B114]
US20090104401=[B01J1918 B32B2728 B32B310 C08J928]
US20090123358=[C01B3312]
US20090178933=[B29B900 C30B3006]
US20090185327US7986509=[B05D512 H01G9022 H01G9042 H01M1004 H01M448 H01M450 H01M452]
US20090229032=[A41D100 A41D2700 B01J1300 B32B2712 B32B306 B32B526 C04B1406 C04B3002 D04H100 D04H1300 D06M1179 E04B176 E04B178 H05K900 D06M10140]
US20090247648US8084506=[A61K4724 A61Q1900]
US20090317619=[B32B326 C03C3062]
US20100028634=[B05D512 B32B1706 B32B2728 B32B2730 B32B2732 B32B2736 B32B2738 B32B2740 B32B702 B32B900]
US20100075024US7927666=[B05D512 C08K304]
US20100107381US8214980=[D04H146 D04H502]
US20100139823US8172964=[C06B4504]
US20100140532US8383238=[E04B178]
US20100140840US8021583=[B29C5518 C04B2400 C08K500 C08L2306 C09D500]
US20100155644=[C08J928 D04H142 E04B174]
US20100187484US8685287=[H01B104 H01B124]
US20100190639=[B01J2118 B01J2306 B01J2372 B01J2374]

US20100304078=[B32B500 G01N1910]
US20110002086US8404384=[B32B900 C01B3100 H01B124 H01B500 H01G9155]
US20110024698=[H01B104 H01B112 B82Y3000]
US20110065820US8679808=[C08J900 B82Y3000]
US20110086100US9125872=[A61K3116 A61K31337 A61K31351 A61K3140 A61K314375 A61K314439 A61K31573 A61K317048 A61K317068 A61K3813 A61K3818 A61K3821 A61K3828 A61K914]
US20110245359=[C08G7738 C08J928]
US20120028798US8809230=[B01J2118 B01J3200 C23C1626 C23C1644 H01B104 B82Y3000 B82Y4000]
US20120037854US9087625=[B05D300 B05D302 B05D512 H01B124 B82B300 B82Y9900]
US20120065163US9498654=[A61K858 A61Q1900]
US20120077006US8629076=[B05D300 B05D302 B05D722 B32B518 B32B904 B82Y3000]
US20120083543=[C08J928]
US20120097907US9115025=[B05D302 B28B114 B29C3922 B29C4708 B29C6700 C09K2102 E04B174]
US20120122652US8664143=[B01J2118 B82Y3000 B82Y4000]
US20120136079US8906973=[C08G7702 C08J928]
US20120152846=[B01D1500 C01B3102 C08G1800 C08J900 B82B100 B82B300 B82Y3000]
US20120168095=[A47H2300 A47H2304]
US20120175546US8952119=[E04B178]
US20120220679US8697766=[B02C1900 C08G1832 C08J928]
US20120228545US9266743=[C01B3316 C09K300]

US20130005842US9133280=[C08F13606 C08F834 C08J928 C08K702]
US20130022769=[B32B102 B32B108 B32B518 E04B178 F16L5900]
US20130260135=[B32B326]
US20130287661US9302247=[B01D5362 B01J2030]
US20130296596US8889749=[C07F718]
US20130330262US8652432=[C01B3312]
US20140170350US9808964=[B29C3900 E04B178]
US20140350134US9206298=[C08J928]
US20150065590US9512287=[C08J928]
US20150082590=[D06B310]
US20150141533US9764301=[B01J1300]
US20150176748=[B32B3706 B32B3712 B32B3714 F16L5902]
US20150325771US9276190=[H01L3514 H01L3534]
US20160046495US10160655=[C01B3314 F16L59065 F26B516]
US20160090463=[C08G1822 C08J928]
US20160115368US9856411=[C09K8508 E21B3100 E21B3312]
US20160272777US9469739=[B65D6538 B65D7500 C08G6106 C08J900 C08J928 C08K710]
US20160289387US9505885=[C08G7306 C08J312]
US20170114249=[C09D18308 C09D508]
US2047398=[C08F2200 C08F800]
US2102113=[F02M1903 F02M310]
US2188007=[A61K3334 B01J1300 B01J2006 B01J2100 B01J2108 C01B3314 C01B33158 C04B3800]
US2723248=[C08L3904]

US3589578=[B65H23188 D06H304]
US3672833=[B01J1300 C01B33158]
US3734874=[C08G63672 C08G63688 C08G6944 C08L6700]
US3779993=[C08G63672 C08G63688 C08G6944 C08L6700]
US3836537=[A61K881 A61Q506 C08F2034 C08F2052 C08F2060]
US3838082=[B01D3908 C03C2530 C09D12718]
US3940426=[C07C5109 C07C51265 C07C5127 C07C51573 C07C67343]
US4031307=[C08B3714]
US4119680=[C08G63688 C08L6706]
US4128631=[A61K881 A61Q1704 A61Q1900 A61Q1910 A61Q500 A61Q902 C11D337]
US4131576=[C08F232 C08F25100]
US4300580=[A61K885 A61Q506]
US4363738=[C04B2602 C04B2800 C04B3002 C04B3200]
US4376674=[D21H1767 D21H1768 D21H2328 D21J108 D21J116]
US4447345=[B32B1800 B32B1900 B32B904 C04B2602 C04B3002 C04B3200 C04B3800 C04B3808 F16L5902 F16L5905]
US4515656=[D21F1100]
US4610863=[B01J1300 C01B33158 C04B3800]
US4619908=[B01J1300 B01J3703 C01B1332 C01B33152 C01B33158 C01F704 C01F736 C01G23053 C01G902 C07C51265 C07C5131 C08F402]
US4667417=[A23J306 A23L1760 B01D1102 B01J1300 B01J3700 C01B3314 C01B33158 C01B3332 C01B3906]
US4681615=[C03B1912 C03B802 C03C100 C03C306]

US4693935=[C08F29006 C09J15100 C09J15500 C09J18300 C09J18310 C09J20100 C09J20102 C09J20110 C09J400 C09J702]
US4717708=[B01J1300 B01J20281 B01J20283 B01J20284 B01J2100 B01J2106 B01J2112 B01J2300 B01J2306 B01J23656 B01J2700 B01J3510 B01J3703 C01B1318 C01B1332 C01B33158 C01F736 C01G23053 C01G902 C08F1000 C08F400 C08F460 C08F464 G01N3088]
US4728571=[C08F23008 C08F26300 C08F26304 C08F26500 C08F26506 C08F28500 C08F29100 C08F3008 C08G77442 C09D18304 C09D18310 C09J14304 C09J14500 C09J15100 C09J15106 C09J18300 C09J18310 C09J702]
US4923547=[C08J508 D04H100 D04H160]
US4958002=[C07C51573 C08G7310]
US4972037=[A61K4724 A61K804 A61K872 A61K889 A61K8891 A61K8894 A61K8897 A61K891 A61K970 A61Q1900 A61Q500 C08F22022 C08F28301 C08F29900]
US4973656=[C08G63688 C08G6944 C08L6700 C08L6702 C08L7712 C09D16700 C09D16702 C09D17700 C09D17712]
US5023208=[C01B3312 C03B802 C03C100 C03C102]
US5124364=[C08J914 C08J932 C08J935 C08K336 C08K700 C08K726 C08L2504]
US5258530=[B01J2713 B01J2725 B01J3104 B01J3122 C07B6100 C07C63331 C07D30789]
US5260855=[C04B3800 C08G804 C08G820 H01G900 H01G9155]
US5275796=[B01J1300 C01B33158 C03C100]
US5306555=[C01B33158 C04B3800]

US5334648=[C03C2534 C08K714 C08L6124 C08L5106]
US5409683=[B01J1300 C01B33158 C03C100]
US5565142=[B01J1300 C01B3316]
US5601938=[H01M496 H01M808 H01M492]
US5660816=[A61K800 A61K802 A61K804 A61K831 A61K834 A61K836 A61K8362 A61K8368 A61K881 A61K885 A61Q506]
US5662893=[A61K800 A61K802 A61K804 A61K831 A61K834 A61K836 A61K8362 A61K8368 A61K881 A61K885 A61Q500 A61Q506]
US5674479=[A61K800 A61K802 A61K804 A61K831 A61K834 A61K836 A61K8362 A61K8368 A61K881 A61K885 A61Q500 A61Q506]
US5698140=[B01J2118 C01B300 H01G900 H01G9155 H01M400 H01M436]
US5705535=[B01J1300 B01J2108 B01J3200 B01J3703 B01J3734 C01B33158 C01B3316 C08J928]
US5746992=[C01B33158]
US5786059=[B32B502 B32B516 D01F804 D04H1413 D04H1435 D04H14374 D04H154 D04H1541 D04H155 D04H1300]
US5789075=[B01J1300 C01B3516 C04B2824 C04B3002 C04B3514 C04B3800]
US5795557=[B01D1100 C01B33158 C01B3316]
US5800816=[A61K800 A61K804 A61K818 A61K825 A61K829 A61K831 A61K855 A61K858 A61K872 A61K889 A61K8891 A61K8894 A61K8895 A61K8897 A61K8898 A61K892 A61Q100 A61Q102 A61Q104 A61Q106 A61Q108 A61Q110 A61Q1704 A61Q1900 C08L8304]
US5830387=[C01B33158]

US5855953=[C04B4145 C04B4181 C23C1604 C23C1616 C23C1618 C23C1626 C23C1644]
US5866027=[B01J1300 C01B1332 C01B3316 C04B2824 C04B3002 C04B3800]
US5911658=[C01B33158]
US5911974=[A61K800 A61K804 A61K818 A61K825 A61K829 A61K831 A61K855 A61K858 A61K872 A61K889 A61K8891 A61K8894 A61K8895 A61K8897 A61K8898 A61K892 A61Q100 A61Q102 A61Q104 A61Q106 A61Q108 A61Q110 A61Q1704 A61Q1900 C08L8304]
US5962539=[B01J1300 C08J928]
US5965112=[A61K800 A61K804 A61K818 A61K825 A61K829 A61K831 A61K855 A61K858 A61K872 A61K889 A61K8891 A61K8894 A61K8895 A61K8897 A61K8898 A61K892 A61Q100 A61Q102 A61Q104 A61Q106 A61Q108 A61Q110 A61Q1704 A61Q1900 C08L8304]
US5966832=[F26B2100 F26B2114 F26B2500 F26B516 F26B700]
US5972254=[B01J1300 C04B3800]
US5973015=[B01J1300]
US5985298=[A61K800 A61K804 A61K818 A61K825 A61K829 A61K831 A61K855 A61K858 A61K872 A61K889 A61K8891 A61K8894 A61K8895 A61K8897 A61K8898 A61K892 A61Q100 A61Q102 A61Q104 A61Q106 A61Q108 A61Q110 A61Q1704 A61Q1900 C08L8304]
US6017505=[B01J1300 B01J204 C01B1332 C01B33158 C01G1902 C01G23047 C01G2502 C01G3702]
US6040375=[C01B33158 C04B2602 C04B3808 C08J900 C08J902 C08J904 C08J912]
US6068882=[C04B1430 C04B1446 C04B2000 C04B3002]

US6080475=[C04B1404 C04B1406 C04B1604 C04B2800 C04B2802 C04B2824 C04B3808 E04B178]
US6083619=[C04B1404 C04B1406 C04B2800 C04B2802 C04B3313 C04B3514 C04B3516]
US6087407=[B01J1300]
US6103036=[B29C6342 C04B3000]
US6127306=[B01J2108 B01J3102 B01J3116 B01J3120 B01J3124 B01J3703 C01B33158 C09K506]
US6140377=[C01B33158 C01B3316 C04B1406]
US6143400=[C04B1404 C04B1406 C04B2600 C04B3002 C04B3808 C09J12904 C09J12914 C09J16106 C09J16124 C09J16128 C04B11128 C04B11140]
US6187250=[B01J2026 B29C3916 C08F201 C08F2056 G01N27447]
US6197270=[C01B33158]
US6447991=[B01D4508 G01N122]
US6464964=[A61K800 A61K804 A61K818 A61K825 A61K829 A61K831 A61K855 A61K858 A61K872 A61K889 A61K8891 A61K8894 A61K8895 A61K8897 A61K8898 A61K892 A61Q100 A61Q102 A61Q104 A61Q106 A61Q108 A61Q110 A61Q1704 A61Q1900 C08L8304]
US6472067=[B29C4318 B29C4320 B29C4358 B32B2704 C08J524]
US6479416=[C04B3002 D04H154 D04H1542 D04H1300]
US6592776=[B24B3700 C09G102 C09K1304 C09K1520 C09K314 C23F300 H01L21304 H01L21306 H01L21321]
US6620355=[B01J1300 B01J220 C01B1314]
US6656527=[B01J1300 C01B1332 C01B3312 C01B33158 H01L21316]

US6670402=[B01D1200 B01J1300 B01J1908 B01J300 C01B1314 C01B1332 C01B33158]
US6764667=[B01J1300 C01B33158 C01B3316]
US7442747=[C08F28300 C08G802 C08G828 C08L6100 C08L6106 C08L8100]
US8067478=[C08F28300 C08F28312 C08G1848 C08G7700 C08G7738 C08J900]
US8568563=[D21H1340 D21H2134 D21H2328]
WO200145651=[A61K800 A61K804 A61K831 A61K837 A61K881 A61K886 A61K892 A61K897 A61Q506 C11D318 C11D337]
WO200357367=[B01J2118 B01J2340 B01J3510 B01J3702 B01J3703 B01J3708 C04B1434 C04B2000 C04B3000 C04B3800 C04B4150 H01M488 H01M490 H01M492]
WO200441398=[B01D1508 B01J2010 B01J2022 B01J2026 B01J20285 B01J20286 B32B514 C08F2056 C08F23008 C08F26510 C08F28312 C08G7720 C08G77442 C08L5300 G01N3036 B01D]
WO200460660=[B32B2730 B32B2734 B32B702 B32B712 H01L2314 H05K103 H05K105 H05K346]
WO200602440=[B32B2700]
WO2006102568=[H01L2924]
WO2006107226=[B01J1300 C01B3312 C01B33152 C01B3316 C01B3346]
WO2006114420=[C09C130 C09C136 C09C142 C09C312 C09D100]
WO200710949=[C08G7704]
WO2007146945=[B32B2740]
WO200751511=[A61K802 A61K825 A61Q506]
WO200800163=[C01B3102]

WO2008110818=[E04B176 E04B180]
WO2008129281=[E04B180]
WO2008134712=[]
WO200844873=[C01B33159]
WO200851029=[B32B308]
WO2009120602=[A61K825 A61K858 A61Q100 A61Q1900]
WO200959869=[A61K825 A61K858 A61K8891 A61Q506]
WO200992819=[A61K930 A61K948]
WO201054980=[A61K804 A61K825 A61K881 A61Q506]
WO2012162644=[B01J2010 B41M500]
WO201285855=[A61K804 A61K825 A61K858 A61K872 A61K881 A61K889 A61K8891 A61K8899 A61K892 A61Q100 A61Q102 A61Q112]
WO201309984=[B01J208 B01J2106 C01B3304 C01B33158]
WO2013116733=[B32B326 C04B2602 C04B2802]
WO201387927=[A61K825 A61K881 A61Q100 A61Q1900 A61Q500]
WO2014128680=[A61K804 A61K826 A61K873 A61K881 A61K889 A61K892 A61Q104]
WO201619308=[C07F704 C08J3075 C08L3308]
WO9203378=[B01J1300 C01B33158 C03C100]
WO9220623=[C01B3316]
WO9323009=[A61K800 A61K836 A61K839 A61K872 A61K889 A61K8891 A61K8899 A61K890 A61K891 A61Q100 A61Q102 A61Q104 A61Q106 A61Q110 A61Q1100 A61Q1500 A61Q1704 A61Q1900 A61Q1910 A61Q300 A61Q302 A61Q500 A61Q502 A61Q506 A61Q512 C08F28312 C08G7720 C08G7728 C08G77392 C08G7742 C08G77442 C08L5108]

```
WO9403510=[A61K800 A61K834 A61K836 A61K8365
   A61K837 A61K840 A61K841 A61K846 A61K887 A61K920
   A61K928 A61K932 A61Q506 C08G1800 C08G1808
   C08G1830 C08G1842 C08G1865 C08G1866 C08L7504
   C09J17506]
WO9425149=[B01J1300 C01B3316]
WO9500578=[C08F1200 C08F842 C08G7742 C08G77442
   C08G8102 C08J518 C08L2302 C08L8306 C08L8308]
WO9518191=[C08G63688 C08G6944 C09J16700 C09J16702
   C09J17700 C09J17712 C09J500 C09J504 D06M15555
   D06M1700]
WO9708261=[C08G63688 C09D16502 C09J16502 C09J16700
    C09J16702 C08G6366]
WO9720899=[B32B712 C08G63688 C08G6944 C09J16702
   C09J16706 C09J17712 C09J506]

%bc= number of cited patent
bc=2
v=1
for i=1:(bc-1)
v=[v,1]
end
A=ones(bc)-diag(v)

%patent 1 of the sample

E=[US20150325771US9276190 CN104851965]
F=tabulate(E)
q=(F(:,3)/100).^0.5
H= wentropy(q,'shannon')
```

```
%jackknife method
for i=1:bc
C=[A(1,i)*US20150325771US9276190 A(2,i)*
    CN104851965]
D=tabulate(C)
n=length(D)

%frequency
p=D(2:n,2)/(sum(D(:,2)) - D(1,2))
s=p.^0.5

%H index
e(i) = wentropy(s,'shannon')
end

HJ=mean(e)
```

6.2 Evaluation of scientific diversity index

We propose the original Matlab algorithm used for the evaluation of the scientific diversity index of a patent of the sample.

```
%all the cited scientific references of the
    patents of the sample, containing Web of Science
     journal articles, conference proceedings, books
     and chapters
```

B1=[ChemistryMultidisciplinary]
B2=[NanoscienceNanotechnology
MaterialsScienceMultidisciplinary]
B3=[ChemistryMultidisciplinary
GreenSustainableScienceTechnology
EngineeringChemical]
B4=[MaterialsScienceMultidisciplinary
MetallurgyMetallurgicalEngineering]
B5=[MaterialsScienceMultidisciplinary
MetallurgyMetallurgicalEngineering]
B6=[MaterialsScienceMultidisciplinary
MetallurgyMetallurgicalEngineering]
B7=[Acoustics]
B8=[ChemistryPhysical EnergyFuels
MaterialsScienceMultidisciplinary PhysicsApplied
PhysicsCondensedMatter]
B9=[ChemistryPhysical EnergyFuels
MaterialsScienceMultidisciplinary PhysicsApplied
PhysicsCondensedMatter]
B10=[ChemistryMultidisciplinary ChemistryPhysical
NanoscienceNanotechnology
MaterialsScienceMultidisciplinary PhysicsApplied
PhysicsCondensedMatter]
B11=[ChemistryMultidisciplinary ChemistryPhysical
NanoscienceNanotechnology
MaterialsScienceMultidisciplinary PhysicsApplied
PhysicsCondensedMatter]
B12=[ChemistryMultidisciplinary ChemistryPhysical
NanoscienceNanotechnology
MaterialsScienceMultidisciplinary PhysicsApplied

PhysicsCondensedMatter]
B13=[ChemistryMultidisciplinary ChemistryPhysical NanoscienceNanotechnology MaterialsScienceMultidisciplinary PhysicsApplied PhysicsCondensedMatter]
B14=[ChemistryMultidisciplinary ChemistryPhysical NanoscienceNanotechnology MaterialsScienceMultidisciplinary PhysicsApplied PhysicsCondensedMatter]
B15=[ChemistryMultidisciplinary]
B16=[ChemistryMultidisciplinary]
B17=[ChemistryMultidisciplinary]
B18=[ChemistryMultidisciplinary]
B19=[ChemistryMultidisciplinary]
B20=[ChemistryPhysical EnvironmentalSciences]
B21=[NanoscienceNanotechnology MaterialsScienceMultidisciplinary]
B22=[NanoscienceNanotechnology MaterialsScienceMultidisciplinary]
B23=[NanoscienceNanotechnology MaterialsScienceMultidisciplinary]
B24=[NanoscienceNanotechnology MaterialsScienceMultidisciplinary]
B25=[NanoscienceNanotechnology MaterialsScienceMultidisciplinary]
B26=[PhysicsApplied]
B27=[ChemistryPhysical MaterialsScienceCoatingsFilms PhysicsApplied PhysicsCondensedMatter]

B28=[EngineeringBiomedical
MaterialsScienceBiomaterials]
B29=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B30=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B31=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B32=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B33=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B34=[ChemistryApplied ChemistryPhysical
EngineeringChemical]
B35=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B36=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B37=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B38=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B39=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B40=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B41=[ChemistryPhysical
PhysicsAtomicMolecularChemical]
B42=[ChemistryMultidisciplinary]
B43=[ChemistryMultidisciplinary]

B44=[Electrochemistry]
B45=[MaterialsScienceTextiles]
B46=[EngineeringChemical]
B47=[EngineeringMultidisciplinary
InstrumentsInstrumentation]
B48=[Thermodynamics EngineeringMechanical
Mechanics]
B49=[EngineeringChemical
MaterialsScienceMultidisciplinary Mechanics]
B50=[MaterialsScienceCeramics]
B51=[MaterialsScienceCeramics]
B52=[MaterialsScienceCeramics]
B53=[MaterialsScienceCeramics]
B54=[ChemistryPhysical EngineeringChemical]
B55=[ChemistryPhysical]
B56=[ChemistryPhysical]
B57=[ChemistryPhysical]
B58=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B59=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B60=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B61=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B62=[ChemistryPhysical
MaterialsScienceMultidisciplinary]
B63=[ChemistryPhysical
MaterialsScienceMultidisciplinary]

```
B64=[EngineeringIndustrial
   EngineeringManufacturing
   MaterialsScienceMultidisciplinary]
B65=[EngineeringIndustrial
   EngineeringManufacturing
   MaterialsScienceMultidisciplinary]
B66=[MaterialsScienceMultidisciplinary]
B67=[MaterialsScienceMultidisciplinary]
B68=[MaterialsScienceMultidisciplinary]
B69=[MaterialsScienceMultidisciplinary]
B70=[MaterialsScienceMultidisciplinary]
B71=[MaterialsScienceMultidisciplinary]
B72=[ChemistryPhysical]
B73=[ChemistryApplied ChemistryPhysical
   EnergyFuels EngineeringChemical]
B74=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
B75=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
B76=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
B77=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
B78=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
B79=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
B80=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
```

```
B81=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
B82=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
B83=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
B84=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
B85=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
B86=[]
B87=[ChemistryPhysical]
B88=[ChemistryPhysical NanoscienceNanotechnology
   MaterialsScienceMultidisciplinary]
B89=[PhysicsApplied]
B90=[]
B91=[]
B92=[ChemistryApplied ChemistryPhysical
   MaterialsScienceMultidisciplinary]
B93=[ChemistryPhysical Electrochemistry
   EnergyFuels MaterialsScienceMultidisciplinary]
B94=[ChemistryPhysical Electrochemistry
   EnergyFuels MaterialsScienceMultidisciplinary]
B95=[ChemistryInorganicNuclear ChemistryPhysical]
B96=[MaterialsScienceCeramics]
B97=[MaterialsScienceCeramics]
B98=[ChemistryPhysical EngineeringChemical]
B99=[ChemistryMultidisciplinary ChemistryPhysical
   MaterialsScienceMultidisciplinary]
```

B100=[ChemistryMultidisciplinary ChemistryPhysical
MaterialsScienceMultidisciplinary]
B101=[ChemistryMultidisciplinary ChemistryPhysical
MaterialsScienceMultidisciplinary]
B102=[ChemistryMultidisciplinary ChemistryPhysical
MaterialsScienceMultidisciplinary]
B103=[PolymerScience]
B104=[MaterialsScienceMultidisciplinary
PhysicsApplied]
B105=[MaterialsScienceMultidisciplinary]
B106=[MaterialsScienceMultidisciplinary
PhysicsCondensedMatter]
B107=[MaterialsScienceMultidisciplinary
MetallurgyMetallurgicalEngineering]
B108=[ChemistryApplied ChemistryPhysical
NanoscienceNanotechnology
MaterialsScienceMultidisciplinary]
B109=[ChemistryApplied ChemistryPhysical
NanoscienceNanotechnology
MaterialsScienceMultidisciplinary]
B110=[EngineeringElectricalElectronic
NanoscienceNanotechnology
MaterialsScienceMultidisciplinary PhysicsApplied
]
B111=[ChemistryMultidisciplinary ChemistryPhysical
NanoscienceNanotechnology
MaterialsScienceMultidisciplinary PhysicsApplied
PhysicsCondensedMatter]
B112=[ChemistryMultidisciplinary ChemistryPhysical
NanoscienceNanotechnology

MaterialsScienceMultidisciplinary PhysicsApplied
PhysicsCondensedMatter]
B113=[ChemistryMultidisciplinary ChemistryPhysical
NanoscienceNanotechnology
MaterialsScienceMultidisciplinary PhysicsApplied
PhysicsCondensedMatter]
B114=[ChemistryMultidisciplinary
NanoscienceNanotechnology
MaterialsScienceMultidisciplinary PhysicsApplied
]
B115=[NanoscienceNanotechnology
MaterialsScienceMultidisciplinary PhysicsApplied
]
B116=[NanoscienceNanotechnology
MaterialsScienceMultidisciplinary PhysicsApplied
]
B117=[MultidisciplinarySciences]
B118=[MultidisciplinarySciences]
B119=[MultidisciplinarySciences]
B120=[MultidisciplinarySciences]
B121=[ChemistryMultidisciplinary]
B122=[ChemistryPhysical
MaterialsScienceMultidisciplinary PhysicsApplied
PhysicsCondensedMatter]
B123=[NanoscienceNanotechnology
MaterialsScienceMultidisciplinary]
B124=[]
B125=[PolymerScience]
B126=[MaterialsScienceComposites PolymerScience]

B127=[ChemistryMultidisciplinary
MaterialsScienceComposites PolymerScience]
B128=[PhysicsMultidisciplinary]
B129=[MultidisciplinarySciences]
B130=[MultidisciplinarySciences]
B131=[MultidisciplinarySciences]
B132=[MultidisciplinarySciences]
B133=[MultidisciplinarySciences]
B134=[ChemistryInorganicNuclear ChemistryPhysical
PhysicsCondensedMatter]
B135=[EngineeringChemical ChemistryPhysical
MaterialsScienceComposites
MaterialsScienceCoatingsFilms
PhysicsCondensedMatter]
B136=[MaterialsScienceMultidisciplinary
MaterialsScienceCoatingsFilms PhysicsApplied
PhysicsCondensedMatter]
OPA1=[EngineeringChemical
ChemistryMultidisciplinary
EngineeringMultidisciplinary
MaterialsScienceMultidisciplinary]
CP1=[ChemistryPhysical Electrochemistry
EnergyFuels]
CP2=[MaterialsScienceCeramics
MaterialsScienceMultidisciplinary]
CP3=[MaterialsScienceCeramics
MaterialsScienceMultidisciplinary]
CP4=[MaterialsScienceCeramics
MaterialsScienceMultidisciplinary]

```
CP5=[MaterialsScienceCeramics
   MaterialsScienceMultidisciplinary]
CP6=[ChemistryPhysical EngineeringChemical]
CP7=[Thermodynamics ChemistryAnalytical
   ChemistryPhysical]
CP8=[NanoscienceNanotechnology
   MaterialsScienceMultidisciplinary]
CP9=[NanoscienceNanotechnology
   MaterialsScienceMultidisciplinary]
CP10=[NanoscienceNanotechnology
   MaterialsScienceMultidisciplinary]
CP11=[NanoscienceNanotechnology
   MaterialsScienceMultidisciplinary]
CP12=[ChemistryMultidisciplinary]
CP13=[ChemistryPhysical PhysicsCondensedMatter]
L1=[EngineeringChemical
   MaterialsScienceCoatingsFilms
   MaterialsScienceComposites]
L2=[MaterialsScienceCeramics
   MaterialsScienceCoatingsFilms]
L3=[ChemistryMultidisciplinary EngineeringChemical
   ]
L4=[PhysicsCondensedMatter
   PhysicsMultidisciplinary
   MaterialsScienceMultidisciplinary]
L5=[ChemistryPhysical ChemistryMultidisciplinary]
L6=[ChemistryMultidisciplinary]
L7=[PhysicsCondensedMatter
   NanoscienceNanotechnology
   PhysicsMultidisciplinary]
```

```
L8=[EngineeringElectricalElectronic Thermodynamics
    Mechanics]
CH1=[PhysicsParticlesFields]
CH2=[NanoscienceNanotechnology
   EngineeringMultidisciplinary EngineeringChemical
   ]
CH3=[ChemistryMultidisciplinary
   EngineeringChemical]

% bc= number of cited scientific references
bc=3
v=1
for i=1:(bc-1)
v=[v,1]
end
A=ones(bc)-diag(v)

% patent 1 of the sample

E=[B16 L4 CH2]
F=tabulate(E)
q=(F(:,3)/100).^0.5
H= wentropy(q,'shannon')

%jackknife method
for i=1:bc
C=[A(1,i)*B16 A(2,i)*L4 A(3,i)*CH2]
D=tabulate(C)
n=size(D,1)
```

```
%frequency
p=D(2:n,2)/(sum(D(:,2))-D(1,2))
s=p.^0.5

%H index
e(i) = wentropy(s,'shannon')
end

HJ=mean(e)
```

6.3 Evaluation of technological novelty

We propose the original Matlab algorithm used for the evaluation of the technological novelty, measured as the number of new pairs of technological knowledge at sub-group level (according to the IPC classification) of the patents in the sample.

```
%IPC of the patents of the sample

%2019

B1=[B65D081]
B2=[B60C001 C08K003 C08K005 C08K013 C08L007
   C08L009 C08L091]
B3=[C09D005 C09D007 C09D101 C09D133]
B4=[C01B033]
B5=[C08K003 C08K007 C08K009 C08L027]
B6=[B01J013]
B7=[C01B033]
B8=[C08K003 C08K009 C08L021 C09C001 C09C003]
```

B10=[C01B033]

%2018

B11=[C01B033]
B12=[D01F008 D06M013 D06M101]
B13=[B01F007 B01J019 C01B033]
B14=[C01B033]
B15=[C01B033]
B16=[B01J020]
B17=[B32B003 B32B007 B32B009 B32B027 B32B037 B32B038 H01M010]
B18=[C01B033]
B19=[C01B032]
B20=[C04B026 E01C003]
B21=[C02F001]
B22=[C01B033]
B23=[A61L009 A61L101 B01D053 B01J020]
B24=[C08G101 C08J009]
B25=[C01B033]
B26=[B01J013 H01L035]
B27=[C01B019 H01L035]
B28=[C01B033]
B29=[C01B011]
B30=[C08J005 F16L059]
B31=[B01J020 B01J021 B01J035 B01J037 C01B033 C01F007 C09K003]
B32=[B32B017 D06M015]
B33=[B32B005 B32B015 B32B027 D01F006 D06N007]

%2017

B34=[C01B033]
B35=[C01B033]
B36=[A61K008 A61Q019]
B37=[C08G071 C08J009]
B38=[C01B033]
B39=[C01B033 C01F005 C01F011]
B40=[C01B033 E04B001]
B41=[C01B033]
B42=[C01B033 C08J009 F16L059]

%2016

B43=[C03C025 C08J009 D06M013 D06M015]
B44=[C01B033]
B45=[C01B033 D04H001]
B46=[C01B033 C04B030 C04B038]
B47=[B01J013 C01B033 C04B014 C04B030 C04B111
D04H001 D04H013 F16L059]
B48=[A61K008]
B49=[C08G077 C08G101]
B50=[A61K008 A61Q005 A61Q017 A61Q019]
B51=[C01B033]

%2015

B52=[C01B033 C04B014]
B53=[C08J009]
B54=[B32B017 B32B037 F16L059]

B55=[B32B001 B32B017 F16L059]
B56=[B32B017 F16L059]
B57=[D06M023 F16L059]
B58=[C08J009 D01F001]
B59=[C08J009]
B60=[A61K008 A61Q005]
B61=[]
B62=[C01B033]
B63=[C01B033 C08J009]
B64=[B01J021 C01B033 C04B030]
B65=[C01B033 C04B038 E04B001]

%2014

B66=[B01J013 D06M011 D06M023 E04B001 F16L059]
B67=[B01J013 C01B033 C04B038]
B68=[A61K009 A61K047 B01J013 C01B033 C08F002 C08F292]
B69=[]%A61K A61Q
B70=[A61K009]

%2013

B71=[A61K008 A61Q019]
B72=[A61K008 A61Q019]
B73=[B01J013]
B74=[B01J013 B01J020 C01B033 C09K021]
B75=[]%C01B
B76=[A61K008 A61Q001 A61Q019]
B77=[A61K008 A61Q019]

B78=[A61K008 A61Q019]
B79=[B01J013]

%2012

B80=[B09B003 C01B033]
B81=[B01J013]
B82=[A61K008 A61Q019]
B83=[C01B033 C08J009]
B84=[B32B003 C01B033 C04B014]
B85=[B01D021 B01F003 B01F017 B01J013 B01J021
B01J023 B05D003 B05D005 B05D007 B32B005 B32B009
B32B015 B32B017 B32B019 B32B021 B32B023 B32B027
C08J003 C08L091 C08L095 C09D195 C09K003 C23C004
C23C008 C23C016 D02G003 H05H001]
B86=[C01B033]

%2011

B87=[C01B033]
B88=[B05D005 B05D007 C09D005 C09D133 C09D183]

%2009

B89=[B32B005]
B90=[B01J019 C01B004 C01B013 C01B025 C01B031
C01C001 C07C001 C07C209 C07F003 C07F007]

%2008

```
B91=[C01B033 C08G077 C08J003]
%B92=[]
B93=[C01B033]

%2007

B94=[C01B033]
B95=[C01B033]
B96=[H05K003]

%2006

B97=[C09K013]



%2019
%returns all combinations of the n elements in B
   taken 2 at a time

C1 = combnk(B1,2)
C2 = combnk(B2,2)
C3 = combnk(B3,2)
C4 = combnk(B4,2)
C5 = combnk(B5,2)
C6 = combnk(B6,2)
C7 = combnk(B7,2)
C8 = combnk(B8,2)
C9 = combnk(B9,2)
C10 = combnk(B10,2)
```

```
%%2018 (11-33)
C11 = combnk(B11,2)
C12 = combnk(B12,2)
C13 = combnk(B13,2)
C14 = combnk(B14,2)
C15 = combnk(B15,2)
C16 = combnk(B16,2)
C17 = combnk(B17,2)
C18 = combnk(B18,2)
C19 = combnk(B19,2)
C20 = combnk(B20,2)
C21 = combnk(B21,2)
C22 = combnk(B22,2)
C23 = combnk(B23,2)
C24 = combnk(B24,2)
C25 = combnk(B25,2)
C26 = combnk(B26,2)
C27 = combnk(B27,2)
C28 = combnk(B28,2)
C29 = combnk(B29,2)
C30 = combnk(B30,2)
C31 = combnk(B31,2)
C32 = combnk(B32,2)
C33 = combnk(B33,2)

%2017
C34 = combnk(B34,2)
C35 = combnk(B35,2)
C36 = combnk(B36,2)
C37 = combnk(B37,2)
```

```
C38 = combnk(B38,2)
C39 = combnk(B39,2)
C40 = combnk(B40,2)
C41 = combnk(B41,2)
C42 = combnk(B42,2)

%2016
C43 = combnk(B43,2)
C44 = combnk(B44,2)
C45 = combnk(B45,2)
C46 = combnk(B46,2)
C47 = combnk(B47,2)
C48 = combnk(B48,2)
C49 = combnk(B49,2)
C50 = combnk(B50,2)
C51 = combnk(B51,2)

%2015

C52 = combnk(B52,2)
C53 = combnk(B53,2)
C54 = combnk(B54,2)
C55 = combnk(B55,2)
C56 = combnk(B56,2)
C57 = combnk(B57,2)
C58 = combnk(B58,2)
C59 = combnk(B59,2)
C60 = combnk(B60,2)
%C61 = combnk(B61,2)
C62 = combnk(B62,2)
```

```
C63 = combnk(B63,2)
C64 = combnk(B64,2)
C65 = combnk(B65,2)

%2014
C66 = combnk(B66,2)
C67 = combnk(B67,2)
C68 = combnk(B68,2)
%C69 = combnk(B69,2)
C70 = combnk(B70,2)

%2013
C71 = combnk(B71,2)
C72 = combnk(B72,2)
C73 = combnk(B73,2)
C74 = combnk(B74,2)
%C75 = combnk(B75,2)
C76 = combnk(B76,2)
C77 = combnk(B77,2)
C78 = combnk(B78,2)
C79 = combnk(B79,2)

%2012

C80 = combnk(B80,2)
C81 = combnk(B81,2)
C82 = combnk(B82,2)
C83 = combnk(B83,2)
C84 = combnk(B84,2)
C85 = combnk(B85,2)
```

```
C86 = combnk(B86,2)

%2011

C87 = combnk(B87,2)
C88 = combnk(B88,2)

%2009

C89 = combnk(B89,2)
C90 = combnk(B90,2)

%2008

C91 = combnk(B91,2)
%C92 = combnk(B92,2)
C93 = combnk(B93,2)

%2007

C94 = combnk(B94,2)
C95 = combnk(B95,2)
C96 = combnk(B96,2)

%2006

C97 = combnk(B97,2)
```

```
C=[C11; C12; C13; C14; C15; C16; C17; C18; C19;
   C20; C21; C22; C23; C24; C25; C26; C27; C28; C29
   ; C30; C31; C32; C33; C34; C35; C36; C37; C38;
   C39; C40; C41; C42; C43; C44; C45; C46; C47; C48
   ; C49; C50; C51; C52; C53; C54; C55; C56; C57;
   C58; C59; C60; C62; C63; C64; C65; C66; C67; C68
   ; C70; C71; C72; C73; C74; C76; C77; C78; C79;
   C80; C81; C82; C83; C84; C85; C86; C87; C88; C89
   ; C90; C91; C93; C94; C95; C96; C97]

D=union(C3,C,'rows') %
E=intersect(C3,C,'rows') %if intersection is null,
    newpair=size(C3)
pair=size(C3,1)
newpair=pair-size(E,1)
perc=newpair/pair %percentage of new pairs
```

Chapter 7

Appendix 2: Data of patents in silica aerogel sector

We show the table of all the patents analyzed in chapter 2, with all the cited patent and references.

Publication date	Title	Applicant/ assignee	IPC	CITING patents	NUM. Citing	NUM. Non Self Citing	CITED patents	CITED SELF/ NON SELF	NUM. CITED	REFERENCES
2019-02-01	(CN208453584U) Method for silica aerogels dried transport device	JIANGXI HENGLONG INDUSTRIA L	B65D-081/26		(CN2084 53584U) 0	(CN2084 53584U) 0			(CN2084 53584U) 0	
2019-01-25	(CN109265765) Composition containing an organic silane coupling agent and silica in the rubber composition and its preparation method	JIANGSU QIXIANG HIGH NEW MATERIAL	B60C-001/00 C08K-003/36 C08K-005/372 C08K-005/548 C08K-013/02 C08L-007/00 C08L-009/00 C08L-091/06		(CN1092 65765) 0	(CN1092 65765) 0			(CN1092 65765) 0	
2019-01-18	(CN109233516) Aqueous silica aerogels with a seashell powder composite exterior wall coating thermal energy saving property	GUANGDO NG OCEAN UNIVERSITY ZHANJIANG XINBEIBEI BIOTECHN OLOGY	C09D-005/33 C09D-007/61 C09D-007/65 C09D-101/28 C09D-133/04		(CN1092 33516) 0	(CN1092 33516) 0			(CN1092 33516) 0	
2019-01-16	(KR101938655) Silica aerogel and a method of manufacturing a silica aerogel blanket		C01B-033/158 C01B-033/159		(KR10193 8655) 0	(KR10193 8655) 0	JP11335115 JP2001524439;JP46 43823 KR20160100082;KR 101789371	N N N	(KR10193 8655) 3	

2019-01-15	(CN109206789) Method for PVC-modified silica aerogel and its preparation method	JIESHOU YONGEN ELECTROM ECHANICAL TECHNOLO GY	C08K-003/34 C08K-003/36 C08K-007/14 C08K-009/02 C08K-009/04 C08K-009/06 C08L-027/06		(CN1092 06789) 0	(CN1092 06789) 0			(CN1092 06789) 0	
2019-01-11	(CN109173945) Composite material and its preparation method carbon aerogels	HEILONGJI ANG UNIVERSITY OF SCIENCE & TECHNOLO GY	B01J-013/00		(CN1091 73945) 0	(CN1091 73945) 0			(CN1091 73945) 0	
2019-01-04	(CN109133070) Method using water glass as a raw material for preparing a hydrophobic silica aerogel method under normal pressure ultra fast	ZHEJIANG UNIVERSITY OF TECHNOLO GY	C01B-033/143 C01B-033/158		(CN1091 33070) 0	(CN1091 33070) 0			(CN1091 33070) 0	
2018-12-28	(CN109096799) Tire with a second-order modified white carbon black	BENGBU WANKE SILICON MATERIALS TECHNOLO GY	C08K-003/36 C08K-009/04 C08K-009/10 C08L-021/00 C09C-001/56 C09C-003/04 C09C-003/06 C09C-003/08 C09C-003/10 C09C-003/12		(CN1090 96799) 0	(CN1090 96799) 0			(CN1090 96799) 0	

2018-12-21	(CN109046190) Pectin composite silica aerogel and its preparation method and application	GUANGDONG UNIVERSITY OF TECHNOLOGY	B01J-013/00 B01J-020/24 B01J-020/28 B01J-020/30		(CN109046190) 0	(CN109046190) 0			(CN109046190) 0	
2018-12-21	(CN109052415) On the basis of the silica aerogel and its preparation method MTMS	SOUTHWEST UNIVERSITY OF SCIENCE AND TECHNOLOGY	C01B-033/158		(CN109052415) 0	(CN109052415) 0			(CN109052415) 0	
2018-12-18	(CN109019611) Block of a transparent silica aerogels and the rapid preparation method and application	CENTRAL SOUTH UNIVERSITY	C01B-033/155 C01B-033/158		(CN109019611) 0	(CN109019611) 0			(CN109019611) 0	
2018-12-18	(CN109023941) Preparation of a textile composite material for a heat-retaining erogels method		D01F-008/02 D01F-008/18 D06M-013/513 D06M-101/06 D06M-101/10 D06M-101/12		(CN109023941) 0	(CN109023941) 0			(CN109023941) 0	
2018-12-18	(CN208244717U) Silicon erogels for producing a rapid-response component reactor	ZHONG HONG NANO FIBER TECHNOLOGY DANYANG	B01F-007/00 B01J-019/00 B01J-019/18 B01J-019/20 C01B-033/158 C01B-033/16		(CN208244717U) 0	(CN208244717U) 0			(CN208244717U) 0	

2018-12-11	(CN108975342) Continuous production of silica aerogels hydrophobic surface using a vibration method of the ball	WUHAN UNIVERSITY OF TECHNOLOGY	C01B-033/152 C01B-033/157 C01B-033/16		(CN108975342) 0	(CN108975342) 0			(CN108975342) 0	
2018-12-04	(CN108928823) Preparation method and use its atmospheric drying silica aerogels and	CENTRAL SOUTH UNIVERSITY	C01B-033/155 C01B-033/158		(CN108928823) 0	(CN108928823) 0			(CN108928823) 0	
2018-11-30	(CN108906005) Graphene silica gel solid phase extraction material and its preparation method	SHANDONG JIAXING ENVIRONMENTAL PROTECTION TECHNOLOGY	B01J-020/20 B01J-020/28 B01J-020/30		(CN108906005) 0	(CN108906005) 0			(CN108906005) 0	
2018-11-23	(CN108859282) Li-ion power battery with a new energy vehicle battery fluid resistant and high-temperature thermal insulation panel of reject and a manufacturing method	JIANGSU PAN ASIAN MICROVENT TECHNOLOGY	B32B-003/24 B32B-007/12 B32B-009/04 B32B-027/06 B32B-027/32 B32B-037/06 B32B-037/10 B32B-037/12 B32B-038/18 H01M-010/615 H01M-010/625 H01M-010/658		(CN108859282) 0	(CN108859282) 0			(CN108859282) 0	

2018-11-23	(CN108862285) Non-pressurized accelerated solvent extraction method for rapid preparation of aerogels	ZHEJIANG YANGU TECHNOLOGY	C01B-033/158		(CN108862285) 0	(CN108862285) 0			(CN108862285) 0	
2018-11-23	(CN108862239) Method of producing a highly tough charcoal erogels		C01B-032/05		(CN108862239) 0	(CN108862239) 0			(CN108862239) 0	
2018-11-13	(CN108797251) Extreme cold district the road surface structure	CHONGQING UNIVERSITY	C04B-026/26 E01C-003/06		(CN108797251) 0	(CN108797251) 0			(CN108797251) 0	
2018-11-06	(CN108751372) Silica aerogel doped calcium zeolite water treatment agent and its preparation method	HEFEI AIFEI NEW MATERIAL	C02F-001/52 C02F-001/56		(CN108751372) 0	(CN108751372) 0			(CN108751372) 0	
2018-11-06	(CN108751206) Pressure swing accelerated solvent extraction method for rapid preparation of aerogels	ZHEJIANG YANGU TECHNOLOGY	C01B-033/158		(CN108751206) 0	(CN108751206) 0			(CN108751206) 0	
2018-10-30	(CN108714417) Aerogel net taste material and preparation method thereof	ANHUI ZHONGHONG TECHNOLOGY DEVELOPMENT	A61L-009/01 A61L-009/014 A61L-101/44 B01D-053/02 B01J-020/22 B01J-020/28 B01J-020/30		(CN108714417) 0	(CN108714417) 0			(CN108714417) 0	

2018-10-11 2019-01-29	(US10189969) Silica-based organogels via hexahydrotriazine-based reactions	IBM	C08G-101/00 C08J-009/28	US20180265664	(US10189969) 1	(US10189969) 1	US20120220679;US8697766 US20130287661;US9302247 US20170114249 US20050131163;US7071287 US20110065820;US8679808 US20120152846 US20150176748 US20160046495;US10160655 US20160090463 US20160115368;US9856411 US20160272777;US9469739 US20160289387;US9505885 WO9425149	N N Y N N N N N N N N N N	(US10189969) 13	(US10189969) Search Report references [Examiner] -Husing, N.; Schubert, U. “Aerogels—Airy Materials: Chemistry, Structure, and Properties” Angew. Chem. Int. Ed. 1998, 37, 22 ± 45 (Year: 1998). Applicant references -Ciriminnia, et al. “Closing the Organosilicon Synthetic Cycle: Efficient Heterogeneous Hydrosilylation of Alkenes over SiliaCat Pt(0)”, ACS Substainable Chemistry and Engineering, American Chemical Society, 2013, 5 pp. -Calas, et al., “Mechanical Strength Evolution from Aerogels to Silica Glass”, Journal of Porous Materials, vol. 4, 1997, pp. 211-217. -Boday, et al. “Strong, Low-Density Nanocomposites by Chemical Vapor Deposition and Polymerization of Cyanoacrylates on Aminated Silica Aerogels” Applied Materials and Interfaces, vol. 1, No. 7, 2009, pp. 1364-1369.
2018-08-24	(CN108439418) Method for producing nano silica aerogel by supercritical extraction and produced nano silica aerogel and aerogel products thereof	TIANJIN MOGAN KUNDOM HIGH TECHNOLOGY DEVELOPMENT	C01B-033/155 C01B-033/158		(CN108439418) 0	(CN108439418) 0			(CN108439418) 0	

2018-07-25	(EP3352234) Apparatus and method for enhancing figure of merit in composite thermoelectric materials with aerogel	ACAD SINICA	B01J-013/00 H01L-035/16 H01L-035/26 H01L-035/34		(EP3352234) 0	(EP3352234) 0	US20150325771;US9276190 CN104851965	N N N N N N N	(EP3352234) 7	(EP3352234) Search Report references [Examiner] -SHREYASHI GANGULY ET AL: "Synthesis and Characterization of Telluride Aerogels: Effect of Gelation on Thermoelectric Performance of Bi 2 Te 3 and Bi 2- x Sb x Te 3 Nanostructures", JOURNAL OF PHYSICAL CHEMISTRY C, vol. 116, no. 33, 14 August 2012 (2012-08-14), pages 17431 - 17439, XP055481697, ISSN: 1932-7447, DOI: 10.1021/jp3055608CC=XP; XP055481697 (Cat. X,A) -WENTING DONG ET AL: "Characterization of bismuth telluride aerogels for thermoelectric applications", MRS PROCEEDINGS, vol. 1306, 1 January 2011 (2011-01-01), XP055481391, DOI: 10.1557/opl.2011.475CC=XP; XP055481391 (Cat. X,A) Applicant references -F. J. DISALVO: "Thermoelectric Cooling and Power Generation", SCIENCE, vol. 285, 1999, pages 703 - 706 -G. J. SNYDER; E. S. TOBERER: "Complex thermoelectric materials", NATURE MATERIALS, vol. 7, 2008, pages 105 - 114 -L. E. BELL: "Cooling, Heating, Generating Power, and Recovering Waste Heat with Thermoelectric Systems", SCIENCE, vol. 321, 2008, pages 1457 - 1461 -K. NIELSCH; J. BACHMANN; J. KIMLING; H. BOTTNER: "Thermoelectric Nanostructures: From Physical Model Systems towards Nanograined Composites", ADV. ENERGY MATER., vol. 1, 2011, pages 713 - 731 -M. S. DRESSELHAUS ET AL.: "New directions for low-dimensional thermoelectric materials", ADVANCED MATERIALS, vol. 19, 2007, pages 1043 - 1053

										-Y. PEI ET AL.: "Convergence of electronic bands for high performance bulk thermoelectrics", NATURE, vol. 473, 2011, pages 66 - 69 -J. P. HEREMANS; M. S. DRESSELHAUS; L. E. BELL; D. T. MORELLI: "When thermoelectrics reached the nanoscale", NAT NANO, vol. 8, 2013, pages 471 - 473 -S. I. KIM ET AL.: "Thermoelectrics. Dense dislocation arrays embedded in grain boundaries for high-performance bulk thermoelectrics", SCIENCE, vol. 348, 2015, pages 109 - 114 -P. GHAEMI; R. S. MONG; J. E. MOORE: "In-plane transport and enhanced thermoelectric performance in thin films of the topological insulators Bi(2)Te(3) and Bi(2)Se(3", PHYS REV LETT, vol. 105, 2010, pages 166603 -B. HAMDOU ET AL.: "The influence of a Te-depleted surface on the thermoelectric transport properties of Bi(2)Te(3) nanowires", NANOTECHNOLOGY, vol. 25, 2014, pages 365401, XP020269377, DOI: doi:10.1088/0957-4484/25/36/365401CC=XP; XP020269377 -T. C. HSIUNG; C. Y. MOU; T. K. LEE; Y. Y. CHEN: "Surface-dominated transport and enhanced thermoelectric figure of merit in topological insulator Bi(1.5)Sb(0.5)Te(1.7)Se(1.3", NANOSCALE, vol. 7, 2015, pages 518 - 523 -K. BISWAS ET AL.: "Strained endotaxial nanostructures with high thermoelectric figure of merit", NAT CHEM, vol. 3, 2011, pages 160 - 166 -K. BISWAS ET AL.: "High-performance bulk thermoelectrics with all-scale hierarchical architectures", NATURE, vol. 489, 2012, pages 414 - 418 -J. LI ET AL.: "BiSbTe-Based Nanocomposites

										with High ZT: The Effect of SiC Nanodispersion on Thermoelectric Properties", ADV. FUNCT. MATER., vol. 23, 2013, pages 4317 - 4323, XP001586980, DOI: doi:10.1002/adfm.201300146CC=XP; XP001586980 -W.-S. LIU ET AL.: "Thermoelectric Property Studies on Cu-Doped n-type Cu_xBi_2Te_2.7Se_0.3 Nanocomposites", ADV. ENERGY MATER., vol. 1, 2011, pages 577 - 587 -P. M. WU ET AL.: "Large thermoelectric power factor enhancement observed in InAs nanowires", NANO LETT, vol. 13, 2013, pages 4080 - 4086 -H. SCHERRER; S. SCHERRER: "CRC Handbook of Thermoelectrics", 1995, CRC PRESS -J. JIANG; L. CHEN; S. BAI; Q. YAO; Q. WANG: "Fabrication and thermoelectric performance of textured n-type Bi_2(Te,Se)_3 by spark plasma sintering", MATERIALS SCIENCE AND ENGINEERING B, vol. 117, 2005, pages 334 - 338, XP025304750, DOI: doi:10.1016/j.mseb.2005.01.002CC=XP; XP025304750
2018-07-19	(US20180204992) Apparatus and method for enhancing figure of merit in composite thermoelectric materials with aerogel	ACAD SINICA	C01B-019/00 H01L-035/16 H01L-035/34		(US20180204992) 0	(US20180204992) 0			(US20180204992) 0	
2018-05-15	(KR20180050607) The sol-gel method for the silica aerogel manufacture	M NANO ANALYSIS & MAT	C01B-033/158		(KR20180050607) 0	(KR20180050607) 0			(KR20180050607) 0	

2018-05-10	(TH-175734) Synthesis of silica aerosol from sodium silicate solution at atmospheric pressure.	MAHIDOL UNIVERSITY OFFICE OF TECHNOLOGY & TECHNOLOGY	C01B-011/00		(TH-175734) 0	(TH-175734) 0			(TH-175734) 0	
2018-03-16	(TW201809085) Hydrophobic fiberglass thermal insulation materials	SUPER INSULATION	C08J-005/08 F16L-059/02		(TW201809085) 0	(TW201809085) 0			(TW201809085) 0	
2018-02-01	(US20180029893) Aerogels	UNIVERSITY OF NEWCASTLE UPON TYNE	B01J-020/08 B01J-020/10 B01J-020/28 B01J-020/30 B01J-021/04 B01J-021/08 B01J-035/00 B01J-037/00 C01B-033/158 C01F-007/02 C09K-003/32		(US20180029893) 0	(US20180029893) 0			(US20180029893) 0	
2018-01-25	(WO201817262) Hydrophobic fiberglass thermal insulation materials	SUPER INSULATION	B32B-017/00 B32B-017/04 D06M-015/00 D06M-015/19 D06M-015/244 D06M-015/256		(WO201817262) 0	(WO201817262) 0	US20060078719 US8568563	N N N	(WO201817262) 3	(WO201817262) International Search Report [Examiner] -BASU ET AL.: "Fabrication of Superhydrophobic Nanocomposite Coatings Using Polytetrafluoroethylene and Silica Nanoparticles", INTERNATIONAL SCHOLARLY RESEARCH NETWORK NANOTECHNOLOGY, 2011, Retrieved from the Internet <URL:https://core.ac.uk/download/pdf/11874752.pdf> [retrieved on 20170814] (Cat. A)

										-GE ET AL.: "Hydrophobic and thermal insulation properties of silica aerogel/epoxy composite", JOURNAL OF NON-CRYSTALLINE SOLIDS, vol. 355, no. 52-54, 26 October 2009 (2009-10-26), pages 2610 - 2615, XP026762407CC=XP; XP026762407 (Cat. A)
2018-01-25	(US20180022059) Hydrophobic Fiberglass Thermal Insulation Materials	SUPER INSULATIO N	B32B-005/06 B32B-005/24 B32B-005/30 B32B-015/14 B32B-027/08 D01F-006/12 D06N-007/00		(US20180 022059) 0	(US20180 022059) 0	US20070231576 US20040109986;US 6919122 US3838082 US4376674 US4515656 US5334648 US20070134488;US 7858188 US4923547	N N N N N N N N	(US20180 022059) 8	(US20180022059) Examiner references -, high temperature, insulation textiles and accessories for industry, 2000 (Cat. 103) -NPL, high temperature, insulation textiles and accessories for industry, 2000 (Cat. 103) -, Comparative Properties ofHydrophilic and Hydrophobic Fumed Silica Filled Two-Component Polyurethane Adhesives, 2012 (Cat. 103) -NPL, Comparative Properties ofHydrophilic and Hydrophobic Fumed Silica Filled Two-Component Polyurethane Adhesives, 2012 (Cat. 103)
2017-12-27	(EP3259232) Aerogels	UNIVERSITY NEWCASTL E	C01B-033/158		(EP32592 32) 0	(EP32592 32) 0	US20130330262;US 8652432 US5705535	N N	(EP32592 32) 2	

2017-11-24 2018-12-26	(JP6446543) Method of manufacturing Aerogel	INTER BLANC SYSTEMS	C01B-033/152		(JP6446543) 0	(JP6446543) 0	JP2002509069;JP4331894 JP2012144428;JP5456089 JP2003212999;JP4128363 JP2008222527;JP4912190 JP2012091943;JP5528296 JP2013203804;JP6042085 JP2005145812;JP5103707	N N N N N N N	(JP6446543) 7	
2017-11-23	(WO2017198561) Rinseable composition comprising exfoliant particles	L'OREAL	A61K-008/25 A61K-008/39 A61K-008/46 A61Q-019/10		(WO2017198561) 0	(WO2017198561) 0	US20060246027 US20010034375;US7470725 FR2851915	N N N N Y	(WO2017198561) 5	(WO2017198561) International Search Report [Examiner] -DATABASE GNPD [online] MINTEL; 2 May 2016 (2016-05-02), "Oily skin renovating care", XP002761808, Database accession no. 4110193CC=XP; XP002761808 (Cat. I) -DATABASE GNPD [online] MINTEL; 2 May 2016 (2016-05-02), "Spots & Blackheads Triple Action Care", XP002761809, Database accession no. 4006295CC=XP; XP002761809 (Cat. I) Applicant references -AP=FR0302809 (A) [2003FR-0002809] -BRINKER C.J.; SCHERER G.W.: "Sol-Gel Science", 1990, NEW YORK, ACADEMIC PRESS -JOURNAL OF THE AMERICAN CHEMICAL SOCIETY, vol. 60, February 1938 (1938-02-01), pages 309 -VAN DE HULST, H.C.: "Light Scattering by Small Particles", 1957, WILEY, NEW YORK,

										article "Chapters 9 and 10" -"CTFA dictionary, 5th ed.", 1993, . -C.M. HANSEN: "The three dimensional solubility parameters", J. PAINT TECHNOL., vol. 39, 1967, pages 105
2017-10-26	(WO2017185009) Methods for fabrication of silica aerogels with custom shapes using freeze drying	UNIVERSITY OF VIRGINIA	C08G-071/02 C08J-009/00		(WO2017185009) 0	(WO2017185009) 0	US20140170350;US9808964 US20060281828;US8029871 WO201619308 US20150141533;US9764301 US20110002086;US8404384 US20090104401 US20140350134;US9206298	N N Y N N N N N	(WO2017185009) 8	(WO2017185009) International Search Report [Examiner] -"Butanol", WIKIPEDIA, BUTANOL, 31 January 2016 (2016-01-31), pages 1/3, XP055431515, Retrieved from the Internet <URL:https://en.wikipedia.org/wiki/Butanol> [retrieved on 20170626]CC=XP; XP055431515 (Cat. A)
2017-10-13	(CN107250040) Aerogels	UNIVERSITY OF NEWCASTLE UPON TYNE	C01B-033/158		(CN107250040) 0	(CN107250040) 0			(CN107250040) 0	
2017-06-23	(KR20170071285) - - Preparation method of metal oxide-silica complex aerogel and metal oxide-silica complex aerogel produced by the same	LG CHEM	C01B-033/158 C01F-005/02 C01F-011/02		(KR20170071285) 0	(KR20170071285) 0			(KR20170071285) 0	
2017-06-22	(DE102016224274) SILICA AEROGEL, HEAT-INSULATING MATERIAL, AND METHOD FOR THE PREPARATION OF SILICA AEROGEL	PANASONIC INTELLECTUAL PROPERTY MANAGEMENT	C01B-033/157 E04B-001/76		(DE102016224274) 0	(DE102016224274) 0	WO200710949 JP07257918;JP3854645 JP2003183529;JP3901534	N N N	(DE102016224274) 3	

2017-06-07 2017-11-23	(KR101800938) Preparation method of hydrophobic silica aerogel and hydrophobic silica aerogel produced by the same	LG CHEM	C01B-033/14 C01B-033/154		(KR101800938) 0	(KR101800938) 0	KR20000057244;KR100566390	N	(KR101800938) 1	
2017-03-16	(US20170074449) Modified hybrid silica aerogels	ASPEN AEROGELS	C01B-033/145 C01B-033/155 C01B-033/158 C08J-009/28 F16L-059/02		(US20170074449) 0	(US20170074449) 0	GB-814740 US20050192367;US7691912 US20040029982;US7378450 US20020094426;US7078359 US20150065590;US9512287 US20120136079;US8906973	N Y Y Y Y Y	(US20170074449) 6	
2016-10-27	(WO2016171558) A process of applying a polymethylsilsesquioxane aerogel coating onto a porous substrate	SEPAREX	C03C-025/00 C03C-025/40 C08J-009/36 C08J-009/40 D06M-013/513 D06M-015/643	EP3346068 WO2018127381 WO2018146137	(WO2016171558) 3	(WO2016171558) 3	US20080200432 US6472067 JP2011136859 US20130022769 US20150082590 US20080200432 US6472067	N N N N N N N	(WO2016171558) 7	(WO2016171558) Applicant references -HAYASE ET AL.: "New flexible aerogels and xerogels derived from methyltrimethoxysilane/ dimethyldimethoxysilane co-precursors", J. MATER. CHEM., vol. 21, 2011, pages 17077 - 17079 -HUANG ET AL., J SOL-GEL SCI TECHNOL, vol. 55, 2010, pages 261 - 268 -BRZEZINSKI ET AL.: "Nanocoat Finishing of Polyester/Cotton Fabrics by the Sol-Gel Method to Improve their Wear Resistance", FIBRES & TEXTILES IN EASTERN EUROPE, vol. 19, no. 6, 2011, pages 83 - 88

2016-08-25	(WO2016132117) Aerogels	UNIVERSITY NEWCASTLE	C01B-033/158		(WO2016132117) 0	(WO2016132117) 0	US20130330262;US8652432 US5705535	N N	(WO2016132117) 2	
2016-07-14	(DE102015200191) Flexible composites based on of aerogels	DEUTSCHE ZENTRUM FUER LUFT & RAUMFAHRT	C01B-033/157 D04H-001/42		(DE102015200191) 0	(DE102015200191) 0	US5306555 EP1457472 KR20110082379;KR101193987	N N N	(DE102015200191) 3	(DE102015200191) Search Report references [Examiner] -HAYASE, G. u.a.: New flexible aerogels and xerogels derived from methyltrimethoxysilane/dimethyldimethoxysilane co-precursors. In: J. Mater. Chem., 2011, Bd. 21, S. 17077 - 17079 -MALEKI, H. u.a.: An overview on silica aerogels synthesis and different mechanical reinforcing strategies. In: J. Non-Crystalline Solids. 2014, Bd. 385, S. 55 - 74 Applicant references -A. V. Rau et al.: Superhydrophobic and Flexible Aerogels, in: M.A. Aegerter et al (EDS), Aerogels Handbook, Advances in Sol Gel derived materials and technologies, Springer Science and Business Media, LLC 2011 Unspecified source -HAYASE, G. u.a.: New flexible aerogels and xerogels derived from methyltrimethoxysilane/dimethyldimethoxysilane co-precursors. In: J. Mater. Chem., 2011, Bd. 21, S. 17077 - 17079 -KR 10 2011 082 379 A (Abstract aus Korean Patent Abstracts) -MALEKI, H. u.a.: An overview on silica aerogels synthesis and different mechanical reinforcing strategies. In: J. Non-Crystalline Solids. 2014, Bd. 385, S. 55 - 74

2016-07-13	(CN105753440) Felt/silica-alumina aerogel composite heat-insulated board	ZHUO NEW MATERIAL TECHNOLOGY	C01B-033/32 C04B-030/02 C04B-038/00		(CN105753440) 0	(CN105753440) 0			(CN105753440) 0	
2016-07-13	(EP3042884) Flexible composites based on aerogels	DEUTSCHE ZENTRUM FUER LUFT & RAUMFAHRT	B01J-013/00 C01B-033/16 C04B-014/06 C04B-030/02 C04B-111/28 C04B-111/50 D04H-001/00 D04H-013/00 F16L-059/00		(EP3042884) 0	(EP3042884) 0	US5789075	N N	(EP3042884) 2	(EP3042884) Search Report references [Examiner] -GEN HAYASE ET AL: "Facile Synthesis of Marshmallow-like Macroporous Gels Usable under Harsh Conditions for the Separation of Oil and Water", ANGEWANDTE CHEMIE INTERNATIONAL EDITION, vol. 52, no. 7, 10 January 2013 (2013-01-10), DE, pages 1986 - 1989, XP055263753, ISSN: 1433-7851, DOI: 10.1002/anie.201207969CC=XP; XP055263753 (Cat. Y) Applicant references -L.J. GIBSON; M.F. ASHBY: "Cellular Solids", 1997, CAMBRIDGE UNIVERSITY PRESS -A. V. RAU ET AL.: "Aerogels Handbook, Advances in Sol Gel derived materials and technologies", 2011, SPRINGER SCIENCE AND BUSINESS MEDIA, article "Superhydrophobic and Flexible Aerogels"

2016-05-27	(IN2013DN06441) Cosmetic composition comprising silica aerogels particles and hydrocarbon based oils	L'OREAL	A61K-008/25 A61K-008/31 A61K-008/34		(IN2013DN06441) 0	(IN2013DN06441) 0			(IN2013DN06441) 0	
2016-04-19	(US9315632) Process for preparing epoxy-reinforced silica aerogels	NASA - NATIONAL AERONAUTICS & SPACE ADMINISTRATION	C08G-077/38 C08G-077/388 C08G-101/00		(US9315632) 0	(US9315632) 0	US3940426 US4958002 US5258530	N N N	(US9315632) 3	(US9315632) Search Report references [Examiner] -Nguyen et al. (Applied Materials and Interfaces, vol. 2(5), 1430-1443, 2010, Available on the Web, Apr. 28, 2010). -Meador et al. (Applied Materials and Interfaces, vol. 2(7), 2162-2168, 2010, Available on the Web, Jun. 30, 2010). -Meador et al. (Applied materials and Interfaces, vol. 1(4), 894-906, 2009). -Meador et al. (Chem. Mater. 2005, 17, 1085-1098). -Wen et al. (Chem. Mater. 1996, 8, 1667-1681).
2016-03-04 2016-12-23	(FR3025094) Gel/gel composition comprising a filter UV and a hydrophobic silica aerogel	L'OREAL	A61K-008/03 A61K-008/30 A61K-008/88 A61Q-005/00 A61Q-017/04 A61Q-019/00		(FR3025094) 0	(FR3025094) 0	FR2986424 FR2986422 WO201387927 WO2014128680	Y Y N Y Y	(FR3025094) 5	(FR3025094) Search Report references [Examiner] -AEROSIL: "Versatile and Effective", DEGUSSA, TECHNICAL INFORMATION,, no. TI 1251, 1 March 2003 (2003-03-01), pages 1 - 21, XP003026229CC=XP; XP003026229 (Cat. Y)
2016-01-13 2017-10-31	(CN105236418) Magnetic silica aerogel and normal pressure dry preparation method therefor	SUZHOU TONGXUAN NEW MATERIALS	C01B-033/16	CN105797677;CN105797677B CN105854744;CN105854744B CN105854744;CN105854744B	(CN105236418B) 3	(CN105236418B) 3	CN101503195;CN101503195B CN101671029;CN101671029B CN102179230;CN102179230B CN103118979;CN103118979B	N N N N	(CN105236418B) 4	

2015-11-12 2017-11-28	(US9828251) Silica aerogels and their preparation	MIT - MASSACHUSETTS INSTITUTE OF TECHNOLOGY	C01B-033/14 C01B-033/158 C04B-014/06		(US9828251) 0	(US9828251) 0	US5746992 US6447991 US5746992 US6447991 US5306555 US6068882 US20030060519;US6620458 US6764667 US20070166222;US7691909 US20070222116;US7560062 US20080229704 US20090087665;US7931940 US20090178933 US20100155644 US20100304078 US20120083543 WO2007146945 WO200844873	N N N N N N N N N N N N N N N N N N	(US9828251) 18	(US9828251) Search Report references [Examiner] -Mosher, B.P.; Synthesis and Characterization of Sol-Gel Nanocomposites Demonstrating Enhanced Mechanical Properties, 2006, p. i-88. -Rao, A.V., et al.; Solid State Sciences, 2004, p. 945-952. Applicant references -Husing et al., “Aerogele—luftige materialien:. Chemie, struktur und eigenschaften”, Angewandte Chemie, 110 (1-2), pp. 23-47 (Jan. 16, 1998). -International Search Report and Written Opinion for PCT Application PCT/US2011/047055 dated Dec. 21, 2011. -Mrowiec-Bialon et al., “Morphology of Silica Aerogels Obtained from the Process Catalyzed by NH4F and NH4DH”, Langmir: The ACS Journal of Surfaces and Colloids, 13(23) pp. 6310-6314 (Jan. 1997). -Pajonk et al., “Section 1. Aerogel Synthesis: Physical Properties of Silica Gels and Aerogels Preapred With New Polymeric Precursors”, Journal of Non-Crystaline Solids, pp. 18-188 (Jun. 1995). -Pierre et al. “Chemistry of Aerogels and Their Applications”, Chem Rev. 102(11) pp. 4243-4265 (2002). -Rutiser et al. “Composite Aerogels of Silica and Minerals of Different Morphologies”, Materials Letters 19 (5-6) pp. 221-224 (May 1994). -[No Author Listed] Aerogel.org “Welcome to Open Source NAnotech”. Main page of website. Retrieved Jun. 6, 2012 from <http://www.aerogelorg>. 11 pages.

										-[No Author Listed] Aspen Aerogels. Aspen Aerogels, Inc. Main page of website and product overview. Retreved Jun. 6, 2012 from <http://www.aerogel.com/products/overview-product.html>. 2001-2011, 3 pages. -[No Author Listed] "Carbon-dioxide pressure/temperature phase diagram" Wikpedia. Diagram. Retrieved Jun. 6, 2012 from <http://en.wikipedia.org/wiki/Filer:carbon—dioxide—pressure-temperature—phase—diagram.svg>. 1 page. -[No Author Listed] Laponite Additives: "Synthetic Silicate Additives" Southern Clay Products, Inc. Main page of website. Retrieved Jun. 6, 2012 from <http://laponite.com>. 2012, 2 pages. -[No Author Listed] Silica AeroGels: "Use of Silica Aerogels, Absorbing Kinetic Energy", E.O. Lawrence BErkley National Laboratory, University of California. Retrieved Jun. 6, 2012 from <http://energy.lbl.gov/ecs/aerogels/sa-kinetic.html>. 2012, 4 pages. -[No Author Listed] Silica AeroGels: Use of Silica Aerogels. Physical Properties. E.O. Lawrence Berkley National Laboratory. University of California. Retrieved Jun. 6, 2012 from <http://energy.lbl.gov/ecs/aerogels/sa-physical.html>2012, 2 pages. -Aelion et al., "Hydrolysis of Ethyl Silicate", J. Am Chem Soc. 72(12) pp. 5705-5712 (1950). -Akimov, Y.K. "Fields of Application of Aerogels" (review) Instruments and Experimental Techniques, 46(3) pp. 287-299, (2003). -Anappara et al. "Impedance Spectroscopic Studies of Sol-Gel Derived Subcritically Dried Silica Aerogels", Acta Materialia. 52(2) pp.

										369-375 (Jan. 2004). -Bhagat et al. "Textural Properties of Ambient Pressure Dried Water-Glass Based Silica Aerogel Beads", One Day Synthesis. Micro Meso Mater, 96 (1-3) pp. 237-244 (Nov. 2006). -Bhagat et al. "Rapid Synthesis of Water-Glass Based Areogels by In Situ Surface Modificaiton of the Hydrogels", Appl. Surf Sci., 253 (6) pp. 3231-3236 (Jan. 2007). -Boday et al. "Formation of Polycyanoacrylate-Silica Nanocomposites by Chemical Vapor Deposition of Cyanoacrylates on Aerogels", Chem Mater, 20(9), pp. 2845-2847 (2008). -Brinker et al. "Sol-Gel Tansition in Simple Silicates", Journal of Non-Crystaline Solids, 48(1), pp. 47-64 (Mar. 1982). -Cantin et al. "Silica Aerogels Used As Cherenkov Radiators", Nuclear Instruments and Methods, 118(1) pp. 177-182 (Jun. 1974). -Dorcheh et al. "Silica Aerogel: Synthesis, Properties and Characterization", J. Mater Process Tech, 199 1-3) pp. 10-26 (Apr. 2008). -Finlay et al. "Biologically Based Fiber-Reinfored/Clay Aerogel Composites", Ind. Eng Chem Res. 47(3) pp. 615-619 (2008). -Fricke, J. "Aerogels" Scientific American, 265(5) pp. 92-97 (May 1988). -Fricke et al. "Aerogels: Production, Characterization, and Applications", Thin Solid Flms, 297(1-2) pp. 212-223 (Apr. 1, 1997). -Gesser et al., "Aerogels and Related Porous Materials" Chem Rev. 89(4) pp. 765-788 (1989).

										-Gibiat et al. "Acoustic Properties and Potential Applications of Silica Aerogels", Journal of Non-Crystaline Solids 186(2) pp. 244-255 (Jun. 1995). -Gupta et al. "Processing and Compressive Properties of Aerogel/Epoxy Composites", J Mater Process TEch. 198(1-3) pp. 178-182 (Mar. 2008). -Hrubesh et al. "Thermal Properties of Organic and Inorganic Aerogels", J Mater Res. 9, pp. 731-738 (Mar. 1994). -Husing et al. "Aerogels—Airy Materials: Chemistry, Structure and Properties", Angewandte Chemie International Edition, 37(1-2) pp. 22-45 (Feb. 2, 1998). -Iler, R.K., The Chemistry of Silica: Solubility, Polymerization, Colloid and Surface Properties, and Biochemistry:, John Wiley & Sons, Inc., New York p. 21 (1979). -Ilerhan et al., "Hydrophobic Monolithic Aerogels by Nanocasting Polystyrene on Amine-Modified Silica", J Mater Chem 16, pp. 3046-3054 (2006). -Kanamori et al. New Transparent Methylsilsesquioxane Aerogels and Xeroels With Improved Mechanical Properties, Adv Mater. 19(12) pp. 1589-1593 (Jun. 2007). -Kanamori et al. "Elastic Organic-Inorganic Hybrid Aerogels and Xerogels", J Sol-Gel Sci TEch. 48 (1-2); pp. 172-181 (2008). -Kang et al. "Synthesis of Low-Density Silica Gel At Ambient Pressure: Effect of Heat Treatment", J. Materials Science. 35(19) pp. 4971-4976, (2000). -Kistler, S.S., Coherent Expanded Aerogels and Jellies, Nature 127(3211) p. 741 (1931). -Leventis et al. "Durable Modification of Silica Aerogel Monoliths With Fluorescent 2,7-diazapyrenium Moieties. Sensing

										Oxygen Near the Speed of Open-Air Diffiusion", Chem Mater, 11(10) pp. 2837-2845 (1999). -Leventis et al. "Nanoengineenng Strong Silica Aerogels", 2(9) pp. 957-960 (2002). -Leventis, N. "Three-Dimensional Core-Shell Superstructures: Mechanicall Strong Aerogels", Acc Chem Res. 4(9) p. 874-884 (2007). -Lu et al. "Thermal Conductivity of Monolithic Organic Aerogels", Science 255 (5047) pp. 971-972 (Feb. 1992). -Mahler et al. "Freeze-Formed Silica Fibres", 280, pp. 27-28 (May 1980). -Maki et al. "Formation of Alumina Fibers by Unidirectional Freezing of Gel", 82(1-3) pp. 239-245 (Jun. 1986). -Mauritz, K. "Sol-Gel Chemistry and Technology" Polymer Science Research Center, University of Southern Mississippi. Retrieved Jun. 2, 2012 from <http://www.psrc.usm.edu/mauritz/solgel.html>. 7 pages. -McNeill et al. "Kinetics and Mechanism of Hydrolysis of a Silicate Triester, tris(2-methoxyethoxy)phenylsilane", J. Am Chem Soc. 102(6) pp. 1859-1865 (1980). -Meador et al. "Cross-Linking Amino-Modified Silica Aerogels With Epoxies: Mechanically Strong Lightweight Porous Materials", Chem Mater, 17(5), pp. 1085-1098 (2005). -Mulik et al. "Cross-Linking 3D Assemblies of Nanoparticles Into Mechanically Strong Aerogels by Surfface-Initiated Free-Radical Polymerization", Chem Mater, 20(15) pp. 5035-5046 (2008). -Nadargi et al. "Studies on Reheological Properties of Methyltriethoxysilane (MTES)

										based flexible Superhydrophobic Silica Aerogels", 117(3) pp. 617-626, (Jan. 2009). -Nagasaka et al. "Absolute Measurement of the Thermal Conductivity of Electrically conducting liquids by the Transient Hot-Wire Method", J Phys E. Sci Instrum. 14(12) pp. 1435-1440 (Dec. 1981). -Nguyen et al. "Tailoring Elastic Properties ofSilica Aerogels Cross-Linked With Polystyrene", ACS Appl Mater Interfaces (1(3) pp. 62-630 (2009). -Ramirez, D. "Preparation of High Surface Area Acid Catalyzed Silica Aerogels" CHED 227. 231st ACS National Meeting, Atlanta, GA, Mar. 26-30, 2006. Undergraduate Research Poster Session: Analytical Chemistry Abstract 1 page. -Rao et al., "Synthesis of Hydrophobic Aerogels for Transparent Window Insulation Applications" Mater Sci Tech, 17(3) pp. 343-348 (Mar. 2001). -Rao et al., "Superhydrophobic Silica Aerogels Based on Methytrimethoxysilane Precursor", J Non-Crystal Sold, 330 (1-3) pp. 187-195 (Nov. 2003). -Rao et al. "Comparative Studies on the Surface Chemical Modiciation of Silica Aerogels Based on Various Organosilane Compounds of the Type RnSIX4?n. J Non-Crystal Sold", 350 pp. 216-223 (Dec. 2004). -Rao et al., "Synthesis and Physical Properties of TEOS-based Silica Aerogels Prepared by Two Step (ACid-Base) Sol-Gel Process", 6(9) pp. 945-952 (Sep. 2004). -Rao et al. "Effect of Preparation Conditions on the Physical and Hydrophobic Properties of Two Step Processed AMbient Pressure Dried Silica Aerogels", J Materials Science 40(13) pp. 3481-3489 (2005). -Rao et al. "Synthesis of Flexible Silica

										Aerogels Using Methyltrimethoxysilane (MTMS) Precursor", J Colloid Inter Sci 300(1) pp. 279-285 (Aug. 2006). -Rao et al. "Absorption and Description of Organic Liquids in Elastic Superhydrophobic Silica Aerogels", J Colloid Iner Sci. 305(1) pp. 124-132 (Jan. 2007). -Sakka et al. "The Sol-Gel Transition in the Hydroysis of Metal Alkoxide Solutions J Non-Crystal Solid" 63(1-2) pp. 223-235 (Feb. 1984). -Scheuerpflug et al. "Apparent Thermal Conducitivy of Evacuated SiO2-Aerogel Tiles Under Variation of Aradiative Boundary Conditions", Int J Heat Mass Transfer, 28(12) pp. 2299-2306 (1985). -Sequeira et al. "Synthesis and Characterisation of Cellulose/Silica Hyrids Obtained by Heteropoly Acid Catalysed Sol-Gel Process" Mater Sci Eng: C., 271) pp. 172-179 (Jan. 2007). -Sequeira et al. "Preparation and Properties of Cellulose/Silica Hybrid Composites" Polymer Composites, 30(9), pp. 1275-1282 (Sep. 2009). -Stober et al. "Controlled Growth of Monodisperse Silica Spheres in the Micron Size Range", J Colloid Inter Sci, 26(1) pp. 62-69 (Jan. 1968). -Tekin et al. "Responsive Microgrooves for the Formation of Harvestable Tissue Constructs", Langmuir, 27(9) pp. 5671-5679; (2011). -Vozar, L. "A Computer-Controlled Apparatus for Thermal Conductivity Measurement by the Transient Hot Wire Method", J. Therm Anal Calorimetry, 46(2) pp. 495-5055 (1996). -Wei et al. "Preparation of Monlithic Silica Aerogel of Low Thermal Conductivity by

										Ambient Pressure Drying", J Am Ceram Soc. 90(7) pp. 2003-2007 (Jul. 2007). -Wittwer, V. "Development of Aerogel Windows" Journal of Non-Crystalline Solids. 145, pp. 233-236 (1992). -Woigner et al. "Analysis of the Elastic Behaviour of Silica Aerogels Taken As a Percolating System", J Phys France. 49 pp. 289-293 (1988). -Woigner et al., "Parameters Affecting Elastic Properties of Silica Aerogels", Better Ceramics Through Chemistry III: Symposium held Apr. 5-8, 1988. Reno, Nvada, U.S.A. Brinker et al., eds. Materials Research Society, Pittsburgh, PA, pp. 697-702 (1988). -Woignier et al. "Parameters Affecting Elastic Properties of Silica Aerogels", Journal of Materials Research., 4(3) pp. 688-692 (May/Jun. 1989). -Woignier et al. "Different Kinds of Structure in aerogels: Relationships With the Mechanical Properties", J Non-Crystal Solid, 24(1) pp. 45-52 (Nov. 1998). -Yeh et al. "Micromolding of Shape-Controlled, Harvestable Cell-Laden Hydrogels", Bomaterials, 27, pp. 5391-5398, (2006). -Zarzycki et al, "Synthesis of Glasses From Gels: The Problem of Monolithic Gels", J Materials Ccience, 17(11) pp. 337-3379 (1982). -Zuo et al. "Preparation of Silica Aerogels with Improved Mechanical Properties and Extremely Low Thermal conductives Through Modified Soi-Gel Process", Department of Mechanical Engineering, Massachusetts Institute of Technology Masters Thesis, Jun. 2010, 96 pages.

2015-09-03 2016-12-06	(US9512286) Polyethylene aerogel and method of production		C08J-009/00 C08J-009/28 C08J-009/33	US20150259499;US9540495	(US9512286) 1	(US9512286) 1	US20060116433;US7691911 US20060229374;US8461223 US20060116433;US7691911 US20110086100;US9125872	N N N N	(US9512286) 4	
2015-07-29	(KR101539950) Silica aerogels and fiberglass laminated heat insulating material and method for producing the same	DAEWON SOLAR	B32B-017/06 B32B-037/00 F16L-059/02		(KR101539950) 0	(KR101539950) 0	KR101155503 KR20050084503 KR101454233 KR20130066582	N N N N N N	(KR101539950) 7	
2015-07-29	(KR101539951) Silica aerogels and fiberglass laminated pipe type heat insulating material and method for producing the same	DAEWON SOLAR	B32B-001/08 B32B-017/06 F16L-059/02		(KR101539951) 0	(KR101539951) 0	KR101454233 KR20130022163;KR101287805 KR20130066582	N N N N N	(KR101539951) 5	
2015-07-14	(KR101536565) Aramid fiber, fiberglass and silica aerogels laminated heat insulating material with iproved impact resistance and method for producing the same	DAEWON SOLAR	B32B-017/02 F16L-059/02		(KR101536565) 0	(KR101536565) 0	KR101171711 KR20100002232 KR20120091788 KR20120113469;KR101292796	N N N N N N N	(KR101536565) 8	

2015-07-14	(KR101536564) Aramid fiber, fiberglass and silica aerogels and laminated pipe type heat insulating material with iproved impact resistance and method for producing the same	DAEWON SOLAR	D06M-023/08 F16L-059/02 F16L-059/147		(KR101536564) 0	(KR101536564) 0	KR101171711 KR20100002232 KR20120113469;KR101292796 KR20140046222	N N N N N N N	(KR101536564) 8	
2015-05-21	(DE102013112522) Thermoelectrically active Aerogel	ELRINGKLINGER	C08J-009/28 D01F-001/09	CN106120007;CN106120007B DE102015110977	(DE102013112522) 2	(DE102013112522) 1	US20130260135 WO2012162644 WO2013116733 DE102006049179	N N N N	(DE102013112522) 4	(DE102013112522) Applicant references -2012 2nd International Conference on Materials, Mechatronics and Automation, Lecture Notes in Information Technology, Vol. 15", Seite 335 bis 340
2015-05-19	(US9034934) Polythylene aerogels and method of their production		C08J-009/00 C08J-009/28 C08J-009/33		(US9034934) 0	(US9034934) 0	US20060116433;US7691911 US20060229374;US8461223 US20060116433;US7691911 US20110086100;US9125872	N N N N	(US9034934) 4	

2015-04-29 2017-10-18	(EP2863861) Cosmetic composition comprising hydrophobic silica aerogel particles and a fixing polymer	L'OREAL	A61K-008/02 A61K-008/25 A61Q-005/00 A61Q-005/06		(EP2863861) 0	(EP2863861) 0	WO200145651 WO201054980 WO200959869 WO200751511 US20010034375;US7470725 FR1222944 DE2330956 LU--75370 LU--75371 FR1580545 FR2265782 FR2265781 FR1564110 FR2439798 US2047398 US2723248 US2102113 GB-839805 FR2350384 FR2357241 FR2198719 US4128631 US3734874 US3779993	N N N N N N Y N N Y Y Y N Y N N N N N Y N N N N N	(EP2863861) 56	

							US4119680 US4300580 US4973656 US5660816 US5662893 US5674479 WO9518191 WO9708261 WO9720899 FR2077143 FR2393573 US3589578 US4031307 US4131576 US3836537 FR1400366 EP-412704 EP-412707 EP-640105 WO9500578 EP-582152 WO9323009 US4693935 US4728571 US4972037	N N N N N N N N N N N N N N Y N N N N N N N N N		

							EP-751162 EP-637600 EP-648485 FR2743297 EP-656021 WO9403510 EP-619111	Y Y Y Y N N N		
2015-04-01	(GB201502613) Aerogels	UNIVERSITY NEWCASTLE			(GB201502613) 0	(GB201502613) 0			(GB201502613) 0	
2015-03-25 2016-05-25	(CN104445225) Method for preparing silica aerogel from straws as raw materials by virtue of low-temperature atmospheric-pressure drying	CHANGZHOU UNIVERSITY	C01B-033/16	CN106927471 CN107010632	(CN104445225B) 2	(CN104445225B) 2	US20130296596;US8889749 CN103435055	N N	(CN104445225B) 2	
2015-03-05 2016-12-06	(US9512287) Modified hybrid silica aerogels	ASPEN AEROGELS	C01B-033/158 C08J-009/28	EP3284719 US20170074449	(US9512287) 2	(US9512287) 1	US2188007 US4363738 US4447345 US4619908 US4667417 US4717708 US5275796 US5306555 US5565142	N N N N N N N N N	(US9512287) 45	

							US5786059 US5789075 US5830387 US5866027 US5962539 US5972254 US5973015 US6068882 US6080475 US6083619 US6087407 US6127306 US6140377 US6187250 US6197270 US6479416 US6620355 US6656527 US6670402 US20030077438;US 6887563 US20050167891;US 6989123 US20040132845;US 7074880 US20020094426;US 7078359	N N N N N N N Y N N N N N N N N N N Y N Y Y Y Y Y		

							US20040029982;US7378450 US20050046086;US7399439 US20040120876;US7402293 US20060199455;US7504346 US20050192367;US7691912 US20080093016;US7780890 US8067478 US20100107381;US8214980 US20050192366 US20050192367;US7691912 US20070152363 US20100155644 US20120097907;US9115025	N Y Y Y N Y Y Y Y Y N		
2015-02-05 2015-04-09	(WO201516730) Method for production of flexible panels of hydrophobic aerogel reinforced with fibre felts	ACTIVE AEROGELS UNIPESSOAL UNIVERSITY DE COIMBRA	B01J-021/06 C01B-033/158 C04B-030/02	CN106808247 CN106826337 EP3208082	(WO201516730) 3	(WO201516730) 3	WO201309984 US5789075 US20050192366 CN101698584;CN101698584B	N N N N	(WO201516730) 4	

2015-02-02	(PT-107101) Painéis flexíveis de aerogel hidrofóbico reforçado com feltro de fibras	ACTIVE AEROGELS UNIPESSOA L UNIVERSITY DE COIMBRA	C01B-033/00 C04B-038/00 E04B-001/00		(PT-107101) 0	(PT-107101) 0	CN102557577;CN102557577B CN103102135;CN103102135B KR20110082379;KR101193987 WO2008110818	N N N N	(PT-107101) 4	(PT-107101) Search Report references [Examiner] -Alex C. Johnson, Antonio Baclig, Daniel V. Harburg, Bo-Kuai Lai, Shriram Ramanathan, 20100101 (Cat. X) -Gui Lu, Xiao-Dong Wang, Yuan-Yuan Duan, Xiong-Wei Li, 20110101 (Cat. X)

2014-08-21 2014-10-16	(WO2014126490) Flexible hybrid aerogels prepared under subcritical conditions and their preparation process	INSTITUTE SUPERIOR TECNICO	B01J-013/00 D06M-011/79 D06M-023/08 E04B-001/78 F16L-059/02	EP3284721	(WO2014126490) 1	(WO2014126490) 1	US20130005842;US9133280 WO2006107226 US20110245359 JP2010167685;JP5354266 US3672833 US6017505 EP-171722 US5962539 WO9203378 EP-396076 US5705535 US5966832 US4610863 US5795557 US5911658 WO9425149 US4681615 WO9220623 US5023208 US6143400 US5124364 US6040375 US20120175546;US8952119	N N N N N N N N N N N N N N N N N N N N N N N N N	(WO2014126490) 45	(WO2014126490) International Search Report [Examiner] -A. FIDALGO ET AL: "Hybrid Silica/Polymer Aerogels Dried at Ambient Pressure", CHEMISTRY OF MATERIALS, vol. 19, no. 10, 1 May 2007 (2007-05-01), pages 2603 - 2609, XP055028508, ISSN: 0897-4756, DOI: 10.1021/cm062962wCC=XP; XP055028508 (Cat. Y) Applicant references -C.A. GARCIA-GONZALEZ; M.C. CAMINO-REYA; M. ALNAIEF; C. ZETZL; I. SMIRNOVA, J. OF SUPERCRITICAL FLUIDS, vol. 66, 2012, pages 297 - 306 -L. A. CAPADONA; M. A. B. MEADOR; A. ALUNNI; E. F. FABRIZIO; P. VASSILARAS; N. LEVENTIS, POLYMER, vol. 47, 2006, pages 5754 - 5761 -J. CAI; S. LIU; J. FENG; S. KIMURA; MA. WADA; S. KUGA; L. ZHANG, ANGEW. CHEM. INT. ED., vol. 51, 2012, pages 2076 - 2079

							US20080188575;US7737189 US20110245359 KR20100092683;KR101064869 WO200851029 KR20090097747;KR100940618 KR20100098905;KR101124383 US6068882 DE102009042526 US6087407 US20070154698 US20100140840;US8021583 CN101671030;CN101671030B US20070173157 WO2008129281 US20080307737;US7947354 US20080229704 KR20100083543;KR101072287 CN101791881;CN101791881B JP2010167685;JP5354266 US20120168095	N N N N N N N N N N N N N N N N N N N N		

PT-103257

2014-08-18	(PT-106781) Aerogéis híbridos flexíveis preparados em condições subcríticas e processo de preparação dos mesmos	INSTITUTE SUPERIOR TECNICO	B01J-013/00 C01B-033/158 C04B-038/00		(PT-106781) 0	(PT-106781) 0	WO2006107226 AU2006231371 PT-103257 EP1879690 US20080188575;US7737189 US20080188575;US7737189 JP2008537570;JP4994360 JP2008537570;JP4994360 BR200607020 US20120228545;US9266743 DE102009053784 KR20120102711;KR101466455 EP2501653 CN102712487;CN102712487B JP2013511461 WO9425149 BR9406431;BRPI9406431 EP-707518 JP08504674;JP2840881 JP08504674;JP2840881	N N N N N N N N N N N N N N N N N N N N N N N N N	(PT-106781) 25	

							US5565142 KR19967001693;KR 100158053 ATE193980 DE69424995			

2014-04-17 2014-10-01	(JP5599522) Surface-initiated photopolymerization through PEG hydrogel encapsulation of hydrophobic and hydrophilic Aerogel	KOCHI UNIVERSE	A61K-009/06 A61K-047/04 A61K-047/34 B01J-013/00 C01B-033/16 C08F-002/44 C08F-292/00	WO2017131106	(JP5599522) 1	(JP5599522) 1	JP63175636 JP2006219446 JP03063218 JP07505330;JP3507492 JP09508055	N N N N N	(JP5599522) 10	
2014-03-26	(ZA201304342) Cosmetic composition comprising silica aerogels particles and hydrocarbon-based oils	L'OREAL	A61K A61Q		(ZA201304342) 0	(ZA201304342) 0			(ZA201304342) 0	
2014-03-06	(US20140065229) Hydrophobic and hydrophylic aerogels encapsulated with peg hydrogel via surface initiated photopolymerization	KOC UNIVERSITESI	A61K-009/50	WO201619308	(US20140065229) 1	(US20140065229) 1	US20070142222 US20090018232 WO200992819 WO200992819	N N N N	(US20140065229) 4	(US20140065229) Pre-Search references [Examiner] -"Surface modification of silica aerogels by hexamethyldisilazane-carbon dioxide mixtures and their phase behavior," Kartal, A. & C. Erkey, J. Supercritical Fluids 53: 115 - 120 (2010). -"Photopolymerization of Poly(Ethylene Glycol) Diacrylate on Eosin-Functionalized Surfaces," Kizilel, S., et al., Langmuir 20: 8652 - 8658 (2004). -"Aerogels: Tailor-made Carriers for Immediate and Prolonged Drug Release," Smirnova, I., et al., KONA Powder and Particle Journal, No. 23, pp. 86 - 97 (2005).

2013-12-27 2015-03-27	(FR2992185) Composition has matting effect comprising particles of hydrophobic aerogels and silica particles	L'OREAL	A61K-008/25 A61Q-019/00		(FR2992185) 0	(FR2992185) 0	WO2008134712 WO201285855	N Y N N	(FR2992185) 4	(FR2992185) Search Report references [Examiner] -Dow Corning: "Control the Shine for Men-facial Cream: Creamy feel", , 12 septembre 2007 (2007-09-12), XP002692608, Extrait de l'Internet: URL:http://www.dowcorning.com/content/publishedlit/FORMUL_01140.pdf [extrait le 2013-02-21]CC=XP; XP002692608 (Cat. I) -DATABASE GNPD [Online] MINTEL; novembre 2008 (2008-11), "Superfit Makeup", XP002650586, Database accession no. 1005357CC=XP; XP002650586 (Cat. A)
2013-12-27 2014-06-27	(FR2992197) Cosmetic composition comprising non interference of scattering particles and particles of aerogel, and cosmetic method of clarification	L'OREAL	A61K-008/06 A61K-008/19 A61K-008/25 A61K-008/58 A61K-008/92 A61Q-019/02	FR3035587 WO201771886	(FR2992197) 2	(FR2992197) 1	DE19939836	N N	(FR2992197) 2	(FR2992197) Search Report references [Examiner] -ANNE-MARIE VINCENT ET AL: "Dow Corning develops a series of five silicone elastomer cosmetic powder variants", IP.COM JOURNAL, IP.COM INC., WEST HENRIETTA, NY, US, 27 mars 2007 (2007-03-27), XP013118762, ISSN: 1533-0001CC=XP; XP013118762 (Cat. I)
2013-11-20 2015-03-18	(EP2663395) Hydrophobic and hydrophilic aerogels encapsulated with peg hydrogel via surface initiated photopolymerization	KOC UNIVERSITESI	B01J-013/00	CN105566583	(EP2663395) 1	(EP2663395) 1	US20040118749;US7160438 US20040118748;US7087156 WO200357367	N N N	(EP2663395) 3	(EP2663395) Search Report references [Examiner] -See references of WO 2012095346A2

2013-11-13 2015-08-05	(CN103386281) Silica aerogel particles with expanded perlite as a carrier, a preparation method and applications thereof	SHAANXI MENGCHUANG NANO NEW MATERIALS	B01J-013/00 B01J-020/291 B01J-020/30 C01B-033/145 C09K-021/02	CN105457339 CN106478051 CN106519312	(CN103386281B) 3	(CN103386281B) 3	CN102795826;CN102795826B CN1214319 CN103301787;CN103301787B CN102976783 CN102964107	N N Y N N	(CN103386281B) 5	
2013-11-01 2017-12-08	(IN-290370) Improved method for producing carbon containing silica aerogel granules	INTERNATIONAL ADVANCED RESEARCH CENTRE FOR POWDER METALLURGY & NEW MATERIALS DEPARTMENT OF SCIENCE & TECHNOLOGY GOVT OF INDIA	C01B	WO201709858	(IN-290370) 1	(IN-290370) 1			(IN-290370) 0	

2013-10-31 2016-04-26	(US9320689) Cosmetic composition comprising silica aerogels particles and hydrocarbon-based oils	L'OREAL	A61K-008/04 A61K-008/25 A61K-008/31 A61K-008/37 A61Q-001/00 A61Q-019/00	EP3177263 US20150190319 US20150320656 US20150366783 US20170189305 WO201620541 WO2018144460 WO201822614 WO201822632	(US9320689) 9	(US9320689) 1	US5800816 US20090247648;US8084506 US5911974 US5965112 US5985298 US6464964 US20030007987;US6562322 US20030147931;US6780422 US20040175345;US7005134 US20060088562;US7160550 US20070092468 US20120065163;US9498654 WO2009120602	N N N N N N N N N N N N N N N	(US9320689) 15	(US9320689) Applicant references -International Search Report issued Dec. 3, 2012, in PCT/EP2011/073188. -"Dow Corning® VM-2270 Aerogel Fine Particles", Dow Corning, http://www2.dowcorning.com/DataFiles/090007c88020e235.pdf XP 002650585, Apr. 2009, 5 pages.CC=XP; XP000265058 -"Silica Silylate Aerogel for Cosmetic Applications", IP.COM Journal, XP 013112635, Jan. 30, 2006, 3 pages.CC=XP; XP001311263

2013-10-09 2017-06-20	(CN103347483) Cosmetic composition comprising silica aerogels particles and hydrocarbon-based oils	L'OREAL	A61K-008/04 A61K-008/25 A61K-008/31 A61K-008/34 A61K-008/37 A61Q-019/00	CN104363882 CN104394830 CN105476877;CN105476877B	(CN103347483B) 3	(CN103347483B) 1	CN1127631 WO2009120602 US5800816 US20070092468 US20090247648;US8084506	N N N N N	(CN103347483B) 5	
2013-07-29 2017-05-22	(MX-347980) Cosmetic composition comprising silica aerogels particles and hydrocarbon-based oils.	L'OREAL	A61K-008/04 A61K-008/25 A61K-008/31 A61K-008/34 A61K-008/37 A61Q-019/00		(MX-347980) 0	(MX-347980) 0			(MX-347980) 0	
2013-07-17 2016-08-03	(CN103203206) Cellulose/titanium dioxide/silica aerogel and preparation method thereof	SHANDONG CAYON TESTING TECHNOLOGY	B01J-013/00	CN103755302;CN103755302B CN103755302;CN103755302B CN103790248;CN103790248B CN106185964;CN106185964B CN106629745;CN106629745B CN107117624 WO201709858	(CN103203206B) 7	(CN103203206B) 7	CN1668372;CN1331588C	N	(CN103203206B) 1	
2012-11-07 2016-03-30	(CN102765726) Method for preparing silica aerogel with rice hulls as raw mateirals		B09B-003/00 C01B-033/16	CN105692631	(CN102765726B) 1	(CN102765726B) 1	CN102602944;CN102602944B	N	(CN102765726B) 1	

2012-07-19 2012-11-08	(WO201295346) Hydrophobic and hydrophilic aerogels encapsulated with peg hydrogel via surface initiated photopolymerization	KOC UNIVERSITE SI	B01J-013/00	WO2017194918	(WO201295346) 1	(WO201295346) 1	US20040118749;US7160438 US20040118748;US7087156 WO200357367	N N N	(WO201295346) 3	
2012-06-28 2013-01-17	(WO201284781) Cosmetic composition comprising silica aerogels particles and hydrocarbon-based oils	L'OREAL	A61K-008/04 A61K-008/25 A61K-008/31 A61K-008/34 A61K-008/37 A61Q-019/00	EP2863870 FR2986425 FR2986428 FR2986429 US20160081889;US10076472 WO2013117548 WO2013189055 WO2013190238 EP3219301	(WO201284781) 9	(WO201284781) 0	WO2009120602 US20070092468	N N N N	(WO201284781) 4	(WO201284781) International Search Report [Examiner] -ANONYMOUS: "Dow Corning VM-2270 Aerogel Fine particles", INTERNET CITATION, April 2009 (2009-04-01), XP002650585, Retrieved from the Internet <URL:http://www2.dowcorning.com/DataFiles/090007c88020e235.pdf> [retrieved on 20110728]CC=XP; XP002650585 (Cat. I) -"Silica Silylate Aerogel for Cosmetic Applications", IP.COM JOURNAL, 30 January 2006 (2006-01-30), IP.COM INC., WEST HENRIETTA, NY, US, XP013112635, ISSN: 1533-0001CC=XP; XP013112635 (Cat. A)
2012-05-31 2014-12-09	(US8906973) Modified hybrid silica aerogels	ASPEN AEROGELS	C01B-033/158 C08J-009/28	CN106883453 CN106883454 CN106967104 US20170074449	(US8906973) 4	(US8906973) 3	US20040029982;US7378450 US20040120876;US7402293 US20050192367;US7691912	Y N Y	(US8906973) 3	

2012-05-24 2015-07-07	(US9073759) Silica aerogels and their preparation	MIT - MASSACHUSETTS INSTITUTE OF TECHNOLOGY	B32B-003/26 C01B-033/158 C04B-014/06	EP2743243 KR20140022491;KR101401754 US20140251565;US10087081 US20140361209 US20150037249 US20130012623;US8691935 US20120097907;US9115025 US20150141533;US9764301 US20140319410;US9850415 WO201427825 US20160152059;US10118426 US20120037838;US10196814 US20140255642;US9593206 WO2017145095	(US9073759) 14	(US9073759) 13	US20080229704 US20100304078 US20120083543 US5306555 US6068882 US20030060519;US6620458 US6764667 US20070166222;US7691909 US20070222116;US7560062 US20090087665;US7931940 US20090178933 US20100155644 WO2007146945 WO200844873	N N N N N N N N N N N N N N	(US9073759) 14	(US9073759) Search Report references [Examiner] -Aerogel definition from Wikipedia, 7 pages, 2013. Applicant references -Hüsing et al., [Aerogele-luftige materialien: Chemie, struktur und eigenschaften]. Angewandte Chemie. Jan. 16, 1998;110(1-2):23-47. (German Language Reference). -International Search Report and Written Opinion mailed Dec. 21, 2011 for Application No. PCT/US2011/047055 (15 Pages). -Mrowiec-Bialon et al., Morphology of silica aerogels obtained from the process catalyzed by NH4F and NH4OH. Langmuir: The ACS Journal of Surfaces and Colloids. Jan. 1997;13(23):6310-6314. -Pajonk et al., Section 1. aerogel synthesis: Physical properties of silica gels and aerogels prepared with new polymeric precursors. Journal of Non-Crystalline Solids. Jun. 1995;186:1-8. -Pierre et al., Chemistry of aerogels and their applications. Chem Rev. 2002;102(11):4243-4265. -Rutiser et al., Composite aerogels of silica and minerals of different morphologies. Materials Letters. May 1994;19 (5-6):221-224. -[No Author Listed] Aerogel.org. Welcome to Open Source Nanotech. Main page of website. Retrieved Jun. 6, 2012 from . 11 pages. -[No Author Listed] Aspen Aerogels. Aspen Aerogels, Inc. Main page of website and product overview. Retrieved Jun. 6, 2012 from and . 2001-2011, 3 pages.

										-[No Author Listed] Carbon-dioxide pressure/temperature phase diagram. Wikipedia. Diagram. Retrieved Jun. 6, 2012 from <http://en.wikipedia.org/wiki/File:carbon-dioxide-pressure-temperature-phase-diagram.svg>. 1 page. -[No Author Listed] Laponite Additives: Synthetic Silicate Additives. Southern Clay Products, Inc. Main page of website. Retrieved Jun. 6, 2012 from . 2012, 2 pages. -[No Author Listed] Silica AeroGels: Use of silica aerogels. Absorbing Kinetic Energy. E.O. Lawrence Berkley National Laboratory, University of California. Retrieved Jun. 6, 2012 from . 2012, 4 pages. -[No Author Listed] Silica AeroGels: Use of silica aerogels. Physical Properties. E.O. Lawrence Berkley National Laboratory, University of California. Retrieved Jun. 6, 2012 from . 2012, 2 pages. -Aelion et al., Hydrolysis of ethyl silicate*. J Am Chem Soc. 1950;72(12):5705-12. -Akimov, Y.K., Fields of application of aerogels (review). Instruments and Experimental Techniques. 2003;46(3):287-99. -Anappara et al., Impedance spectroscopic studies of sol-gel derived subcritically dried silica aerogels. Acta Materialia. Jan. 2004;52(2):369-75. -Bhagat et al., Textural properties of ambient pressure dried water-glass based silica aerogel beads: One day synthesis. Micro Meso Mater. Nov. 2006;96(1-3):237-44. -Bhagat et al., Rapid synthesis of water-glass based aerogels by in situ surface modification of the hydrogels. App Surf Sci. Jan. 2007;253(6):3231-6.

										-Boday et al., Formation of polycyanoacrylate-silica nanocomposites by chemical vapor deposition of cyanoacrylates on aerogels. Chem Mater. 2008;20(9):2845-7. -Brinker et al., Sol-gel transition in simple silicates. Journal of Non-Crystalline Solids. Mar. 1982;48(1):47-64. -Cantin et al., Silica aerogels used as Cherenkov radiators. Nuclear Instruments and Methods. Jun. 1974;118 (1):177-82. -Dorcheh et al., Silica aerogel; synthesis, properties and characterization. J Mater Process Tech. Apr. 2008;199 (1-3):10-26. -Finlay et al., Biologically based fiber-reinforced/clay aerogel composites. Ind Eng Chem Res. 2008;47(3):615-9. -Fricke, J., Aerogels. Scientific American. May 1988;265(5):92-7. -Fricke et al., Aerogels: production, characterization, and applications. Thin Solid Films. Apr. 1, 1997;297(1-2):212-23. -Gesser et al., Aerogels and related porous materials. Chem Rev. 1989;89(4):765-88. -Gibiat et al., Acoustic properties and potential applications of silica aerogels. Journal of Non-Crystaline Solids. Jun. 1995;186(2):244-55. -Gupta et al., Processing and compressive properties of aerogel/epoxy composites. J Mater Process Tech. Mar. 2008;198(1-3):178-82. -Hrubesh et al., Thermal properties of organic and inorganic aerogels. J Mater Res. Mar. 1994;9:731-8. -Hüsing et al., Aerogels-Airy Materials: Chemistry, Structure, and Properties.

										Angewandte Chemie International Edition. Feb. 2, 1998;37(1-2):22-45. -Iler, R.K., the Chemistry of Silica: Solubility, Polymerization, Colloid and Surface Properties, and Biochemistry. John Wiley & Sons, Inc., New York, 1979, p. 21. -Ilhan et al., Hydrophobic monolithic aerogels by nanocasting polystyrene on amine-modified silica. J Mater Chem. 2006;16:3046-54. -Kanamori et al., New transparent methylsilsesquioxane aerogels and xerogels with improved mechanical properties. Adv Mater. Jun. 2007;19(12):1589-93. -Kanamori et al., Elastic organic-inorganic hybrid aerogels and xerogels. J Sol-Gel Sci Tech. 2008;48(1-2):172-81. -Kang et al., Synthesis of low-density silica gel at ambient pressure: Effect of heat treatment. J Materials Science. 2000;35(19):4971-6. -Kistler, S.S., Coherent expanded aerogels and jellies. Nature. 1931;127(3211):741. -Leventis et al., Durable modification of silica aerogel monoliths with fluorescent 2,7-diazapyrenium moieties. Sensing oxygen near the speed of open-air diffusion. Chem Mater. 1999;11(10):2837-45. -Leventis et al., Nanoengineering strong silica aerogels. Nano Letters. 2002;2(9):957-60. -Leventis et al., Using nanoscopic hosts, magnetic guests, and field alignment to create anisotropic composite gels and aerogels. Nano Letters. 2002;2(1):63-7. -Leventis, N., Three-dimensional core-shell superstructures: Mechanically strong aerogels. Acc Chem Res. 2007;40 (9):874-84.

										-Lu et al., Thermal conductivity of monolithic organic aerogels. Science. Feb. 1992;255(5047):971-2. -Mahler et al., Freeze-formed silica fibres. Nature. May 1980;280:27-8. -Maki et al., Formation of alumina fibers by unidirectional freezing of gel. J Non-Crystal Solid. Jun. 1986;82 (1-3):239-45. -Mauritz, K., Sol-Gel Chemistry and Technology. Polymer Science Research Center, University of Southern Mississippi. Retrieved Jun. 2, 2012 from . 7 Pages. -McNeill et al., Kinetics and mechanism of hydrolysis of a silicate triester, tris(2-methoxyethoxy)phenylsilane. J Am Chem Soc. 1980;102(6):1859-65. -Meador et al., Cross-linking amine-modified silica aerogels with epoxies: Mechanically strong lightweight porous materials. Chem Mater. 2005;17(5):1085-98. -Mulik et al., Cross-linking 3D assemblies of nanoparticles into mechanically strong aerogels by surface-initiated free-radical polymerization. Chem Mater. 2008;20(15):5035-46. -Nadargi et al., Studies on rheological properties of methyltriethoxysilane (MTES) based flexible superhydrophobic silica aerogels. Micro Meso Mater. Jan. 2009;117(3):617-26. -Nagasaka et al., Absolute measurement of the thermal conductivity of electrically conducting liquids by the transient hot-wire method. J Phys E: Sci Instrum. Dec. 1981;14(12):1435-40. -Nguyen et al., Tailoring elastic properties of silica aerogels cross-linked with polystyrene. ACS Appl Mater Interfaces. 2009;1(3):621-30.

										-Ramirez, D., Preparation of high surface area acid catalyzed silica aerogels. CHED 227. 231st ACS National Meeting, Atlanta, GA, Mar. 26-30, 2006. Undergraduate Research Poster Session: Analytical Chemistry. Abstract. 1 page. -Rao et al., Synthesis of hydrophobic aerogels for transparent window insulation applications. Mater Sci Tech. Mar. 2001;17(3):343-8. -Rao et al., Superhydrophobic silica aerogels based on methyltrimethoxysilane precursor. J Non-Crystal Solid. Nov. 2003;330(1-3):187-95. -Rao et al., Comparative studies on the surface chemical modification of silica aerogels based on various organosilane compounds of the type RnSiX4?n. J Non-Crystal Solid. Dec. 2004;350:216-23. -Rao et al., Synthesis and physical properties of TEOS-based silica aerogels prepared by two step (acid-base) sol-gel process. Solid State Sci. Sep. 2004;6(9):945-52. -Rao et al., Effect of preparation conditions on the physical and hydrophobic properties of two step processed ambient pressure dried silica aerogels. J Materials Science. 2005;40(13):3481-9. -Rao et al., Synthesis of flexible silica aerogels using methyltrimethoxysilane (MTMS) precursor. J Colloid Inter Sci. Aug. 2006;300(1):279-85. -Rao et al., Absorption and desorption of organic liquids in elastic superhydrophobic silica aerogels. J Colloid Inter Sci. Jan. 2007;305(1):124-32. -Sakka et al., The sol-gel transition in the hydrolysis of metal alkoxides in relation to the formation of glass fibers and films. J Non-Crystal Solid. Mar. 1982;48(1):31-46.

										-Sakka et al., Formation of sheets and coating films from alkoxide solutions. J Non-Crystal Solid. Feb. 1984;63 (1-2):223-35. -Scheuerpflug et al., Apparent thermal conductivity of evacuated SiO2-aerogel tiles under variation of radiative boundary conditions. Int J Heat Mass Transfer. 1985;28(12):2299-306. -Sequeira et al., Synthesis and characterisation of cellulose/silica hybrids obtained by heteropoly acid catalysed sol-gel process. Mater Sci Eng: C. Jan. 2007;27(1):172-9. -Sequeira et al., Preparation and properties of cellulose/silica hybrid composites. Polymer Composites. Sep. 2009;30(9):1275-82. -Stober et al., Controlled growth of monodisperse silica spheres in the micron size range. J Colloid Inter Sci. Jan. 1968;26(1):62-9. -Tekin et al., Responsive microgrooves for the formation of harvestable tissue constructs. Langmuir. 2011;27(9):5671-9. -Vozar, L., A computer-controlled apparatus for thermal conductivity measurement by the transient hot wire method. J Therm Anal Calorimetry. 1996;46(2):495-505. -Wei et al., Preparation of monolithic silica aerogel of low thermal conductivity by ambient pressure drying. J Am Ceram Soc. Jul. 2007;90(7):2003-7. -Wittwer, V., Development of aerogel windows. Journal of Non-Crystalline Solids. 1992;145:233-36. -Woignier et al., Analysis of the elastic behaviour of silica aerogels taken as a percolating system. J Phys France. 1988;49:289-93.

										-Woigner et al., Parameters affecting elastic properties of silica aerogels. Better Ceramics Through Chemistry III: Symposium held Apr. 5-8, 1988, Reno, Nevada, U.S.A. Brinker et al., eds. Materials Research Society, Pittsburgh, PA, 1988, pp. 697-702. -Woignier et al., Parameters affecting elastic properties of silica aerogels. Journal of Materials Research. May / Jun. 1989;4(3):688-92. -Woignier et al., Different kinds of structure in aerogels: relationships with the mechanical properties. J Non-Crystal Solid. Nov. 1998;241(1):45-52. -Yeh et al., Micromolding of shape-controlled, harvestable cell-laden hydrogels. Biomaterials. 2006;27:5391-8. -Zarzycki et al., Synthesis of glasses from gels: the problem of monolithic gels. J Materials Science. 1982;17 (11):3371-9. -Zuo et al., Preparation of silica aerogels with improved mechanical properties and extremely low thermal conductives through modified sol-gel process. Department of Mechanical Engineering, Massacusetts Institute of Technology. Masters thesis. Jun. 2010, 96 pages.

2012-03-29 2014-01-14	(US8629076) High surface area silicon carbide-coated carbon aerogel	LAWRENCE LIVERMORE NATIONAL SECURITY	B01D-021/01 B01F-003/00 B01F-003/04 B01F-003/06 B01F-003/08 B01F-017/00 B01J-013/00 B01J-021/18 B01J-023/02 B01J-023/06 B05D-003/00 B05D-003/02 B05D-005/12 B05D-007/00 B32B-005/16 B32B-009/00 B32B-015/02 B32B-017/02 B32B-019/00 B32B-021/02 B32B-023/02 B32B-027/02 C08J-003/02 C08L-091/08 C08L-095/00	CN103295796;CN103295796B CN103295796;CN103295796B CN105706277 DE102014116868 EP3044820 US20110024698 US20150063521;US9437335 US20150262763;US9972448 US20120077006;US8629076 US20140217330;US9082524 US20150063521;US9437335 US20150357650;US9755244 US20150072145;US9795944 US20150262763;US9972448 WO2014137879 WO201554239 WO2017106797 WO201791815	(US8629076) 25	(US8629076) 17	US5698140 US5855953 US20040202602;US7390474 US20050103990;US7799726 US20100140532;US8383238 US20080261116;US8828481 US20120028798;US8809230 US20120077006;US8629076 WO2006102568 US5260855 US5409683 US5601938 US20020028385;US6500401 US20020005145;US6653356 US20030176277;US6809060 US20040065619;US6843919 US20050064279;US6906003 US20020104599;US6986818 US20040058808;US	N N N N N N Y Y N Y Y Y N N N N N N N N N N N N Y	(US8629076) 46	(US8629076) Applicant references -Baumann et al., "High surface area carbon aerogel monoliths with hierarchical porosity", J. Non-Cryst. Solids, 354:3513-3515 (2008). -Becker et al., "Layered Silicate Nanocomposites Based on Various High-Functionality Epoxy Resins: The influence of Cure Temperature on Morphology, Mechanical Properties, and Free Volume" Macromolecules 36:1616-1625 (2003). -Bordjiba, T. "New Class of Carbon-Nanotube Aerogel Electrodes for Electrochemical Power Sources". Advanced Materials, 20:815-819. (2008). -Bryning et al., "Carbon Nanotube Aerogels", Advanced Materials 19:661-664 (2007). -Gregg et al., Adsorption, Surface Area and Porosity, Academic, London, 2nd edn, 1982. -Hasegawa et al., "Fabrication of macroporous silicon carbide ceramics by intramolecular carbothermal reduction of phenyl-bridged polysilsesquioxane", J. Mater. Chem., 19:7716-7720 (2009). -Hwang et al., "Synthesis and Characterization of Tin Oxide/Carbon Aerogel Composite Electrodes for Electrochemical Supercapacitors". Journal of Power Sources, 172:451-459 (2007). -Keller et al., "Influence of the preparation conditions on the synthesis of high surface area SiC for use as a heterogeneous catalyst support", J. Mater. Sci. 34:3189-3202 (1999). -Krawiec et al., "Thermal stability of high surface area silicon carbide materials" J. Solid State Chem., 179:2281-2289 (2006).

			C09D-195/00 C09K-003/00 C09K-003/30 C23C-004/04 C23C-004/10 C23C-008/00 C23C-016/00 C23C-016/24 C23C-016/30 C23C-016/48 D02G-003/00 H05H-001/02 H05H-001/24	US20100187484;US8685287 US20140121425;US9314777 US9327472 US20140225044;US9384870 US20160260550;US9460865 US20160101398;US9844762 WO2017145095			7005401 US20040132845;US7074880 US20050215068;US7256147 US20060093808;US7270851 US20060099139;US7282466 US20040029982;US7378450 US20050066574;US7410718 US7442747 US20060155376;US7780875 US20100075024;US7927666 US20100139823;US8172964 US20020094426;US7078359 US20040176643;US6927309 US20060293434 US20070292732;US7816413 US20090123358 US20090185327;US7986509 US20090229032	N N N Y N N N N N N N N N N Y Y Y Y Y Y N		-Kucheyev et al., "Ion-beam-induced stiffening of nanoporous silica" J. Phys. D: Appl.Phys., 42:182003-182006 (2009). -Kucheyev et al., "Depth-Sensing Indentation of Low-Density Brittle Naoporous Solids." Acta Materialia 57:3472-3480 (2009). -Ledoux et al., "New Synthesis and Uses of High-Specific-Surface SIC as a Catalytic Support that is Chemically Inert and Has High Thermal Resistance" J. Catal., 114:176-185 (1988). -Lee et al., "Carbon-coated nano-Si dispersed oxides/graphite composites as anode material for lithium ion batteries" Electrochem. Commun., 6:465-469 (2004). -Lee et al., "Shrinkage ratio of PDMS and it's alignment method for the wafer level process" Microsyst Technol, 14:205-208 (2008). -Li et al., "Porous Silicon Carbide/Carbon Composite Microspherules for Methane Storage" J. Nat. Gas Chem., 16:363-370 (2007). -Li et al., "Synthesis and characterization of carbon-doped titania as an artificial solar light sensitive photocatalyst" Chem. Phys. Lett., 404:25-29 (2005). -Maldonado-Hodar et al., "Metal-Carbon Aerogels as Catalysts and Catalyst Support". Studies in Surface Science and Catalysis, 130:1007-1012 (2000). -Mishra et al., "Synthesis of carbon nanotube-TiO2 nanotubular material for reversible hydrogen storage" Nanotechnology, 19:445607(7pp) (2008). -Moene et al., "Coating of Activated Carbon with Silicon Carbide by Chemical Vapour Deposition" Carbon 34(5):567-579 (1996).

							US20090317619 US20100028634 US20100075024;US 7927666 US20100139823;US 8172964 US20100187484;US 8685287 US20100190639 US20110024698 US20120037854;US 9087625 US20120122652;US 8664143 WO200800163			-Moreno-Castilla et al., "Group 6 metal oxide-carbon aerogels. Their Synthesis, characterization and catalytic activity in the skeletal isomeriation of 1-butene," Applied Catalysis A: General 183:345-356 (1999). -Nhut et al., "Synthesis and catalytic uses of carbon and silicon carbide nanostructures" Catal. Today, 76:11-32 (2002). -Pekala et al., "Carbon Aerogels for Electrochemical Applications". Journal of Non-Crystalline Solids, 225:74-80 (1998). -Petricevic et al., "Planar Fibre Reinforced Carbon Aerogels for Application in PEM Fuel Cells". Carbon 39:857-867 (2001). -Poole et al. "Introduction to Nanotechnology". John Wiley & Sons, 2003. -Preiss et al., "Formation of Black Glasses and Silicon Carbide From Binary Carbonaceous/Silica Hydrogels", Carbon 33(12):1739-1746 (1995). -Sakthivel et al., "Daylight Photocatalysis by Carbon-Modified Titanium Dioxide" Angew. Chem., Int. Ed., 42:4908-4911 (2003). -Stegenga et al., "Stability of Carbon-Supported Catalysts in an Oxidizing Environment", Carbon, 30(4):577-585 (1992). -US Office Action on U.S. Appl. No. 13/281,185 DTD May 15, 2013. -US Office Action on U.S. Appl. No. 12/652,616 DTD Oct. 9, 2012. -Vix-Guterl et al., "Effect of the Properties of a Carbon Substrate on its Reaction with Silica for Silicon Carbide Formation", Carbon, 35(10-11):1587-1592 (1997). -Worsley et al. "High Surface Area Carbon Nanotube-Supported Titanium Carbonitride

										Aerogels". J. Mater. Chem., 19:5503-5506 (2009). -Worsley et al. "Properties of single-walled carbon nanotube-based aerogels as a function of nanotube loading". Acta Materialia, 57:5131-5136 (2009). -Worsley et al., "Synthesis and Characterization of Carbon Aerogel Nanocomposites Containing Double-walled Carbon Nanotubes" ACS Philadelphia Aug. 17, 2008. -Worsley et al., "Synthesis and Characerization of Monolithic Carbon Aerogel Nanocomposites Containing Double-walled Carbon Nanotubes" Langmuir 24:9763-9766 (2008). -Worsley, M. et al. "Mechanically robust and electrically conductive carbon nanotube foams". Applied Physics Letters, 94:073115 (2009). -Worsley, M. et al. "Route to High Surface Area TiO2/C and TiCN/C Composites". J. Mater. Chem., 19:7146-7150 (2009). -Worsley, M. et al. "Stiff and Electrically Conductive Composites of Carbon Nanotube Aerogels and Polymers". J. Mater. Chem., 19:3370-3372 (2009). -Worsley, M. et al. "Synthesis and Characterization of Nanocarbon-Supported Titanium Dioxide". Mater. Res. Soc. Proc. vol. 1174, 2009 (6 pp). -Yang et al., "SiOx-based anodes for secondary lithium batteries" Solid State Ionics 152-153:125-129 (2002). -Zheng et al., "Preparations of C/SiC composites and their use as supports for Ru catalyst in ammonia synthesis", J. Mol. Catal. A: Chem. 301:79-83 (2009). -Zhu et al., "Fast hydrogen generation from

										NaBH4 hydrolysis catalyzed by carbon aerogels supported cobalt nanoparticles," International Journal of Hydrogen Energy pp. 1-7 (2013).

2012-02-16	(WO201221499) Silica aerogels and their preparation	MIT - MASSACHUSETTS INSTITUTE OF TECHNOLOGY	C01B-033/158	CN102951650;CN102951650B CN102951650;CN102951650B CN103342367;CN103342367B CN105189104 WO2014197028	(WO201221499) 5	(WO201221499) 5	US5306555 WO200844873 WO2007146945 US6068882 US20070222116;US7560062	N N N N N N N N N N	(WO201221499) 10	(WO201221499) Search Report references [Examiner] -PAJONK G M ET AL: "SECTION 1. AEROGEL SYNTHESIS. PHYSICAL PROPERTIES OF SILICA GELS AND AEROGELS PREPARED WITH NEW POLYMERIC PRECURSORS", JOURNAL OF NON-CRYSTALLINE SOLIDS, NORTH-HOLLAND PHYSICS PUBLISHING. AMSTERDAM, NL, vol. 186, 15 June 1995 (1995-06-15), pages 1-08, XP000683677, ISSN: 0022-3093, DOI: 10.1016/0022-3093(95)00210-3CC=XP; XP000683677 (Cat. Y) -RUTISER C ET AL: "Composite aerogels of silica and minerals of different morphologies", MATERIALS LETTERS, NORTH HOLLAND PUBLISHING COMPANY. AMSTERDAM, NL, vol. 19, no. 5-6, 1 May 1994 (1994-05-01), pages 221-224, XP024150838, ISSN: 0167-577X, DOI: 10.1016/0167-577X(94)90160-0 [retrieved on 1994-05-01]CC=XP; XP024150838 (Cat. Y) -MROWIEC-BIALON J ET AL: "Morphology of Silica Aerogels Obtained from the Process Catalyzed by NH4F and NH4OH", LANGMUIR: THE ACS JOURNAL OF SURFACES AND COLLOIDS, AMERICAN CHEMICAL SOCIETY, WASHINGTON, DC, USA, vol. 13, 1 January 1997 (1997-01-01), pages 6310-6314, XP002355133, ISSN: 0743-7463, DOI: 10.1021/LA9703454CC=XP; XP002355133 (Cat. A) -HÜSING N ET AL: "Aerogele - luftige Materialien: Chemie, Struktur und Eigenschaften", ANGEWANDTE CHEMIE, WILEY - V C H VERLAG GMBH & CO. KGAA, DE, vol. 110, no. 1, 16 January 1998 (1998-01-16), pages 22-47, XP002552209, ISSN: 0044-8249, DOI: 10.1002/(SICI)1521-3757(19980116)110:1/2<2 2::AID-ANGE22>3.0.CO;2-9 [retrieved on 1999-03-12]CC=XP; XP002552209 (Cat. A)

										-ALAIN C. PIERRE ET AL: "Chemistry of Aerogels and Their Applications", CHEMICAL REVIEWS, vol. 102, no. 11, 1 November 2002 (2002-11-01), pages 4243-4266, XP55014091, ISSN: 0009-2665, DOI: 10.1021/cr0101306CC=XP; XP055014091 (Cat. A) Applicant references -'Sol-Gel Science: The Physics and Chemistry of Sol-Gel Processing', 1990, ACADEMIC PRESS, INC. -ILER: 'The Chemistry of Silica', 1979, WILEY -SAKKA ET AL.: 'Better Ceramics Through Chemistry', 1984, NORTH-HOLLAND page 91 -J. OF NON-CRYSTALLINE SOLIDS vol. 63, 1984, page 223 -J. OF NON-CRYSTALLINE SOLIDS vol. 48, 1982, page 31 -KISTLER NATURE vol. 127, 1931, page 741 -LEVENTIS ET AL. CHEM. OF MATER. vol. 11, 1999, page 2837 -NANO LET. vol. 2, 2002, page 957 -MULIK J. OF MUTER. PROCESSING TECH. vol. 198, 2008, page 178 -CHEM. OF MUTER. vol. 17, 2005, page L085 -APPL. MATER. AND INTERFACES vol. 1, 2009, page 621 -CHEM. OF MATE vol. 20, 2008, page 5035 -FINLAY IND. & ENG. CHEM. RES. vol. 47, 2008, page 615 -WOIGNIER ET AL.: 'Better Ceramics Through Chemistry III', 1988, MATERIALS RESEARCH SOCIETY page 697

										-J. DE PHYSIQUE vol. 49, 1988, page 289 -HRUBESH, PEKALA J. OF MATER. RES. vol. 9, 1994, page 731 -FRICKE SCIENTIFIC AM. vol. 256, no. 5, 1988, page 92 -CANTIN ET AL. NUCLEAR INSTRUMENTS AND METHODS vol. 118, 1974, page 177 -GONAUER, FRICKE ACUSTICA vol. 59, 1986, page 177 -ANAPPARA ET AL. ACTA MATERIA vol. 52, 2004, page 369 -ASHLEY ET AL.: 'Chemical Processing of Advanced Materials', 1992, WILEY page 999 -1. OF NON- CRYSTALLINE SOLIDS vol. 330, 2003, page 187 -NAGASAKA, NAGASHIMA J. OF PHYSICS E: SCIENTIFIC INSTRUMENTS vol. 14, 1981, page 1435 -POLING ET AL.: 'The properties of gases and liquids', 2001, MCGRAW-HILL pages 10 - 42

2011-10-26	(CN102225769) Method for preparing elastic silica aerogel	BEIJING UNIVERSITY OF CHEMICAL TECHNOLOGY	C01B-033/16	CN102679599 CN103691370 CN103708476;CN103708476B CN103708476;CN103708476B CN104016360 CN105671687;CN105671687B CN105688815 CN106032276 CN106183513 CN107614392	(CN102225769) 10	(CN102225769) 10	CN101372337;CN101372337B	N	(CN102225769) 1	
2011-03-16	(EP2294147) Durable polymer-aerogel based superhydrophobic coatings: a composite material	STC UNIVERSITY OF NEW MEXICO	B05D-005/00 B05D-007/00 C09D-005/00 C09D-133/04 C09D-183/02		(EP2294147) 0	(EP2294147) 0	EP--68671 EP1412415 EP-122483 WO2006114420	N N N N	(EP2294147) 8	(EP2294147) Search Report references [Examiner] -See references of WO 2010033288A2
2009-09-16 2010-04-21	(GB2464369) Thermally insulating sandwich wall liner panel with aerogel and fibre core	PROCTOR A	B32B-005/24	DK201400604 EP2737138 EP2828444 ES2398119 IT2011MO0298 IT2012PD0039 US2012010345	(GB2464369) 10	(GB2464369) 10	GB1350661 US6103036 WO200602440 WO2008110818	N N N Y	(GB2464369) 4	

				7;US8539986 WO201312084 5 WO201314683 WO201410242 4						
2009-05-21 2010-08-03	(US7767063) Photo-formed metal nanoparticles and aerogel materials comprising the same	BROWN UNIVERSITY	B01J-019/12 C01B-004/00 C01B-013/00 C01B-025/00 C01B-031/00 C01C-001/00 C07C-001/00 C07C-209/68 C07F-003/00 C07F-003/10 C07F-007/12	AU2009333387 CN104014316;CN104014316B CN104014316;CN104014316B US20100150828;US8309135 WO2017117157	(US7767063) 5	(US7767063) 5	US20060054487;US7238261	Y	(US7767063) 1	(US7767063) Search Report references [Examiner] -Hund et al., "Formation and Entrapment of Noble Metal Clusters in Silica Aerogel Monoliths by .gamma.-Radiolysis", J. Phys. Chem. B (no month, 2003), vol. 107, pp. 465-469.
2008-09-18 2012-08-08	(JP4994360) Alkoxysilane group-modified hybrid Monolithic xerogel/aerogel and made of latex under subcritical manufacturing method.	INSTITUTE SUPERIOR TECHNICO	C01B-033/12 C01B-033/152 C01B-033/16 C01B-033/18 C01B-033/46 C08G-077/442 C08J-003/12	JP2012172378;JP5669617 JP2013511460 KR20110093526;KR101782624 PT-106781 JP2007145710	(JP4994360) 5	(JP4994360) 5	JP2002173534 JP2001316474 WO200441398	N N N	(JP4994360) 3	

2008-09-17	(GB200814789) Wall liner	PROCTOR A			(GB200814789) 0	(GB200814789) 0			(GB200814789) 0	
2008-05-15	(WO200857297) Shape memory polymer aerogel composites	UNIVERSITY OF AKRON	C01B-033/155 C01B-033/16	US20140186679;US9190649	(WO200857297) 1	(WO200857297) 1	US20020161114;US6858680 US20030055198;US6720402 US20060154195 US20060036045	N N N N N	(WO200857297) 5	(WO200857297) International Search Report [Examiner] -KAZARIAN: "Polymer Processing with Supercritical Fluids", POLYMER SCIENCE SER. C., vol. 42, 2000, pages 78 - 101, XP002739176CC=XP; XP002739176 (Cat. Y)
2007-07-05	(US20070154379) Process for producing silica aerogel	DYNAX	C01B-033/12 C01B-033/158 C01B-033/16	CN102659121;CN102659121B US20100116321 US20150141533;US9764301 US20170081201;US10077193	(US20070154379) 4	(US20070154379) 4			(US20070154379) 0	
2007-05-11 2013-04-26	(IN-256017) Ormosil aerogels containing silicon bonded linear polymers	ASPEN AEROGELS	C01B-033/00		(IN-256017) 0	(IN-256017) 0			(IN-256017) 0	
2007-03-01	(WO200723742) Multilayered circuit board and electronic equipment	UNIVERSITY TOHOKU	H05K-003/46		(WO200723742) 0	(WO200723742) 0	JP2005116660 JP2005050860 WO200460660 JP07202439 JP62169392 JP2003027035	N N N N N N	(WO200723742) 6	(WO200723742) International Search Report [Examiner] -See also references of EP 1931186A1

2006-11-09 2006-12-14	(WO2006119249) Aerogels and methods of using the same for chemical mechanical planarization and for extracting metal ions	BROWN UNIVERSITY	C09K-013/00		(WO2006 119249) 0	(WO2006 119249) 0	US20030203635;US 6767476 US6592776	N N	(WO2006 119249) 2	