Harvesting reflective knowledge exchange for inbound open innovation in complex collaborative networks: an empirical verification in Europe

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Abstract

Purpose – *This study aims to investigate the effects of open innovation (OI) and big data analytics (BDA) on reflective knowledge exchange (RKE) within the context of complex collaborative networks. Specifically, it considers the relationships between sourcing knowledge from an external environment, transferring knowledge to an external environment and adopting solutions that are useful to appropriate returns from innovation.*

Design/methodology/approach – *This study analyzes the connection between the number of patent applications and the amount of OI, as well as the association between the number of patent applications and the use of BDA. Data from firms in the 27 European Union countries were retrieved from the Eurostat database for the period 2014–2019 and were investigated using an ordinary least squares regression analysis.*

Findings – *Because of its twofold lens based on both knowledge management and OI, this study sheds light on OI collaboration modes and highlights the crucial role they could play in innovation. In particular, the results suggest that OI collaboration modes have a strong effect on innovation performance, stimulating the search for RKE.*

Originality/value – *This study furthers a deeper understanding of RKE, which is shown to be an important mechanism that incentivizes firms to increase their efforts in the innovation process. Further, RKE supports firms in taking full advantage of the innovative knowledge they generate within their inter-organizational network.*

Keywords *Open innovation, Knowledge dissemination, Big data analytics, Complex collaborative networks, Patent applications, Reflective knowledge exchange*

Paper type *Research paper*

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1. Introduction

In a complex business environment where markets are affected by several transformations, firms are often required to address intensified competitive pressure without delay to survive, while facing an international scenario that has become increasingly dynamic and turbulent (Ferraris *et al.*, 2016). The emergent interdependence of the world's economies, cultures and populations, the rapid shift of many industries and borders, the growth of technology intensity and increased competition require firms to adopt innovative solutions to handle the constant change (Weber and Tarba, 2014).

To respond to the challenges presented by these new elements, firms need to continuously upgrade and improve their learning processes and establish new knowledge

(Del Giudice and Maggioni, 2014). To accomplish this in a dynamic environment, firms have to continuously renew and redefine their resources and competencies (Nonaka and Takeuchi, 1995) and reconfigure existing knowledge assets (Jiménez-Jiménez *et al.*, 2014) to acquire sustainable competitiveness. From this perspective, innovation – which can be defined as a firms' capacity to produce novel product or services continuously (Galunic and Rodan, 1998) – plays a pivotal role, owing to firms' capacity to develop new knowledge. Input from different internal functions represents the key elements for generating new opportunities to innovate, even though a growing number of innovation processes rely on opportunities identified, developed and harnessed in collaboration with outside sources (Terwiesch and Xu, 2008).

This phenomenon, also known as open innovation (OI) (Chesbrough, 2003; Gassmann, 2006), represents a new paradigm in innovation management (Chesbrough and Crowther, 2006). It originated in the high-tech industry and has recently increased dramatically in forms from different sectors and industries (Bughin *et al.*, 2008). OI is a complex issue that has been investigated by different research streams (Gassmann, 2006). The first line of research investigates technology transactions, focusing on inward technology transfer and R&D alliances to explain why firms have to establish internal organizational capability (Lichtenthaler and Lichtenthaler, 2009). Another stream of research moves on from Von Hippel's (1978, 1986) seminal works regarding the role of users in the generation of innovations; it mainly investigates firms' relationships with customers as external sources of new knowledge and ideas in the OI process (Bogers *et al.*, 2010). A further line of research studies innovation markets, in particular, it analyzes how firms can be supported in developing OI modes (Chesbrough, 2007). A last line of research investigates the role of business models in the OI framework while focusing on how firms can exploit knowledge and appropriate the innovation it generates (van der Meer, 2007). OI refers to the use of both inflowing and outflowing knowledge to support and enhance the innovation process. It represents a strategic management tool for firms to cope with constant change and to resolve issues relying only on internal R&D for generating innovation (Lee *et al.*, 2015). It also provides a concrete solution for firms that need to develop partnerships that are useful for establishing sustainable innovation (Kauppila, 2010).

In the OI scenario, firms are enhancing their competitiveness by promoting collaborative approaches, both inside the organization (among employees) and outside (among shareholders) (Battistella *et al.*, 2013). Big data, known as huge amounts of structured and unstructured data, accessible in real time (O'Leary, 2013) have recently been found to significantly support OI, as big data offer a concrete contribution to setting up communities and contests where firms can disseminate new ideas and solutions regarding their OI strategies. Nevertheless, to experience the full advantages of big data, firms must be able to analyze the extensive information comprised in big data by themselves. Only firms that are capable of managing large amounts of data generated by different sources in real time and who adopt big data analytics (BDA) have the opportunity to fully exploit big data for gaining better insights, effectively supporting the decision-making process and developing innovation (Chen *et al.*, 2012; Del Vecchio *et al.*, 2018).

Although previous studies have highlighted the growing penetration of OI and management literature has suggested that strategic alliances between firms could lead to significant benefits (Lee *et al.*, 2010), firms are struggling to understand the role of appropriability in enabling OI practices. In fact, the adoption of an openness approach requires managers to reassess the processes of value creation and value capture; more specifically, the mechanism by which firms can appropriate the returns on the inventions originated from OI processes should be better understood (West *et al.*, 2014). As innovation relying on knowledge exchange and collaborative networks turned out to play a crucial role in managing complex knowledge (Singh, 2005), firms are often interested in establishing relationships and partnerships with external actors (Shi *et al.*, 2019). Some literature suggests that establishing collaborations with external entities could represent a strategic driver that may support firms in obtaining feedback and in developing their own knowledge and skills with outside expertise, thus assimilating new advanced technical and scientific information and seeding for future developments (Chesbrough, 2003; Kafouros and Forsans, 2012). Even if knowledge transfer is considered to be one of the most promising paths to strengthening firm competitiveness, previous studies suggest that interorganizational collaborations and alliances could lead to jarring results (Inkpen, 2008). However, knowledge exchange is a sophisticated process that requires firms to manage several challenging tasks, ranging from developing routines that support interaction and collaboration within the collaborative network to collective learning and sharing ideas and solutions with partners. The positive impact of external collaboration and networking may be coupled with negative side effects, not only because these collaborative processes could fail but also because these associations expose firms to competitive loss, as strategic knowledge could be dispersed outside of firms (Hurmelinna-Laukkanen, 2011). In fact, when engaged in collaborative networks, firms may have to manage some criticalities such as the dispersion of critical knowledge (Khanna *et al.*, 1998) and conflicts regarding the division of returns derived from shared information, experience and knowledge.

The current state of OI research calls for extended research (Chesbrough *et al.*, 2014); therefore, the present study moves from these considerations and proposes a model that – by examining data from firms located in the 27 European Union (EU) countries – investigates the relationships among reflective knowledge exchange (RKE), the extent of OI, the amount of BDA and the number of applications for patents. Even though a plethora of studies support the idea that effective interorganizational networks that implement OI practices and BDA enjoy the benefits of idea generation, innovativeness and intellectual property outcomes, the empirical evidence on a larger scale is still lacking (Clark and Stoddard, 1996; Del Giudice and Maggioni, 2014; Jenssen and Nybakk, 2013). The current study contributes to the existing literature in several areas. Existing literature on the OI process shows that OI is about the use of inflows and outflows of knowledge to stimulate firms to generate innovation and succeed. This study aims to understand whether collaborations with other firms to generate innovation should be enacted in a protected environment. More specifically, the main aim of the study is to provide a better understanding of the determinants of participation in both outside-in and inside-out OI projects. Further, the research contributes to the OI literature by proposing a quantitative investigation on whether firms cooperating with other partners to generate new knowledge require protection for their innovation.

As a second contribution, the present study sheds light on the role of BDA in the OI process by investigating the connection between the number of patent applications and the use of BDA in the process of knowledge creation, exchange and dissemination.

The remainder of the study is structured as follows: Section 2 presents the literature review and develops the research hypotheses. Sections 3 and 4 describe the methodology and the main findings of the research, respectively, while a critical discussion of the results is presented in Section 5. This section also points out the implications and the limitations of the study and presents the conclusions drawn.

2. Literature review and hypotheses development

2.1 Open innovation and patent applications in complex knowledge relationships

Because innovation represents one of the most important sources of competitive advantage, several studies have attempted to identify its main drivers (Jiménez-Jiménez *et al.*, 2014). In short, firm innovation is rooted in both social networks, referring to relationships with their stakeholders, and knowledge networks, which are created through collaborative knowledge associations (Guan and Liu, 2016).

Assuming a within-firm perspective, organizations have long strived to understand how they can support employees when they collaborate in a distributed team. As globalization has encouraged firms to establish subsidiaries across the world, employees find themselves working in an environment with few space, time and organizational boundaries, to develop new knowledge and to pursue common aims (Majchrzak *et al.*, 2005; Malhotra and Majchrzak, 2004). RKE is set not only within and between different business organizations; managers have also attempted to develop alliances and collaborations to support knowledge sharing with several stakeholders, such as suppliers (Lager *et al.*, 2014), partners (de Zubielqui *et al.*, 2019) and universities (Meng *et al.*, 2019).

Knowledge has a pivotal role in the value creation process and internal R&D is no longer adequate to compete in a highly demanding environment. Therefore, the OI approach has been introduced to support firms in understanding how they can create knowledge and which pathways they can follow to achieve a competitive advantage. Since the seminal study of Chesbrough (2003), the OI theory asserts that firms should exploit "external ideas as well as internal ideas, and internal and external paths to market [...]" (Chesbrough, 2003, p. 24), recognizing that knowledge resources can be derived both internally and externally. Inbound OI is described as an outside-in process and involves the practice of leveraging knowledge and technologies retrieved from outside the firm. This practice requires firms to establish interorganizational relationships with external actors to exploit their knowledge and competencies (Bianchi *et al.*, 2011; Chesbrough, 2007). In addition to the collaborative outside-in OI, firms can obtain an additional advantage from another practice, so-called outbound OI, which is an inside-out process that allows firms to commercially exploit their unused knowledge by transferring intellectual property to external actors (Chesbrough, 2007, 2003).

Generally speaking, the co-existence of these two different OI perspectives paves the way for further debate on how firms can effectively manage different knowledge flows to improve competitiveness. In fact, many firms have decided to simultaneously adopt both the inbound and the outbound approaches (van de Vrande *et al.*, 2009). Further, because of the increase in international competition, firms cannot rely on one of these two approaches alone. Considering that the stimulation of co-operations and networks has become very popular, firms should establish relationships with several external stakeholders to access and leverage inputs from the external environment that can be useful in generating new knowledge (Scuotto *et al.*, 2017). However, while staying on top of the competition and constantly developing new knowledge and innovation is a highly resource-demanding task, imperfect appropriability has been identified as a factor that induces both partners in and outsiders to the cooperative agreement to free ride on firms' knowledge (Greenlee and Cassiman, 1999; Kesteloot and Veugelers, 1995). Specifically, firms are continuously seeking solutions such as trademarks, copyrights and patents that could contribute toward reducing the involuntary dispersion of knowledge and effectively support them in claiming ownership of inventions by their R&D departments. In fact, it is especially difficult to obtain value solely from leveraging knowledge in highly competitive markets. Therefore, many firms find setting up collaborative networks in which they can exchange knowledge and technology by selling or revealing them particularly attractive (Lichtenthaler, 2009); accordingly, they tend to exploit the outbound OI opportunities.

It is therefore important to investigate the relationships between sourcing knowledge from the external environment, transferring knowledge to the external environment and the firms' choices involving appropriate returns from innovation.

Previous studies have also documented a direct association between OI practices and intellectual property outputs, including patents. For instance, Veugelers *et al.* (2010) argued that early access to OI and relevant technologies increased commitment to technology investment strategies, which could predict scientific organizational breakthroughs and intellectual property output. Furthermore, the organizations that promote OI practices by transforming intellectual property strategies as enablers will further enjoy idea provocation, knowledge creation and knowledge distribution among relevant interorganizational collaborators (Alexy *et al.*, 2009). In existing literature, the volume of OI is often operationalized and measured by the number of collective patent applications made by interorganizational networks. A relatively recent study comprising a network analysis of OI conducted by Yun *et al.* (2016) also indicated that the number of joint patents submitted by interorganizational alliances are heavily influenced by OI practices, which are shaped by the structure of organizational collaboration networks; the stronger the ties between the organizations, the more collaboratively they perform. Hence, we propose the following research hypothesis:

H1. The number of patent applications is associated with the amount of OI.

2.2 Impact of big data analytics on patent applications

During the past decade, both academics and practitioners have paid increasing attention to big data. This increase is motivated by the possible contribution of big data toward solving business challenges and generating innovation. In particular, BDA has come to play a crucial role for firms seeking to innovate, as it contributes toward reducing uncertainty. This is especially relevant to uncertainty rooted in the external environment, such as variations in consumer preferences and exogenous technological change (Buckley and Carter, 2002). When using BDA, firms have to process both structured and unstructured data on customers and markets (Akter and Wamba, 2016) to acquire meaningful insights that can be used to generate new knowledge and promote effective decision-making. However, dealing with big data is a challenging task that involves large amounts of different kinds of information, such as transaction data from both online and offline stores, clickstream data from social media and video and voice data (Akter *et al.*, 2016). Hence, to fully exploit the superior opportunities offered by big data, firms have to navigate three main challenges:

1. choosing the data sources and which information to use;
2. developing the capabilities to analyze data and manage analytics; and
3. using the insights gained from big data to transform the firms' operations (Del Vecchio *et al.*, 2018; McGuire *et al.*, 2013).

In an OI scenario, firms have to adopt a critical attitude to address these three issues. Concerning the source and selection of data, firms need to consider that the value derived from big data depends on the quality of the different processes of data collection and analysis. To exploit the full potential of BDA and to take advantage of its unique characteristics, firms cannot adopt traditional methods of data selection; they need to develop *ad hoc* human and technical capabilities (Davenport *et al.*, 2012). Firms also need to be aware that returns on investment in big data occur only if employees are trained to understand, use and include the related analytics in their decision-making processes (Shah *et al.*, 2012). Furthermore, the combination of OI and the availability of big data offer new challenges, as it offers the opportunity to identify innovation that could represent solutions to unsolved problems. Finally, BDA and its associated insights represent a powerful source of innovation that can contribute toward completely redesigning firm processes and identifying new business opportunities. From this perspective, it is also fundamental for firms to use BDA to develop innovation regarding their knowledge creation processes through a clearer understanding of the business environment (Davenport *et al.*, 2012).

Managing relevant knowledge gained from BDA is complex; it requires firms to implement a structured approach to knowledge management (KM) (Ferraris *et al.*, 2018). Previous studies have suggested that for BDA to contribute toward generating new knowledge, firms need to develop the capabilities of gaining information from external sources, understanding the external environment and generating innovative solutions through appropriate KM practices (De Dreu and West, 2001; Nguyen *et al.*, 2015). Moreover, to make effective use of BDA, firms have to develop the skills for extracting significant information from a huge amount of heterogeneous data, exploit this information for making strategic and operational decisions and develop solutions for disseminating insights throughout the organization as well as to the partners in the collaborative networks they belong to. If correctly managed, BDA could foster internal knowledge creation, sharing of common knowledge or business intelligence and the development of human knowledge (Khan and Vorley, 2017). From a knowledge spillover perspective, firms' activities and innovative solutions could involuntarily generate dispersed knowledge to other firms. These firms that are operating in either the same industry or in a different sector could then take advantage of this knowledge to enhance their performance (Del Giudice *et al.*, 2017). As BDA could result in a significant improvement in KM, firms may want to protect the mechanism they adopt to effectively contribute to the decision-making process and improve business functions, as well as the knowledge obtained by adopting BDA (Gold *et al.*, 2001; Malhotra and Majchrzak, 2004).

The ever-changing nature of knowledge creation, generation and distribution in organizations is affected by the introduction of new technologies and the capabilities of these new technologies. Technological capacity has been shown to be a crucial indicator of innovativeness, using patent applications as a predictor (Tong and Frame, 1994). Increasingly, firms are not only competing in the organizational resources they hold but also in knowledge creation. To do so, they use their existing resources by using predictive and prescriptive business analytics and converting big data into new, meaningful and actionable knowledge (Philip, 2018). These capabilities allow firms to not only excel in forecasting, production and quality control management but also provide access to novel information for improved decision-making to gain a competitive advantage. The association between innovation performance – measured by the number of patent applications – patent quality and technological investments and BDA has been a cumbersome issue, as the quantification of the amount of the big data used by organizations is challenging (Zhang *et al.*, 2017). However, previous studies used a wide range of measures – including information on investments for implementing big data, the size of data analyzed and patents using BDA – to investigate these associations (Braganza *et al.*, 2017). As the patents using big data have been previously highlighted in the literature examining innovative performance, we state the following research hypothesis:

H2. The number of patent applications is associated with the amount of BDA.

For convenience, the research steps performed in this study are summarized in Figure 1.

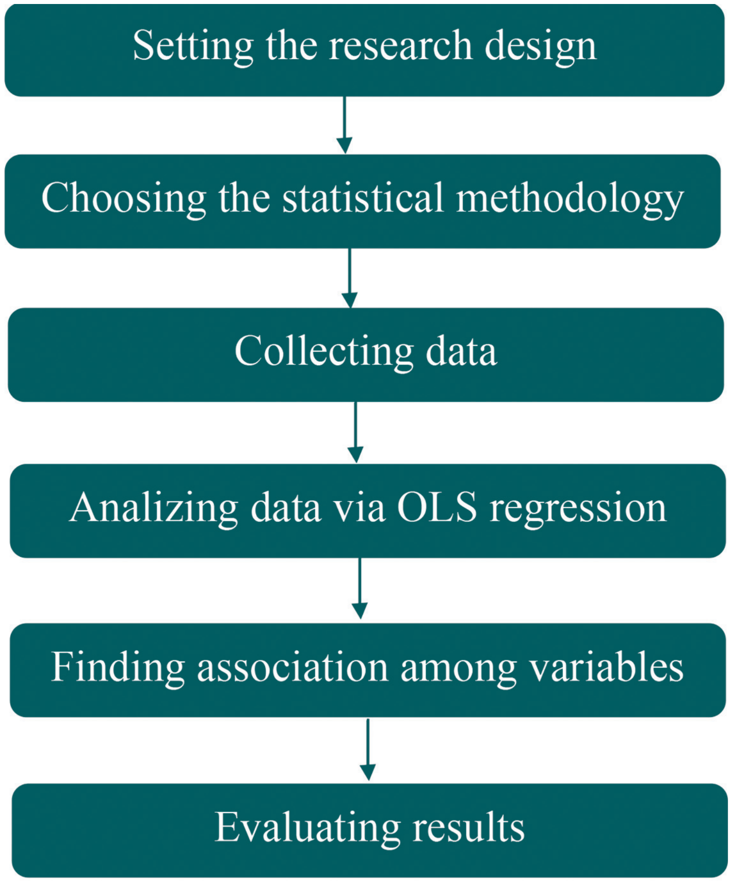
3. Empirical analysis

3.1 Research context

To test our hypotheses, we used an ordinary least squares (OLS) linear regression to empirically test the structural relationships of our conceptual model (Stock and Watson, 2003; Wooldridge, 2002). This methodology allows us to confirm or reject H_1 and H_2 by evaluating if the relationships between the dependent and the independent variables are statistically significant.

In our case, the use of a regression technique appears to be appropriate, as all the variables included in our analysis are perfectly measured, meaning that there is no latent (unobserved) factor to consider. In addition, it is worth noting that the OLS approach is widely used in practical applications – particularly in economics – to estimate the parameters of regression models (Hellwig, 1963; Kennedy, 1998; Wooldridge, 2002). The OLS method yields a direct and practical test to assess the significance of the regressors used, especially when it is used in conjunction with a robust standard error estimator (Darlington and Hayes, 2016; Stock and Watson, 2003; White, 1980; Wooldridge, 2002).

Figure 1 Research steps



Source: Author’s elaboration

As stated earlier, the regression technique is used to investigate the association between the number of patent applications and the amount of OI and of the BDA used by enterprises. For our analysis, we focus on several European countries. We chose these countries for a few reasons. First, the number of European patent applications has been growing rapidly in the past few years, with an all-time high of about 170,000 in 2018, as reported by the European Patent Office (EPO)[1]. Second, the literature (Kumar, 1996) highlights that European companies are strongly characterized by a high rate of intellectual property activities. Third, from a practical standpoint, focusing on Europe enables us to easily obtain all the data that our analysis requires by taking advantage of the Eurostat data set, and in particular, of the Community Innovation Survey (CIS) for innovation and technology statistics.

3.2 Data sample

Data are taken from the Eurostat data set mentioned earlier[2]. In particular, the data concerning OI is derived from the CIS, a database that provides innovation and technology statistics of European countries. Surveys are voluntary and are directly carried out by EU countries.

The selected data set includes statistics on the country, type of innovators, economic activity and firm size. Using the CIS data set allowed us to obtain a sample that is representative of the population of active EU companies, considering dimensional characteristics and different industries. The CIS data set also enabled us to explore various aspects of the innovation process according to the conceptualization proposed by Gassmann (2006). Finally, the CIS repository is used frequently among international and KM scholars (Del Giudice and Maggioni, 2014; Darroch and McNaughton, 2002; Papa *et al.*, 2018; Kotabe and Aulakh, 2002) because of its accuracy and high data reliability.

Regarding the European countries, we include all of the 27 EU member countries, namely, Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden. We also include the UK and Norway, as they are two of the most developed countries in Europe. The Eurostat data set contains yearly data from 2014 to 2019 for these 29 EU countries. Thus, we use the average of each variable over the entire study period, excluding those years for which no data are available.

3.3 Dependent variable

We set *Patent Applications (PatApp)* as the dependent variable; this variable is defined as the total number of patent applications to the EPO during the reference period.

3.4 Independent variables

The independent variables in our regression are as follows:

Open innovation in the sector (OpenInnov) is a variable measuring OI within the companies' sector. More specifically, it indicates the number of enterprises in each of the countries that cooperate with competitors or other enterprises in the same sector during the reference period.

Big Data Analysis (BigData) is a measure of the amount of big data used by enterprises. Specifically, we proxy it by the percentage of enterprises in each country that analyze big data generated from social media during the reference period (considering all the enterprises with ten persons employed or more, without financial sector).

3.5 Control variables

The following variables are included to control for the digital readiness level of every country:

R&D Expenditures (RD) are the intramural expenditures on research and development activities in each country. R&D expenditures can have a direct effect on productivity and patent (Danguy *et al.*, 2009). We measured the total expenditure in million Euros of all R&D activities for every country during the reference period.

ICT Training (ICTTrain) is a measure of the enterprises that provides training to improve employees' information and communications technology (ICT) skills. Specifically, it is the percentage of enterprises in each country that provides ICT training during the reference period (considering all the enterprises with ten persons employed or more, without financial sector). ICT skills together with the internet itself allow organizations access to knowledge, boosting the potential of their research activities and improving their efficiency for innovativeness (García Manjón, 2010; Wood, 2004).

Internet use (Internet) is defined as the percentage of individuals in each of the 29 EU countries who used the internet in past three months (before the survey).

All the variables are listed in Table 1. In addition, a block diagram that summarizes the research hypotheses and the approach followed to test them is presented in Figure 2.

3.6 Regression model

To test our research hypotheses, we use the following baseline regression model:

$$Patent = \beta_0 + \beta_1 OpenInnov + \beta_2 BigData + \beta_3 ICTTrain + \beta_4 Internet + \beta_5 RD + \varepsilon \tag{1}$$

where the β coefficients are obtained by OLS estimation. By computing the variance inflation factors (Wooldridge, 2002), we confirmed that there are no multi-collinearity issues (we obtain VIFs smaller than or equal to 2.22). Moreover, following a common approach to test the statistical significance of the regression coefficients, standard errors are computed by applying the robust standard error estimator (White, 1980).

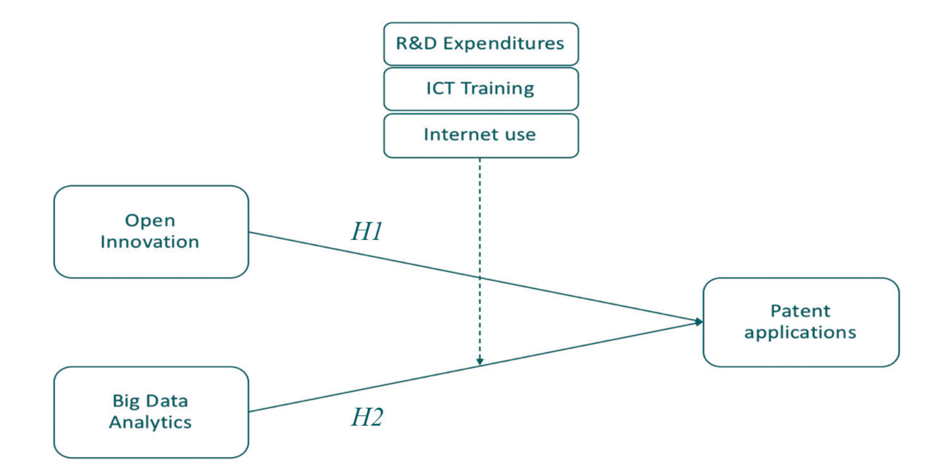
4. Findings

The descriptive statistics for all the regression variables are shown in Table 2. We observe that *Patent* has a rather large variability among the European countries, with a minimum and a maximum of 6.9 and 20201.2, respectively. Moreover, the minimum and maximum values show that the regressor variables also have a quite large degree of variability. This large

Table 1 Variable names and descriptions

Variable name	*Description*
Patent	Number of patent applications to the EPO
OpenInnov	Number of enterprises cooperating within the same sector
BigData	Percentage of enterprises that analyzed big data
RD	R&D expenditures (in million Euros)
ICTTrain	Percentage of enterprises that provide training in ICT skills
Internet	Percentage of individuals who used the internet in the past three months

Figure 2 Research designSource: Author's elaboration



Source: Author's elaboration

Table 2 Descriptive statistics				
Variable	*Mean*	*Standard deviation*	*Minimum*	*Maximum*
Patent	1953.7	4098.7	6.9	20201.2
OpenInnov	801.2	1344.9	8	6868
BigData	46.6	10.7	29	67
RD	11132.3	20352.0	65.98	96319.2
ICTTrain	22.3	8.7	5	42.1
Internet	78.2	11.7	55.1	95.9

variability is not as surprising, if we consider that our data set includes very small countries such as Malta and much bigger countries, such as France and Germany.

Before running the regression analysis, we determined the Pearson's correlation coefficients of the variables (Table 3). Correlation coefficients can indicate which of the used regressors have a significant association with the number of patent applications. In particular, *Patent* has a large positive correlation with both *RD* (0.9888) and *OpenInnov* (0.5614). Therefore, we can expect to find a positive and significant association between the number of patent applications and the R&D expenditure, as well as a positive association between the number of patent applications and the amount of OI. In contrast, the correlation between *Patent* and *BigData* is quite small (–0.1088), indicating that the number of patent applications is not associated with the use of BDA (the following regression analysis will confirm this on a rigorous statistical basis).

Finally, it is interesting to observe that the correlation between *OpenInnov* and *RD* is quite strong and positive (0.6583).

The results of the regression analysis are reported in Table 4. First, we observe that, overall, the regression is statistically significant with a *p*-value (associated with the *F*-statistic) smaller than 0.01. We also observe that the linear regression used is overall statistically

Table 3 Pearson's correlations						
Variable	Patapp	OpenInnov	Bigdata	RD	ICTTrain	Internet
Patent	1	–	–	–	–	–
OpenInnov	0.5614	1	–	–	–	–
BigData	–0.1088	0.2052	1	–	–	–
RD	0.9888	0.6583	–0.0642	1	–	–
ICTTrain	0.2026	0.1652	0.3430	0.2265	1	–
Internet	0.2836	0.2818	0.3186	0.3046	0.7167	1

Table 4 Regression results	
Variable	β
Constant	–256.5
OpenInnov	-0.486^{***}
BigData	–0.175
RD	0.221^{***}
ICTTrain	–14.859
Internet	6.174
F-stat	766.7^{***}
R^2	0.992
Adjusted R^2	0.991

Note: *; **; *** denote significance at the 10%, 5% and 1% levels, respectively significant. Moreover, the proportion of the variance of the dependent variable that the regression is capable of predicting is high, as the R^2 is greater than 0.9. This means that the linear regression model is a good fit for the empirical data. The coefficient of *OpenInnov* is negative and highly significant (at a 0.01 level), which indicates that higher amounts of OI are associated with smaller numbers of patent applications. H_1 is therefore supported. Specifically, the negative relationship between *Patent* and *OpenInnov* has relevant implications, which will be discussed in Section 5.

The regression coefficient of *BigData* is not statistically significant, which suggests that there is no association between the use of big data and the number of patent applications. These results do not support H_2.

The number of patent applications is also positively and significantly associated with R&D expenditure at a 0.01 level. This is in accordance with the large correlation coefficient between *Patent* and *RD* that was reported previously.

There is no significant association between *Patent* and the remaining control variables (*ICTTrain* and *Internet*). As a further check, we performed another linear regression, in which these two control variables were removed. The results (not reported in this document) are very similar to those of the analysis including *ICTTrain* and *Internet*. Therefore, we can conclude that our findings are robust to the exclusion of control variables related to the skills and the familiarity of firms' personnel with ICT.

Finally, to summarize the results, Table 5 shows the associations that we have found between the dependent variables and each of the independent and control variables.

5. Discussion and concluding remarks

The main purpose of this study is to investigate the impact of OI modes and BDA on RKE in complex collaborative networks. To accomplish this, we investigate the connection between the number of patent applications and the extent of OI, as well as the connection between the number of patent applications and the use of BDA. Specifically, we perform an empirical investigation to test two main hypotheses, based on KM and OI. The results show that the number of patent applications is positively associated with the amount of OI. Moreover, there is no significant connection between the number of patent applications and the use of BDA. Our analysis and its results contribute to knowledge regarding the impact of innovation collaborations on reflective knowledge creation, knowledge access, knowledge exchange and knowledge application within interorganizational contexts in Europe.

We are conscious that previous literature has hardly addressed how the distance in the dissemination of knowledge among the actors involved in open collaborations could foster inventiveness and innovation (Majchrzak *et al.*, 2005; Meng *et al.*, 2019; Zeithaml *et al.*, 2002). However, the findings of the present study suggest that OI collaboration modes have a significant effect on innovation performance, which stimulates the pursuit of RKE. Although the subject of knowledge and innovation in internal R&D departments is typically studied, the exploration of new knowledge is receiving growing attention in the literature because of the depreciation of internal knowledge and the prominence of innovation

Table 5 Relationships with the dependent variable

Regressors	*Variable*	*Relationship with* Patent
Independent variables	*OpenInnov*	Significantly and negatively related
	BigData	Not significantly related
Control variables	*RD*	Significantly and positively related
	ICTTrain	Not significantly related
	Internet	Not significantly related

outside the firms (Chesbrough and Crowther, 2006; Jeppesen and Lakhani, 2010; Garriga *et al.*, 2013). Participation in collaborative networks combines external knowledge search with familiar internal knowledge, leading to more diverse innovations within firms (Almirall and Casadesus-Masanell, 2010; Dahlander *et al.*, 2016; Kafouros and Forsans, 2012). Following Laursen and Salter (2006), our proposed model for addressing OI alliances is focused mainly on the knowledge width neglecting the wisdom of knowledge exchange, as it may reveal the relationship between innovation effectiveness and external knowledge acquisition more clearly than other measures (Katila and Ahuja, 2002).

Only *H1* is supported by the results. As for *H2*, the results show no evidence of a direct correlation between the use of BDA and the number of patent applications; they further indicate that among the control variables, only R&D expenditure can explain the reflection of knowledge in inbound collaborative relationships.

Our results confirm those of an existing study showing a stronger and more significantly negative relationship between OI modes and formal knowledge creation modes (Santoro *et al.*, 2018). These findings highlight the importance of external knowledge sourcing for improving innovation efficiency and affecting innovation performance positively, which is consistent with numerous previous OI studies (Ahn *et al.*, 2015; Scuotto *et al.*, 2017; Van de Vrande *et al.*, 2009).

Our results verify that firms engaged in OI collaboration gain a competitive advantage by capitalizing shared knowledge through collaborative activities, which encourages them to progressively develop new products and investigate new innovation opportunities (Del Vecchio *et al.*, 2018; Hurmelinna-Laukkanen, 2011; Jiménez-Jiménez *et al.*, 2014).

This is especially beneficial for both multinational enterprises (MNEs) and small to medium enterprises (SMEs) that can enhance their competitive advantage and gain reverse knowledge flows by selecting appropriate OI modes and effective KM partners (Buckley and Carter, 2002; Ferraris *et al.*, 2017b; Oliva and Kotabe, 2019; Van de Vrande *et al.*, 2009).

Although mainstream literature explores the antecedents of OI and the outcomes of external knowledge sources, it is not completely clear how different inbound OI modes affect the new product development at the industry level (Von Hippel, 1978; Mudambi *et al.*, 2014; Kotabe and Murray, 2018). This study finds OI collaboration to not only be an important driver of innovation performance but also be related to the effectiveness of R&D expenditures. The greater the RKE success, the smaller the need to protect intellectual property. This depends on absorptive and desorptive capacities (Dell'Anno and Del Giudice, 2015; Sarala *et al.*, 2016; Matricano *et al.*, 2019) and also confirms that firms cannot assimilate inbound and outbound OI practices, as advancing in product and services development requires high inclusiveness in the value capture mechanisms. Even if interorganizational collaborations could significantly contribute to generating and transferring new knowledge, firms involved in these relationships are exposed to some criticalities, such as involuntarily knowledge dispersion. Although the subject has been addressed in previous studies, our findings highlight how OI encourages collaborative knowledge access. In particular, they suggest that an effective R&D partnership strongly impacts appropriate knowledge manipulation, organizational learning, knowledge sharing processes and firms' cooperation, by reducing the effect of negative spillover among partners (Romano *et al.*, 2014; Kesteloot and Veugelers, 1995; Gassmann, 2006; Martin and Salomon, 2003).

As already stated, our study brings three main contributions to KM literature. First, as previous studies have focused mainly on KM practices, we extend the literature by shifting the attention from KM practices to the relationship between KM processes and OI. It is worth observing that among all the control variables, R&D expenditure is the only one found to be significant for OI efficiency. This implies that a high propensity for exploration can stimulate the shared innovation process (Gibson and Birkinshaw, 2004). Otherwise, R&D could support the search for heterogeneous knowledge sources when exploration is open and decrease it when the innovation output is a patent. Many firms have increased their patent activity to defend their specific internal innovation and others have created industrial liaison offices and technology transfer offices to support the exploration and execution of their own innovation results (Chakravarthy, 1997; Del Giudice *et al.*, 2014; Spender *et al.*, 2017).

Second, our findings confirm that organizations need to use more knowledge creation and knowledge access practices that contribute to new product development. This suggests that inbound OI modes are very appropriate for knowledge access and knowledge transfer, stimulating high-intensity learning interactions (Scuotto *et al.*, 2020). Our results are also consistent with recent literature that points out the increase of both supported knowledge dissemination and research productivity and innovation (Hewitt-Dundas, 2012; Veer-Ramjeawon and Rowley, 2019). There are two possible reasons for this. On the one hand, OI allows firms to face new problems in addressing intellectual properties and knowledge allocation among partners, thus improving efficiency and reducing R&D expenditures (Davenport and Prusak, 1998; Newell *et al.*, 2003; Mintzberg, 1993). On the other hand, knowledge dissemination has no impact on financial statements, only on absorptive capacity (i.e. the knowledge base) and innovation efficiency (Malhotra *et al.*, 2005; Malhotra and Majchrzak, 2014). Therefore, the larger the absorptive capacity of an industrial partner, the higher the motivation and engagement in inbound OI. Accordingly, organizations may also turn tacit knowledge into explicit knowledge (Rowley, 2000; Pirkkalainen and Pawlowski, 2014).

Third, our findings suggest that adopting OI strategies can intensify efficiency and efficacy in knowledge access by minimizing the risk of negative spillover and augmenting the knowledge base among the firms' partners, regardless of the different stages of the development. This is usually considered a core asset value for successful innovation (Scuotto *et al.*, 2017a). Based upon these considerations, we state that the role of inbound OI practice is a vital topic to investigate, even if it has been rather neglected in previous studies (Lichtenthaler, 2009; Vrontis *et al.*, 2017).

Considering our hypotheses, our results yield an original contribution. Furthermore, in line with mainstream literature (Davenport and Prusak, 1998; Ambrosini and Bowman, 2009; Soto-Acosta *et al.*, 2018; Teece *et al.*, 2016), we find that ICT and digital capabilities have no discernible effect on the number of patent applications. This confirms a limited impact on knowledge creation and knowledge appropriation processes. This result also confirms the preference for inbound rather than outbound relationships in RKE processes.

5.1 Management and policy implications

To summarize our contributions, this article has both practical and theoretical implications, as it contributes toward the understanding of RKE, which emerged as a key mechanism for firms spending more time and effort on the innovation process. Additionally, in line with our research design, the need for access and sharing knowledge from the external environment encourages firms to engage in collaborative relationships with outside partners. This fact leads to some interesting theoretical and managerial implications.

Our analysis presents an implication that is very relevant for practitioners, managers and policymakers. Companies should extend the boundaries of their organization by initiating and sustaining OI alliances across the value chain (Tallman and Chacar, 2011). Under a knowledge intensive and digital competition, this is mostly because of the fact that the innovation and value creation process suffers from short technology and product life cycles. In contrast, OI fosters perpetual product and service development in a complex competition network where innovation and knowledge activities are globally dispersed (Merritt, 1974;

Kotabe and Kothari, 2016). In this vein, companies should consider balancing the costs and benefits of knowledge exchange in OI relationships. This implies that firms should actively participate and interact with other firms across value creation networks to generate useful knowledge procurement through collective and multiple sources and forms (Yoon and Hughes, 2016; O'Mahoney *et al.*, 2013).

Complex collaborative networks are important knowledge incubators that can connect knowledge and technological providers from different countries (Singh, 2005). Participating enterprises can gain several advantages regarding managing new experiences and learning new practices, rather than reducing the risk of negative spillover. This will increase the creation of new knowledge and improve the innovation process. As absorptive capacity represents the knowledge base of enterprises, RKE is also an important mechanism that affects the firms' ability to innovate by increasing access to and the use of external knowledge on both intraorganizational and firm levels. Conversely, it also acquires and facilitates the creation of new knowledge from the networks (De Long and Fahey, 2000).

Another implication is related to the effect of the absorptive capacity. In particular, the fact that the correlation between *OpenInnov* and *RD* is very large suggests that a network collaboration increases training and incentives for R&D expenditure, including firms with a low knowledge base who can make full use of their absorptive capacity for innovation through RKE. In this vein, open alliances help firms to import advanced knowledge from abroad that could otherwise not be explored directly, except through high-risk and unsustainable R&D investments.

Finally, the effects of RKE on innovation performance may also have implications on a macro level. It may sustain the formulation of government trade policies that stimulate alternative knowledge ownership mechanisms, incentivizing the adoption of OI solutions. This is especially valid for developing countries and SMEs (Malhotra *et al.*, 2017). Accordingly, our findings confirm those of previous studies that emphasize a positive momentum between the internalization of knowledge and innovation creation (Chen and Wang, 2006; Xu *et al.*, 2010; Vahlne and Johanson, 2013). This consideration also highlights another relevant implication for KM and innovation. The firm's ability to access, exchange and receive knowledge from complex collaborative networks depends upon not only the effectiveness of interorganizational collaboration but also on the corporate knowledge base. This is related to R&D expenditure and the firm's absorptive and desorptive capabilities that support product development by reusing and recombining knowledge for different innovation processes. This confirms firms' pursuit of organizational flexibility and strategic agility, already widely confirmed in the literature (Kotabe and Mudambi, 2009; Oliva *et al.*, 2019; Shams *et al.*, 2020; Weber and Tarba, 2014).

5.2 Theoretical contributions

From a theoretical point of view, the manuscript contributes to the existing literature by answering the call for a better understanding of KM and innovation literature. Specifically, the study aims to elucidate the role of OI collaboration modes in the process of knowledge dissemination, based on an international cross-industry perspective (Alavi and Leidner, 2001; Cavusgil and Knight, 2015). The originality of the present study can be seen from the perspective of international management. It emphasizes the relevance of innovation capabilities and absorptive capacity for new and external sources of knowledge (Ahammad *et al.*, 2016; Del Giudice *et al.*, 2017). International business requires new organizational structures that can make firms more efficient in complex and volatile environments. Therefore, various companies that operate in international networks that involve knowledge-sharing strategies with partners value the development of products and services innovation (Bennis and Nanus, 1985; Caputo *et al.*, 2019). New corporate structures deliver a fresh combination of collaborative networks and diverse innovation bases that are useful for integrating open, digital and global KM practices into firms (Cheng and Fu, 2013; Dyer and Singh, 1998; du Plessis, 2007).

Beyond knowledge appropriation mechanisms, this study suggests that focusing on patent application is not sufficient to ensure a firms' responsiveness in the long run (Inkinen, 2016). This relevant implication infers that academics should consider the drivers affecting interorganizational collaboration over time. In particular, ideas and interorganizational knowledge seem to stimulate knowledge aggregation and innovation creation within networks. In this regard, we recognize that OI collaboration could offer a number of opportunities to build specific knowledge transfer capabilities, leading to improved innovation efficiency. This implication is intriguing, as it consecrates that the effective exploitation of external knowledge depends on a firm's absorptive capacity (Kotabe *et al.*, 2014; Khan *et al.*, 2016). This may be because collaborating firms have more knowledge and research capacity to learn and capitalize on imported knowledge (Oliva *et al.*, 2019).

Finally, our study addresses how managers should exploit the reflectiveness of knowledge in cooperative learning by combining internal and external knowledge sources. From this perspective, the firm's absorptive capacity must shift to desorptive capacity through a decodification process that prepares the firm for an internal change to interorganizational dynamic capabilities (Teece *et al.*, 1997; Kothari *et al.*, 2013; Dell'Anno and Del Giudice, 2015; Sarala *et al.*, 2016). In this regard, knowledge co-creation because of OI collaboration adds a new level to a firm's competitiveness, encouraging researchers to consider RKE as an interesting topic – not only for MNEs but also among collaborative networks – and as a transformative KM practice for externally dispersed knowledge allocation (Oliva and Kotabe, 2019; Andreeva and Kianto, 2012).

Knowledge sharing increases the effectiveness of innovation for the companies involved, whereas knowledge access stimulates quality product and service development (Cheng and Fu, 2013). Our findings fill the theoretical gap regarding the accumulation of knowledge, reducing the impact of knowledge obsolescence in intellectual property rights (Marra *et al.*, 2012; Oliva, 2014). This interpretation can be seen as a crossroad for future research in management disciplines.

5.3 Boundaries and future research directions

This study has certain limitations, which we will address further. We also establish directions for future studies in the researched area.

Despite the appropriateness of the methodology, the main limitation of this quantitative study is well established in management literature; we cannot overlook the questions of "how" and "why" firms encourage individual search for sharing ideas and knowledge. Hence, a qualitative study should further investigate the micro-foundations of the above relationships. In a sense, our study can also be considered a meta-analysis that aims to interpret RKE among cooperative and complex networks (Tallman and Chacar, 2011; Del Giudice *et al.*, 2017). The rest of the limitations are as follows: first, our research is a first effort to investigating this aspect. Using data from non-European countries or undertaking some comparative studies across different contexts could increase our study's generalizability. Second, our research focuses on a specific European panel and ignores the differences in the sample composition at firm level (i.e. domestic vs international, SMEs vs MNEs, manufacturing vs digital and public vs private companies). Future studies should focus on the effect of companies' characteristics on innovation modes. Third, we acknowledge that our investigation does not directly measure the intensity and impact of related external search of knowledge on innovation patent activities. A more robust analysis of this should be done in future.

Other research contributions that go beyond the scope of the present study are as follows. First, investigating the impact of other variables such as internationalization, market orientation or learning orientation will add value to existing knowledge. Moreover, it might be interesting to extend our analysis to also consider variables related to management (such as homogeneity of dynamic capabilities and absorptive capacity) and organization aspects (such as formal vs informal collaboration modes and intra vs inter-organizational networks) (Castaneda *et al.*, 2018; Knight and Cavusgil, 2004).

Finally, our empirical investigation does not investigate whether the dissemination of knowledge in inbound OI collaboration leads to superior innovation performances. Hence, future research should aim to provide a clear picture of how the OI dynamics influence the accrual of knowledge in complex collaborative networks.

Notes

1 Report EPO 2019, see the website https://www.epo.org/news-issues/news/2019/20190312.html

2 Eurostat is the statistical office of the EU, see the official Eurostat website at http://ec.europa.eu/eurostat

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