IBIMA Publishing
Journal of Innovation & Business Best Practice
http://www.ibimapublishing.com/journals/JIBBP/jibbp.html
Vol. 2015 (2015), Article ID 316698, 13 pages
DOI: 10.5171/2015.316698

Research Article

Patent data analysis of innovation behaviours in technology hardware & equipment industry

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Received date: 8 September 2014; Accepted date: 11 December 2014; Published date: 5 October 2015

Academic Editor: Pedro Maia Malta

Abstract

The paper presents an analytical method to define innovation behaviours and technology strategies of companies using patent data.The framework can be used to: 1) analyse single innovation behaviours, 2) map innovation strategies defined as combinations of different innovation behaviours, and 3) describe the patterns of technological evolutions over time.
The methodology is tested on a sample of 133 top research and development (R&D) companies belonging to technology hardware & equipment industry, by analysing their patents applied from 2008 to 2012. From the analysis of the behaviours, a preponderance of exploitation strategies that lead to radical outputs is detected. We also uncovered a growing adoption of open innovation and an increasing concentration of R&D efforts on radical outputs.

Keywords: Innovation strategies, exploration vs. exploitation, open innovation, radical vs. incremental innovation, patent data analysis.

Introduction

Patent data are widely used in literature as a measure of innovation, being the only formally and publicly verified output of inventive activities and. we use patent data to study innovation strategies related to exploitative vs. explorative activities, closed vs. open processes and incremental vs. radical outputs. in this paper, we propose an integrated framework based on the combination of such variables, in order to analyse capabilities, activities and competencies related to r&d processes. twelve different behaviours were detected considering four dimensions of innovative processes. if combined together, such

Cite this Article as: Francesca Michelino, Antonello Cammarano, Emilia Lamberti and Mauro Caputo (2015),"Patent data analysis of innovation behaviours in technology hardware & equipment industry", Journal of Innovation & Business Best Practice, Vol. 2015 (2015), Article ID 316698, DOI: 10.5171/2015.316698

behaviours describe the overall innovation strategy of a company.

our research question is: how innovation strategies of companies can be analysed and technological evolution can be tracked through patent statistics?

the research is based on objective data detected from patstat database, and on some variables already acknowledged and operationalized in scientific literature, that we combine in an integrated framework. the output of our analysis consists of a map summarising the strategies of companies towards innovation and providing information about the prevailing innovation paths (firm level). the framework can be also applied for mapping innovation strategies in specific industries and describing their technological evolution (industry level).

the methodology is tested on a sample of 133 r&d intense companies from technology hardware & equipment (the) industry, by analysing over 300,000 patents applied from 2008 to 2012, validating both the framework applicability and its explicative power and usefulness. from the analysis of the behaviours of companies, exploitation strategies that lead to radical outputs seem to be the most relevant within the sample. we also detected a growing adoption of open innovation and an increasing concentration of r&d efforts on radical outputs.
in what follows, after a brief literature review on patent-based metrics for innovation, the measurement framework is presented and then applied to the sample. results are discussed and conclusions will close the work.

Literature Review

A large number of scholars have used patent data as a proxy for innovation (Acs and Audretsch, 1989; Chakrabarti, 1991; Grupp, 1992; Belderbos, 2001; Frietsch and Grupp, 2006; Hanel, 2006). Patent data offer a valuable source of information, useful to both keep track of the technological strategy evolution of companies and make comparisons, as they contain standardized data, stored for a long period and continuously updated (Griliches, 1990). Furthermore, patents are the only formally and publicly verified outputs of inventive activities (Ma and Lee, 2008).

The integrated framework we suggest is based on the combination of variables already acknowledged in scientific literature concerning: 1) exploitative vs. explorative activities, 2) closed vs. open processes and 3) incremental vs. radical outputs. In what follows, a deepening of the operationalization of each dimension under investigation is reported.

Since March's (1991) work, a wide debate has raged over the need for a balance between exploiting the knowledge an organization already holds (local search) and exploring for knowledge that is different and new to the organization (distant search). Exploitation is associated with current viability and thus leads to more capability at current activities, while exploration is related to the acquisition of diverse and novel body of knowledge that will serve as the seed for future technological developments. Such concepts can be operationalized through the investigation of patent classification codes: international patent classification (IPC) codes allow analysing the technology field in which patents impact and can be considered as a proxy of skills developed by the firm in a specific technology domain. A patent is considered as an explorative one when it is situated in a technology domain that is new or unfamiliar to the firm, i.e. the firm did not patent in the technology domain in the past five years (Belderbos et al., 2010). On the contrary, exploitative technological processes are acts of creation in technological domains where the firm has already patented technology in the previous five years. Such approach is widely diffused among scholars, e.g. Lo Storto (2006), by studying the IPC information disclosed in patent data, detected exploitative and explorative activities of companies and related them to innovation in components or combinations.

Regarding the organizational dimension of R&D activities, firms can either invest on their own resources and efforts, developing closed innovation processes, or open up

their R&D processes, adopting the open innovation paradigm. Companies can develop patents either internally - pursuing a closed innovation strategy - or jointly, through collaboration activities with third parties. Therefore co-patents seem to be a relevant indicator for signalling the occurrence of open innovation strategies (Chesbrough, 2006) and the number of patents deriving from collaborative projects can be considered as a proxy of open innovation (Al-Ashaab et al., 2011). By analysing the number of applicants disclosed in the assignee field of a patent application, information about the ownership of innovation can be detected and it is possible to understand whether the patent is the result of collaborative activities. Such operationalization is widely diffused and many scholars, using joint-patenting information, reported a growing open innovation adoption (Kim and Song, 2007).

As regards the outputs of R&D processes (radical vs. incremental), the distinction between refining and improving an existing design and introducing a new concept that departs in a significant way from past practice is one of the most addressed topics in innovation strategy literature. Incremental innovations are minor improvements or simple adjustments in current technology (Munson and Pelz, 1979), while radical innovation is based on a different set of engineering and scientific principles and often opens up whole new markets and potential applications (Dess and Beard, 1984; Ettlie et al., 1984; Dewar and Dutton, 1986). While the concepts of exploration and exploitation summarise how firms manage their internal knowledge and capabilities in their R&D activities, radical and incremental innovation are related to the results of the R&D effort. According to literature, the radicalness of an innovation can be detected through the analysis of backward citations. The principal assumption driving the research is that citations trace out knowledge flows and technological learning: a citation from patent Y to patent X indicates that inventors on Y knew about and used X in developing Y, therefore patents without backward citations to prior technical art can be considered 'pioneering' (Ahuja and Lampert, 2001), thus determining an innovation based on a different set of engineering and scientific principles, i.e. a radical innovation. On the contrary, the existence of backwards citations may be a proxy of incremental innovations.

Even if patent data are widely used to investigate technological innovation strategies implemented by innovative firms, most attention has been devoted to only one dimension of R&D processes at time, e.g. Sakata et al., (2009) study only IPC combinations in order to define the innovation position of Japanese companies. However, some contributions analyse the mix of concepts related to innovation activities, e.g. evaluating the impact of open innovation on exploitative and explorative processes through patent statistics (Dittrich and Duysters, 2007; Belderbos et al., 2010). Further, although many contributions aimed at identifying the evolution of technological patterns of companies, they show only a partial overview of the innovation strategies pursued, e.g. Suzuki and Kodama (2004) defined technological trajectories and technology diversification strategies by analysing IPCs. Therefore, an integrated patent-based map of innovation capabilities, processes and competencies seems to be lacking. In this paper we aim at investigating patent data after a multidimensional point of view, in order to: 1) analyse the whole innovation process in terms of capabilities, activities and competencies, 2) keep track of the evolution of such innovation process and 3) study the innovation strategies of companies.

Methodological Framework

Starting from the literature review, we designed a framework that combines all the aforementioned variables with the aim of defining the innovation strategies adopted by companies after a multidimensional perspective. By simulating innovation through an input-process-output model, we believe that innovation strategies are pursued through management choices on capabilities, activities and competencies. In particular, capabilities are considered as the input of our model and can be related to exploitation and exploration strategies on

each technological domain in which the firm is involved. Activities are linked to the organization of R&D efforts and are here summarised by the choice of collaborating or not with other firms. Finally, the patent, which is the concrete manifestation of competencies developed by the company at the end of the innovation process, can be considered as a proxy of radical or incremental innovation, depending on the potential pioneering of the output.

A fourth dimension is added to the input-process-output model: the relevance of the process, that can be defined high if the capabilities which gave raise to the process are core, low otherwise (Figure 1)

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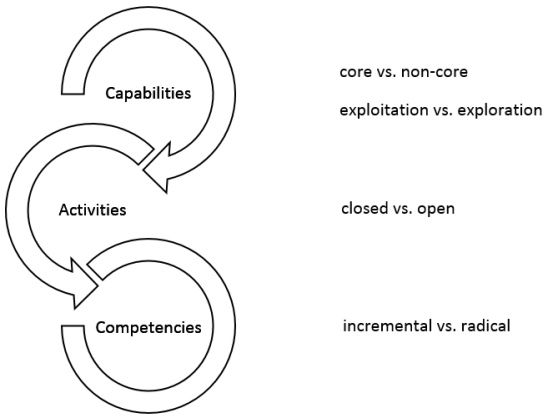

Figure1: Input-process-output model for simulating innovation strategies

The starting point of our work is the extraction of patents from PATSTAT database: for each analysed company we considered all its patents applied in the investigated time interval, and recorded patent classification codes, number of applicants and number of backward citations, in order to analyse capabilities, activities and competencies.

As suggested by scientific literature, technology fields can be analysed by detecting IPCs recorded in patent applications. In our framework, we used the cooperative patent classification (CPC) system, a new patent classification system - jointly developed by the European Patent Office and the United States Patent and Trademark Office - which can be considered as an evolution of IPC, since it is more specific and detailed. At least one CPC is related to a patent application, in order to define the technological areas on which patents have impact. CPCs categorize technological fields into a five-level hierarchical system, from the broadest to the very specific: section, class, subclass, main group and subgroup. For example, the "details of semiconductor or other solid state devices" field belongs to a main group expressed in an alpha-numerical code, H01L23: H identifies the section "electricity", H01 the class "basic electric elements", and H01L represent the subclass "semiconductors devices or other solid state devices". Finally, the subgroup is represented by adding a slash symbol (/) and numerical digits, e.g. "H01L23/02" specifically defines patents related to "containers for semiconductors devices or other solid state devices". In order to identify the technology field, we decided to cut the code and consider only the information before the slash, since the operationalization of the variable capability clearly requires more generalization.
After data extraction, for each company we obtained a list of all the CPCs detected in the patents it filed in the selected time horizon. CPCs can be labelled as core or non-core and exploitative or explorative. In particular, each CPC is defined core if it is declared in at least 10% of the patents filed in the previous five years, non-core otherwise; exploitative if the company filed patents in such technology domain in the past five years, explorative otherwise. Obviously, from these two definitions, no core and explorative CPCs can be found. In Table 1 the methodology for CPCs labelling is provided.

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Table 1: Methodology for CPC labelling

CPC label	If
core exploitative	the company filed more than 10% of its patents of the previous five years in the technology domain described by the CPC
non-core exploitative	the company filed some patents, but less than 10% of those registered in the previous five years, in the technology domain described by the CPC
non-core explorative	the company did not file any patent in the previous five years in the technology domain described by the CPC

Further, by analysing patents that declare the specific technological field and detecting the number of owners and backward citations, we can define their nature as (see Table 2):

- *closed* if only one applicant is found, *open* otherwise;
- *incremental* if at least one backward citation is detected, *radical* otherwise.

Table 2: Methodology for patent labelling

		No. of applicants of the patent	
		one	*two or more*
The patent has backward citations	*yes*	closed incremental	open incremental
	no	closed radical	open radical

Given that a CPC can be detected in more than one patent for each company, both closed and open patents, as well as both incremental and radical ones, can be found, i.e. the competencies can be used by companies in both their closed and their open innovation processes and can give raise to both incremental and radical innovation.

Thus, our framework describes the innovation processes adopted for each CPC through four dimensions. Each patent that contains the analysed CPC is described with four different labels, the first two inherited from the belonging CPC, and associated to only one of the twelve available different behaviours in R&D processes explained in Figure 2.

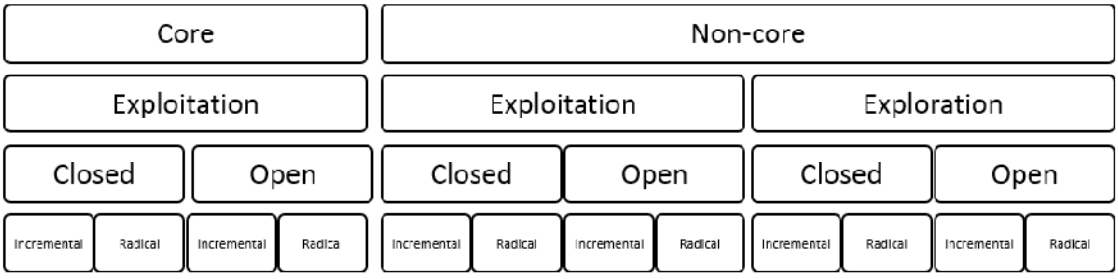

Figure 2: Twelve different combinations of labels defining specific behaviours in R&D processes

At a firm-level, for each company we obtained the number of patents related to each configuration: the combination of behaviours describes the innovation strategy pursued in such technology domain. The individual information collected for each

technological class is used to study the overall behaviour of a firm, summing the results obtained from all the CPCs.Therefore, our framework can evaluate the weight of a single behaviour on the mix of innovation strategies of companies in a specific time interval, i.e. the map of innovation processes. A share indicator that summarises the impact of a specific combination on the overall innovation strategy describes each behaviour.

Two of the most discussed trade-off in the scientific literature, are exploration vs. exploitation and radical vs. incremental innovation strategies. Through our framework, we can evaluate the adoption of such strategies, or their mix (Table 3).

Table 3: Capabilities-competencies matrix

		capabilities	
		exploitation	*exploration*
competencies	*radical*	advancement	explosion
	incremental	strengthening	expansion

Companies that exploit their capabilities in order to obtain incremental innovations pursue a strengthening innovation strategy, related to continuous improvement and evolution on already known technologies; otherwise, if their outputs are radical they carry on an advancement strategy, based on the development of potential revolutionary innovations and the exploitation of capabilities already owned. Firms may also explore new unknown technological fields, through the expansion in new technology domains of innovations already available, or obtain radical innovation through activities trespassing knowledge boundaries and leading to new concepts that depart from past practices, carrying on an explosion innovation strategy. As they are defined, the four strategies are complementary and considering their four share indicators we can summarise the overall innovation strategy of the company.

Starting from the behaviours described through the capabilities-competencies matrix, by adding the information about relevance and process organization, we can define a simple nomenclature for the twelve different combinations (Table 4).

Table 4: Nomenclature for the twelve possible innovative behaviours

Label	Behaviour
Core - Exploitation - Closed – Incremental	Core closed strengthening
Non-core - Exploitation - Closed – Incremental	Non-core closed strengthening
Core - Exploitation - Open – Incremental	Core open strengthening
Non-core - Exploitation - Open – Incremental	Non-core open strengthening
Non-core - Exploitation - Closed – Radical	Core closed advancement
Core - Exploitation - Closed – Radical	Non-core closed advancement
Core - Exploitation - Open - Radical	Core open advancement
Non-core - Exploitation - Open - Radical	Non-core open advancement
Non-core - Exploration - Closed - Incremental	Closed expansion
Non-core - Exploration - Open - Incremental	Open expansion
Non-core - Exploration - Closed - Radical	Closed explosion
Non-core - Exploration - Open - Radical	Open explosion

Therefore, our framework supports us in identifying innovation strategies of firms in a specific time interval and provides a useful instrument for benchmarking.

Further, by selecting a sample of companies, the framework provides information about innovation in specific industries, allowing to perform an industry level analysis.

By comparing results obtained in different time intervals, we can study the innovation paths undertaken by companies and find the continuous innovation strategies of companies or industries, verifying the evolution on the adoption of the twelve different combinations.

Findings

The framework was applied to a sample of 133 R&D intense companies from THE industry ranked by their investment in R&D, according to The 2012 EU Industrial R&D Investment Scoreboard (JRC, 2012), excluding the firms whose 2012 annual reports were not available and those for which the list of subsidiaries was not found in such documents. We choose this industry because it is R&D intense, uses patents as a means of appropriation of innovation (Pavitt, 1984) and is characterised by companies incorporating strategic technology alliances into the core of their technology strategies. In order to consider the impact of R&D activities on the corporate group, we searched patents developed by both the parent company and its subsidiaries disclosed in annual reports, also taking into account patents related to acquired companies and applied after the acquisition. We considered five years of analysis - from 2008 to 2012 - and gathered data from PATSTAT database, downloading patents applications from 2003 to 2012 and analysing 316,015 documents. As a matter of fact, for each year of analysis we have to consider also the patents in the previous five years in order to define the relevance and the exploitation vs. exploration of capabilities (Table 5).

Table 5: Patent data involved in the analysis

Year of analysis	Years analysed for relevance and competence labelling
2008	2003-2004-2005-2006-2007
2009	2004-2005-2006-2007-2008
2010	2005-2006-2007-2008-2009
2011	2006-2007-2008-2009-2010
2012	2007-2008-2009-2010-2011

For example, for the year 2012 we downloaded all patent applications of companies, including documents related to their subsidiaries, identifying the CPCs registered and verifying if they were core/non-core and exploitative/explorative by analysing patents data from 2007 to 2011 and recording information about number of applicants and backward citations. We applied our framework in order to estimate the overall innovation strategy of each company and, by comparing results obtained from a group of firms, a benchmark is available. Table 6 provides an example of benchmarking, aiming at comparing the innovation strategies adopted in 2012 by four companies belonging to our sample. Different behaviours emerge: Infineon Technologies mostly addresses its R&D efforts to advancement; Alcatel-Lucent focus on strengthening, while Logitech International mostly relies on expansion; finally, only Lexmark among the four companies has a significant share of patents exploring new technological fields and obtaining radical innovation.

Table 6: Firm level analysis for benchmarking activities

Company	Strengthening	Advancement	Expansion	Explosion
Alcatel-Lucent	83,79%	14,71%	0,58%	0,92%
Infineon Technologies	17,18%	81,42%	0,00%	1,40%
Logitech International	17,78%	62,22%	11,11%	8,89%
Lexmark	28,26%	39,13%	9,78%	22,83%

In order to perform an industry level analysis, we cumulated the results obtained for each firm, evaluating the behaviour of the whole sample. Table7 reports the share of the twelve configurations for the year 2012 for the whole sample, while Table 8 shows the capabilities-competencies matrix for patents applied in 2012.

The non-core closed advancement is detected in over one third of innovative activities, with companies obtaining radical outputs starting from capabilities that currently are less relevant for their business. A similar behaviour was found in core activities, with core closed advancement representing the most pursued strategy for relevant technology fields. Regarding open innovation adoption, in general, it is detected in about 28% of the patent applications and companies seem to prefer such behaviour in strengthening activities, exploiting the capabilities of partners in order to achieve improvements on already known technologies. As a matter of fact, in the analysed industry the modularity of IT design and the crucial role of partnership agreements with other companies which manufacture parts, components and products that are incorporated into their products encourage the adoption of open innovation.

Table 7: Characteristics of patents applied in 2012 by companies belonging to the sample

Behaviour	Share
Core closed strengthening	3.34%
Non-core closed strengthening	18.56%
Core open strengthening	2.47%
Non-core open strengthening	20.34%
Core closed advancement	7.64%
Non-core closed advancement	40.24%
Core open advancement	0.73%
Non-core open advancement	4.04%
Closed expansion	0.57%
Open expansion	0.59%
Closed explosion	1.19%
Open explosion	0.30%

Table 8: Capabilities-competencies matrix for patents applied in 2012

		Capabilities	
competencies		*exploitation*	*exploration*
	radical	52.64%	1.50%
		advancement	explosion
	incremental	44.70%	1.16%
		strengthening	expansion

Strengthening and advancement strategies are the most relevant ones, and in particular, the latter was detected in over half of the patent applications. In the analysed industry - where the development pace is very fast and the life cycle of products is short, exploitation strategies are strongly preferred. Furthermore, radical innovation seems to strongly characterize this industry, with about 54% of R&D activities leading to a radical output and patents without backward citations.

In order to detect the evolution of the technological patterns of the sample and analyse the innovation strategies, we applied the framework, year by year, on patent applications from 2008 to 2012 and studied the result obtained on the eight cumulative share indicators. In Figure 3 the trends for core, exploration, open and radical shares

are reported, being those of non-core, exploitation, closed and incremental complementary to the former. In the five-year period the shares of exploration and core innovation do not vary significantly, the former always being less than 4% and the latter on average around 14%. A continuous leveraging of existing capabilities through exploitation processes is observed. A growth in the adoption of open strategies is observed from 17% to 28% patents of the sample being registered by two or more applicants. Finally, the growth of the radical share indicator from 39% to 54% denotes an increased concentration of activities towards outputs that are pioneering for the companies of the sample. Only in 2012 radical outputs prevail on incremental ones.

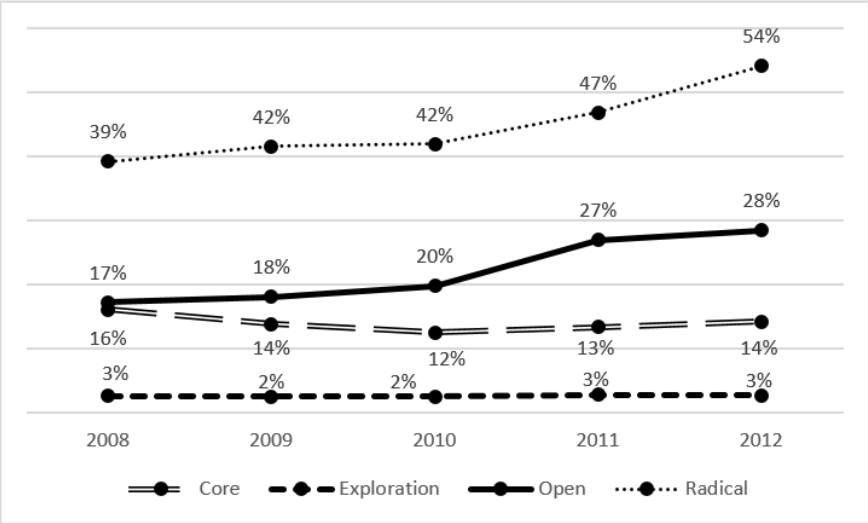

Figure3: Evolution of core, exploration, open and radical shares from 2008 to 2012

Conclusions

The paper aims at contributing to the current literature on innovation management by describing how companies manage technological evolution and organize R&D activities, through the use of patent data. A capabilities-competencies matrix is defined, pointing out the differences between exploitation vs. exploration strategies and incremental vs. radical outputs. Noteworthy, these concepts are often treated alternatively in current literature but they can be evaluated separately since they describe two different dimensions of innovation activities. Mapping innovation strategies on the basis of patent applications, allows to consider the direct outcomes of the inventive process and, more specifically, of those inventions which are expected to have a commercial impact.

The paper addresses the need for operative, practical instruments, which can help managers to monitor and control their innovation paths. Given the availability and objectivity of patent documents, studying innovation through the analysis of patent data can help decision-makers to assess the status of their own strategies and compare it over time and space, also allowing the benchmarking with competitors.

A sample of 133 companies from THE industry over the period2008-2012 was studied, validating both the framework applicability and its explicative power and usefulness. Advancement strategies seem to be characteristics in such industry, while exploration activities are negligible as a whole. An increasing adoption of open innovation and a growing concentration of R&D efforts on radical outputs are also detected.

Two operationalization issues arise. First, the results are affected by our definition of core and non-core activities - CPCs are considered core if they are declared in at least 10% of the patents filed in the previous five years -as well as by the decision of cutting CPCs without considering the subgroup number, in order to avoid excessive detail on the definition of the capabilities of companies. Second, as to the definition of exploitative activities, companies may lose experience if they did not patent in a specific technology domain in a previous time interval lower than five years, since in THE industry the development pace is faster and the life cycle of product is shorter. Therefore considering a shorter time interval may probably improve the definition of exploitative and explorative R&D processes. We preferred to follow the approach already acknowledged in scientific literature but our consideration suggests a deepening of the operationalization of exploration and exploitation variables in such industry.
Some general limitations can be defined for the work. First, the use of patent data as a proxy of technological activities might underestimate the phenomenon, since not all R&D efforts will result in an application for a patent. Second, the use of patent data for investigating the adoption of open innovation could be questionable, since not all collaborations will be captured by co-patenting activities (Hagedoorn et al., 2003). Furthermore, the research is limited to only one industry.

Further research will be addressed to widening our sample of investigation, by analysing different industries and making comparisons among innovation strategies of companies with different features. In order to evaluate the overall impact of open innovation adoption, we plan to enforce our framework introducing other open models already studied by scientific literature, like licensing, trading and incorporation (Michelino et al., 2014a). Correlations between strategic behaviours detected through our framework, context features (e.g., firm's age and dimension) and financial performance indicators are under investigation. Finally, we are trying to match the openness indicator provided by this framework with the openness ratios measuring the pecuniary dimension of open innovation (Michelino et al., 2014b).

Notes

[1]We recorded the number of owners through the applicant sequence number field detected from PATSTAT database. Many joint-patenting activities deriving from intra-group R&D efforts have been labelled as open.

[2]Even though only in 2012 radical outputs prevail on incremental ones, the non-core closed advancement behaviour is the most common one until 2009. Only in 2008 we recorded a preponderance of non-core closed strengthening activities.

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