Open innovation and intellectual property
A knowledge-based approach

PURPOSE
To provide a patent-based framework for investigating the effect of previous and current open innovation adoption on firms' knowledge management strategies and type of innovation output.

DESIGN/METHODOLOGY/APPROACH
Patent data are employed for gauging innovation practices, exploitation vs. exploration strategies, specialization vs. diversification choices and type of innovation. The study is performed on a sample of 1,280 patents granted to 66 top R&D spending bio-pharmaceutical companies. The year of analysis is 2010.

FINDINGS
The previous recourse to specific innovation practices influences the current practice selection. R&D collaboration, outsourcing and M&As are employed to pursue exploration. Past purchase of patents increases the likelihood to achieve architectural and radical innovation in current activities.

RESEARCH LIMITATIONS/IMPLICATIONS
The work recommends the use of patent data to gauge many key elements for knowledge and innovation management. Results exhort scholars to investigate innovation practices at the knowledge domain level in order to detect specific behaviors.

PRACTICAL IMPLICATIONS
The study provides a methodology for supporting decision-makers in assessing firms' open innovation adoption, also performing the benchmark with competitors and R&D partners. Given the high computational effort required for applying the methodology, we are planning to give access to the software specifically developed for this study.

ORIGINALITY/VALUE
The work contributes to the current debate considering the effect of a combination of innovation practices on knowledge management strategies and type of innovation output, with a particular focus on open innovation activities. Moreover, the separation between the impact of previous and current innovation practices provides useful insights.

Keywords: Open innovation; Knowledge management strategies; Stock of knowledge; Type of innovation; Patent data.

Paper type: Research paper.

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1. Introduction

The open innovation (OI) paradigm (Chesbrough, 2003) has found a ready audience amongst scholars, business people and policy makers who recognize new opportunities to innovate in the access to external sources of knowledge and technology. In opposition to the closed model, which is centered on internal R&D efforts, OI employs outer knowledge sources to improve profits (Garriga *et al*., 2013). When firms engage in formal external collaboration and, more in general, in OI activities, they protect their knowledge to facilitate interaction (Ebersberger *et al.*, 2012) and achieve benefits from their stock of knowledge (Spithoven *et al.*, 2013). The interplay between openness, knowledge flows and adequate instruments of intellectual property (IP) protection figures promptly in OI literature (West, 2006) since it generates appropriability issues (Laursen and Salter, 2014; Spithoven *et al.*, 2010).

In this work, patent data are employed to investigate the effect of OI on firms' knowledge management strategies and type of innovation output.

So far in OI literature, researchers tended to concentrate on the trade-off between closed and open approach (see, e.g., Almirall and Casadesus-Masanell, 2010; Felin and Zenger, 2014; Herzog and Leker, 2010), instead of considering that each OI practice is selected for a specific purpose, provides a proper output and is carried out to achieve a particular knowledge management strategy. Even though a wide literature has investigated the effect of single practices (see § 2.1), to our knowledge, no contribution proposes to simultaneously consider a mix of OI modes in order to uncover their combined effect. Therefore, the first theoretical gap we intend to overcome is to define the effect of a combination of innovation practices on knowledge management strategies and type of innovation output.

A second gap we intend to fill is the separation between the impact of previous and current innovation practices. Indeed, from one side, the mix of innovation practices formerly employed influences the building of the stock of knowledge. Such a stock affects the current knowledge management strategy to pursue, the innovation practice to adopt in new R&D efforts, and the type of innovation output that may be achieved in current activities. Such an assumption is in line with various theories, such as R&D path dependency, knowledge accumulation, knowledge recombination and absorptive capacity (see, e.g., Arthur, 1986; Arts, 2012; Cohen and Levinthal, 1990; Katila and Ahuja, 2002). From the other side, OI allows firms to access new knowledge and technology, therefore its adoption depends on the actual knowledge management strategy. Indeed, technical knowledge evolves and current strategies may deviate, even partially, from previous ones. Furthermore, the selection of a specific innovation practice can affect the output resulting from the current R&D effort.

Based on such premises, we suggest an instrument for investigating knowledge management strategies and type of innovation output, analyzing the effect of OI adoption on firm's knowledge accumulation, recombination and generation, also considering the role of context-related issues. Figure 1 displays the relationships under investigation. In summary, we pose the following research questions:

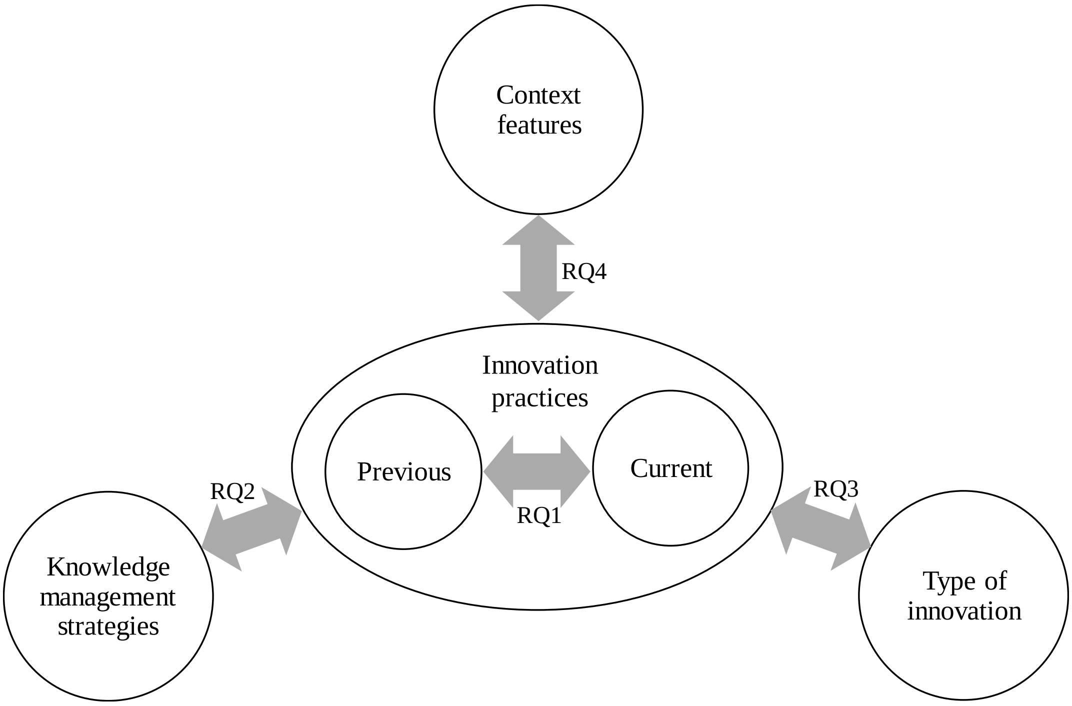
RQ1: *How does the previous recourse to innovation practices influence the current practice selection?*

RQ2: *Which current knowledge management strategy results from past OI adoption? Is the selection of a current innovation practice linked to such strategy?*

RQ3: *Is the innovation output related to previous and current innovation practices?*

RQ4: *How are the size of patent portfolio and the belongingness to a specific segment related to innovation practices?*

Figure 1. Relationships under investigation



The study is performed on a sample of 1,280 patents granted to 66 top R&D spending bio-pharmaceutical companies. A set of operationalizations is devised for innovation practices, knowledge management strategies and type of innovation, which are defined at the knowledge domain level. As a matter of fact, since each technical area is featured by a different knowledge accumulation process, (i) a specific combination of past OI practices adopted by the focal company, (ii) a custom technological strategy and (iii) the innovation output resulting from current R&D efforts may be not only firm-specific, but also knowledge domain-specific.

Results show that previous innovation activities affect the current practice selection. Moreover, specific insights are found as to the relationships of each practice with the areas under investigation.

In what follows, the reviewed literature forming the backbone of this work is presented. Subsequently, the methodological framework is delineated and then applied to the selected sample. Results are discussed and conclusions close the work.

2. Theoretical background

This study intends to uncover how previous and current innovation practices are related to knowledge management strategies and type of innovation output. In what follows, after a brief presentation of knowledge management strategies and type of innovation, a deepen analysis on innovation practices is presented, with a focus on their relationships with these two areas, as well as with the context features. In this way, theoretical gaps emerge clarifying the contribution of our work. As a matter of fact, a dearth of analysis occurs on the combined effect of OI practices as well as on the distinction between previous and current openness adoption.

Knowledge management strategies are considered in terms of exploitation vs. exploration and specialization vs. diversification.

Exploitation regards the leveraging of existing capabilities by the means of activities such as standardization, upscaling, and refinement, whereas exploration refers to the access to new knowledge domains through fundamental research, experimentation, and search (March, 1991). Exploitative activities allow firms to achieve economies of scale and lead to short-term effects (Belderbos *et al.*, 2010). They are based on local search and build on the current technological trajectory, improving existing product-market domains (He and Wong, 2004). Differently, the exploration of new possibilities and ideas is based on distant search and associated with experimentation, play and risk taking, in order to both create new capabilities (Belderbos *et al.*, 2010) and produce new knowledge (Miner *et al.*, 2001). Such a novel body of knowledge will serve as the seed for future technological development (Miller *et al.*, 2007) with companies involved in shifting to a different technological trajectory (Benner and Tushman, 2002) and aiming at entering new product-market domains (He and Wong, 2004) to achieve a long-term growth.

The distinction between specialization and diversification regards the different levels of exploitation of existing knowledge. Indeed, different degrees of exploitation lead to varying levels of familiarity with the knowledge, thus affecting the specialization vs. diversification choice (Campbell, 1990; Santalo and Becerra, 2008). Actually, with specialization strategies companies focus on a narrow area of knowledge or skill or activity (Brusoni *et al.*, 2001; Duysters and Hagedoorn, 2000). On the other side, organizations may diversify in order to extend business activities into disparate fields (Argyres, 1996; Granstrand *et al.*, 1997), accumulating knowledge with potential application in multiple product-market domains (Miller, 2006). Technology portfolios in which knowledge is spread over many fields are considered as signaling higher levels of technological diversification (Leten *et al.*, 2007).

The **type of innovation output** resulting from the current R&D effort is identified following the classification by Henderson and Clark (1990). Two features are taken into account: core concepts and linkages between core concepts and components. Changes of core concepts can be defined through the lack of technological antecedents (Ahuja and Lampert, 2001; Kaplan and Vakili, 2012; Rosenkopf and Nerkar, 2001; Shane, 2001; Trajtenberg *et al.*, 1992; 1997), whereas their presence denotes a reinforcement of core concepts (Hall *et al.*, 2001; Jaffe *et al.*, 1993). As to the impact of the linkages between components, innovation can be achieved through recombining already established elements (Fleming, 2001) or by introducing an established element into a new setting (Hargadon and Sutton, 1997). Therefore, new technologies can derive from the combination of elements and settings not previously observed (Dahlin and Behrens, 2005). Hence, four types of innovation can be defined: incremental, architectural, modular and radical.

2.1 Innovation practices

For the purpose of this work, innovation practices are defined including both the closed and the open approach. In particular, four open practices are set against the internal development of technologies: R&D outsourcing, R&D collaboration, purchase of external technologies and incorporation by the means of mergers and acquisitions (M&As).

2.1.1 Internal development

The internal development of new products and services allows companies to directly exploit the result of their R&D efforts, and enter the market first and win (Chandler, 1990). Actually - when technological complexity is high - if the focal firm possesses all the capabilities and resources required, products can be developed better, faster and more efficiently internally than in collaboration with other companies (Almirall and Casadesus-Masanell, 2010; Boudreau, 2006). Even though firms pursue a closed approach, they still need to access to external inputs and be able to assimilate, absorb, assess and use new knowledge (Cohen and Levinthal, 1990) in order to stimulate internal R&D activities (Dzikovski, 2015; Gomes *et al.*, 2011; Mothe and Nguyen-Thi, 2013). Indeed, if the R&D process is performed in isolation from external environment, companies may suffer of longer time to commercialize products because of poor market resources (Clausen *et al.*, 2013). In addition, by relying only on internal development, it could be challenging for firms to reconfigure their R&D processes to adapt to novel technologies, due to organizational inertia (Xu *et al.*, 2013).

Knowledge management strategies

Internal development is the most common practice to achieve exploitation. Indeed, firms conduct a local search to exploit current knowledge and resources within their boundaries to reduce the likelihood of errors, increase the predictability of R&D efforts and enhance innovation performance (Clausen *et al.*, 2013; Katila and Ahuja, 2002).

In-house activities allow firms to specialize by using their core technological capabilities, since specialization leads to a better understanding of technology and improves companies' innovation performance (Stolwijk *et al.*, 2012). Indeed, continuing action and experience in a particular technical area creates deeper knowledge of such area, making a firm a superior learner and increasing its domain-specific performance (De Clercq and Dimov, 2008). In addition, a company specializing in some specific technological fields could enter into a number of complementary domains, hence leading to diversification in areas in which its resources can be extended (Guadamillas *et al.*, 2008). However, a highly diversified technological portfolio can cause a lack of focus in R&D efforts and divert a firm's attention from effectively developing innovations based on its core competences (Xu *et al.*, 2013).

Type of innovation output

Ayari (2013) argues that that firms focusing on their internal R&D activities are more likely to generate innovative products and that radical innovations are stimulated by higher R&D intensity. Indeed, technology orientation facilitates the development of breakthrough innovations as it encourages creative ideas. However, the positive effect of internal technological strength may subside after it reaches a certain level (Zhou and Wu, 2010), since it is difficult for a firm to build new knowledge into the existing knowledge base once it is well entrenched and has been associated to organizational routines difficult to reconfigure (Xu *et al.*, 2013). This will lead to incremental outputs.

Context features

Internal development is more suitable for large companies, since they have the means to set up large-scale in-house research activities and benefit from economies of scale and specialization (Andries and

Thorwarth, 2014). In addition, productivity effects of R&D activities increase with firm size in high-tech industries (Czarnitzki and Thorwarth, 2012).

As to the bio-pharmaceutical industry, the higher the R&D experience accumulated the higher the likelihood to employ in-house activities, since companies tend to behave according to routines developed in the past (Veugelers and Cassiman, 1999). Indeed, many traditional pharmaceutical companies have their own in-house capacities and normally cover the whole or most of the value chain from drug discovery/development up to production and marketing/sales (Festel *et al.*, 2010).

2.1.2 R&D outsourcing

Firms enter into agreements with third parties for the development of a new technology by outsourcing parts of the R&D activities (van de Vrande *et al.*, 2009). In outsourcing practices there is an undeniable one-way transfer of external knowledge inside the company (Teirlinck and Spithoven, 2008). Firms hire the services of an external organization to perform R&D in order to gain the advantage of tapping available and specialized knowledge (Santamaría *et al.*, 2010) that is neither available inside the firm nor can be produced internally in a cost-effective way (Martinez-Noya *et al.*, 2012; Teirlinck and Poelmans, 2012). The main difficulty for the outsourcer is to define its core business to allow the delegation of R&D efforts within peripheral knowledge fields to external parties (Ayerbe *et al.*, 2014), also constraining future learning and action, with core capabilities turning into core rigidities (Gadde, 2014). In addition, IP rights resulting from outsourced activities may be difficult to allocate (Andries and Thorwarth, 2014), with a high moral hazard danger that is caused by strong information asymmetries between suppliers and outsourcers (Howells *et al.*, 2012).

Knowledge management strategies

Companies mainly tend to involve partners that fall outside of their specialization, while developing their core products internally (Ciravegna and Maielli, 2011; Laursen and Salter, 2006). In this way, they access to a wide variety of technological capabilities not available in-house (Andries and Thorwarth, 2014; Chesbrough, 2003; Teirlinck and Spithoven, 2013) and focus their R&D efforts on a narrow range of technologies (Gadde, 2014). On one hand, specialization is one of the main effects of a company employing R&D outsourcing (Narula, 2001). On the other hand, with the externalization of R&D activities, firms aim at diversifying their businesses, by generating new knowledge also in areas that are less known to them and tapping into a broader set of technical fields (Amin and Cohendet, 2004; Quinn and Hilmer, 1994). As a consequence, through the utilization of R&D outsourcing organizations may both exploit existing technology capabilities - by identifying, searching and assimilating some information from the partner - and explore new technology learning opportunities by acquiring novel knowledge (Chuang *et al.*, 2015).

Type of innovation output

Since the supplier firm is able to take up only its part of the task, e.g. without coming into contact with any actual user of the product or service supplied, the most frequent type of innovation is incremental (Contractor and Lorange, 2002; Roy and Sivakumar, 2011). When product knowledge is widespread across the supply chain, the outsourcer firm engages external partners only to achieve incremental innovation within activities that fall outside of its specialization. This also implies that architectural innovations are difficult to obtain, since companies involve suppliers by partitioning the R&D tasks (Ciravegna and Maielli, 2011).

Context features

Innovation literature suggests that, even though R&D outsourcing cannot help small firms to overcome the disadvantages related to their limited stock of knowledge, it can help them to start risky research projects and profit more than large companies employing the same innovation strategy (Andries and Thorwarth, 2014). In addition, a smaller technological portfolio creates few opportunities for small and medium enterprises to employ other OI practices, thus orienting them to R&D outsourcing (Teirlinck and Spithoven, 2013).

Regarding specific behaviors within the bio-pharmaceutical industry, pharmaceutical companies look at R&D outsourcing as an effective method to capture capacity and expertise without investing much money in internal resources (Festel *et al.*, 2010). They absorb new knowledge within peripheral and non-core R&D activities from smaller but more specialized biotechnology firms (Howells *et al.*, 2012), even integrating external experts into internal R&D teams. Such specialized partners leave IP rights in the ownership of the pharmaceutical customer (Festel *et al.*, 2010).

2.1.3 R&D collaboration

Joint development is based on a deliberate two-way exchange of knowledge between the focal company and another party (Cappa *et al.*, 2016; Teirlinck and Spithoven, 2008). R&D collaboration gives access to both codified and tacit knowledge residing in partners, which cannot be easily contracted through market transactions (Spithoven *et al.*, 2010). Firms enter into cooperation with third parties for many reasons, e.g. because it can help companies to reduce uncertainty in terms of costs and risks (Das and Teng, 2000) and share the costs of exploiting a certain form of technology embodied into new products (Nakamura, 2003). Furthermore, it is a source of complementary expertise for companies operating in industries typified by technological complexity, where no single firm possesses all the knowledge, skills and techniques required (Hung and Tang, 2008). The issue of technological appropriability is relevant for this practice. Indeed, the availability of protective means is a determinant of the company's decision to engage in R&D collaboration, since firms fear knowledge leakages of unintended spillovers, and through IP rights may prevent legal risks and improve mutual trust (van Beers and Zand, 2014). Therefore, co-patenting is crucial for R&D alliances, since it protects firms from the exposition of critical resources and capabilities during the knowledge transfer, where economically valuable knowledge may be expropriated (Belderbos *et al.*, 2014).

Knowledge management strategies

When firms engage external entities in their R&D effort, they can focus on their core competencies and import other knowledge required from alliance partners (Zhang, 2016), extending their technological boundaries and achieving diversification (del Henar Alcalde Heras, 2014). R&D collaboration can be pursued to both exploit and explore technological domains. On one hand, exploitation alliances build on complementarities, enabling companies to benefit from the expertise of the partner and achieve efficient transactions and utilizations of resources, leveraging existing internal capabilities (Grant and Baden-Fuller, 2004; Yamakawa *et al.*, 2011). On the other hand, exploration partnerships enable the sharing and the learning of new technologies in order to discover new opportunities and develop novel technology through the acquisition of knowledge, skills and capabilities that are new to the firm, but necessary to adapt to the environment (Kale *et al.*, 2000;

Yamakawa *et al.*, 2011). Indeed, when companies seek new partners, they search for new learning opportunities, even accepting risks and uncertainty deriving from the collaboration, whereas alliances with existing partners bring to exploitative activities based on their prior experiences and existing trust-based relationships (Zhang, 2016). Consequently, exploration alliances are featured by long and unpredictable time horizons, with high variance returns, whilst exploitation ones involve shorter time horizons, with more predictable results and low variance benefits, and are focused on incremental technological improvements (Hoang and Rothaermel, 2010).

Type of innovation output

Joint development allows firms to access high-quality component technologies which complement their internal knowledge base, thus, enabling to build architectural innovations (Jaspers *et al.*, 2012; Sosa *et al.*, 2004), especially when products are featured by modular design since partners will find easier to develop shared knowledge (Bouncken *et al.*, 2015; Jacobides *et al.*, 2006; Lew *et al.*, 2016). The higher the complementarity and the difference between the knowledge resources, the higher the likelihood to achieve radical innovation, even though the development of breakthroughs is unpredictable, sporadic and difficult, since firms have to possess the capacity to efficiently absorb both the inflowing tacit and explicit knowledge (Oerlemans *et al.*, 2013).

Context features

Small companies seek for alliances with larger ones to obtain legitimacy and reputation, access complementary resources and, hence, exploit their current technological knowledge. Yet, small firms may suffer from partnerships with large companies, because the latter tend to outlearn and exploit them, which are often at a high risk of appropriation and vulnerable in contract design and outcome sharing due to their weak bargaining power (Yang *et al.*, 2014).

Regarding the bio-pharmaceutical industry - because of technological complexity and high cost of product innovation - for decades pharmaceutical firms have built their knowledge base by collaborating with universities, research centers and biotech companies, combining forces in the development of new drugs and compounds (Zhang, 2016). Such relationships are beneficial to both biotech and pharmaceutical firms. Indeed, biotech companies seek for R&D collaboration to attract capital and increase their chance of survival, whereas pharmaceutical firms need to keep their product lines broad and commission to a more agile innovator part of their R&D activities in order to focus on their market and commercial efforts (Dan and Zondag, 2016).

2.1.4 Purchase of external technology

The purchase of external technology consists of the acquisition of IP and non-patented inventions from other organizations (Acha, 2008). The role of technology acquisition can be regarded as the "buy" decision in the context of "make or buy" strategic choices, which respectively refer to conduct R&D in-house or commercially buy-in technology (Huang and Rice, 2009). Firms rely on acquisition when 1) they need quick access to a specific already-available technology, 2) the technology developed by other parties offers the best option or 3) they do not have enough knowledge and R&D expertise for developing it (Lee *et al.*, 2010). Therefore, such a practice gives the possibility to rapidly integrate external know-how (Schroll and Mild, 2011). The main issue that companies purchasing IP rights have to face is the reduced level of in-house capability in the long term (Huang and Rice, 2009), since R&D staff may realize that the technology introduced from outside is preferred to those developed from their own research efforts. This also implies the loss of absorptive capacity and the absence of know-how on the acquired technology, thus elongating the time required for a firm to commercialize it.

Knowledge management strategies

Messeni Petruzzelli *et al.* (2015) suggest that firms acquire patents with a narrow scope that provide specific solutions and contributions to solve rapidly and effectively ongoing issues, as well as detailed and defined problems. Such patented technologies are employed to support diversification strategies, by acquiring technology available on the market on which firms lack of experience. Hence, companies rely upon markets for technologies to explore new opportunities (Cesaroni, 2004).

Type of innovation output

Companies may both acquire incremental or radical technologies (Messeni Petruzzelli *et al.*, 2015). The first can contribute to solve ongoing issues and are sold at a lower price, thus increasing the chance of acquisition, being lower the risks of under-exploitation of the acquired invention (Adner and Levinthal, 2002). The second may offer a more significant technological contribution, but imply a considerable monetary effort and require complementary assets and capabilities for sustaining their translation into marketable and profitable solutions.

Context features

Markets for technologies constitute an important channel for small firms and individual inventors - who lack the capacity for large-scale development, production and marketing - to transfer their technologies to larger companies, which are able to commercialize the inventions (Galasso *et al.*, 2013). Yet, technology acquisition is attractive only if markets for technologies operate efficiently, i.e. firms may benefit from more strategic options (Cesaroni, 2004), as in the bio-pharmaceutical sector.

2.1.5 Mergers and acquisitions

M&As are useful to extend firms' resources by combining or acquiring new knowledge and capabilities from the target company. Indeed, such technological resources may either deviate from the firm's core abilities - and, thus, are difficult for firms' members to comprehend and subsequently apply - or remain in tacit form, therefore impeding the transmission and the codification of knowledge once it is identified (Lin *et al.*, 2015; Miller *et al.*, 2007). Efficiency gains are realized with the diffusion of know-how within the merged entity and the reallocation of technology to more efficient uses and synergies resulting from the M&A (Stiebale, 2013). Such a practice allows to achieve superior innovation performance by combining technological knowledge found in two companies (Ensign *et al.*, 2014). Actually, M&As most improve innovation performance when the technological knowledge is similar enough to facilitate learning, but different enough to provide both new opportunities and incentives to explore it (Grimpe and Hussinger, 2014; Makri *et al.*, 2010). However, the advantages of performing M&As may be balanced or outweighed by many issues, such as information asymmetries deriving from the challenging integration of the acquired firm's embedded knowledge, difficulties in synergy realization, cultural distances between companies and technical incompatibility (Bena and Li, 2014; Hoberg and Phillips, 2010; Stettner and Lavie, 2014).

Knowledge management strategies

Mergers between firms with similar product markets are associated with larger positive effects than diversifying mergers (Ahuja and Katila, 2001; Arvanitis and Stucki, 2014; Bena and Li, 2014; Fan and Goyal, 2006). Companies merge with partners with technological proximity or complementary assets that expand their range of products through new products introductions (Hoberg and Phillips, 2010). Accordingly, in acquisitions firms search targets with a medium overlap. When the overlap is low, the acquirer may be not able to recombine knowledge because it lacks of absorptive capacity, while high overlap implies fewer possibilities for recombination (Sears and Hoetker, 2014). In addition, when the overlap is high the acquiring firm's workers will find themselves in competition with the target's knowledge workers for limited resources. Hence, M&As can be employed to achieve multiple knowledge management strategies. Indeed, companies may both explore by acquiring new businesses beyond their industry boundaries and exploit by incorporating closely related businesses (Stettner and Lavie, 2014). However, exploring through M&As implies the management of unfamiliar knowledge, uncertainty and information asymmetries, with coordination difficulties. Therefore, efficiency gains may be achieved only with the exploitation of complementary assets (Dunlap *et al.*, 2016; Jovanovic and Braguinsky, 2004; Puranam *et al.*, 2009; Stiebale and Trax, 2011). Nevertheless, in technology-intensive sectors, companies use M&As within their innovation-driven industry to facilitate the exploration of new knowledge, bringing people with technological and managerial skills into the acquiring firm, especially in presence of target's technological uniqueness (Phene *et al.*, 2012).

Type of innovation output

The integration of different knowledge bases and the creation of common social context give rise to higher-order learning, but take time (Wubben *et al.*, 2015). Therefore, M&As are expected to produce radical innovations in the long run.

Context features

It is widely acknowledged that M&As are suitable for large companies, having the resources to better sustain and integrate the assets and the knowledge of the target firm (Arvanitis and Stucki, 2014; Khansa, 2015). Within the bio-pharmaceutical industry, M&As have been a frequent strategic response to the difficulties to refill the product pipelines and manage the growing complexity of R&D (Kirchhoff and Schiereck, 2011). Therefore, many pharmaceutical companies with weak research activities show a strong tendency towards acquisition to control the patent rights necessary for manufacturing various products (Marco and Rausser, 2008).

Table 1 synthesizes the aforementioned literature contributions by crossing innovation practices with the three areas under investigation.

	Internal development	**R&D outsourcing**	**R&D collaboration**	**Purchase of external technology**	**M&As**
knowledge management strategies	Clausen *et al.* (2013); De Clercq and Dimov (2008); Guadamillas *et al.* (2008); Katila and Ahuja (2002); Stolwijk *et al.* (2012); Xu *et al.* (2013)	Amin and Cohendet (2004); Andries and Thorwarth (2014); Chesbrough (2003); Chuang *et al.* (2015); Ciravegna and Maielli (2011); Gadde (2014); Laursen and Salter, (2006); Narula (2001); Quinn and Hilmer (1994); Teirlinck and Spithoven (2013)	del Henar Alcalde Heras (2014); Grant and Baden-Fuller (2004); Hoang and Rothaermel (2010); Kale *et al.* (2000); Yamakawa *et al.* (2011); Zhang (2016)	Cesaroni (2004); Messeni Petruzzelli *et al.* (2015)	Ahuja and Katila, (2001); Arvanitis and Stucki (2014); Bena and Li (2014); Dunlap *et al.* (2016); Fan and Goyal (2006); Hoberg and Phillips (2010); Jovanovic and Braguinsky (2004); Phene *et al.* (2012); Puranam *et al.* (2009); Sears and Hoetker (2014); Stettner and Lavie (2014); Stiebale and Trax (2011)
type of innovation output	Ayari (2013); Xu *et al.* (2013); Zhou and Wu (2010)	Ciravegna and Maielli (2011); Contractor and Lorange (2002); Roy and Sivakumar (2011)	Bouncken *et al.* (2015); Jacobides *et al.* (2006); Jaspers *et al.* (2012); Lew *et al.* (2016); Oerlemans *et al.* (2013); Sosa *et al.* (2004)	Adner and Levinthal (2002); Messeni Petruzzelli *et al.* (2015)	Wubben *et al.* (2015)
context features	Andries and Thorwarth (2014); Czarnitzki and Thorwarth (2012); Festel *et al.* (2010); Veugelers and Cassiman (1999)	Andries and Thorwarth (2014); Festel *et al.* (2010); Howells *et al.* (2012); Teirlinck and Spithoven (2013)	Dan and Zondag (2016); Yang *et al.* (2014); Zhang (2016)	Cesaroni (2004); Galasso *et al.* (2013)	Arvanitis and Stucki (2014); Khansa (2015); Kirchhoff and Schiereck (2011); Marco and Rausser (2008)

Table 1. Summary of theoretical contributions

3. Methodology

3.1 Patent data and sample

In this work, patent data are employed to build an integrated framework that investigates the relationship of previous and current innovation practices with knowledge management strategies and innovation output, also taking into account the role of patent portfolio size and industry as context features.

Patent documents allow to access a wide range of objective and standardized information (Belderbos *et al.*, 2010), continuously updated and covering decades of innovation activities (Griliches, 1990). Moreover, they exhibit a specific focus on the appropriability issue, capturing the proprietary and competitive dimension of technological change (Archibugi and Pianta, 1996), providing information about the ownership, the actors involved in the R&D effort and the eventual transfer of rights. Since patent statistics can be disaggregated into specific technological domains (Johnstone *et al.*, 2012), the analysis can be performed at the knowledge domain level. Previous literature pointed out that, within a single technological field, knowledge management strategies are mutually exclusive, whilst across different domains they are orthogonal; thus, different knowledge management strategies may coexist within the same firm (Gupta *et al.*, 2006).

The research was performed on 1,280 patents of a sample of 66 worldwide top R&D spending bio-pharmaceutical companies. The industry was selected since it is the first for R&D investments, uses patents as a means of appropriation of innovation (Pavitt, 1984) and shows a great propensity in OI adoption (Caputo *et al.*, 2016; Fetterhoff and Voelkel, 2006; Gassmann *et al.*, 2008; Kleyn *et al.*, 2007). The sampled firms were selected from *The EU Industrial R&D Investment Scoreboard*.

PATSTAT database was used as the source of patent data and a PHP based software was developed to support data collection. For each company, the list of subsidiaries was extracted from consolidated annual reports. Thereafter, the names of both the parent company and its subsidiaries were searched in the assignee field, i.e. firms are assumed to have a patent portfolio consisting of the current granted patents of both parent companies and subsidiaries. Only claimed priorities related to already granted technologies were examined, since these are considered to be the high-value applications (Johnstone *et al.*, 2012).

3.2 Current and previous innovation effort

The year of analysis is 2010. The current innovation effort corresponds to 1) patents filed in 2010 by the focal firm, and thereafter granted, and 2) technologies applied before 2010 by other companies, but owned by the focal firm from 2010, after the transfer of rights or the incorporation of the previous holder.

For the identification of the previous innovation effort (i.e. patented technologies within the stock of knowledge), it is necessary to enclose only the granted documents inside the patent portfolio with filing date within the previous seven years. Actually, in literature, a five-year time span was employed when scholars examine knowledge accumulated by firms. This is based on the assumption that knowledge evolves rapidly and companies lose most of their technical experience if they abandon a technological field for five years (Ahuja and Lampert, 2001; Argote, 1999; Fleming, 2001; Hall *et al.*, 2005; Leten *et al.*, 2007), with previously accumulated competencies resulting obsolete. Yet, by considering the specific features of the bio-pharmaceutical industry - where development times are longer - the time span was extended to seven years (Michelino *et al.*, 2015). Indeed, the development of a new drug can take more than five years: the lack of patent applications in a specific technological domain in the previous five years does not necessarily imply the loss of knowledge, since an invention may still be in the development phase. Moreover, we underline that, from a knowledge-based perspective, the number of patents effectively contributing to the stock of knowledge is lower than the real patent portfolio owned by the focal firm at the beginning of the year *t*, since the term of the legal patent protection is higher.

Thus, granted patents filed or acquired in 2010 were regarded as part of the current innovation effort, whereas the stock of knowledge is defined by all the documents filed and acquired from 2003 to 2009 and still owned by the focal firm in 2010: overall, 1,280 applications filed in 2010, and thereafter granted, and a stock of knowledge of 11,683 documents were found.

3.3 Innovation practices

For each patent in both the current innovation effort and the stock of knowledge, five categories were introduced according to the innovation practice adopted by the focal company to obtain it:

- patents developed with the use of only internal resources, without engaging external actors;

- patents developed with the use of external partners. When the focal firm is found as the only assignee, but some inventors do not belong to it, it is reasonable to suppose that a part of the development process was outsourced to third parties;
- co-patents, jointly developed by the focal company with one or more organizations/coassignees, after a collaborative perspective;
- patents developed by external organizations and subsequently transferred to the focal company by the means of a separate acquisition;
- patents developed by firms that were afterwards incorporated in the focal company through M&As.

In order to gauge such categories, different steps were followed. Before starting the analysis, any inventor disclosed in the assignee field was removed, so that only organizations were reported as assignees. After this intervention, all the patent documents disclosing the focal company in the assignee field were analyzed. If two or more assignees were uncovered in the assignee field, the patent was labelled as joint, according to many scholars (Agostini and Caviggioli, 2015; Al-Ashaab *et al.*, 2011; Kim and Song, 2007). Otherwise, the inventors' affiliation was detected: for each inventor, the list of all the distinct assignees disclosed in past patent applications reporting the focal person was extracted and it was assumed that the inventor belongs to the organization mostly occurring in such documents. Therefore, if all the inventors found in an application belong to the focal firm, the patent was labelled as internal, outsourced otherwise.

Furthermore, by examining the legal status of the patent documents, the transfers of patent rights toward the focal company were detected, and such patents were termed as purchased. Lastly, in order to detect patents deriving from M&As, each subsidiary belonging to the focal firm was further investigated to understand whether it was previously acquired/merged or not. For acquired and merged units the patent portfolio prior to the acquisition/merge date was identified and all the patents labelled as incorporated.

As to current innovation effort, five dummy variables are used to define the adoption of each practice - *internal development*, *R&D outsourcing*, *R&D collaboration*, *purchase of external technology* and

M&As - whereas as for the stock of knowledge, the shares of adoption of practices are calculated. As a matter of fact, while each patent can be obtained by the use of only one practice, the stock of knowledge - being made up of more patents - was built by the implementation of a mix of practices.

3.4 Knowledge management strategies

Since knowledge management strategies are investigated at the knowledge domain level, it is necessary to operationalize technological fields. Knowledge areas are defined through Cooperative Patent Classification (CPC) codes: each CPC code consists of a hierarchical symbol denoting section, class, sub-class, main group and sub-group. By considering the entire code, innovation can be studied at the component level, or rather at the maximum level of disaggregation. Yet, when knowledge domains are investigated, the fourth-level code (i.e. until the main group) should be used. Actually, different products or components can be developed within the same knowledge domain, since competencies required in the innovation process may be almost the same.

In order to examine exploitation vs. exploration strategy at the knowledge domain level, literature suggests the following operationalization (Belderbos *et al.*, 2010):

- a knowledge domain is labelled as exploitative if the company filed patents in such technological field in the past five years, explorative otherwise;
- the technological field keeps its explorative status for a period of three consecutive years.

Yet, as also stated before (§ 3.2), considering only five years for determining the stock of knowledge of bio-pharmaceutical companies is not enough. In a similar way, the time needed by firms to master a technology before it becomes really exploitable can be longer than three years in this sector. Actually, the bio-pharmaceutical industry is featured by innovation activities deriving from basic search: the integral nature of the products forces companies to spend more time to make a technological field exploitable. For this reason, not only the investigated period was extended to seven years, but also the exploration time span was enlarged to four years (Michelino *et al*., 2015).

Therefore, each CPC code disclosed in a patent document filed or acquired in 2010 can be regarded as:

- exploitative, if at least a patent application within the stock of knowledge reporting the same field was deposited from 2003 to 2006, having certainly trespassed the explorative phase, which takes four years. For instance, if a firm starts to explore a new knowledge field in 2005, it will conclude the exploration phase after four years, i.e. in 2008. This implies that in 2010 the knowledge management strategy that can be achieved in such a field is exploitation;
- explorative otherwise. This may occur both if the knowledge field has been previously explored, but it is still in explorative phase in 2010 or when a novel technological area has been reported for the first time in a patent filed in 2010.

Once evaluated the exploitation vs. exploration strategy pursued within each knowledge domain involved in each patent, the ratio of CPC codes in exploration phase on the total number of codes in the document is calculated. Therefore, the percentage variable *exploration* is defined, ranging from 0% - if all CPC codes declared in the document are in the exploitation phase - to 100%, if all of them are explorative.

As for specialization vs. diversification strategy, although scholars take into account the frequency with which companies operate within a specific technological field, no contribution employing patent data was uncovered about the weight of such field on the overall innovation strategy carried out by firms. As a matter of fact, not all the domains are equally relevant for the company: only some knowledge areas are strongly stressed and mostly contribute to the development of the core technology of current business activities. Thus, a different technological specialization may be detected in each technological field. All in all, companies concentrating their R&D efforts on few relevant fields are carrying out a specialization strategy. On the contrary, working on a larger body of knowledge can be seen as a proxy of diversification strategies. In literature, a similar concept is expressed by the so called technological familiarity: a component is familiar to the firm when it has been recently and frequently used (Arts and Veugelers, 2012; Fleming, 2001).

For each knowledge domain, specialization is estimated by dividing the number of patents disclosing the CPC code by the total amount of patent applications within the stock of knowledge. Technological *specialization* of a patent is then calculated as the average value of the specialization of the different CPC codes it declares: it is a percentage variable ranging from 0% - if no CPC code declared in the document was found in any patent in the stock of knowledge - to 100%, if all the technological fields in the focal patent are disclosed in all the documents of the stock of knowledge.

3.5 Type of innovation output

In order to gauge the type of innovation, the novelty level is assessed through backward citations while the impact on the linkages between components is evaluated considering the novelty of the combination of technological fields disclosed in patent documents (Figure 2).

On one side, patents without backward citations to prior technical art can be considered pioneering (Ahuja and Lampert, 2001; Kaplan and Vakili, 2012; Shane, 2001), whereas the existence of backward citations is a proxy of innovations based on the reinforcement of core concepts (Hall *et al.*, 2001; Jaffe *et al.*, 1993). On the other side, the entire CPC code was used to identify the components, so that their combination constitutes an architecture (Dahlin and Behrens, 2005; Fleming, 2001). In order to understand whether the combination is "new to the world", it was verified whether the same combination occurred in the previous seven years in any patent applications recorded in PATSTAT. Only when no identical combination was detected, the focal combination is regarded as new (i.e. the architecture is new).

Figure 2. Types of innovation (adapted from Henderson and Clark, 1990)

		Core concepts	
		Presence of backward citations	*Lack of backward citations*
Linkages between core concepts and components	*New combination of CPC codes*	Architectural innovation	Radical innovation
	Existing combination of CPC codes	Incremental innovation	Modular innovation

Each document in the current innovation effort is thus defined as:

- *incremental*, if backward citations are present and no new combination of components is found;
- *architectural*, when there is a new combination of technological components and references to prior art were discovered;
- *modular*, if it does not refer to prior knowledge but no new combination is detected;
- *radical*, when it is featured by technological originality and generates a new combination of technological components,

and four dummies are identified accordingly.

Apart from the definition of the variables, it is possible to give a specific interpretation for the types of innovation in the investigated sector, starting from the "new drug classification" of the Food and Drug Administration (FDA). Actually, FDA labels new drugs at the time of approval along two dimensions: therapeutic potential and chemical composition. On the basis of their therapeutic potential, drugs are classified into two classes: "priority review" drugs - which represent a therapeutic advance over available therapy - and "standard review" drugs, which have therapeutic qualities similar to those of an already marketed drug. Regarding chemical composition, a distinction is made between new molecular entities "NMEs" and "old" drugs. The former are the most technologically advanced products based on an active ingredient that has never been marketed before. The latter are either new formulations or have new indications of use. Conceptually speaking, such two dimensions can be traced to the types of innovation (Figure 3). Specifically, the FDA's therapeutic potential corresponds to the "core concepts" dimension, while the chemical composition corresponds to the "linkages between components" (i.e. a new chemical composition can be seen as a new architecture). Accordingly, a radical innovation involves products with a new composition, representing an advance over available therapy. A modular innovation provides significantly greater benefits, but the composition is not considerably new. An architectural innovation uses a substantially different composition if compared to existing products but appears to have therapeutic qualities similar to those of an already marketed drug. At last, an incremental innovation consists only on the improvement of a specific drug in terms of limited advancements in safety and efficacy.

Figure 3. Types of innovation in the bio-pharmaceutical industry

		Therapeutic potential	
		Standard review	*Priority review*
Chemical composition / molecular entity	*New (NME)*	Architectural innovation	Radical innovation
	Updated	Incremental innovation	Modular innovation

3.6 Context features

In order to better understand the relationships under investigation, two controls were employed: segment and patent portfolio size.

Within the investigated industry, two segments are distinguished according to the four-digit ICB code - biotechnological and pharmaceutical - and the dummy variable *pharma* is defined.

As of *patent portfolio size*, we calculated the number of patents effectively contributing to the stock of knowledge (i.e. developed or acquired with innovation efforts from 2003 to 2009) instead of considering the real portfolio owned by the focal firm at the beginning of 2010, which includes also patents filed before 2003 and still active in 2010. This enables to better identify the potential innovative capacity of the focal firm and understand which differences typify small and large portfolio holders.

4. Data analysis and results

Table 2 displays descriptive statistics for the sample. As expected, pharmaceutical firms exhibit a larger patent productivity and a higher number of patented technologies within their stock of knowledge.

segment	**# firms**	**# patents in current innovation effort**	**# patents in stock of knowledge**	**avg. # patents per firm / year[1]**
biotech	22	153	695	5
pharma	44	1,127	10,988	34
total	66	1,280	11,683	25

Table 2. Descriptive statistics

Table 3 reports the composition of the stock of knowledge and the current innovation practices. More than one half of the knowledge recovered in current innovation activities derives from previous innovation efforts carried out through internal development. Also R&D outsourcing played a key role in generating knowledge useful for further efforts, both for pharmaceutical companies - which have acquired new knowledge from their partners - and for biotech firms, which have accumulated experience that enhances the value of their know-how (Howells *et al.*, 2012). In addition, pharmaceutical firms are featured by higher shares of knowledge acquired through purchasing and incorporation, confirming that in this segment markets for technologies are widely employed (Cesaroni, 2004). Indeed, many pharmaceutical companies with weak research activities have assimilated knowledge by controlling the patent rights necessary for producing various products,

[1] The value is calculated as the sum of the number of patents in current innovation effort (year 2010) and the number of patents within the stock of knowledge (years 2003-2009), divided by 8

avoiding overlapping or mutually blocking property rights (Marco and Rausser, 2008). On the contrary, in the biotech segment, R&D outsourcing and collaboration have been largely adopted. Such activities involve both other bio-pharmaceutical companies and scientific partners, allowing the generation and the future recombination of knowledge, mainly when biotech researchers have been integrated in partners' R&D teams (Bahemia and Squire, 2010; Dan and Zondag, 2016; Parida *et al.*, 2012; Su *et al.*, 2009; Teirlinck and Poelmans, 2012).

Regarding the current innovation practices adopted by bio-pharmaceutical companies, we uncovered a growth in the acquisition of already patented technologies and the incorporation of knowledge-intensive firms, if compared with previous behaviors. Indeed, the acquisition of external patents is viable only when the focal firm has the maturity and the resources to achieve economies of scale and scope and market exploitation in order to increase new drug approvals after the incorporation (Banerjee and Nayak, 2015).

segment	**Previous innovation practices - stock of knowledge composition**					
	internal development	*R&D outsourcing*	*R&D collaboration*	*purchase of external tech.*	*M&As*	*total*
biotech	47.47%	30.51%	12.38%	4.73%	4.91%	100%
pharma	56.98%	21.76%	5.18%	8.96%	7.13%	100%
total	53.81%	24.68%	7.58%	7.55%	6.39%	100%
segment	**Current innovation practices**					
	internal development	*R&D outsourcing*	*R&D collaboration*	*purchase of external tech.*	*M&As*	*total*
biotech	29.41%	20.92%	4.58%	16.34%	28.76%	100%
pharma	53.68%	9.67%	2.75%	15.71%	18.19%	100%
total	50.78%	11.02%	2.97%	15.78%	19.45%	100%

Table 3. Stock of knowledge composition and current innovation practices by segment

As shown in Table 4, biotech companies are more prone to exploration, since their R&D efforts are concentrated on the discovery of novel compounds and the manipulation of microorganisms or biological substances. On the contrary, pharmaceutical firms are featured by higher shares of exploitation activities, since they are more market-oriented. Even though specialization is quite similar, the value resulting for biotech firms can be regarded as a mean between low levels of familiarity in new technological fields in the exploration phase and high levels within their core technologies.

As to the type of innovation, incremental and modular innovation is mostly produced by biotech firms, i.e. they work on the update of already existing compositions, whereas architectural innovation is obtained by pharmaceutical companies developing new compositions on already marketed therapies. No difference between segments is discovered for radical innovation.

segment	KM strategies		Type of innovation output				
	exploration	*specialization*	*incremental innovation*	*architectural innovation*	*modular innovation*	*radical innovation*	*total*
biotech	60.52%	9.36%	40.52%	32.68%	16.99%	9.80%	100%
pharma	20.64%	11.23%	27.42%	53.33%	9.14%	10.12%	100%
total	25.40%	11.01%	28.98%	50.86%	10.08%	10.08%	100%

Table 4. Knowledge management (KM) strategies and type of innovation output by segment

As to what follows, each research question is answered using Spearman's correlation analysis.

4.1 How does the previous recourse to innovation practices influence the current practice selection?

The prior recourse to specific innovation practices affects the current practice selection (Table 5). Specifically, the adoption of innovation practices is positively correlated with the share of previous efforts carried out through similar activities. After an OI perspective, this means that companies historically employing an innovation practice are likely to use the same practice to absorb external knowledge in new processes, showing a path-dependent behavior. This is true for all open practices but R&D collaboration, where the relationship is not significant, meaning that the choices of further developing technologies jointly with third parties are independent from past collaboration. Actually, the technological alliances can differ in forms, motivations, types of partners and phases involved, so that some partnerships survive whereas others are abandoned. In particular, a positive relation is found between past recourse to collaboration and current M&As. Indeed, in this sector pharmaceutical companies often incorporate biotech firms after having collaborated with them for a certain period (Al-Laham *et al.*, 2010).

Moreover, the higher the share of previous internal development, the lower the odds to further adopt OI in all forms but M&As. In addition, when companies have mostly acquired external knowledge through the purchase of already-patented technologies, the likelihood to employ other OI practices in new innovation efforts is lower. Actually, the purchase of technology is the only open activity in which third parties do not enter in direct contact with the technological knowledge of the acquirer. Therefore, this results in the acquisition of external technologies without sharing the internal knowledge occurring in the other OI practices. On the contrary, previous M&As favor the future employment of R&D outsourcing and hinder the purchase of patented technologies.

		Current innovation practices				
		internal development	*R&D outsourcing*	*R&D collaboration*	*purchase of external tech.*	*M&As*
Previous innovation practices	*internal development*	0.163**	-0.070*	-0.066*	-0.230**	0.090**
	R&D outsourcing	0.007	0.178**	0.037	-0.220**	0.038
	R&D collaboration	-0.193**	0.026	-0.043	-0.055*	0.292**
	purchase of external tech.	0.031	-0.179**	-0.061*	0.397**	-0.237**
	M&As	-0.189**	0.109**	-0.017	-0.086**	0.239**

* correlation is significant at 0.050 level; ** correlation is significant at 0.010 level

Table 5. Correlations between previous and current innovation practices

4.2 Which current knowledge management strategy results from past OI adoption? Is the selection of a current innovation practice linked to such strategy?

Table 6 exhibits the relationship between innovation practices and knowledge management strategies, enabling to answer the second research question.

Exploration is positively associated with higher shares of knowledge accumulation through M&As, R&D outsourcing and collaboration (Andries and Thorwarth, 2014; Stettner and Lavie, 2014; Yamakawa *et al.*, 2011), whilst exploitation is possible thanks to previous efforts in purchase of external technologies. Moreover, companies achieve a higher specialization when they have accumulated knowledge through internal development, whereas previous R&D outsourcing and M&As lead to diversification. Such results are consistent with previous research (Arvanitis and Stucki, 2014; Hoberg and Phillips, 2010; Teirlinck and Spithoven, 2013).

Regarding the current innovation practice selection, exploration is further supported through joint development and incorporation of firms. Conversely, when companies have to keep exploitation strategies they adopt internal development or acquire already known technologies. Companies highly specialized on core technological domains keep their closed approach in current efforts, whereas M&As are a choice for further diversifying their technological portfolio.

		Exploration	Specialization
Previous innovation practices	*internal development*	-0.022	0.071*
	R&D outsourcing	0.222**	-0.297**
	R&D collaboration	0.155**	-0.016
	purchase of external tech.	-0.210**	-0.012
	M&As	0.077**	-0.126**
Current innovation practices	*internal development*	-0.132**	0.154**
	R&D outsourcing	0.038	-0.028
	R&D collaboration	0.118**	-0.054
	purchase of external tech.	-0.064*	0.003
	M&As	0.145**	-0.153**

* correlation is significant at 0.050 level; ** correlation is significant at 0.010 level

Table 6. Correlations between innovation practices and knowledge management strategies

4.3 Is the innovation output related to previous and current innovation practices?

A positive linkage of the share of previous R&D outsourcing activities with incremental innovation was uncovered (Table 7). In addition, companies that have mostly acquired external patented technologies are likely to achieve architectural and radical innovation in current activities. Actually, the knowledge absorption obtained through the transfer of IP rights allows bio-pharmaceutical firms to obtain new molecular entities with varying degrees of therapeutic potential.

As for current innovation efforts aiming at accumulating new knowledge, firms acquiring other companies, mainly incorporate incremental innovations. Such a result has a double explanation: from one side, incremental innovation is generally more represented in the patent portfolio of any company; from the other side, within M&As the acquiring company is interested not only in the patented technologies of the target firm, but also in its tacit knowledge residing in R&D workers. Conversely, companies purchasing external inventions are interested in the modular innovation innate in the patented technology. Hence, they acquire drugs that represent an advance over available therapies without any significant novelty in terms of chemical composition. The modular innovation can be achieved also by engaging third parties in the outsourcing of R&D services. Finally, architectural innovation is obtained through internal development, since it requires the possession of the overall architectural knowledge necessary to develop new drugs.

		Incremental innovation	Architectural innovation	Modular innovation	Radical innovation
Previous innovation practices	*internal development*	0.024	0.026	-0.037	-0.041
	R&D outsourcing	0.064*	-0.008	0.001	-0.085**
	R&D collaboration	0.043	0.008	0.000	-0.047
	purchase of external tech.	-0.094**	0.060*	-0.052	0.095**
	M&As	0.017	0.017	0.018	-0.072*
Current innovation practices	*internal development*	-0.025	0.067*	-0.112**	0.039
	R&D outsourcing	0.023	-0.029	0.065*	-0.051
	R&D collaboration	-0.010	-0.012	0.048	-0.013
	purchase of external tech.	-0.050	-0.037	0.090**	0.047
	M&As	0.065*	-0.022	-0.014	-0.047

* correlation is significant at 0.050 level; ** correlation is significant at 0.010 level

Table 7. Correlations between innovation practices and type of innovation output

4.4 How are the size of patent portfolio and the belongingness to a specific segment related to innovation practices?

Table 8 reports the relationship between innovation practices and context features, allowing to answer the fourth research question. Companies that strongly purchased IP rights have built wider stocks of knowledge. Large portfolio holders tend to continue such a practice (Galasso *et al.*, 2013) or internally develop new technologies. Conversely, small portfolio holders tend to employ M&As, R&D outsourcing and collaboration to carry out current innovation efforts (Andries and Thorwarth, 2014; Banerjee and Nayak, 2015; Yang *et al.*, 2014).

As to segments, pharmaceutical companies mostly tend to accumulate knowledge through internal development and purchase of external technologies, whereas the weight of R&D outsourcing, R&D collaboration and M&As on the building of biotech firms' stock of knowledge is higher. Some of such practices are further employed within current activities, with the pharmaceutical sector exhibiting a positive correlation with internal development and the biotech one with outsourcing and incorporation.

		Patent portfolio size	Pharma
Previous innovation practices	*internal development*	-0.141**	0.239**
	R&D outsourcing	-0.313**	-0.284**
	R&D collaboration	-0.344**	-0.293**
	purchase of external tech.	0.688**	0.220**
	M&As	-0.187**	-0.097**
Current innovation practices	*internal development*	0.203**	0.157**
	R&D outsourcing	-0.107**	-0.117**
	R&D collaboration	-0.098**	-0.035
	purchase of external tech.	0.223**	-0.006
	M&As	-0.336**	-0.087**

* correlation is significant at 0.050 level; ** correlation is significant at 0.010 level

Table 8. Correlations between innovation practices and context features

5. Conclusions

The paper analyses patent data in order to understand how bio-pharmaceutical companies sustain knowledge management strategies and obtain specific innovation outputs by carrying out different innovation practices. Hence, the relationship between innovation practices and knowledge management strategies was examined, also investigating the connection with the potential innovativeness of the patented technologies. In addition to the closed approach, four OI practices were considered: outsourcing of R&D activities, R&D collaboration, purchase of external technology and incorporation of knowledge through M&As. A patent-based framework, which considers both the innovation effort in 2010 and the stock of knowledge accumulated from 2003 to 2009, was tested on a sample of 1,280 patents granted to 66 top R&D spending bio-pharmaceutical companies.

Results from the exploratory analysis on the bio-pharmaceutical industry show that OI practices cover about one-half of the total number of patents within firms' stock of knowledge, with acquisition activities featuring pharmaceutical companies and outsourcing and joint development characterizing biotech ones. Moreover, on average, exploration covers about one-fourth of the R&D efforts carried out by firms, with biotech companies more devoted to such strategy. The previous recourse to specific innovation practices influences the current practice selection. Specifically, companies historically employing an OI practice are likely to use the same practice to absorb external knowledge in new processes. Among the OI practices adopted to pursue exploration, companies mostly rely on R&D collaboration, outsourcing and incorporation, while the purchase of IP rights is useful to exploit external knowledge. Additionally, diversification strategies have been carried out through R&D outsourcing and M&As. As to the potential level of innovativeness of patented technologies, previous R&D outsourcing enables further incremental innovation, whereas past purchase of patents increases the likelihood to achieve architectural and radical innovation in current activities. Among current innovation practices, M&As allow firms to embed incremental innovation, whereas modular innovation is acquired through the transfer of IP rights.

5.1 Contributions

From a theoretical point of view, the work contributes to the current debate considering the effect of a combination of innovation practices on knowledge management strategies and type of innovation output, with a particular focus on OI activities. Since knowledge management is at the basis of the OI paradigm, focusing on it allows to understand the reasons why firms use each OI practice and are interested in the ownership of specific patents. By linking IP, OI adoption and knowledge management, the study suggests a deepening of the mutual effects, e.g. understanding whether the need to explore new technological areas occurs in the use of specific practices. Additionally, our results confirm that it is necessary to separate between the impact of previous and current innovation practices, since knowledge evolves and firms adequate their strategies to new objectives, even though previous adoption strongly influences current choices.

In technical terms, the work recommends the use of patent data to gauge many key elements for knowledge and innovation management, such as stock of knowledge, exploitation vs. exploration, specialization vs. diversification, type of innovation and practices. Regarding OI practices, the paper demonstrates the explicative power of patent statistics to assess openness adoption. Through our methodology, it is possible to investigate the use of specific innovation practices at the knowledge domain level.

As the paper demonstrates, openness is crucial for companies, specifically in R&D intense industries. Therefore, this study suggests the development of a methodology for supporting managers' decisions regarding the tension between IP management and OI adoption. Since the framework employs publicly available, objective and standardized data, firms can operatively access to such information from free on-line sources (e.g., Espacenet by EPO). In this way, decision-makers may assess the status of firms' OI adoption, also performing the benchmark with competitors and R&D partners. Given the high computational effort required for applying the methodology, we are planning to give access to the PHP based software specifically developed for this study. Actually, we are developing a more user-friendly interface to support organizations in extracting and analyzing patent data.

Moreover, the methodology may be applied for both industry- and firm-level analysis, providing business analysts a practical instrument for detecting companies' innovation practices and investigating the impact of specific behaviors on the potential level of innovativeness.

5.2 Limitations and future research

Some limitations can be outlined for the work. Firstly, the use of patents for examining joint development could be questionable, since not all R&D collaboration activities will be captured by co-patents (Hagedoorn *et al.*, 2003). This means that the amount of collaborative R&D efforts detected should be viewed as a conservative estimation of the total number of partnerships taking place, with actual levels of R&D collaboration being higher (Belderbos *et al.*, 2010). Secondly, the research is confined to bio-pharmaceutical companies; thus, the results are affected by industry-specific features and cannot be generalized. Thirdly, not all technological inventions are patented and patent propensities vary across firms and industries, even though in sectors characterized by intense R&D efforts patents are used as a means of appropriation of innovation (Pavitt, 1984). This leads to the consideration that our framework may not be useful for examining innovation in all sectors.

Future research will be addressed to examine other industries - such as technology hardware and automotive - since the analysis of new sectors is required in order to better distinguish between generalizable and industry-specific findings. Furthermore, by considering current innovation efforts for consecutive years, a deepen analysis on how companies modify their open behavior and recombine, integrate and expand their stock of knowledge over time will be performed. Moreover, it is possible to investigate innovation performance within the framework by adding patent-based measures gauging market and technological quality, such as forward citations, patent family size and fee payment status.

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