Open innovation for start-ups

A patent-based analysis of bio-pharmaceutical firms at the knowledge domain level

Abstract

Purpose - The aim of this paper is to provide a methodological framework for evaluating the impact of open innovation adoption on start-up ventures at the knowledge domain level, taking into account the technological specialization and the quality of innovation output.

Design/methodology/approach - The framework employs patent data for investigating joint development activities between start-ups and partners, thus defining an openness degree of R&D. The partner typology and the levels of specialization on the knowledge fields affected by each invention are investigated. The methodology is tested on a sample of bio-pharmaceutical start-ups.

Findings - On average, the openness level in the start-up phase is higher than in the consolidation one. Furthermore, the higher the level of openness during the start-up phase, the higher the propensity to collaborate with scientific organizations. And yet, the occurrence of R&D collaborations is positively correlated to the level of specialization on the knowledge fields involved in joint development activities.

Practical implications - Open innovation strategies are valuable for start-ups, particularly in the bio-pharmaceutical industry, since their adoption improves the quality of innovation output. This is particularly true when R&D collaborations are established with scientific entities.

Originality/value - This work investigates the impact of open innovation adoption on start-up ventures at the knowledge domain level, by employing objective and standardized data. Hence, the methodology can be considered as a first step in developing a useful tool for managers, researchers and business analysts.

Keywords - Open innovation, Start-ups, R&D collaboration, Knowledge domains, Patents, Innovation quality.

Paper type - Research paper.

Introduction

Start-ups are an important engine of growth for the worldwide economy, create new jobs and bring innovative products and services to the market, as well as new technologies. An extensive body of literature has examined and tried to explain the determinants for the success of start-up ventures (Robinson, 1990; Baum *et al.*, 2000; Heirman and Clarysse, 2007; Neyens *et al.*, 2010; Hormiga *et al.*, 2011; Zalesky, 2011). Start-ups are new enterprises in the first stage of their operations, working to solve a problem, where the solution is not obvious and the success is not guaranteed. They are organizations designed to search for a repeatable and scalable business model (Blank, 2010), whose business is typically technology-oriented and has high growth potential. There's no universally acknowledged definition, but most business analysts argue that the start-up is determined by its age, growth, revenue, profitability or stability. The start-up period often ends with an acquisition by a larger company or a growth in terms of revenues and number of employees, i.e. when it becomes profitable. After our perspective, the start-up phase ends with the building of the first stock of knowledge, which is necessary for the existence and the survival of the business and will serve as the basis for future developments.

Despite their innate innovation potential, many new ventures fail because they lack of complementary assets, such as market access, distribution infrastructures, operational expertise, strategic and technical know-how, funds for supporting R&D and development processes (Baum *et al.*, 2000; Alvarez and Barney, 2001; Heirman and Clarysse, 2007). Therefore, start-ups may overcome their business limits by forming relationships with external partners and organizations. Such relationships improve the quality of start-ups' products and services and positively affect their business models. In his pioneering work on open innovation (OI), Chesbrough (2003) suggested that companies might improve their innovation and financial performances by both internally using external technologies and externally exploiting internal knowledge. Hence, in contrast to the vertically integrated model of innovation (Chandler, 1990), the OI paradigm is typified by its porous innovation process and the strong interaction between the company and its environment.

OI literature strongly stressed the impact of open strategies on consolidated businesses and large enterprises, excluding from the mainstream discussion specific organizations, such as SMEs and start-ups (exceptions are, e.g., Grimaldi *et al.*, 2013; Perez *et al.*, 2013; Brunswicker and Vanhaverbeke, 2015). More specifically - regarding start-up ventures - there is a lack of both theoretical models and empirical findings to understand the implications of OI processes activation on the overall innovation strategy, quality of innovation output and stock of knowledge.

This work aims at filling such gap by focusing on R&D collaborations to examine how OI affects start-ups at the knowledge domain level, taking into account the technological specialization and the quality of innovation output. While most OI contributions analyze the effect of OI adoption at the industry- or firm-level, we take into account the different behaviors within each technological field in which new technologies are arising. In this sense, our approach is particularly fitting in the case of start-ups, where it is possible to study how the stock of knowledge has been built and its evolution, also evaluating how much OI contributes to its development.

Specifically, the paper intends to perform an explorative analysis on the role of OI collaborations in innovation strategies of start-up companies, using patent data. In particular, it considers: 1) the openness degree, 2) the partner typology, 3) the level of specialization on the technological domains jointly explored during the start-up phase, 4) the level of specialization on the same fields after the start-up phase and 5) the quality of innovation output (Figure 1). The contribution of OI to the creation and the development of companies' stock of knowledge is determined. It is investigated whether OI collaborations carried out during the start-up phase are effectively affecting the future innovation performances of firms and if knowledge fields involved in early partnerships are exploited in future inventions.

Insert Figure 1 here

Figure 1. The framework.

In what follows, after a literature review on stock of knowledge, start-ups and OI collaboration, the methodological framework is delineated. Then, it is applied to analyze the start-up phase of 62 successful bio-pharmaceutical companies established from 1990 to 2001 and still operating in 2011, which have been classified among top R&D spending firms by *The EU Industrial R&D Investment Scoreboard*. Results are presented and discussions close the work.

Literature review

Stock of knowledge and OI collaboration

The technology of a firm is the result of its accumulated experience in design, production and problem solving. Companies' existing body of knowledge is history dependent and affects their future technological development (Hung and Tang, 2008). Indeed, a firm's ability to develop technologies and products is strongly affected by its stock of knowledge, expertise and technology from previous R&D activities (Arts, 2012). Specifically, firms try to recombine and integrate capabilities belonging to different knowledge domains. R&D activities can be seen as investment processes whose output is the firm's knowledge stock. This asset positively contributes to the companies' future financial performance and, then, to their market value (Hall *et al.*, 2005). Actually, the higher the level of innovativeness of inventions, the higher the expected technological and financial impact. The capability of properly managing the stock of knowledge is particularly strategic in R&D intense industries, where companies are forced to operate on a wide range of knowledge fields and dynamically expand their knowledge stock over time (Miller, 2004).

Companies can build their stock of knowledge not only through internal efforts, but also opening up their R&D processes. The OI paradigm (Chesbrough, 2003) is conceived on the idea that when the innovation funnel boundaries become permeable, firms are able to explore and exploit technologies by sharing their innovative processes with third parties. Therefore, OI constitutes a new opportunity for a firm's strategy to profit from innovation (Chesbrough *et al.*, 2006), suggesting that companies should use inflows and outflows of knowledge to foster internal R&D, and to expand markets for external use of innovation, respectively (Chesbrough, 2006). OI has become one of the most addressed research topics in innovation studies, and many scholars investigated the impact of such strategy on companies' stock of knowledge (Belderbos *et al.*, 2004; Prahalad and Ramaswamy, 2004; Perez *et al.*, 2013). In particular, when internalization strategies are pursued, external know-how can be acquired from third parties or shared within collaborative development processes (Schroll and Mild, 2011). Different business models can emerge from OI adoption, ranging from R&D collaborations to the incorporation of knowledge-intensive firms (Michelino *et al.*, 2015a).

This work focuses on the collaborative dimension of OI, by investigating the impact of R&D collaboration activities on start-ups' stock of knowledge. Indeed, for firms operating in dynamic environments - featured by rapid development and increasing knowledge complexity - it is very difficult to contain and capitalize on all relevant knowledge. Therefore, companies specialize and employ R&D collaborations to complement their knowledge (Perez *et al.*, 2013). This leads to the creation of complex networks of relationships with customers, suppliers and other industrial and scientific organizations, in which firms team up to generate new products and technologies (Dittrich and Duysters, 2007). Indeed, companies may potentially learn from such interactions, which open up opportunities for joint value creation and innovation (Prahalad and Ramaswamy, 2004). Therefore, the joint development can be a source of competitive advantage, since it gives access to external sources and information (Belderbos *et al.*, 2004). For these reasons, R&D collaborations and strategic technological alliances are increasingly part of companies' innovation model (Archibugi and Pianta, 1996). However, many difficulties in managing the complexity of such relationships occur; therefore, the share of alliance failures is significant (Patzelt and Shepherd, 2008). Thus, a key determinant for a successful collaboration is absorptive capacity, which is "the ability of a firm to recognize the value of new, external information, assimilate, and apply it to commercial ends" (Cohen and Levinthal, 1990).

In summary, the reasons why companies enter into R&D collaboration are various. First, it can help firms reduce uncertainty in terms of costs and risks (Tyler and Steensma, 1995; Das and Teng, 2000), share the costs of exploiting a certain form of technology embodied into new products (Nakamura, 2003), share risks and costs of innovation under growing technological complexity (Hung and Tang, 2008). Second, it is required to shorten innovation cycles (Pisano, 1990) and enter the market first and win. Third, it is necessary to define regulations and industry standards more effectively (Benfratello and Sembenelli, 2002). In addition, R&D collaboration gives access to new knowledge bases, ideas and possibilities through the interaction with partners (Granovetter, 1973) and 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 (Powell *et al.*, 1996; Rausser, 1999).

Many scholars studied the determinants of partners' selection and defined different factors that affect the collaboration performance. Some examples are: complementary skills and capabilities, cooperative culture, compatible goals, technological expertise, marketing system and knowledge, competitive strength, production efficiency, positive prior experience, labor negotiation experience, intangible assets, prior ties with universities (Brouthers *et al.*, 1995; Rausser, 1999; Nielsen, 2003; Wu *et al.*, 2009).

Start-ups and OI collaboration

Newly founded firms develop and market new products or services based on a proprietary technology or skill (Heirman and Clarysse, 2007). They contribute to the worldwide economy in terms of exports, employment, R&D, and innovation (Schumpeter, 1934; Christensen, 1997). For such new ventures, time to market is a crucial factor (Schoonhoven *et al.*, 1990), as well as the innovation speed. As a matter of fact, in order to increase the likelihood of survival, research-based start-ups need to gain as early as possible: a) cash flow for achieving the financial independence, b) external visibility and legitimacy, and c) market share (Heirman and Clarysse, 2007).

New business start-ups are typically small entities with few personnel and financial resources. Because of their smallness, such firms often lack the necessary physical, human, and financial assets to bring a new technology or product to the market (Alvarez and Barney, 2001). They also need to face the challenge of creating a new organizational structure and defining roles, tasks and operative processes. Such challenge often causes inefficiency and conflict among organizational members, additionally putting start-ups in a disadvantageous position compared to successful companies, which employ consolidated business practices (Gruber and Henkel, 2004). Similarly, regarding the interaction between a new firm and its environment, start-ups lack exchange relationships with all kinds of external actors such as customers, buyers, suppliers, distributors, banks and governmental agencies. These relationships have to be created by new firms, yet without possessing the access, experience, reputation, and legitimacy of high-status entities. For these reasons, start-up ventures are featured by higher failure rates than established firms (Baum *et al.*, 2000).

By forming strategic R&D alliances with other companies, start-ups can potentially access social, technical, and commercial resources that normally require years of operating experience to acquire (Ahuja, 2000). As suggested by Baum *et al.* (2000), by developing an R&D collaboration network, start-ups may employ relationships and resources featuring more established actors. In this way, they mitigate the risks of newness because of their knowledge, resources, dimension and stability. Furthermore, the associative legitimacy that partners confer on the start-up may compensate for the disadvantages of organizational inexperience (Hite and Hesterly, 1999). Regarding the visibility, partnerships with established companies enhance the reputation of start-up firms (Stuart *et al.*, 1999). In industries typified by high uncertainty, the endorsement of a start-up's technology standard should greatly increase its reputation and visibility. Such endorsements by industrial partners improve the visibility and perceived quality of the start-up and serve as a form of free advertising, which, in addition, leads to new relationships with other high-status actors (Waguespack and Fleming, 2009). Having a technology standard acknowledged should enhance the firm's reputation and bring it to the attention of important potential customers, investors, and partners. Thus, by collaborating with industrial partners, start-ups access to complementary capabilities (i.e., distribution, manufacturing, and marketing capabilities) critical to successful development and commercialization. They also may employ partners' production facilities and the expertise in managing R&D and development processes. In addition, new ventures may access to additional financial capital to support the start-up phase and exploit partners' experience in evaluating payoffs far in the future, experience on how to operate and grow a firm in the same industry, strategic and operational know-how (Arora and Gambardella, 1990; Pisano, 1990; Teece, 1992). In brief, R&D alliances with industrial partners allow start-ups to: a) possess stable exchange relationships (Stinchcombe, 1965), b) acquire innovative capabilities (Shan *et al.*, 1994), c) achieve external endorsement of their operations (Baum and Oliver, 1991), d) employ the perceived quality and reliability of partners' products and services among potential customers, suppliers, employees, collaborators and investors (Stuart *et al.*, 1999).

On the other hand, start-ups provide their capabilities on new technologies and, then, their specialization, useful for established firms. For example, many biotech start-ups completely rely on OI as the unique source of revenues, by operating as innovation sellers towards larger pharmaceutical companies (Michelino *et al.*, 2015b).

Even though engaging alliances entails a number of risks for start-ups, such as emergence of unintended knowledge spillovers, loss of control over their own activities and low effectiveness due to cultural issues (Neyens *et al.*, 2010), many studies report that collaborations positively influence both innovation output (e.g., patents) and start-up performance (Shan *et al.*, 1994; Walker *et al.*, 1997; Stuart, 1998; Stuart *et al.*, 1999; Baum *et al.*, 2000). However, there are limitations to the positive performance effects of alliances: Rothaermel and Deeds (2006) report that innovation performance is inversely U-shaped related to the amount of alliances and depends on efforts for accessing complementary resources as well as governance costs.

Another issue affecting innovation performance is the alliance portfolio diversity. As a matter of fact, the higher the diversity in terms of types of partners involved, the higher the innovation performance deriving from R&D alliances (Baum *et al.*, 2000), since firms are more likely to access to a wide variety of technological capabilities. Indeed, start-ups may collaborate not only with industrial entities, but also with scientific partners, such as universities and research centers. In particular, collaboration with suppliers and customers is associated with incremental innovation, while collaboration with universities and research institutes is positively linked to radical innovation (Belderbos *et al.*, 2004; Faems *et al.*, 2005).

More specifically, collaborations with universities, research institutes, government labs and hospitals lead to various advantages. Such partners are a source of up-to-date information and knowledge, which is too tacit to be transferred through licensing or acquisition (Liebeskind *et al.*, 1996) and collaboration with universities gives access to international knowledge networks (Okubo and Sjöberg, 2000) and, consequently, to international markets. In addition, universities and scientific partners can be involved in developing prototypes and handling patents and licenses (Cyert and Goodman, 1997). R&D collaborations provide interaction opportunities, which generate new concepts, business ideas, emerging knowledge and technological know-how that start-ups can translate into new products (Powell *et al.*, 1996). By partnering with scientific entities, companies may access to public resources and funds (Bayona Saez *et al.*, 2002). In fact, collaboration is stimulated by public programs promoting research and partnerships between public and private entities. R&D partners can give an answer to the demand for both basic knowledge and pre-competitive research (Arora and Gambardella, 1994) and more specific knowledge, which focuses on problem solving and product design and development, i.e. applied research (Bayona Saez *et al.*, 2002). Finally, partnerships with universities and research centers allow companies to keep up-to-date in industrial standards and to access to government information useful to find out on what other firms in the sector are investing (Sakakibara, 1997).

R&D alliances with scientific organizations are usually characterized by long-term activities because of the basic and complex nature of the joint research, which requires larger learning processes (Hall *et al.*, 2000a). In these partnerships, companies need to be particularly able to absorb the knowledge transferred by scientific authorities and have a strong internal capacity for R&D (Bayona Saez *et al.*, 2002). In many cases, the results obtained are not directly exploitable for business applications. Another relevant feature typifying such collaboration is the geographical proximity, which significantly improves the efficiency of the relationships (Baptista and Mendonça, 2000). Moreover, it simplifies and reduces the R&D efforts, which are affected by differences in aims, management styles and culture.

Data and methods

The suggested framework explores the role played by OI collaborations in innovation strategies of start-up companies exploiting patent data. In particular, it conceptualizes: 1) the openness degree, 2) the partner typology, 3) the level of specialization on the technological domains jointly explored during the start-up phase, 4) the level of specialization on the same fields after the start-up phase and 5) the quality of innovation output.

Patent data

Among the various data sources from which innovation metrics can be gauged - such as surveys, case studies or interviews, annual reports, announcements on companies' websites - we decided to employ patent statistics extracted from PATSTAT database. Actually, the use of patents for analyzing technological innovation involves some advantages. Firstly, patent data are standardized, contain information about the whole population of innovating firms, are stored for a long period and continuously updated (Griliches, 1990). Secondly, patents are a direct outcome of the inventive process and, more specifically, of those inventions that are expected to have a commercial impact. They can be considered as objective because they have been processed and validated by patent examiners (Belderbos *et al.*, 2010). Thus, patents are the only formally and publicly verified output of inventive activities and are widely accepted as a measure of innovation. Further, they capture the proprietary and competitive dimension of technological change (Archibugi and Pianta, 1996). Since obtaining protection is costly and time-consuming, only inventions that are expected to provide benefits that outweigh costs are applied. Patent statistics provide very specific and detailed information for evaluating inventive activities (Acs and Audretsch, 1989; Chakrabarti, 1991; Grupp, 1992). For all these reasons, patents have been treated as the most important output indicators of innovative activities and patent data have become the focus of many tools and techniques to measure innovation (Ma and Lee, 2008). Indeed, unlike other proxies of innovation (e.g. R&D expenditures, number of R&D employees) which regard the input of R&D activities, patent data focus on the output of the inventive process, provide a valuable information about the effects of technological innovation and can be disaggregated into specific technological domains (Johnstone *et al.*, 2012).

Data sample

The methodology is tested on a sample of worldwide top R&D spending bio-pharmaceutical companies. We took into account R&D efforts carried out by firms during their start-up phase, since such efforts were fundamental for the achievement of their success. According to the definition of start-up, all the firms in our sample can be considered as start-up ventures, because they belong to a research-based industry and are technology-oriented. We selected the bio-pharmaceutical industry 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 (Cooke, 2005; Chesbrough and Crowther, 2006; Khanna, 2012).

The firms were selected from *The EU Industrial R&D Investment Scoreboard*. We limited the analysis to the companies established from 1990 to 2001 and still operating in 2011. An initial set of 62 enterprises was extracted. The first step of the analysis concerns the linkage between the firms of the sample and the PATSTAT applicant table. First, for each company we downloaded the 2011 consolidated annual report and found the list of subsidiaries. Then, we searched the name of both the parent company and its subsidiaries in the assignee field.

Start-up and consolidation phases

The numerical determination and the operationalization of the start-up phase is a very tricky issue. Nevertheless, most scholars investigating start-ups confine the study to a definite number of years from the establishment, e.g. considering firms at the second year of life (Neyens *et al.*, 2010; De Winnie and Sels, 2010), or the first four/five years from the establishment (Robinson, 1990; Baum *et al.*, 2000).

After the knowledge management perspective, the start-up phase ends with the composition of the first stock of knowledge, which is necessary for the existence and the survival of the business and will serve as the basis for future developments. If t is the establishment year of a company, we defined the intervals:

- from t to $t+2$ as the start-up phase;
- from $t+3$ to $t+9$ as the consolidation period.

Therefore, inventions applied by the company within the first three years are regarded as innovations during the start-up phase and contribute to the building of the stock of knowledge. The three-year time span is defined by assuming that it is a proper period for the creation of a primary stock of knowledge, which has enabled the business and represents the reason why the company was founded. Furthermore, for start-up companies, the first three years constitute a “check point” for evaluating the early financial results and the achievement of short- and medium-term objectives.

As to the consolidation phase, given that bio-pharmaceutical companies have to apply the patent before a drug is subject to the evaluation of public health authorities, in mean, they file the invention within seven years from the beginning of the project. Therefore, a first moment for evaluating the consolidation of a business is after seven years from the end of the start-up phase.

Only 9 out of 62 companies did not file any patent application in the start-up period. Hence, the initial sample was reduced to 53 firms, for a total of about 4,000 patent applications in the start-up phase and 22,000 in the consolidation period (see Appendix for the list of firms).

Stock of knowledge and specialization

The knowledge domain level was used to investigate the stock of knowledge of companies and their level of specialization. Consistently with literature (Almeida and Kogut, 1999; Abraham and Moitra, 2001; Ahuja and Katila, 2001; Ahuja and Lampert, 2001), patent data at the technological domain level can be used to study the relationship between innovation and knowledge.

An *ad hoc* software was developed for the investigation of start-ups’ stock of knowledge, which is defined as the list of the distinct knowledge domains in which companies are involved and, then, the list of technological domains affected by companies’ inventions. When scholars need to analyze knowledge domains, they focus on International Patent Classification (IPC) codes, which identify the belonging technological fields of an innovation. Indeed, all patents are categorized into at least one IPC: such technological index operates like a keyword system (Graff, 2003). IPC codes are widely employed to investigate technological innovation strategies implemented by innovative firms: e.g., Sakata *et al.* (2009) studied IPC combinations in order to define the innovation position of Japanese companies, while Suzuki and Kodama (2004) described technological trajectories and technological diversification strategies by examining patent classification codes.

In this work, we preferred the Cooperative Patent Classification (CPC) system, since it allows to examine patent applications with both the EPO and the USPTO as receiving office. It can be considered as an evolution of the IPC, since it is more specific and detailed: while the IPC has about 70,000 entries, the CPC has more than 250,000. Each CPC consists of a hierarchical symbol denoting section, class, sub-class, main group and sub-group. Table 1 shows the hierarchical composition of two CPCs with our interpretation about the meaning to be assigned for research purposes.

Insert Table 1 here

Table 1. Example of CPC hierarchical composition.

By considering the entire code (level 5), we may study innovation at the component level, or rather at the maximum level of disaggregation. Yet, for the investigation of knowledge domains, we use the code at level 4 (main group). As a matter of fact, we hypothesize that different products or components may be developed within the same knowledge domain, since competencies required in the innovative process are almost the same.

Given that not all the domains are relevant for the start-up, only some CPCs are strongly stressed and mostly contribute to the development of the core technology of current business activities. In other words, each technological domain is featured by a specific specialization, estimated dividing the number of patents declaring the analyzed CPC during the start-up phase by the total amount of patent applications recorded in the same period, considering only those reporting at least one CPC (Michelino *et al.*, 2015c). The idea is based on the assumption that the start-up venture is more specialized in a technological field if its accumulation of knowledge in the start-up phase generates a larger number of patent applications on the focal technological area.

Therefore, in order to define specialization, the following indicators were considered for each CPC:

- SPEC_S, as the company's specialization on the technological domain during the start-up phase;
- SPEC_C, as the specialization within the consolidation phase;
- ABAND_C, as a dummy variable assuming value 1 when the focal CPC is abandoned in the consolidation phase.

Note that for the analysis of the level of specialization we considered both internally and joint developed patents, in order to estimate the effective impact of each CPC on the overall innovation strategy carried out by start-ups. For the same CPCs we also evaluate the specialization in the consolidation phase, in order to understand if the knowledge field is already exploited or has been abandoned, i.e. no patent application has been filed by the focal company during the consolidation phase (Figure 2).

Insert Figure 2 here

Figure 2. Stock of knowledge in start-up and consolidation phases.

OI collaborations: openness degree and partner typology

Our research is confined to alliances established by start-ups only for R&D collaboration. In order to detect such relationships, we focus on the assignee field disclosed in patent documents. Indeed, when a firm develops a new technology in-house, only one applicant is recorded in the patent application. On the contrary, a co-patent is detected when two or more entities are involved in the development and contribute to the final invention, sharing the ownership of the technology. Thus, co-patents seem to be a relevant indicator for signaling the occurrence of OI strategies (Chesbrough, 2006) and the number of patents deriving from collaborative R&D activities can be considered as a proxy of OI (Al-Ashaab *et al.*, 2011). Kim and Song (2007), using joint-patenting information, reported a growing OI adoption. As we aim at investigating OI collaborations between start-ups and third parties, we left out any inventor eventually reported in the assignee field.

Regarding the typology, each partner is labelled as:

- industrial, if the patent document reports an industrial organization;
- scientific, when relationships involve universities, research institutes, government labs, hospitals and any other scientific authority.

One of the purposes of the work is to understand if the partner typology affects the other variables under investigation. Therefore, three indicators can be defined for each knowledge field under investigation:

- OPEN_S, as the share of joint patents on the total number of documents filed during the start-up phase;
- OPEN_PARTN, taking the value 0 if no R&D collaborations were uncovered in the start-up phase, 1 if only industrial partners are involved in the alliances with the new venture, 2 if only scientific organizations are reported in the applicant field together with the focal firm, 3 if both typologies of partners are found;
- OPEN_C, as the share of joint patents on the total number of documents reported in the consolidation phase and recording the focal CPC.

Quality of innovation output

When scholars need to understand the impact of an invention, they refer to backward citations, forward citations and patent family size. Backward citations pertain to the novelty level of the innovation and are widely explored in literature. Ahuja and Lampert (2001) termed technologies without technological antecedents as pioneering, since they focus on completely *de novo* solutions. Hence, patents without backward citations to prior technical art can be considered as pioneering (Trajtenberg *et al.*, 1992, 1997; Rosenkopf and Nerkar, 2001; Shane, 2001; Kaplan and Vakili, 2012). The lack of prior art citations is a proxy of originality, creativity and novelty of a patent. Conversely, the existence of backward citations is a proxy of innovations based on the reinforcement of already existing knowledge (Jaffe *et al.*, 1993; Hall *et al.*, 2001). Patents disclosing backward citations can be considered as spillovers. Even though the applicant may deliberately avoid backward citations, he has the legal duty to disclose any citation to prior art. The decision regarding which patents to cite ultimately rests with the patent examiner, who is an expert in the area and able to identify relevant prior art that the applicants omitted. Furthermore, applicants may cite their previous inventions, signaling an internal spillover and the reinforcement of already known concepts.

While the number of backward citations is a backward looking measure which detects the relationship between a patent and the worldwide body of knowledge that preceded it, the number of forward citations is a forward looking measure, which captures the relationship between a patent and subsequent technological developments that build up on it (Mazzucato and Tancioni, 2012). In this work, we employed information provided by five-year forward citations (Hall *et al.*, 2000b; Lahiri, 2010), estimated as the number of patent applications declaring the focal patent in the five years following its publication. Such measure can be regarded as a proxy of the technological value of the invention (Miller *et al.*, 2007). Indeed, the quality of innovation output can be regarded as the impact of the new technology. From the technological point of view, inventions can be related to the concept of breakthrough innovation. Breakthroughs offer high improvements in the price vs. performance ratio over existing solutions (Tushman and Anderson, 1986) and are generally considered as competence-destroying. Such inventions serve as the basis for many subsequent technological developments (Trajtenberg, 1990a; 1990b) and can be regarded as breakthrough because they have demonstrated their utility on the path of the technological progress (Fleming, 1998). Breakthrough inventions can be identified through patent citation counts. When a patent is cited by other inventors, a higher technical importance can be presumed (Albert *et al.*, 1991; Rosenkopf and Nerkar, 2001; Dahlin and Behrens, 2005; Alcácer and Gittelman, 2006; Miller *et al.*, 2007; Lahiri, 2010; Mazzucato and Tancioni, 2012). Fleming and Sorenson (2004) argued that the number of forward citations of a patent highly correlates with its technological importance, as measured by expert opinions, social value, and industry awards.

Yet, not only technological quality has to be considered, since also patents with a low technological impact can have a market value. Hence, we took into account the patent family size, estimated as the number of all patent applications declaring the focal patent in the five years following its application. The count of family patents represents the number of different nations in which a patent is published (Breitzman and Mogee, 2002; Harhoff et al., 2003) and has been considered as indicating the level of R&D or technological activity relevant to international diffusion, thus implying marketability (Geum et al., 2013). The family size increases when inventions have been applied for protection in multiple countries (Johnstone et al., 2012), claiming the priority patent. Moreover, follow-on patents may be further filed by applicants for numerous reasons: to apply for different uses from the same claims, and to file new claims that emerge over time in the R&D process (Gittelman, 2008). Graham and Mowery (2004) reported that about one quarter of patent applications are continuations on prior inventions. They are particularly important in fields where development processes are long, specifically bio-pharmaceuticals. Even though many scholars discovered that patents in large families will be more likely to receive higher numbers of future citations (Cockburn and Henderson, 1998; Gittleman and Kogut, 2003; Harhoff et al., 2003), and then technological and market impact are closely related, as mentioned before not all marketable innovations are necessary technological breakthroughs.

In summary, the quality of a joint patent is higher if: 1) no backward citation was recorded, i.e. the invention is potentially pioneering; 2) at least a forward citation is detected, i.e. the technology is acknowledged and useful for the development of further inventions; 3) the patent family size increases, i.e. the focal patent is followed by new applications within the same family.

Therefore, three shares are defined for each knowledge field recorded in patent applications filed during the start-up phase:

- QUAL_PION, as the ratio of potentially pioneering inventions on the total number of patents;

- QUAL_TECH, as the share of documents recording at least a forward citation;
- QUAL_MKT, as the ratio of inventions originating further applications on the total number of applications.

Results

In Table 2 we compared the whole sample with start-ups disclosing at least a joint patent. On average, firms adopting OI strategies filed a larger number of patent applications in both start-up and consolidation phases, signaling that R&D collaboration activities stimulate and positively affect the development of new inventions. The number of patents increases almost three times during the consolidation phase; therefore, our definition of start-up phase seems to capture the boundary between two different periods of the life of such companies.

Insert Table 2 here

Table 2. Sample description.

We aim at investigating innovation performances at the knowledge domain level during the start-up phase. Therefore, our statistical unit is the distinct CPC declared by a firm, for which we estimated the metrics previously defined. Since we aim at uncovering the behaviors within each technological field for each company, the total number of statistical units is the sum of the distinct CPC-firm couples detected from patent filed during the start-up phase. For each couple we gauged the values of openness and specialization on the technological field in both start-up and consolidation phases.

Closed vs. open technological fields

Table 3 reports the mean values detected for openness, specialization and quality of innovation output. The degree of openness for the total sample is around 9%, whereas the average value considering only the technological fields within which at least one collaboration takes place during the start-up phase is about 50%. Since we aim at discovering whether OI adoption impacts on innovation strategies and performances, one-way ANOVA was performed to determine whether the occurrence of OI practices is a discriminating factor for the variables under study. All the variables under investigation show statistically different behaviors between open and closed fields.

In particular, the level of specialization on open technological fields is almost double than the one on closed domains, during both start-up and consolidation phases.

As to quality indicators, on average higher levels of pioneering patents are detected in closed knowledge domains, but collaboration within technological fields imply higher technological and market impact. In open CPCs, more than 60% of patent applications displays a potential technological quality, but only about 35% demonstrates to be a real breakthrough. As to market quality, more than 80% of inventions is featured by further patent application within the same patent family.

Insert Table 3 here

Table 3. Closed vs. open technological fields.

In addition, we employed a correlation analysis in order to detect the relationships between the variables under investigation. The Shapiro-Wilk test of normality was performed and, since the data do not show a normal distribution, Spearman correlation is used. The analysis confirms the previous results, as long as within a technological field involved in R&D efforts carried out by start-ups the openness degree is positively associated with both levels of specialization (Table 4). This means that the occurrence of at least a joint patent correlates with the relevance of the knowledge domain for the new venture. Moreover, higher levels of openness are negatively correlated to the pioneering quality of patents but positively related to both technological and market quality. Therefore, even though inventions originated by joint development are mainly spillovers (i.e. are based on the reinforcement of already known concepts), subsequent technological developments were built up on them and are used for market purposes.

Regarding the specialization, the two degrees - during start-up and consolidation phases - are directly linked each other, meaning that the fields on which companies are more focused in their initial phase of life are typically strengthened during the consolidation phase.

While technological and market impact of a patent are positively correlated each other, its pioneering potential is negatively linked to both. This means that patents filed by start-ups which do not refer to prior knowledge (i.e. do not have backward citations) typically have a lower impact as to both technology (i.e. they do not receive forward citations) and market (i.e. they do not contribute to the further extension of the patent family). As a matter of fact, technology spillovers are more likely to generate in the future five years technological acknowledgement and market outcomes, since they originate from prior technology and knowledge. On the other hand, innovations that significantly depart from past practice may require more time, since bio-pharmaceutical firms have to prove the effectiveness and the quality of the developed technology.

Insert Table 4 here

Table 4. Spearman’s correlation coefficients between the variables under investigation.

Different regression models were tested to analyze the causality relationship between the openness degree and the three quality metrics. Yet, no model provided good values for R-square and, thus, it is not possible to assert that the only adoption of R&D collaboration strategies on certain technological fields produces patents of better quality. Indeed, it is necessary to underline that innovation is a multidimensional phenomenon, which is affected by many issues and can be considered as the result of business strategies involving many units, functions and management decisions. Therefore, it is not possible to define the perfect “formula” for successful innovations by considering only the OI adoption.

OI collaborations and quality of innovation output

Given the existence of significant correlations but no significant regression, the collaborative attitude of companies during their start-up period requires further investigation. Therefore, joint activities were discriminated on the basis of the partners involved (OPEN_PARTN): industrial, scientific or both (Table 5). R&D collaborations with only industrial partners are the most frequent and cover two-thirds of the cases.

On average, the highest degree of openness during the start-up phase is registered when only scientific partners are involved. Thus, the firms who mostly invest on OI collaborations during their start-up phase are more likely to select scientific organizations as R&D partners. In all the cases, the openness in the start-up phase (OPEN_S) is higher than the share of joint patents during the consolidation one (OPEN_C), thus signaling that OI is vital in the first stage of existence of companies, when the stock of knowledge is not completely built, whilst the role of knowledge networks loses importance in consolidation. Such reduction is more pronounced in CPCs where we detected collaborations with only scientific partners, suggesting that R&D alliances with such partners have provided new concepts, ideas, knowledge and research, which have been absorbed by the firm and afterwards internally exploited during the consolidation phase.

Regarding the specialization, its level decreases from the start-up phase to the consolidation period for the whole sample. Therefore, the impact of the CPCs recorded in patent applications during the first three years is significantly decreased in the following period, probably because firms carried out a differentiation strategy, investing on new knowledge domains. In addition, about 11% of the technological domains jointly explored with third parties were abandoned in the consolidation phase. During both start-up and consolidation phases, the degree of specialization of companies on knowledge domains is lower when only industrial partners are involved and higher when collaboration takes place with both typologies, i.e. when also scientific partners were recorded. Actually, joint development activities with industrial partners during the start-up phase focus on less relevant and specialized domains, i.e. more frequently they refer to R&D efforts on complementary assets or, in general, on non-core knowledge fields. In addition, the higher level of potential competition between business partners leads to collaborations within less relevant knowledge fields. On the other hand, when CPCs involve more relevant domains, bio-pharmaceutical start-ups prefer OI collaborations with scientific organizations, since the technological fields affected by their inventions are disclosed in about 40% of the patent applications filed by the focal enterprise during the first three years from the establishment.

As of quality indicators, only the technological impact significantly differs among the three types of collaboration, being higher when only scientific partners are involved. Therefore, high quality innovations derive from the joint development with scientific entities, in line with literature (Belderbos *et al.*, 2004; Faems *et al.*, 2005).

Insert Table 5 here

Table 5. Innovation strategies and quality by partner typology.

By performing the correlation analysis only for the technological fields in which collaboration takes place, a negative correlation is found between openness degree and specialization in both start-up and consolidation phases (Table 6). The result provides opposite insights than the previous one, referring to the total sample of knowledge domains (both open and closed). This means that the R&D collaboration occurs within the technological domains considered as crucial by the start-up, but without covering high shares of the R&D effort carried out by the new venture. Indeed, when the openness is high, the knowledge field is less relevant for the firm, i.e. the specialization is low, and the start-up adopts OI practices in order to access to new capabilities, concepts, ideas, knowledge and research within knowledge domains in which it lacks of experience and familiarity.

Regarding the abandonment of CPCs during the consolidation phase, we uncovered a positive linkage with the openness in the start-up period and a negative one with the specialization. It seems that new ventures employ OI also for exploring non-core knowledge fields, which are afterwards abandoned.

All the other correlation results are consistent with the previous analysis, being the two degrees of specialization - during start-up and consolidation phase - positively associated each other and the level of openness of the new venture directly linked to both post-hoc metrics of patent quality.

Insert Table 6 here

Table 6. Spearman’s correlation coefficients between the variables under investigation for open CPCs.

In order to test the impact of the openness degree during the start-up phase on the quality of innovation output, depending on the partner typology, different regression models were tested. The only significant models were obtained for those technological fields in which companies collaborate with both industrial and scientific partners (i.e. OPEN_PARTN equal to 3). In particular, the cubic model provided the best fit for all the metrics of patent quality (Table 7).

Insert Table 7 here

Table 7. Regression models for CPCs involved in collaborations with both industrial and scientific partners.

Figure 3 graphically shows the quality curves obtained by applying the cubic model to the openness degree. Regarding QUAL_PION, the highest values are reached in totally open knowledge fields. As to QUAL_TECH, low levels of openness lead to higher values of technological acknowledgement, while larger OI adoption generates values ranging around 20%. Lastly, growing values of QUAL_MKT are obtained with growing OI shares, but for openness values higher than 80% the quality decreases. In brief, we detected a U-shaped relationship with QUAL_PION and an inverted U-shaped one for QUAL_MKT.

Insert Figure 3 here

Figure 3. Relationship between openness and quality of innovation output.

Discussions

The goal of this paper is to contribute to the current debate on OI for start-ups by providing a methodological framework for evaluating the impact of OI on new ventures' innovation strategies. Specifically, we investigate the mutual influence of OI collaboration features, specialization on knowledge domains involved in partnerships and quality of innovation output.

Results show that, in mean, R&D collaboration during the start-up phase covers about 50% of R&D efforts in open technological fields and that the openness level in the start-up phase is higher than in the consolidation one, thus signaling the importance of investigating OI adoption in new ventures. The highest degrees of openness are reached when firms intensively collaborate with scientific organizations and such collaborations generate high quality innovations. In addition, we discovered that the R&D collaborations are often carried out within technological domains considered as crucial for the development of the business, since the level of specialization within open CPCs is higher than the specialization estimated for closed knowledge fields. Also, the specialization in the consolidated phase is positively influenced by the occurrence of R&D collaborations within the focal knowledge field during the start-up phase. In general, OI positively affects the metrics signaling ex-post quality, even though the potential quality of joint patents is lower.

As the paper demonstrates, OI adoption is crucial for the new venture. Therefore, this study can be considered as a first step in developing a methodology for supporting managers' decisions. The concepts of specialization and quality may be considered in managerial tools to monitor and control OI processes. Indeed, by focusing on R&D efforts at the knowledge domain level, the methodology shows how the quality of innovation output is affected by the propensity to collaborate (i.e. openness degree) and the partner typology. Our results suggest decision-makers, managers and researchers to deepen the effects of OI strategies by evaluating the performances at the knowledge domain level. Since the framework employs publicly available, objective and standardized data, start-uppers can operatively access to such information from free on-line sources (e.g., Espacenet by EPO). Actually, decision-makers may assess the status of start-ups' OI collaborations, also performing the benchmarking with competitors and partners. For instance, by analyzing the applicant field, start-uppers may understand the weight of OI on the overall business of their companies, as well as studying competitors. Also, an easy-to-use operationalization was defined for gauging the quality of innovation output, therefore anyone who might access the internet can simply employ it. Moreover, our methodology may be applied for both industry- and firm-level analysis, providing business analysts a practical instrument for detecting the OI strategies carried out by new ventures and investigating the impact of specific behaviors on the quality of innovation output. At last, the paper stimulates policy makers to address new partnerships between scientific organizations and start-ups towards specific objectives and on R&D activities in which collaborations have already demonstrated their effectiveness.

Some limitations can be defined for the work. Firstly, the use of patents for examining OI collaborations could be questionable, since not all partnerships will be captured by co-patents (Hagedoorn *et al.*, 2003). This means that the amount of collaborative R&D efforts we detected should be viewed as a conservative estimation of the total number of joint development activities taking place, with actual levels of OI collaboration being higher (Belderbos *et al.*, 2010). Secondly, the research is confined to bio-pharmaceutical start-ups; hence, our results may be affected by industry-specific OI features and cannot be generalized. Thirdly, we have considered only successful start-ups, i.e. new ventures that afterwards have achieved positive results, reached their objectives and trespassed the start-up phase.

Since the use of patent data brings the above limitations, future research will match information deriving from patents with other sources, such as surveys, case studies, interviews, accounting data, information within annual reports and public announcements, in order to validate the framework with additional data. For instance, by performing case studies and interviews we plan to investigate OI processes at the project-level, combining patent data with in-depth qualitative information. Furthermore, the research will be addressed to examining different industries. Actually, the investigation of other sectors is required in order to generalize our findings. Finally, we aim at considering other business features of start-ups and partners involved into joint development activities, in order to define the determinants of partners' selection and other factors affecting the collaboration performances.

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