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EFFECT OF CORPORATE SCIENTISTS ON FIRMS' INNOVATION ACTIVITY: A LITERATURE REVIEW

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Abstract. This study reviews the literature on the effect of corporate scientists on firms' innovation activities. Traditionally, the scientist's role in a firm is linked to the processes of generation and absorption of scientific knowledge. However, a growing number of studies over the years show that the scientist's role in firm innovation processes is more extensive and that they contribute to the development of successful new products, processes and services. However, there are no comprehensive reviews of this literature. This paper fills the gap by providing a systematic review of the empirical literature on the role of the corporate scientists in the innovation process by investigating: (1) theoretical approaches used to evaluate the impact of scientists, (2) the importance for the firm's innovation activity of scientists' heterogeneity, (3) those firm innovation activities over which scientists exhibit more influence, (4) the variables moderating the effect of scientists and (5) research implications for managers.

Keywords. Firm innovation activity; inventors; PhD holders; R&D activity; scientists, scientific workforce

1. Introduction

It is widely accepted that firms' innovation activities have an important impact on economic development and growth (Griliches, 1984; Adams, 1990). The contribution of human resources to these activities has been analysed extensively in the literature because individuals are responsible for some of the most important discoveries and are essential to initiating the innovation process (Maggitti *et al.*, 2013; Paruchuri and Awate, 2017). The types of firm employees involved in innovation activities are diverse and the literature shows that this diversity has different impacts on firms' innovation performance (Ding, 2011; Carnabuci and Operti, 2013; Subramanian *et al.*, 2016; Mohammadi *et al.*, 2017).

Corporate scientists are a particular group of employees who participate in the firm's innovation process. Traditionally, their role in the firm has been linked to the generation and absorption of new knowledge (Herrera and Nieto, 2015). The seminal work of Allen (1977) portrays them as a specific group of individuals who differ from other specialist employees (such as engineers) in terms of education background, behaviour and social ties, particularly, in the context of Research and Development (R&D) projects. A study by Gruber *et al.* (2013) examines these differences in more detail and shows that scientific education provides a more abstract understanding of the technological problem-solving process, a working knowledge of new technologies and greater capacity to understand, analyse and assimilate disparate pieces of technological knowledge.

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Nonetheless, the study of scientists is particularly important due to their role in translating science into new technologies. The links between science and innovation are clear (Cohen *et al.*, 2002). Firms can exploit scientific knowledge to develop important new products and processes and to improve their ability to absorb external knowledge (Salter *et al.*, 2015), which, however, can be difficult to access. According to Bikard (2018, p. 819), the firm's science-based innovation process 'is complicated not only by the tacit and complex nature of scientific knowledge but also by the fact that the scientific commons are vast, fast-changing, and often unreliable'. Scientific knowledge does not reach the firm as an input that can be used immediately in the innovation process; it requires the active participation of individuals with specific knowledge, background and skills to absorb, translate and exploit it (Zucker *et al.*, 1998; Lee *et al.*, 2010).

Due to their exposure to breakthrough scientific knowledge and market needs, scientists working in firms are expected to play important roles in the process of transferring scientific knowledge to industry through the accurate assessment of the implications of current research from a commercial perspective (Zellner, 2003) and taking an active role in the development of successful new products, processes and services (Salter *et al.*, 2015). Although the association between the firm's intellectual capital and technological performance has been acknowledged (Herrera *et al.*, 2010), the finer aspects of how scientists contribute to firms' innovation activities need more research. The literature in this field analyses the contribution made by 'academic scientists', in the context of firms' cooperation with universities (Perkmann *et al.*, 2013) and academic entrepreneurship (Bercovitz and Feldman, 2008; Grimaldi *et al.*, 2011; Bozeman *et al.*, 2013). Less attention has been paid to their contribution as firm employees or 'corporate scientists'. Distinguishing between academic and corporate scientists is important due to the different knowledge production regimes in academia and industry (e.g. open versus closed science), the different incentive structures to which these scientists respond (e.g. academic recognition versus economic incentives) and the fact that academia is no longer the primary sector of employment for scientists (Herrera and Nieto, 2016).

There is a growing but highly fragmented strand of work analysing the role of corporate scientists, which needs systematic review. Theoretical approaches differ and measures of firm innovation activities are diverse, making it difficult to integrate the results of these studies. Consequently, how scientists working in firms contribute to firm innovation and the factors influencing their contribution are unclear. In this context, the objective of this analysis is to offer a critical review of the work analysing the importance of corporate scientists to firms. The research question guiding our analysis is: what are the effects of corporate scientists on firms' innovation activities? We address this question by examining five critical aspects of the research in this area: (1) the theoretical approaches used to evaluate the impact of scientists on the firm's innovation activity, (2) the importance of scientists' heterogeneity in relation to the firm's innovation activity, (3) those aspects of firm innovation activity over which scientists have the most influence, (4) the factors moderating scientists' effects on the firm's innovation activity and (5) the implications for managers.

The review involved extensive searches of the abstracts of published, peer-reviewed articles included in the ISI Web of Science. The search process adopts the methodology employed in Vivas and Barge-Gil (2015). Searches were performed combining three categories of keywords. The first included keywords referring to firms, such as: 'firm*', 'enterprise*', 'private sector', 'industry*', 'SME' and 'company*'. The second included keywords for scientists, such as: 'scientist*', 'PhD', 'R&D researchers' and 'doctor*'. The third included keywords describing firms' innovation activities, such as: 'R&D', 'innovat*', 'patent*', 'new product' and 'innovative product'. The timespan chosen was 'all years'. The search string returned 6354 potential articles. After filtering by social science category, we obtained a total of 3440 articles for our analysis. We performed four search rounds between January 2017 and October 2018. To maintain the focus on scientists, we consider several criteria for the inclusion or exclusion of the papers to be reviewed. Work analysing the contribution of human resources to firms' innovation

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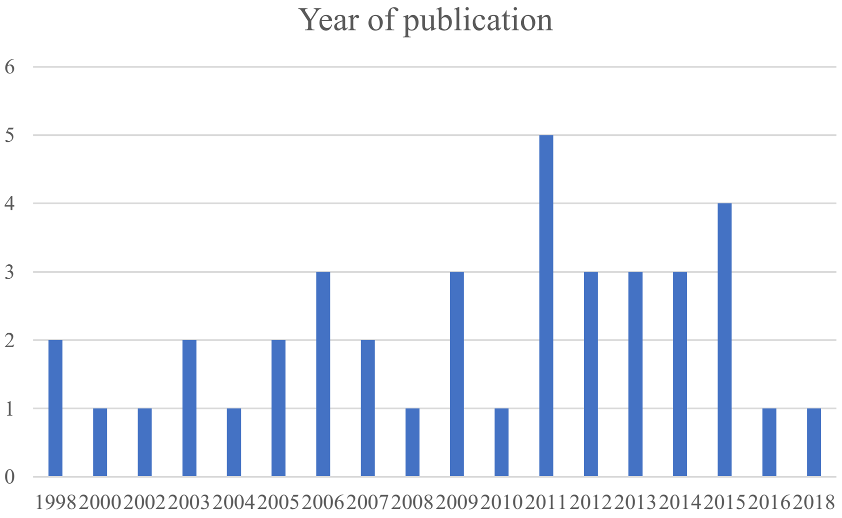

Figure 1. Articles Published by Year. For 2018, the Figure Shows the Number of Publications for January to October Only. [Colour figure can be viewed at wileyonlinelibrary.com]

processes is extensive and scientists are a particular group of employees who tend to be included in the R&D workforce category with no differentiation from other employees; hence, their analysis is more difficult.

Since the present review focuses on ‘scientists’ effects on firms’, the articles reviewed need to provide empirical evidence and be based on the firm as the unit of analysis, with the dependent variable or potential outcome a measure of the firm’s innovation activity. The articles should include a measure of the scientific workforce in the group of explanatory variables used, and test hypotheses or have a research objective related to the firm’s innovation activity and corporate scientists.

After sorting the articles according to these criteria and verifying that the authors use the word ‘scientist’ in their hypotheses and research objectives, we obtained a sample of 40 articles. The review covers the period 1998–2018. Figure 1 depicts annual publication frequency. Most of the articles were published in the period 2009–2015. Table 1 presents the journals that published the articles which is of interest in terms of the different research areas.

The Appendix presents the 40 articles considered in the analysis including: number of citations received, their samples, data structure, data sources, methods, dependent and independent variables and hypotheses or research objectives. The Appendix shows that 27 articles focus on the biotechnology and pharmaceutical industries and only nine include firms from several sectors. As a result, knowledge about the role of scientists in firms comes from the study of science-driven industries. The Appendix also shows that 19 articles analyse US firms with only eight using data from firms in European countries. The most commonly exploited data are patent data.

The present study makes three important contributions. Firstly, it offers the first systematic review of the role of corporate scientists in firms and provides a comprehensive picture of the influence of scientists on firm innovation processes. Secondly, it contributes methodologically by outlining three critical aspects that need to be accounted for when estimating scientists’ effects: scientists’ heterogeneity, the factors moderating scientists’ effects and the endogeneity problem. Thirdly, it identifies aspects that are either less well researched or are contested, providing scope for future research.

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Table 1. Number of Papers Published by Journals.

Research Policy	9
Strategic Management Journal	5
Management Science	4
IEEE Transactions on Engineering Management	2
Industrial and Corporate Change	2
Journal of Management	2
Organization Science	2
Technovation	2
Academy of Management Journal	1
Advances in Strategic Management	1
Economic Inquiry	1
International Journal of Innovation Management	1
Journal of Business Venturing	1
Journal of Economic Behavior Organization	1
Journal of Industrial Economics	1
Journal of Marketing	1
Journal of Product Innovation Management	1
Journal of Strategic Management	1
Rand Journal of Economics	1
Scientometrics	1
Total	40

The remainder of the paper is organized as follows. Section 2 presents the theoretical approaches used for the literature review. Section 3 discusses the definition of scientist employed in the studies and the strategies used to identify scientists among the group of human resources engaged in R&D activities. Section 4 analyses the measures of firms' innovation activities and some lessons learned. Section 5 describes the main methodological approaches in the empirical evidence. Section 6 summarizes the managerial implications and Section 7 offers some conclusions and recommendations for future research.

2. Theoretical Background

The impact of scientists on firms' innovation activity has been analysed using various theoretical lenses, which makes it impossible to analyse all of them exhaustively. However, there are some more frequent approaches and some that are used in combination with others to justify hypotheses and to highlight the importance of scientists for firms' innovation activities. These approaches include the resource-based view, the knowledge-based view, the learning-by-hiring approach, the social network and social capital perspectives and the national innovation system vision, among others. These approaches are described below along with the basic premises of the sample studies.

In studies that adopt the resource-based view or the human capital perspective, scientists are considered valuable firm resources (Deeds *et al.*, 2000; Subramaniam and Youndt, 2005; Baba *et al.*, 2009; Luo *et al.*, 2009). Their knowledge and capabilities are tacit, complex and firm-specific and, as a result, are inimitable by rivals and can be the source of competitive advantage for their firms (Deeds *et al.*, 2000). Their knowledge and capabilities constitute scientific human capital, which is the product, also, of higher

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education and research training and the research experience acquired by the scientist in the course of his or her career (Subramaniam and Youndt, 2005; Luo *et al.*, 2009). The literature highlights the heterogeneous characteristics of this human capital and empirical studies show that it has different components which affect the firm's innovation performance differently (Baba *et al.*, 2009; Subramanian *et al.*, 2013). In general, studies that adopt these theoretical approaches assume that employees with better education and longer experience will be more productive than comparable employees in the high-tech sectors (Kaiser *et al.*, 2018).

The hypotheses in the studies in this review also find justification in the 'knowledge-based view', according to which the knowledge and skills of employees are a main determinant of the firm's innovation success (Tzabbar, 2009; Al-Laham *et al.*, 2011). Successful innovation requires not only application of the firm's existing knowledge stock but also the capabilities to update and renew it by accessing new knowledge using different mechanisms, which include recruitment of scientists (Tzabbar, 2009; Al-Laham *et al.*, 2011; Kaiser *et al.*, 2018). In this context, corporate scientists play an important role based on their in-depth understanding of scientific progress, which makes it more likely that firms will search for and identify opportunities in academia that can be developed into commercial applications (Tegarden *et al.*, 2012).

Also, the extant literature relates scientists' qualitative skills to the concept of 'absorptive capacity'. Scientists play an important role in the transfer and integration of knowledge, based on their abilities to screen, interpret and assimilate external knowledge (Spithoven and Teirlinck, 2010). Several studies in this vein analyse the role of scientists in the processes of knowledge transfer and the formation of alliances (Furukawa and Goto, 2006a,b; Stuart *et al.*, 2007; Luo *et al.*, 2009).

Scientists' contributions to firm innovation activities include their network contacts, as underlined in studies that adopt social network and social capital perspectives (Luo *et al.*, 2009). Almeida *et al.* (2011) point out that firms are able to access external knowledge within the scientific communities to which they belong. Scientists use these communities to develop links to scientists in other firms, universities and research centres, and facilitate flows of knowledge between them. Luo *et al.* (2009) suggest that the scientist's human and social capital can be a signal of the firm's quality in the industry. Thus, the presence of scientists in the firm can signal to stakeholders that the venture has the technological capabilities needed to operate in the market (Rao *et al.*, 2008)

Finally, the study by Herrmann and Peine (2011) is notable in being the only work that compares two groups of theoretical approaches in terms of the importance of different human resources qualifications for firms' innovation strategies. They study the literatures on varieties of capitalism and national innovation systems. While the former argues that radical innovation requires employees with general skills because they can adapt more easily to changes, the latter argues that advanced qualifications enable firms to pursue more innovative strategies.

3. Scientists

This section presents the different types of scientists. Most studies fail to define scientists in terms of educational background, research orientation and productivity.[1] However, they note that scientists, unlike other firm employees, participate in the processes of generation and absorption of scientific knowledge. This work also indicates that the scientific workforce is composed of individuals who participate actively in the firm's research activities, generate publications and patents and have higher education qualifications such as doctoral degrees. To estimate the impact of scientists on firms' innovation activities, several studies consider different measures or dimensions of the scientific workforce. For example, the more basic measures range from number of PhDs as a percentage of total employees (Luo *et al.*, 2009) or number of inventors listed on patents (Sapsalis *et al.*, 2006), to more refined measures that focus on

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scientists' characteristics (Tzabbar, 2009; Tzabbar *et al.*, 2013). The large number of methods employed by these studies to identify scientists is revealing of the numerous sources of heterogeneity among scientists who need to be considered when analysing their role in firms. In what follows, we discuss the sources of heterogeneity identified in the course of the review, which are related to the type of relations the scientists maintain with their firms, their productivity levels and research orientations, their roles in management activities and the types of knowledge they embody.

3.1 *Scientist's Links to the Firm*

One of the most challenging sources of heterogeneity is the scientist's links to the firm. A significant number of studies use the affiliation information on publications or patents to identify corporate scientists (Zucker *et al.*, 1998; Gittelman and Kogut, 2003; Sapsalis *et al.*, 2006; Subramanian, 2012). In the science-based sectors, such as biotechnology (the most frequently analysed sector), this is problematic because it is not always possible to establish the degree of a scientist's participation in the firm's activities. Zucker *et al.* (1998), based on the responses to a telephone survey, find that scientists can be linked to the firm in several different ways: through exclusive direct employment, full or part-ownership, exclusive and non-exclusive consulting contracts and chairing roles. The authors found that most scientists 'choose to retain their university positions, even when employed full-time by a firm' (Zucker *et al.* 1998, p. 69). Exclusive high-level involvement in firms' research activities could lead to different innovation performance compared to with low level or partial involvement. Zucker *et al.* (1998, 2002) classify scientists as affiliated, linked or not tied to firms, in order to analyse the impact of their involvement in the firm's research efforts. These studies show that linked scientists (those who are unaffiliated to the firm, but have co-authors who are firm employees) and affiliated scientists might have different impacts depending on the type of innovation activity considered. For example, the presence of an affiliated star scientist increases the number of product innovations, while unaffiliated scientists reduce it (Zucker *et al.*, 1998).

3.2 *Scientist's Position in the Firm*

Studies also show that the scientist's position in the firm is another source of heterogeneity. They include analyses of scientists occupying positions such as chief executive officer (McMillan and Thomas, 2005), founding team member (Ding, 2011) and board member (Rao *et al.*, 2008; Swift, 2018). According to Ding (2011), scientists in top management positions may develop more favourable perceptions of research activities; he notes that, during their doctoral training, scientists acquire or develop a science-oriented cognitive structure that can affect how a scientific manager processes information when making decisions. This finding, combined with the fact that scientists have been exposed to the norms of science and may have better access to and understanding of new disclosures, has important repercussions for a wide range of firm activities (Rao *et al.*, 2008; Almeida *et al.*, 2011). In addition, some studies show that the research activities of firms with scientists in top management positions are awarded scientific legitimacy. Rao *et al.* (2008) show that a high ratio of scientists on the firm's board conveys to stakeholders that the firm has the capabilities to produce successful innovation.

3.3 *Scientists' Entry and Exit Positions in Firms*

The impact of scientists has also been analysed from the perspective of their entry and exit positions in the firm. Because most of the knowledge underlying breakthroughs is embedded in individuals, scientists' mobility is important. Scientists are seen as effective mechanisms for knowledge transfer and drivers of changes to organizational capabilities (Lacetera *et al.*, 2004). Kaiser *et al.* (2015) present empirical

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evidence supporting the idea that scientists' mobility is related to a significant increase in the total inventions of both the previous and the new employer. From the point of view of new hirings, the evidence shows that new recruits have potential effects on the firm's innovation activities. However, these effects differ depending on the scientist's provenance (Rosenkopf and Almeida, 2003; Lacetera *et al.*, 2004; Al-Laham *et al.*, 2011) or type of their embedded knowledge (Tzabbar, 2009; Tzabbar *et al.*, 2013). In the case of scientists' exits from firms, it has been argued that departures represent the migration of critical knowledge that can affect both exploitation and exploration activities (Tzabbar and Kehoe, 2014) and also the inputs and outputs of the innovation process (Kim and Marschke, 2005).

3.4 *Scientific Productivity*

Studies show that scientific productivity is another source of differentiation among scientists. It has been argued that star scientists, that is, those with both more productive and more influential behaviours, produce more innovative outputs (Cockburn and Henderson, 1998; Rothaermel and Hess, 2007; Hess and Rothaermel, 2011). Star scientists not only make important scientific contributions but also occupy strategic positions in their social and academic networks (Almeida *et al.*, 2011; Subramanian *et al.*, 2013). Such scientists are identified using several strategies, which introduce other scientist types (for a review, see Subramanian *et al.*, 2013; Han and Niosi, 2016). However, stars, generally, are defined as researchers who publish widely and whose articles are cited frequently. A small group of studies use other criteria, such as scientists' publications reporting gene-sequence discovery (Zucker *et al.*, 1998, 2002) or patents (Baba *et al.*, 2009), to identify stars. As a result of these different identification strategies, some studies analyse the impact of both star and non-star scientists and find that their roles in firms' innovation activities are different (Rothaermel and Hess, 2007; Hess and Rothaermel, 2011). Star scientists are visionaries in discovery tasks, while non-star scientists are more active in the development of products (Rothaermel and Hess, 2007).

3.5 *Scientists' Ties*

The study by Grigoriou and Rothaermel (2014) goes beyond individual productivity and offers a more societal vision of human capital engaged in knowledge-generating activities. They propose the concept of 'relational stars', who are individuals who are both strong knowledge producers and form, maintain and manage intra-firm networks (in other words, collaborative outliers). The study identifies two types of relational stars: integrators (individuals with extensive network collaborative ties) and connectors (individual whose collaborative ties span firms' knowledge networks and link the firm to distant knowledge clusters). They find that relational stars show patterns of collaborative behaviour that increase organizational capabilities and generate more high-quality inventions.

3.6 *Scientists' Research Orientations*

There is a literature stream that analyses the impact of scientists, building on Stokes's (1997) research, and classifies scientists into different categories based on whether they are involved in fundamental or applied knowledge (see Baba *et al.*, 2009; Subramanian *et al.*, 2013). These scientist typologies include star scientists (engaged in fundamental research), Edison scientists (engaged in applied research) and Pasteur scientists (involved in numerous patent applications and high-quality scientific papers). The studies by Gittelman and Kogut (2003) and Subramanian *et al.* (2013) focus on the corporate scientists' heterogeneity and propose the concept of 'bridging scientist' to capture the effect of scientists who engage in both publishing and patenting and contribute to transforming scientific knowledge into inventions within

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organizations. Subramanian *et al.* (2013) build on Stokes's research and classify bridging scientists as Pasteur bridging scientists (those with above average patenting and publication records), Edison bridging scientists (those with good patenting records, but below average publications records) and other bridging scientists (those with lower-than-average patenting activity). The results of this study show different effects on firms' innovation activities. For example, Pasteur bridging scientists help to reduce the firm's dependence on external knowledge, while Edison bridging scientists, compared to other scientists within the firm, have a positive and significant impact on the firm's innovation performance.

3.7 *Scientists' Knowledge*

The type of embedded knowledge is another source of heterogeneity that affects the firm's innovation output. Studies show that scientists differ in their knowledge diversity (Herrmann and Peine, 2011), their different knowledge from the firm's existing knowledge base (Tzabbar, 2009; Tzabbar *et al.*, 2013) and their knowledge-related experience (Kaiser *et al.*, 2018).

Herrmann and Peine (2011) distinguish between heterogeneous and homogeneous scientific knowledge to show that scientists' knowledge diversity is a determinant of changes to the direction of the firm's innovation strategy. Based on the scientists' different universities, disciplines and countries as indicators of their knowledge diversity, the authors conclude that heterogeneous scientific knowledge facilitates radical product innovation strategies, while homogeneous scientific knowledge is required for incremental innovations.

Tzabbar (2009) and Tzabbar *et al.* (2013) add another knowledge dimension and argue that the knowledge of newly hired scientists can be close to or more distant from the firm's existing knowledge. Using patents, the authors examine the technical positions of hiring firm and hired scientists. A technologically distant scientist is an individual who possesses knowledge that is outside the firm's existing technological boundaries. These studies show that recruiting distant scientists increases the rate of knowledge integration (Tzabbar *et al.*, 2013) and the firm's potential to explore new opportunities (Tzabbar, 2009).

There is a body of work that focuses on the knowledge-related experience of scientists and its impact on firms' innovation output. Kaiser *et al.* (2018) analyse scientists' previous university research experience and scientists' experience of working in technology active firms. This study shows that hiring scientists with university experience has a greater effect on the firm's innovation output than hiring scientists with other types of experience. However, to obtain the maximum benefits from these scientists, the hiring firm must have a university research-friendly culture.

4. Scientists' Effects on firms' Innovation Activities

It is clear that scientists play an important role in firms' innovation activities. This can be concluded from an analysis of scientists' effects on certain dimensions of innovation activity, especially the outputs of the innovation process. The use of outputs is frequent in the literature because indicators, such as patents, allow researchers to follow the scientist's experience in industry and identify certain characteristics. In general, the innovation management literature considers scientists as belonging to the firms' R&D personnel and does not distinguish between the scientific and non-scientific workforce. One reason for this is that it is difficult to obtain relevant data. Scientists are human resources that are not useful to all firms. Their specialized scientific backgrounds and skills make them suited to working in science-based sectors and, in these sectors, access to detailed information on firm strategies is limited.

To analyse the effect of scientists, the empirical evidence is grouped according to the variables used to measure firm innovation activities. Other methods used to group the studies were discarded due to

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the broad range of objectives pursued by the researchers in the field. The following subsections present the main results starting with the most frequent indicators of firms' innovation activity. Most studies use patents and new products to analyse scientists' effects and, in a few cases, indicators of firm innovation strategies.

4.1 *Lessons Learned from Use of Patent Measures*

Sixty per cent of the studies analysed use of patents to measure firm innovation performance (see the Appendix). Patenting is oriented towards the generation of practical and appropriate applications of technologies in the high-tech sectors and allows researchers to follow the paper trails of other scientists (Almeida *et al.*, 2011). Patents provide information on the number of scientists involved in the innovation activity, the scientific knowledge used by the firm, the firm's alliances, its decisions related to its technological positioning, etc. Studies show that scientists not only affect the firm's probability of applying for a patent but also the number and importance of the patents.

4.1.1 *Number of Patents*

Focusing on the group of studies analysing the impact of scientists on the number of patents, the evidence is inconclusive and most of this work primarily analyses the role of star scientists (those with high levels of productivity). The importance of stars in this research field derives from two facts: (1) they have tacit knowledge which is important for successful innovation and (2) they receive a large proportion of the organizational resources to support their research. As a result, they exert disproportionate influence over a firm's research direction (Kehoe and Tzabbar, 2015). Despite the prominent role of star scientists, in general, the idea prevails that their presence in firms does not increase the number of the firm's patents (Furukawa and Goto, 2006a; Rothaermel and Hess, 2007; Baba *et al.*, 2009). Furukawa and Goto (2006a,b) find that firms employing scientists who publish numerous academic papers and whose papers are cited frequently do not apply for a larger number of patents. However, some studies identify a marginal effect of star scientists. Zucker *et al.* (2002) find that firms whose scientists collaborate with stars apply for more patents and have more highly cited patents, and Furukawa and Goto (2006a) find that stars promote patenting by their co-authors in the firm. These results suggest that the presence of a star scientist in the firm is not a sufficient guarantee of successful innovation and firms that want to take advantage of star scientists should implement mechanisms that promote collaboration and interaction among scientists with different types of knowledge and skills (Baba *et al.*, 2009). The study by Almeida *et al.* (2011) sheds more light on the importance of connectivity among scientists and shows that individual (often informal) collaborations contribute to enhancing the firm's innovative capabilities. Along similar lines, Guler and Nerkar (2012) show that local cohesion among scientists in closely co-located firms enhances creativity and innovative outcomes.

4.1.2 *Patent Citations*

The impact of scientists on the number of forward patent citations has also been analysed. Forward citations refer to the number of times a patent is cited in subsequent patents (Gittelman and Kogut, 2003) and they are seen as correlated to the technological importance and economic value of the patent (Subramanian *et al.*, 2013). Several authors use forward patent citations to measure the firm's innovative productivity and to track inter-firm knowledge flows and inter-firm scientist mobility. Also, studies using citations as a measure of productivity show a positive effect of scientists (Zucker *et al.*, 2002; Gittelman and Kogut, 2003; Sapsalis *et al.*, 2006; Subramanian *et al.*, 2013). Kehoe and Tzabbar (2015) find that, on average, the innovation productivity of firms employing star scientists is 71% higher compared to

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firms with no star scientist employees. Sapsalis *et al.* (2006), based on a comparison among the values of corporate and academic patents, conclude that the value of the firm's patents increases with a higher number of inventors and when they rely on their own scientific publications. Gittelman and Kogut (2003) find a positive effect on patent value of scientists who bridge discovery and innovation[2] and suggest that they may perform the important function of identifying and applying scientific research useful for business purposes.

Some studies use citations to track firms' decisions and produce some interesting results. Hess and Rothaermel (2011) analyse recruitment of scientists and R&D alliances as mechanisms to obtain upstream knowledge and find that they are substitutes when predicting citation-weighted patents. Rosenkopf and Almeida (2003) provide a table of citations to the patents of other firms, where each citation is treated as one instance of the focal firm drawing on the knowledge of the cited firm. Their results show that inventor mobility facilitates inter-firm knowledge flows and that the effectiveness of inventor mobility increases with technological distance.

4.1.3 *General Information from Patents*

Patents have also been used to show the impact of scientists on firms' strategic decisions related to the type of innovation pursued, firms' technological positions and the exploration versus exploitation knowledge dilemma. There are four important implications of use of patent information. Firstly, the heterogeneity of scientists has significant effects on the kinds of exploratory innovative outcomes pursued by the firm. Subramanian (2012) analyses the impact of scientists on recombinatory innovation (i.e. the extent to which patents issued to focal firms recombine ideas from patents from diverse classes) versus pioneering innovation (i.e. the proportion of patents issued to focal firms with no citations to prior patents). Her study reveals that both bridging scientists and pure inventors have a positive effect on recombinatory and pioneering innovation. Despite the fact that a strong background in applied knowledge is a key competence for non-pioneering innovation, her results reveal that scientific competence plays an important role when firms undertake the process of technological recombination.

Secondly, the recruitment of scientists increases the firm's likelihood of combining knowledge from outside its existing technological boundaries, that is, technological repositioning. Tzabbar (2009) estimates the degree of technological repositioning by comparing the firm's technological position before the patent application, to its position after application. His study reveals that recruitment of distant scientists results in significant technological repositioning of the hiring firm. However, the firm's potential to explore further is limited to the extent that its productivity depends on the number of incumbent star scientists. Also, the results in Hohberger *et al.* (2015) support the idea that the collaborations of individual scientists across organizations provide firms with knowledge that can help to redirect their decisions and reorient their innovation activity towards emerging areas.

Thirdly, scientists contribute to the firm's knowledge integration process. Tzabbar *et al.* (2013) use patent citations data to show that knowledge integration occurs when the hiring firm's patent cites both its own patents and those of its hired scientists. The results show that the recruitment of scientists with distant knowledge speeds up knowledge integration.

Fourthly, the turnover of star scientists disrupts innovation routines in firms and increases their propensity to undertake exploration activities. Tzabbar and Kehoe (2014) operationalize exploration as the ratio of the number of patent applications in unfamiliar technological classes to the number of total patent class applications in a period, and exploitation as the ratio of the firm's citations to its own patents over all citations made by the firm in a specific period. Their results show that the departure of a star scientist who was responsible for maintaining collaborations with colleagues in the firm has a negative effect on exploitation activities and a positive effect on exploration, compared to the departure of other star scientists.

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4.2 *Lessons Obtained from Product Measures*

Other innovative outputs used in studies estimating the effect of scientists include firm products, which, unlike patents, capture the economic impact of inventive activity (Zucker *et al.*, 1998). Because the effect of scientists is analysed mainly in the context of science-based sectors, such as pharmaceuticals or biotechnology, these studies use the number of products in development (e.g. the number of products that a firm has in regulatory trials) and the number of products on the market. In general, these works show a positive relationship between the firm's new product development and the scientific workforce (Deeds *et al.*, 2000). However, some studies note that the rate of new products increases with the quality of the firm's scientific team (Deeds *et al.*, 2000) and the collaborations that the firm's scientists maintain with academic star scientists via co-authoring of academic papers (Zucker *et al.*, 1998, 2002). There are two studies that go further and explore the effect of scientists on the firm's decisions about the technology employed to obtain new products and the product-market strategy. For instance, Tegarden *et al.* (2012) analyse the impact of scientists on the firm's ability to offer an extensive range of products embodying the same technology (exploitation via greater product scope) and the number of times that a firm offers pioneering products which embody emerging technologies (exploration via product pioneering). The results reveal a positive relationship between the publishing activity of scientists, and the firms' commercial exploitation and exploration of an emerging technology. The study concludes that firms whose products rely on emerging technologies need to develop the ability to search and identify new opportunities, and scientists provide a means to connect with the communities where these opportunities are likely to be found. Also, Herrmann and Peine (2011) show that radical product innovation strategies are facilitated by scientists with heterogeneous knowledge backgrounds, whereas incremental product innovation strategies benefit from scientists with homogeneous knowledge. Their results reveal that firms that combine adequate levels of scientific knowledge and skills are exponentially more successful at achieving radical innovation.

4.3 *Lessons Obtained from Organizational Strategic Measures*

There are numerous studies examining how scientists shape the organizational strategies of firms. The evidence focuses mainly on strategic alliances and the adoption of science-driven strategies. In the first case, the presence of scientists in the firm increases the number of alliances (Stuart *et al.*, 2007; Luo *et al.*, 2009; Spithoven and Teirlinck, 2010; Teirlinck and Spithoven, 2013). This is because scientists are critical for integrating different and diffuse knowledge sources (Hess and Rothaermel, 2011); they connect firms to the producers of scientific knowledge (Subramaniam and Youndt, 2005) and attract research partners by signalling organizational legitimacy (expert personnel managing R&D), which reduces the potential partner's evaluative uncertainties (Luo *et al.*, 2009). There is also evidence that scientists are especially useful in alliances aimed at the creation of new knowledge or the exchange of knowledge. Spithoven and Teirlinck (2010) show that a high level of education (such as a PhD) among R&D personnel is important for promoting alliances. In the science-based industries, such as biotechnology, this role is crucial for attracting partners, especially if firms are located outside of the main industry network or are not well connected (Luo *et al.*, 2009). In addition, scientists play an important role for firms that need access to knowledge located outside national borders.

Some studies analyse scientists' effects on firms' adoption of strategies for using science in the innovation process (Lacetera *et al.*, 2004; Ding, 2011). Scientific exploratory activities are important for firms since science establishes the principles that guide the discovery process in research, enables the generation of novel elements to be used in the solutions to technological problems and enhances the ability of firms to absorb external knowledge by creating awareness of external discoveries (Lowe and Veloso, 2015). Ding (2011) points to the several benefits associated with use of science by firms, which include increased capability to absorb public sector research and attraction of high-quality human resources.

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In this context, Lacetera *et al.*'s (2004) study shows that the recruitment of scientists had a significant relationship to the adoption of science-driven research in the pharmaceutical industry during the 1980s and early 1990s, and to the changes experienced by firms in relation to their internal organizational capabilities. In the biotechnology context, Ding (2011) shows that these changes can lead firms to adopt an open-science strategy. In his study, the presence of doctoral graduate founders increases the firm's count of research paper publications in ISI-indexed scientific journals.

5. Methodological Issues

5.1 *Data*

Most empirical work on the effect of scientists on firms' innovation activity focuses on science-driven sectors. The biotechnology industry seems to be the most frequently analysed industry, followed by pharmaceuticals, advanced materials and semiconductors.

Biotechnology firms are chosen specifically for their genesis in university labs and, unsurprisingly, many of them employ scientists (McMillan and Tomas, 2005). At the end of the 1990s and the beginning of 2000, the biotechnology industry became of interest because its knowledge base was emerging and represented a confluence of diverse disciplines (Deeds *et al.*, 2000). In addition, this industry has been identified as having a high propensity to patent and publish and to build alliances (Tzabbar, 2009; Subramanian *et al.*, 2013). The wide use of patents and publications in this industry has provided researchers with systematic records of innovation activities (Rosenkopf and Almeida, 2003).

According to Luo *et al.* (2009), the recruitment of a relatively high percentage of individuals with advanced education and training has become a hallmark of the science-based industries and, as a result, they are suitable subjects for an analysis of the role of the scientific workforce. It has been noted that firms in these industries present characteristics that demand highly qualified human resources. For example, technology-based firms need to demonstrate their scientific competence to generate high-quality innovations and also need to rely on networking due to the highly differentiated and specialized knowledge on which they rely. Other reasons to focus on the science-driven industries rely on the fact that, often, the most important innovations in these industries come from R&D collaborations between universities and firms (Baba *et al.*, 2009). Gittelman and Kogut (2003) suggest that biotechnology firms act as vehicles for the private appropriation of knowledge produced in universities and its transfer to the market. For these reasons, few studies analyse the effect of scientists in different industries (Kim and Marschke, 2005; Criscuolo *et al.*, 2014; Kaiser *et al.*, 2015; Salter *et al.*, 2015) or include firms in the service sector (Spithoven and Teirlinck, 2010; Teirlinck and Spithoven, 2013).

The Appendix provides detailed information on the sources of data, the sample and the data structure of the studies analysed. In general, work on the science-driven industries is based on small samples of firms which makes it difficult to generalize about the effects of scientists. Consequently, the results should be interpreted in terms of the context in which the firms operate. In the case of data sources and data structure, the review shows that studies in this field use more than one data source. Information on patents and scientific publications are the most frequent sources, with a few studies based on private surveys. Panel and cross-sectional data are used equally, with a few studies using event history data.

5.2 *Empirical Models*

In general, the functional forms of the empirical models include a dependent variable to measure the firm's innovation activity or R&D strategy, an independent variable for the presence of scientists or scientific workforce activity, and a vector of the explanatory variables which includes firms' characteristics, scientists' characteristics and the interaction terms. Studies in this area present important differences

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regarding data structure and analytical methodologies, which makes it impossible to undertake an exhaustive analysis of all of them. However, controls for endogeneity and analysis of the interaction terms are found in many studies.

5.2.1 *Endogeneity*

One of several difficulties related to empirical analysis in this area is identification of causal effects. Although many studies include robustness tests, the results remain subject to some endogeneity concerns which do not allow authors to make strong causal claims. Therefore, many studies establish only statistical associations between scientists and firms' innovation activity (see the Appendix). However, there is an important strand of work which does tackle the endogeneity problem. The basic premise is that a positive correlation between the presence of scientists in the firm and a change in the firm's innovation activities does not necessarily imply that the former causes the latter. Lacetera *et al.* (2004, p. 135) properly explain the endogeneity problem in this research field:

> It may be the case, for example, that the adoption of a new strategy leads simultaneously both to a deliberate investment in new organisational processes and routines and to the decision to hire new people with new skills. Firms which have adopted such a strategy will 'select into' hiring new people, with the result that both hiring rates and organizational capabilities may change, without hiring having caused the change in organisational capabilities.

Some studies also point out that the employment of scientists might be endogenous if correlated to unobservable effects which influence change, such as unobserved firm quality or firm competence (Tzabbar, 2009) and unobserved characteristics of R&D projects (Tzabbar *et al.*, 2013). These studies use different strategies to address potential endogeneity, including instrumental variables (IVs) (Lacetera *et al.*, 2004; Kim and Marschke, 2005; Kaiser *et al.*, 2015), two-stage Heckman selection process (Rao *et al.*, 2008; Tzabbar, 2009; Tzabbar and Kehoe, 2014; Kehoe and Tzabbar, 2015), lagged variables (Rothaermel and Hess, 2007; Almeida *et al.*, 2011) and additional sensitivity analyses (Kim and Marschke, 2005). The Appendix describes the different identification strategies used to separate causal effects from statistical association in each of the studies analysed.

Addressing endogeneity problems raises two issues for future research in this area. Firstly, identifying the variables influencing the presence of corporate scientists in the firm. To our knowledge, there are no theoretical approaches to guide the selection of these variables (Herrera and Nieto, 2015). In general, most papers use indicators of the firm's technological behaviour to explain the recruitment of scientists (Tzabbar, 2009; Kehoe and Tzabbar, 2015). The reason for this choice of variables is that firms with high levels of innovation performance attract more scientists. Other potential factors related to firm strategies, leadership, management of human resources or public policies are ignored. As a result, future research should increase our knowledge about the factors that influence firms' decisions related to recruiting scientists. The second issue is linked to the selection of appropriate IVs. Valid instruments must be correlated to the endogenous variable (scientific workforce), but not related to the dependent variable (an indicator of the firm's innovation activity) in the model. Achieving this is not easy because, in many cases, the presence of scientists in firms is linked closely to the firm's innovation behaviour. To address this, several papers employ variables for the quality or quantity of PhD programmes in science or the features of the scientist job market (Lacetera *et al.*, 2004; Kim and Marschke, 2005; Swift, 2018). Some authors argue that these variables could influence demand for or supply of scientific workforce, but not the firm's innovation strategy (Lacetera *et al.*, 2004). Future studies should extent some more recent studies which analyse the mobility on or the labour market for highly trained employees, in order to select appropriate instruments.

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5.2.2 *Contingent Factors*

The interaction terms are included to explore whether the impact of scientists on firms' innovation activities is direct or is moderated by factors related to the scientists' individual characteristics and positions in the firm, or firm characteristics. A summary of these factors is presented below.

1. Orientation of scientists' human capital: Interactions with individual characteristics highlight the heterogeneous characteristics of the scientific workforce and their importance. Several studies analyse the effect that produces the interactions among different types of scientists, classified according to their research orientation (Subramanian, 2012) or productivity (Rothaermel and Hess, 2007).
2. Scientists' positions in firms and the social interdependence associated with these positions: Kehoe and Tzabbar (2015) point out that scientists with high levels of power in firms (such as star scientists) may influence other scientists' opportunities for innovative production and leadership. Their analysis demonstrates that the breadth of stars' expertise and their collaboration with colleagues are determinants of their effects on the firms' innovative outcomes.
3. Firms' involvement in alliances: Some studies analyse whether the interaction between recruitment of scientists and firms' alliances influences innovation activity. In general, the interest in this interaction is emphasized by the fact that firms use both recruitment and alliances to access new knowledge, and these mechanisms can be substitutes or complements. Rothaermel and Hess (2007) and Hess and Rothaermel (2011) found that the simultaneous pursuit of these mechanisms results in a marginal decrease in the firm's innovative performance. From another perspective, Subramanian *et al.* (2013) show that the firm's innovation activity depends on the composition of its human capital and how that human capital interacts with external R&D alliances.
4. The level of connectivity of firms or their network position: Luo *et al.* (2009) present arguments to show that the impact of scientists on alliance formation depends on whether the scientists work for less-connected or well-connected firms. Considering that scientists play both productive and legitimating roles, which can be useful for attracting partners, we expect a stronger effect of scientists in less-connected firms. However, in industries, such as biotechnology and other science-based fields, where collaboration becomes institutionalized over time, the value of the signal provided by scientists declines. In this context, Luo *et al.* (2009) analyse the interaction between the presence of scientists in firms and the low-centrality measure of firms and industry partnership norms.
5. The organizational environment: The basic premise for including interactions between scientists' presence and the organizational environment is that the environment constrains the choice of organizational strategies, especially if they are linked to innovation. Ding (2011) analyses how the interaction between scientists in the firm's founder group and the technological and institutional environments influences the firm's choice of organizational strategy (e.g. implementing an open-science policy). The study demonstrates that scientists may counterbalance the effect of the organizational environment because firms with scientist founders are less deterred by a high-risk technological environment in the pursuit of an open-science strategy. The organizational environment is also important in situations where scientists attempt to achieve greater autonomy to pursue their ideas. Criscuolo *et al.* (2014) show that these individual efforts tend to be successful in high-performance work settings and in the presence of other individuals involved in similar efforts.
6. The motivation and ability of the firm to use the knowledge of newly hired scientists: Tzabbar (2009) analyses the conditions in which the recruitment of scientists results in significant technological repositioning of the hiring firms. The author presents arguments to show that the final impact of scientists depends on the interaction between the number of distant scientists and two internal contingencies associated with the firm's ability to use the knowledge of newly hired scientists. These contingencies are related to the power of the asymmetries that emerge from the distribution of

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innovative productivity among scientists and the breadth of the organization's existing technological knowledge. According to Tzabbar (2009, p. 874), the premises behind these interactions are twofold:

> [1)] The more a firm's existing technological knowledge is driven by one or a few 'star' scientists, the less likely the firm is to significantly shift its technological position... [and 2)] ...recruiting technologically distant scientists may have greater effects at moderate levels of technological breadth than at very high or very low technological breadth.

Following the focus on internal contingencies, Tzabbar *et al.* (2013) analyse the moderating role of the firm's experience of recruiting scientists. The authors test the hypothesis that the rate of integration of knowledge (dependent variable) from distant scientists is faster if firms have previous experience of recruiting scientists. The results show that firms with more experience are able to exploit new sources of information, more efficiently and more quickly, than firms with more limited experience.

6. Managerial Implications

Although the empirical analysis of the studies provides important information on the role of scientists in firms' innovation activities, only a few studies offer explicit managerial implications. Some of these implications are summarized below.

Some studies recommend that managers put in place appropriate scientist-selection processes to ensure that the knowledge and experience of the scientists matches the firm's requirements (Baba *et al.*, 2009; Spithoven and Teirlinck, 2010). This match is important since it has been shown that scientists draw on their educational background and experience to inform their business visions and that these visions affect the firm's strategies (Ding, 2011). In addition, the importance of the match between the specialized human capital and the firm's tasks has been highlighted (Deeds *et al.*, 2000; Baba *et al.*, 2009). For example, Deeds *et al.* (2000, p. 225) note that firms with research scientists in their top management teams 'are wasting the time of these scientists on day to day management activities, rather than allowing them to focus on their research'.

Several studies allude to the need to promote interactions among the scientists employed in the firm. Furukawa and Goto (2006a) suggest that core scientists who represent innovation resources should not be isolated from other researchers and employees because the interactions among them facilitate the cross-fertilization of ideas, which increases the firm's capability to be more innovative (Herrmann and Peine, 2011; Guler and Nerkar, 2012).

Studies also offer recommendations about scientists' involvement in scientific activities such as the publication of papers and participation in academic meetings. According to Furukawa and Goto (2006a), these activities should not be viewed as a means to fulfil these scientists. Rather, the scientists who publish academic papers and are members of the academic research communities have an edge in the technology-driven markets and facilitate the firm's ability to commercialize emerging technologies (Tegarden *et al.*, 2012). The study by Criscuolo *et al.* (2014) also note that it is necessary for scientists to have a certain level of autonomy to work on their own ideas without any formal organizational support. According to them, undertaking non-programmed R&D activities helps scientists to develop innovations based on exploration of unconventional directions and gives them time to develop embryonic ideas before organizational assessment.

It has also been suggested that scientists' knowledge search behaviours affect innovation outcomes. Individuals with greater external search breadth (or openness) may be more innovative than those with narrower contacts with external sources (Dahlander *et al.*, 2016). However, as Salter *et al.* (2015) found, there is a threshold to openness after which individual-level returns become negative due to the increasing costs of managing diverse sets of external knowledge.

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Scientists also provide strategic benefits. Luo *et al.* (2009) emphasize the importance of scientists for attracting partners. Their scientific activities can make the firm more attractive for alliances, and their credentials can enhance the firm's organizational legitimacy. Ding (2011) considers that the recruitment of scientists is particularly important in the early stages of an industry and for less-connected firms. However, some studies warn that firms that invest simultaneously in scientific human capital and R&D alliances with universities may experience redundancy in their knowledge assets (Hess and Rothaermel, 2011; Subramanian *et al.*, 2013).

Finally, the recruitment of scientists is recommended for firms with limited capabilities for generating novel knowledge re-combinations and for young firms with insufficient resources to develop sophisticated RD alliances. In the first case, Al-Laham *et al.* (2011) indicate that new scientists can shed light on existing problems and increase the firm's pool of knowledge and capabilities to explore beyond its existing knowledge boundaries. In the second case, Tzabbar *et al.* (2013) note that the recruitment of scientists is particularly useful in the case of young firms with neither the time nor the opportunities to develop alliances or internal capabilities to integrate external knowledge. Recruitment of scientists allows a faster impact on innovation than use of the R&D alliances.

7. Conclusions

This study presented a systematic review of the empirical literature analysing the effects of corporate scientists on firms' innovation activity. Although this review confirms that scientists are crucial for firms' innovation activity and they play a critical role in the process of transfer scientific knowledge to industry, we observe that the literature in this field has advanced little in the last years and faces some major challenges. One of these issues is formulating the research questions in line with the new dynamics driving use of science in the private sector. A strong focus on manufacturing firms and patenting seems now to be outdated when considered against the advances in the use of science in the service industries or non-traditional science-driven industries. In this context, this review has some important implications and recommendations for future research. Firstly, the studies use different theoretical approaches to highlight the importance of highly qualified human resources for firms' innovation activity; however, they do not result in useful assumptions to guide the evaluation of scientists' effects. In general, the hypotheses are supported by the empirical evidence and future research should focus on refining the theoretical background supporting the relations being analysed.

Secondly, empirical evidence relating to the heterogeneity of scientists shows that different types of scientists have different effects on firms' innovation activities. The main sources of heterogeneity analysed are scientific productivity and scientists' preferences for publishing or patenting. Other sources of heterogeneity are equally important, but remain rather unexplored. These sources are related to the link between scientist's background and the firm or the scientist's position in the firm, which can be decisive for understanding the role of scientists in firm decision-making. Future work could try to clarify the real relationship between scientists and firms.

Thirdly, the effect of scientists is analysed in terms of innovative outcomes such as patents. This limits our understanding of the role of scientists in the broader innovation process. Because patents are an intermediate outcome, future research could adopt an upstream–downstream approach to identify the critical roles played by scientists during the whole innovation process. Several innovation activities emerge as interesting topics for research knowledge procurement, R&D investment, project orientation, new methods to protect innovations (trademarks, designs, etc.) and the commercialization of scientific knowledge. In addition, using the management innovation literature framework, future research could analyse scientists' effects on organizational performance. The studies reviewed highlight the importance of aligning human capital to organizational resources and the social and technological structures of the firm.

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Fourthly, the empirical evidence shows that there are several factors that moderate scientists' effects on firms' innovation activity. This suggests that hiring scientists is a necessary, but not sufficient condition for improved firm innovative performance. Future studies could deepen analysis of the factors that enhance or limit scientists' effects. In addition, because recruitment of scientists is seen as a mechanism to obtain knowledge, it would be interesting to analyse whether recruitment complements or substitutes other mechanisms employed by the firm. The studies reviewed analyse the interaction with alliances; however, there are several other knowledge procurement mechanisms that could be investigated.

Fifthly, these studies emphasize the role of scientists in the biotechnology industry; consequently, the results may be biased towards technological areas where knowledge is more easily patentable or where there is a long tradition of publishing or patenting. Thus, studies of other sectors are needed to validate the arguments related to the role played by scientists in firms' innovation activity.

Finally, although some works offer some managerial implications, among the 40 studies analysed, only one offers some implications for policymakers (Furukawa and Goto, 2006a). A strong academic career orientation becomes problematic if academia is unable to absorb all the doctoral graduates; industry is becoming a major source of employment for scientists (Herrera and Nieto, 2016). This suggests the need for comprehensive policies to tackle the issues of scientists' mobility to firms, scientific knowledge transfer, adaptation of academic programmes to firms' needs and networking between firms and universities.

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Notes

1. Because this is a first review of this literature, it does not focus on a definition of scientist. Allen's (1977) seminal work describes scientists as individuals whose education focused on the natural sciences and distinguishes them from other employees such as engineers. However, as Gruber *et al.* (2013 p. 837) point out, the differences highlighted by Allen 'have not been considered in contemporary theorizing about technological knowledge recombination processes and outcomes, nor they have been subject of a large-scale empirical test'. In addition, these authors highlight that, nowadays, engineering curricula have a major science content.
2. These are individuals named on a patent and at least 1 publication.

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Appendix: Articles Analysed.

No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
1	Cockburn and Henderson (1998) Times cited: 526	Worldwide	Pharmaceutical (20 firms)	1980–1984 (Panel data)	ISI Science Citation Index	Statistical association	OLS regression	(1) Type of co-authors: self, hospitals, public, private, non-profit, universities, US NIH, (2) Research output: patent being granted in at least two out of three major world markets – Japan, USA and Europe, (3) Research input: expenditure on the 'discovery' phase of R&D.	The extent to which each firm was 'pro-publication' rated on a five-point Likert scale.	'Does more participation in the wider scientific community through publication or co-authoring give a private sector firm a relative advantage in conducting research?' (p. 172)
2	Zucker *et al.* (1998) Times cited: 418	USA	Biotechnology (110 firms)	1989–1994 (Cross-sectional data)	Private survey	Statistical association	Poisson regression/ Tobit model	(1) The number of products in development, (2) the number of products on the market and (3) the net employment growth.	The number of gene-sequence–discovery articles written by star scientists.	The paper examines 'the effects of one scientific breakthrough on a relatively small number of industries which experience a technological transformation as a result'. (p. 66)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
3	Deeds *et al.* (2000) Times cited:183	USA	Pharmaceutical (94 firms)	1992–1993 (Cross-sectional)	Private survey	Statistical association	OLS regression	The number of new products a firm has on the market or in trials.	The number of citations for each scientist in the firm (Science Citation Index).	'H2: The quality of the firm's research team will have a positive relationship with the number of new products developed by the firm'. (p. 217)
4	Zucker *et al.* (2002) Times cited: 449	USA	Biotechnology (3152 observations by firm and year)	1976–1991 (Panel data)	Private survey/ ISI Science Citation Index	Statistical association	Poisson regression	(1) Cumulative patents granted, (2) cumulative citation-weighted patents granted, (3) total products in development, (4) total products on the market and (5) total employees.	Articles written by a star scientist affiliated with the firm.	The paper identifies 'the main and robust empirical effects due to real scientific labor contributions of star scientists to performance of the firm'. (p. 138)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
5	Gittelman and Kogut (2003) Times cited: 279	USA	Biotechnology (116 firms)	1982–1997 (Cross-sectional)	Private survey/ Derwent Biotechnology Abstracts	Statistical association	Negative binomial regression	Forward patent citations.	The total number of firm publications. The percentage of joint patent-publishers at the firm level.	'PROPOSITION 4. Scientists who bridge discovery and innovation are able to reconcile these two conflicting logics more effectively than those specializing in either science or technology'. (p. 369)
6	Rosenkopf and Almeida (2003) Times cited: 618	USA	Semiconductor (74 firms)	1980–1989 and 1990–1995 (Panel data)	Private survey/ ICE and Dataquest	Statistical association	Negative binomial regression	Patent citations.	Mobility of inventors.	'HYPOTHESIS 4. The likelihood that a focal firm will draw upon the knowledge stock of another increases when the focal firm hires inventors previously employed by the other firm'. (p. 754)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
7	Lacetera *et al.* (2004) Times cited: 33	Worldwide	Pharmaceutical (21 firms)	1980–1994 (Panel Data)	Private survey/ ISI Science Citation Index	Causal effects (instrumental variable)	OLS regression/2SLS regression/Poisson regression	The degree of science-driven discovery adoption.	The number of star scientists.	The paper explores the degree to which the hiring of 'star' scientists was instrumental in changing the ability of pharmaceutical firms to adopt science-based drug discovery.
8	Kim and Marschke (2005) Times cited: 85	USA	15 industries (31503)	1975–1992 (Panel data)	Annual Demographic Files of the Current Population Survey/ NBER	Causal effects (instrumental variables/lagged variables)	Maximum likelihood regression	The firm's patent count.	The share of scientists leaving the firm.	The article examines 'theoretically and empirically how the threat of a scientist leaving affects the firm's patenting and R&D decisions'. (p. 298)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
9	McMillan and Thomas (2005) Times cited: 8	USA	Biotechnology (35 firms)	1990–1997 and 2003 (Repeated cross-sectional data)	Mergent Online/ SEC company	Statistical association	Multiple regression	The technology and stock market valuations of companies.	The percentage of PhD- or MD-level scientists as CEOs.	The paper examines 'the relationship between the three company characteristics (age of company, percentage of top management with a PhD or MD, and whether the CEO has a PhD or MD), and the technology and stock market valuations of companies'. (p. 466)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
10	Furukawa and Goto (2006a) Times cited: 35	Japan	Pharmaceutical (5 firms)	1987–2002 (Pool data)	Web of Science/ Japanese Patent Office	Statistical association	Multiple regression	The cumulative number of patent applications.	Corporate scientists with the highest publication performance score.	'The purpose of this paper is to investigate the role played in the process of innovation by corporate scientists who have published numerous academic papers or whose papers have been frequently cited in other studies'. (p. 24)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
11	Furukawa and Goto (2006b) Times cited: 18	Japan	Electronics (10 firms)	1987–2002 (Cross-sectional data)	Web of Science/ Japanese Patent Office	Statistical association	Non-parametric Mann–Whitney U-test	The cumulative number of patent applications.	The number of corporate scientists and the number of papers per corporate scientists.	'Our research questions are whether core scientists in Japanese electronics companies promote the number of patent applications by their collaborators in their companies or not, and how core scientists increase the patent applications of collaborators'. (p. 229)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
12	Sapsalis *et al.* (2006) Times cited: 82	Belgium	Biotech-related sectors (239 corporate patent families and 155 academic patent families)	1985–1999 (Panel data)	European Patent Office (EPO)/Delphion Database	Statistical association	Negative binomial regression	The number of forward patent citations.	The number of inventors listed in a patent.	This paper compares the patenting performance of the academic and corporate sectors to determine if they have the same value determinants.
13	Rothaermel and Hess (2007) 366	Worldwide	Pharmaceutical (93 firms)	1980–2001 (Panel data)	Private survey/U.S. Patent and Trademark Office (USPTO)	Statistical association	Negative binomial model	Innovative output = the number of patent applications granted.	The number of firm scientists who published in academic journals and the number of star scientists.	'Hypothesis 1A. A firm's innovative output is a positive function of its intellectual human capital'. 'Hypothesis 1B. A firm's innovative output is a positive function of its star scientists, controlling for non-star scientists'. (p. 900)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
14	Stuart *et al.* (2007) Times cited: 139	USA	Biotechnology (492 firms)	1972–2002 (Panel data)	Center for Research in Securities Prices (CRSP)/The Recombinant Capital Alliance Database/Web of Science	Statistical association	Negative binomial regression	The annual count of university alliances established by a firm.	The paper citation counts for each scientist affiliated with the firm.	'Hypothesis 3. Biotechnology firms with founders and scientific advisors that are well networked in the academic community will be more likely to enter formal technology-access agreements with universities'. (p. 484)
15	Rao *et al.* (2008) Times cited: 118	USA	Biotechnology (93 product introductions by public firms)	1982–2002 (Pool data)	9 sources of data	Causal effects (Heckman selection model)	Maximum likelihood regression	The rewards to product introduction.	The ratio of scientists on the biotech firm's board to the total size of the board.	'H3: The greater a new venture's scientific legitimacy, the larger are its gains from introducing a product on its own than from doing so through an alliance with an established firm'. (p. 64)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
16	Baba *et al.* (2009) Times cited: 97	Japan	Advance materials (455 firms)	1970–2006 (Cross-sectional data)	Japanese Patent Organization (JPO)/ Japanese Science and Technology Corporation, Grants-in-Aid for Science Research	Statistical association	Negative binomial regression	R&D productivity in terms of the number of registered patents taken by a firm.	The total number of publications authored by firms' members or core scientists	This paper analyses factors affecting firms' innovation performance.
17	Luo *et al.* (2009) Times cited: 19	USA	Biotechnology (482 firms)	1988–1999 (Panel data)	BioScan database, industry directories, company documents.	Statistical association	Generalized least squares model	The number of partners involved in R&D alliances and the number in finance alliances.	The number of PhDs or MDs as a percentage of total employees.	'Hypothesis 1. Firms with a large number of scientists are more likely to attract partners in science-based industries for both R&D and finance alliances'. (p. 1316)
18	Tzabbar (2009) Times cited: 59	USA	Biotechnology (456 firms)	1973–1999 (Event history data structure)	BioScan database/ Bioworld/ NBER/ USPTO	Causal effects (Heckman selection model)	Parametric survival models	The Firm's technological repositioning.	The number of distant scientists hired in the three years prior to each measurement time.	'Hypothesis 1. Hiring distant scientists increases the likelihood of significant technological repositioning by a firm'. (p. 877)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
19	Spithoven and Teirlinck (2010) Times cited: 58	Belgium	Several industries including services (645 firms)	2008 (Cross-sectional data)	OECD Business R&D Survey	Statistical association	Non-recursive bivariate probit Model	Two binary dependent variables: (1) 1 if the firm undertakes formal collaborative agreements and (2) 1 if an exchange of knowledge was generated in the framework of formal agreements.	The number of full-time doctorate holders.	'Hypothesis 1 The higher the share of researchers and R&D managers in the R&D personnel; the higher the probability to cooperate in order to create new knowledge or in order to exchange knowledge developed in the firm'. (p. 970) 'Hypothesis 2 The higher the share of highly qualified employees in the R&D personnel; the higher the probability to cooperate in order to create new knowledge or in order to exchange knowledge developed in the firm'. (p. 971)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
20	Al-Laham *et al.* (2011) Times cited: 42	USA	Biotechnology (857 firms)	1973–1999 (Event history data structure)	BioScan database/ Bioword	Statistical association	Maximum likelihood regression	The firm's patent rate.	The cumulative number of inventors.	'Hypothesis 1: The effect of the cumulative number of inventors on the rate at which the firm generates new patents is moderated by the time elapsed since the most recent scientist recruitment. The effect of the cumulative number of inventor's decreases with the time elapsed since the most recent recruitment'. (p. 565)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
21	Almeida *et al.* (2011) Times cited: 31	USA and Europe	Biotechnology (149 firms)	1990–2003 (Panel data)	BioScan database/ EuropaBio and BioCom/Derwer database	Statistical association	Negative binomial regression	The patent innovative output = the number of patent families per firm per year.	The total number of articles in scientific journals co-authored by employees of the focal firm with employees of another organization.	Does the total number of individual-level collaborations by scientists within a firm positively affect firm-level patented innovation output?
22	Ding (2011) Times cited: 27	USA	Biotechnology (512 firms)	1969–2000 (Panel data)	BioScan database/ Compustat/ Recombinant Capital Database	Statistical association	Poisson model	The adoption of open science = the firm's publication counts of research papers published in ISI-index scientific journals after the fifth year it was founded.	The proportion of the firm's founders with PhD	'Hypothesis 1 (H1). Firms with a higher proportion of Ph.D.s on the founding team are more likely to adopt an open-science strategy'. (p. 260)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
23	Herrmann and Peine (2011) Times cited: 25	Germany, Italy and UK	Pharmaceutical (102 firms)	2004–2006 (Cross-sectional data)	Private Survey	Statistical association	Logistic regression	(1) Radical product innovation (RPI), (2) incremental product innovation (IPI) and (3) product imitation (PI).	Indicators for: (1) heterogeneous scientific knowledge and (2) homogeneous scientific knowledge.	'H5. Scientists with heterogeneous knowledge facilitate the pursuit of RPI strategies, whereas H6. Scientists with homogeneous knowledge are at the basis of IPI. H7. PI strategies benefit from no scientific knowledge.' (p. 694)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
24	Hess and Rothaermel (2011) Times cited: 145	Worldwide	Pharmaceutical (108 firms)	1974–2003 (Panel data)	NEBER patent data	Statistical association	Negative binomial regression	(1) Citation-weighted patents and (2) new drugs in development.	The number of star scientists.	'Hypothesis 1: Different upstream activities are substitutes, such that the interaction between star scientists and upstream alliances is negative and thus decreases a firm's innovative performance at the margin'. (p. 888–889) 'Hypothesis 2: Upstream and downstream activities are complements, such that the interaction between star scientists and downstream alliances is positive and thus increases a firm's innovative performance at the margin'. (p. 888–889)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
25	Guler and Nerkar (2012) Times cited: 44	Worldwide	Pharmaceutical (33 firms)	1981–1990 (Cross-sectional data)	Private survey	Statistical association	Negative binomial regression	The number of patents that led to new drugs.	Local cohesion: The density of the scientist's immediate network; Global cohesion: The average density of the immediate network around each scientist.	The paper examines how the configuration of interorganizational networks of scientists influences organizations' innovative output.
26	Tegarden *et al.* (2012) Times cited: 3	USA	Fibre-optic products (695 firms)	1976–1994 (Cross-sectional data)	Luaurin Publishing's Photonics Directory/Inspec Database	Statistical association	Cross-sectional time-series regression	(1) Fibre-optic product scope, (2) fibre-optic product pioneering.	The variable denotes scientific activity by recording whether or not a firm published research.	'Hypothesis 1a: Commercial firms that have employees conduct and publish academic research will have greater product scope than those that do not'. (p. 600)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
										'Hypothesis 1b: Commercial firms that have employees conduct and publish academic research will move into more new product categories as pioneers than those that do not'. (p. 601)
27	Subramanian (2012) Times cited: 8	Worldwide	Biotechnology (222 firms)	1990–2000 (Panel data)	Plunkett's Directory/ NUS Patent Database/ ISI Science Citation Index/ Compustat	Statistical association	Panel linear regression, Fractional logit regression, Tobit model	(1) Re-combinatory innovation: captures the extent to which patents issued to focal firms include combined knowledge from diverse technologies; (2) Pioneering innovation: the proportion of pioneering patents issued to a firm in a year.	The percentage of scientists within a firm whose names appear in publications or patents. Scientists are classified in: pure scientists, bridging scientists and pure inventors.	'H1a: Pure inventors within a firm are positively related to the firm's recombinatory innovation'. (p. 542) 'H1b: Bridging scientists within a firm are positively related to the firm's recombinatory innovation'. (p. 542)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
										'H2a: Pure scientists within a firm are positively related to the firm's pioneering innovation'. (p. 543) 'H2b: Bridging scientists within a firm are positively related to the firm's pioneering innovation'. (p. 543)
28	Subramanian *et al.* (2013) Times cited: 25	Worldwide	Biotechnology (222 firms)	1990–2000 (Panel data)	Plunkett's Directory/ NUS Patent Database/ ISI Science Citation Index/ Compustat	Statistical association	Negative binomial regression	The cumulative number of forward citations accrued to each patent.	The percentage of scientists within a firm whose names appear in publications or patents. Scientists are classified in: star scientists, non-patenting scientists and bridging scientists (Pasteur bridging scientists and Edison bridging scientists).	'Hypothesis 1. The proportion of bridging scientists in a firm positively influences the firm's patent performance'. (p. 598)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
29	Teirlinck and Spithoven (2013) Times cited: 58	Belgium	Pavitt sector classification including services (140 firms)	2004–2005 (Cross-sectional data)	OECD Business R&D Survey	Statistical association	Probit model	Two binary variables which take the value of 1 if a firm engaged in: (1) research cooperation and (2) R&D outsourcing.	The share of research managers and R&D experts holding a PhD.	'Research hypothesis 1a. A higher internal availability in SMEs of research managers, R&D experts as well as their higher levels of qualification and involvement in training should be related to an environment favourable to external knowledge relations by means of research cooperation'. (p. 146) 'Research hypothesis 1b. A lower internal availability in SMEs of research managers, R&D experts as well as their lower levels of qualification and involvement in training should be related to an environment favourable to external knowledge relations by means of R&D outsourcing'. (p. 146)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
30	Tzabbar *et al.* (2013) Times cited: 37	USA	Biotechnology (456 firms)	1973–2003 (Event history data structure)	BioScan Database/ Bioworld Database/ NBER/ USPTO	Statistical association	Maximum likelihood survival models	Knowledge integration = 1 when the hiring firm's patent cites both its own prior patents and the hired scientist's prior patents.	A dichotomous variable indicates if the firm recruited scientists with distal knowledge.	'Hypothesis 1. The rate of knowledge integration is higher for the recruitment of scientists with distal knowledge than for an alliance with a familiar partner'. (p. 483) 'Hypothesis 2. The rate of integration of the knowledge of distance scientists is faster when the firm has general experience with scientist recruitment'. (p. 484)
31	Criscuolo *et al.* (2014) Times cited: 21	Multinational company	Technology-intensive (1 firm)	2010 (Cross-sectional data)	Private survey	Statistical association	Logit model	A rating of individual innovative performance.	A measure of underground R&D efforts conducted by scientists with the aim of producing innovations that will benefit the firm.	The paper analyses the impact of underground R&D efforts conducted by scientists and engineers on firms' innovative performance.

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
32	Grigoriou and Rothaermel (2014) Times cited: 37	Worldwide	Pharmaceutical (106 firms)	1974–2006 (Data panel)	NBER/ USPTO	Statistical association	Negative binomial regression	The annual count of patents granted to the firm	Collaborative behaviour of inventors	'Hypothesis 1: A firm's innovation output is a positive function of the number of integrators in its internal collaborative network'. (p. 593) 'Hypothesis 2: A firm's innovation output is a positive function of the number of connectors in its internal collaborative network'. (p. 594).
33	Tzabbar and Kehoe (2014)Times cited: 25	US	Biotechnology (197 firms)	1973–2003 (Panel data)	BioScan Database/ Bioworld Database/ NBER/ USPTO	Causal effects (Heckman Selection Model)	Generalized Least Squares Estimation	Exploitation= the ratio of a firm's citations to its own patents, Exploration= the ratio of the number of patent applications in unfamiliar technological classes.	Star scientist turnover: A dichotomous variable indicates if a star scientist departed from a firm in the previous 3 years.	'Hypothesis 1a: Star scientist turnover decreases a firm's technological exploitation.' (p. 454) 'Hypothesis 1b: Star scientist turnover increases a firm's technological exploration.' (p. 454)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
34	Kaiser *et al.* (2015) Times cited: 22	Denmark	Several industries (5385 firms)	2000–2004 (Panel data)	EPO's PATSTAT Database	Causal effects (instrumental variables, lagged variables)	Poisson regression/ Generalized method of moments	The total number of a firms' patent applications	R&D workers (i) holding a university degree in natural sciences, engineering and other technical fields, and (ii) who are employed to use and produce knowledge at an advanced level.	The paper analyses the mobility of highly skilled workers (scientists) with respect to the total patenting activity of the firms.
35	Kehoe and Tzabbar (2015) Times cited: 26	USA	Biotechnology (456 firms)	1973–2003 (Penel data)	BioScan Database/ Bioworld Database	Causal effects (Heckman selection model)	Generalized least squares estimation	Innovative productivity: weighted patents by citations received in the 5 years after issuance to account for variance in patent's value.	Star scientist = a dummy variable to indicate if the scientist is a star based on her/his patents.	'Hypothesis 1a: The presence of a star increases a firm's innovative productivity'. (p. 713)

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
36	Hohberger *et al.* (2015) Times cited: 18	USA and Europe	Biotechnology (147 firms)	1990–2005 (Panel data)	BioScan Database/ ISI Science Citation Index	Statistical association	OLS regression	The change in the extent of alignment between a firm and the field in innovative space.	External individual collaborations = the extent to which scientists of a firm engage in collaborative activities with scientists outside of their firms.	'Hypothesis 1. With increasing numbers of external scientific individual collaborations, a firm will become more aligned to the emerging focus of innovation in the field'. (p. 1475)
37	Salter *et al.* (2015) Times cited: 39	Non-available	Technology-intensive (1 firm)	2010 (Cross-sectional data)	Private survey	Statistical association	Negative binomial regression	Ideation performance. The ability of individuals to generate new ideas is based on the number of projects that demonstrated proof-of-concept and passed the corresponding 'implementation gate' in the firm.	Degree of openness of individuals' search efforts; Knowledge breadth.	'We focus on the impact of individual openness to external sources of knowledge on their ability to develop new and useful ideas for the organization'. (p. 488–489).

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No.	Author(s) times cited up to June of 2019	Country	Sector (sample)	Period (data structure)	Source of data	Identification strategy	Methodology	Dependent variables	Independent variables	Research question, hypothesis or paper's objectives
38	Dahlander *et al.* (2016) Times cited: 46	USA	Technology intensive (1 firm)	2008 (Cross-sectional data)	Private survey	Statistical association	Poisson regression	The individual's total number of *patents* granted inversely weighted by the number of inventors on the patent.	The number of scientific publications.	'How does individuals' search breadth affect innovation outcomes? How does individuals' allocation of attention affect the efficacy of search breadth?' (p. 281)
39	Kaiser *et al.* (2018) Times cited: 1	Denmark	Several industries (293 firms)	2000–2004 (Panel data)	EPO's PatStat Database/ Employer–employee Database	Causal effects (lagged variables)	Negative binomial regression/General method of moments (GMM)	The number of forward patent citations.	Workers with scientific and technological capability. Scientists on the top management team (TMT)	'Hypothesis 1 (H1) Newly hired individuals coming from universities, or individuals with university research experience who are hired from firms, should provide higher positive returns with respect to quality-adjusted innovation output than individuals with no university research experience who are hired from firms'. (p. 1939)

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40	Swift (2018) Times cited: 1	USA	Chemical (322 firms)	1996–2005 (Panel data)	NBER US Patent Citations Data File/ SEC Filings	Causal effects (instrumental variables)	2SLS regression	The number of patents granted to a firm, and the number of patent citations.	The number of board members with advanced technological expertise. The number of appointments on the boards of other chemicals company held by board directors with terminal degrees in relevant physical sciences.	'H1. The number of board directors with terminal degrees in chemistry, biology or biochemistry is positively related to firm innovative output'. (p. 188)

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