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Gaining or losing PhDs: What are the effects on firms' linkages with universities?

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ABSTRACT

PhD graduates can help companies transfer knowledge from universities to firms. Scholars have analysed the determinants of PhD recruitment by firms and its effects on their innovation activities. However, little is known about what happens when a firm loses employees with PhDs. The aim of this paper is to compare the effects on the relationships of firms with universities when these firms lose PhDs versus when they hire PhDs to work in R&D. These effects may be symmetrical or non-symmetrical depending on the abilities of firms to retain the connections and knowledge acquired by hiring PhDs. We consider four types of relationships: collaboration with universities, universities as a source of innovation, academic journals as a source of innovation and the purchase of R&D services from universities. We use data from the Spanish Technological Innovation Panel (PITEC) for the period 2006 to 2015. The results illustrate the central role of PhDs in the linkages between industry and academia. The recruitment of PhDs has a positive effect on collaboration between firms and universities and on the purchase of R&D services from universities. By contrast, the loss of PhDs has a negative effect on collaboration with universities but not on the acquisition of R&D.

1. Introduction

Studies have examined the determinants of the recruitment by firms of PhD graduates to carry out research and development (R&D) activities. Studies have also shown the positive effects of hiring PhDs on firms' innovation activities and performance (Stephan et al., 2004; Garcia-Quevedo et al., 2012; Herrera and Nieto, 2015). However, this academically important issue has even broader repercussions because of its relevance, practical impact and policy implications. According to the European Commission, the effective impact of hiring PhDs has led several countries to promote PhD graduate recruitment by companies (European Commission, 2001). However, little is known about the possible harmful effects of PhD loss on firms' innovative projects and performance. The OECD (2019) recently reported that "Doctorate holders are of particular relevance (...) to research and innovation", also explicitly affirming the need to monitor the careers of doctorate holders. The main contribution of this paper is to advance this line of research by examining the impact of dismissal or resignation of PhDs on the performance and innovative projects of the firms they leave.

Different approaches (Waldinger, 2016; Grinza and Quatraro, 2019) have been used to show that the loss of human capital and skilled personnel has negative effects on knowledge production and that these shocks have long-term effects (Waldinger, 2016). Empirical studies have also confirmed that skills complement R&D collaboration, making firms more profitable (Leiponen, 2005). PhD graduates working at firms play a key role in university–industry connections (Thune, 2009). Engagement by firms in these relationships positively affects their innovation performance (Apa et al., 2020). Therefore, it is reasonable to expect the loss of these PhDs to affect the relationships between firms and universities negatively in terms of knowledge production and firms' innovation outcomes.

Although some researchers (Cantabene and Grassi, 2020) have examined the role of human capital in firms' R&D cooperation with other institutions, including universities, to the best of our knowledge, no studies have investigated the impact of the loss of human capital on the relationship between firms and universities. Our main research question is therefore: what is the effect of *losing* PhDs employed in R&D in comparison with the effect of *hiring* PhDs? The aim of addressing this question is to analyse whether these effects are symmetrical or non-symmetrical. The existence of potential differences in these effects

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may be related to the characteristics of the relationships between universities and the business environment, as well as the role that PhDs play in these relationships.

Two factors are particularly important for our analysis. First, the incentives for businesses differ from the incentives for research in universities. University research activity aims to advance the frontiers of knowledge, usually measured in terms of the number of scientific publications (Cowan and Zinovyeva, 2013; Garcia-Alvarez-Coque et al., 2019). This focus can be an obstacle to transforming scientific knowledge into innovation. Hence, having PhDs in companies can be advantageous, with these human resources showing particular sensitivity to research aimed at the potential transformation of knowledge into innovation. Conversely, a negative impact on business activity may result from the loss of PhDs. Second, university activity tends to lead to codified knowledge. However, in practice, it is often tacit knowledge that is required for innovations that are applicable to industry activity (Cowan et al., 2000). Therefore, establishing strong university–industry relationships requires the transfer of complex knowledge that is frequently tacit. Most of this knowledge is embedded in individuals, and it is very likely that firms with PhDs employed in R&D cooperate more with universities. Therefore, a firm's relationship with universities due to the recruitment of PhD researchers may be lost once that firm has no employees with PhDs. In contrast, during the period where PhDs are with a firm, there may be an increase in the resource and knowledge base of that firm. There may also be a learning process by technicians and other non-PhD researchers. Together, these conclusions imply that there may be an increase in the absorptive capacity of the firm, which may help maintain relationships with universities. Therefore, the effect of losing PhDs may not be the exact opposite of the effect of hiring PhDs. This idea is important because if the benefits of previously having PhD employees disappear when these employees leave, the loss of PhDs would have negative long-term effects on the innovation capabilities of the affected firms. Despite the discussion of the potential explanations of the effects of hiring and losing PhDs, there is no established theoretical framework to postulate well-grounded hypotheses. Therefore, we consider our work an exploratory analysis based on a rich longitudinal data set and empirical estimations.

In this study, we examine the impact of PhDs on the connections or linkages between companies and universities by considering four types of linkages: (i) collaboration with universities for innovation, (ii) universities as a source of information for innovation, (iii) academic journals as a source of information for innovation and (iv) the purchase of R&D services from universities. The Community Innovation Survey (CIS) provides information on these four linkages between university and industry. They are representative of the mechanisms behind university–industry relationships. Each one requires different levels of business participation and, very likely, PhD involvement. Although firms have relationships in innovation with other partners, we focus on university–industry connections. In this area, the conceptual and empirical literature (Herrera, 2020; Cantabene and Grassi, 2020) emphasises the key role of PhDs and human capital in these relationships.

To examine the effects of hiring and losing PhDs on university–industry relationships, we first provide a detailed descriptive analysis that shows a positive correlation between having PhDs in firms and cooperating with universities. Moreover, this correlation is greater than the correlation with other partners. Next, we present empirical analysis of the data provided by the Spanish Technological Innovation Panel (PITEC) for the period 2006 to 2015. Built using the Spanish version of the CIS, this database provides data on the educational level of R&D workers, including the number of PhDs (in full-time equivalent) since 2006. These data on the qualifications of R&D employees are rarely available at the firm level (Thomson and Jensen, 2013; Afcha and Garcia-Quevedo, 2016). PITEC also provides rich data on firms' innovation activities and performance.

The rest of the paper is organised as follows. Section 2 describes the conceptual framework. Section 3 describes the method and data used for the empirical analysis. Section 4 discusses the results. Section 5 presents the conclusions.

2. Background

2.1. Human capital and innovation

Human capital is one of the determining factors of the innovation process and socioeconomic well-being. Both directly and indirectly, human capital affects the ability of firms to improve their performance and compete (Cantabene and Grassi, 2020). Specifically, human capital is essential in innovation processes because it boosts the capacity to absorb internal and external knowledge. Studies have shown a positive relationship between human capital and innovative capacity (Subramaniam and Youndt, 2005; Alegre et al., 2006; Mc Guirk et al., 2015). Scholars have also noted the importance of highly qualified people in the emergence of high technology sectors (Phelps, 2013; Santos et al., 2016).

In the relationship between human capital and innovation, there are three key aspects. First, high levels of education give people the right skills to assimilate technological change (Lundvall, 2008) whilst also channelling the acquisition of innovative skills and learning capabilities. These two elements are essential to capitalise on technological opportunities. Second, the innovation process is an increasingly complex activity that requires multidisciplinary approaches. Therefore, each individual's knowledge is extended and enriched when that individual has access to the knowledge bases of others (Leonard and Sensiper, 1998). Interacting with other people and organisations helps generate new knowledge by synthesising existing knowledge. Third, although the range of perspectives of different people contributes to the emergence of new ideas, the tacit and complex nature of scientific knowledge hinders the transfer and exploitation of these ideas. Hence, the recruitment of PhD graduates by firms can help overcome these difficulties by providing connections with universities and public research institutions (Thune, 2009; Garcia-Quevedo et al., 2012).

Although the literature shows that highly qualified workers generally play a fundamental role, hiring PhDs can specifically have an effective impact on business performance through innovation (Hess and Rothaermel, 2011; Herrera and Nieto, 2015). PhDs are trained to carry out tasks related to the search for knowledge that may apply to firms, as well as assessing the possibility of introducing this knowledge to firms. Employing PhDs in the business sector can drive knowledge transfer and innovation (Heidenreich, 2009). PhD holders perform three interrelated functions. First, they incubate ideas that can form the basis of innovative projects. Second, they monitor the external environment to take advantage of knowledge generated outside the firm (Herrera et al., 2010; Herrera and Nieto, 2015) and incorporate this knowledge into the firm (Hess and Rothaermel, 2011). Third, they evaluate commercial potential in the market and the applicability of available knowledge.

The literature underlines the importance of the presence of PhDs in firms for the efficient absorption and application of knowledge generated outside the borders of companies (Barge-Gil et al., 2020; Cantabene and Grassi, 2020). Having PhDs carrying out R&D activities is crucial when external knowledge comes from research centres where the relational capital of such people (Steinmo and Rasmussen, 2018) facilitates relationships between industry and university institutions. Thus, the presence of PhDs who carry out R&D within companies can facilitate and support relationships with external sources of knowledge such as universities and research centres. In short, to facilitate the transfer of knowledge from universities and research centres to productive activity, having PhD graduates working at firms is crucial (Stephan et al., 2005). The recruitment of PhDs is a transmission path for skills and accumulated knowledge developed at research centres (Zellner, 2003; Agrawal, 2006).

2.2. The university–industry (U—I) relationship

One of the crucial channels for the production and dissemination of knowledge is university–industry collaboration (Atta-Owusu et al., 2021). The key feature of this collaboration is that different agents cooperate with each other to achieve complementary advantages for their respective objectives (Bonaccorsi and Piccaluga, 1994; Mao et al., 2020). The factors that influence the decision to collaborate include certain business characteristics and the specific type of relationship adopted by the firm (acquisition of R&D services, research collaboration, etc.). However, as Atta-Owusu et al. (2021) reported, most of the available research has examined the impact of firm characteristics or the type of university–industry relationship separately, with some notable exceptions (e.g. García et al., 2015; Maietta, 2015).

In this paper, we adopt an integrated approach to studying these two aspects. We focus in particular on the impact of two potentially important factors that influence the decisions of firms to collaborate with universities: the type of relationship and the hiring or loss of PhDs working in R&D. University–industry collaboration is heterogeneous. In fact, the likelihood that knowledge becomes innovation is enhanced by the combination of multiple types of knowledge from different sources through the interaction of heterogeneous partners (Sammarra and Biggiero, 2008; Ivanova and Leydesdorff, 2014). The heterogeneity of the university–industry relationship manifests itself in various ways (Mao et al., 2020). First, different actors behave differently. Universities try to transfer their knowledge, whereas firms try to create commercial value from this knowledge. Second, knowledge comes in different types. Universities have explicit knowledge (basic research), whereas firms usually have tacit (applicable) knowledge. Finally, as noted in the introduction, relationships can be channelled in a wide range of ways: collaboration with universities for innovation, use of universities as a source of information for innovation, academic journals as a source of information for innovation and the purchase of R&D services from universities.

Given that the relationships between universities and firms are heterogeneous and take different forms, the loss of PhDs carrying out R&D within firms may have a different impact on each type of relationship. Based on previous research (Apa et al., 2020), it is expected that university–industry relations that require more intense connections will be severely affected by the loss of PhDs. This prediction is justified by the lack of access to the capabilities and competencies offered by PhDs that are fundamental for the use of the knowledge provided by university research centres. Moreover, the hiring of PhDs by companies makes it easier for them to set and adjust protocols and ways to facilitate and standardise the external purchase of R&D services. Once these protocols have been established, the need to have PhDs performing R&D on the company payroll to acquire R&D services externally is minimised. Forms of knowledge transfer that do not require highly technical scientific knowledge to be applied by firms, such as externally purchasing R&D, require only a certain degree of absorptive capacity. The purchase of external knowledge is less complex because it requires a lower absorptive capacity by firms beyond the basic skills needed for identification and application (Ferreras-Méndez et al., 2016). Absorptive capacity plays a moderating role that can largely help overcome the perceived division between the external acquisition of knowledge and the availability of internal R&D resources. This moderating role arises because the absorptive capacity of companies is based on their learning capacity and intangible and relational capital (Zouaghi et al., 2018). Hence, the availability of a highly qualified workforce, such as PhD holders, is crucial for the assimilation and integration of external knowledge into internal innovation processes (Huang et al., 2015). In particular, highly specific human capital, such as PhD holders, is required to absorb external knowledge with a high degree of tacit content (Gibbons and Waldman, 2004). Some research results (Kobarg et al., 2018) are consistent with this argument. That is, depending on the complexity of the university–industry relationship, the role of PhDs in firms has a different value. Consequently, losing PhDs has a different impact on the firm depending on the type of relationship with research centres. It is expected that the purchase of R&D services from a university is less affected by the loss of PhDs who perform R&D tasks than a collaborative relationship that requires intense, continuous and stable communication.

2.3. University–industry (U—I) relationships: gains and losses of PhDs in firms

Three aspects should be kept in mind in the interaction between university and industry. First, academics and firms collaborate with each other for different reasons. For instance, university researchers may look for practical applications for their findings or seek financing for equipment and research (D'Este and Perkmann, 2011; Scandura and Iammarino, 2021; Nsanzumuhire et al., 2021). In contrast, companies may collaborate with universities to carry out exploratory research that generates ideas for new products, technologies, and markets. They can thus also claim to have the scientific capabilities to solve difficulties or apply for subsidies and public funding (Carayol, 2003; Arza, 2010; Subramanian et al., 2013). Second, universities and industry interact through a variety of channels. Based on the typology proposed by some authors (Arza, 2010; Nsanzumuhire et al., 2021), for the purposes of this research, these channels can be classified into three types: (a) traditional channels such as access to information produced by innovative universities (e.g. through scientific publications) that may be relevant for business innovation; (b) service and commercial channels such as the purchase of R&D or consultancy services from universities; and (c) bidirectional channels, the paradigmatic example being collaboration in the preparation and implementation of R&D projects. Third, these channels differ in many respects, particularly in the following three: the level of interaction between university and firm, especially if personal interaction is required; the existence of explicit agreements; and the type of knowledge (tacit or codified) that is transferred (Schartinger et al., 2002; Arza, 2010, D'Este and Perkmann, 2011). These differences entail different requirements for the type of R&D personnel (particularly in terms of the presence of PhDs) that firms need in each type of relationship.

The following brief overview of these three channels (access to scientific publications, purchase of R&D services and university–industry collaboration) will be useful in framing this research. The first, access to information through scientific publications, is a predominantly codified form of knowledge transfer that does not require personal contacts or interaction. For such university–industry linkages, companies must have certain internal capabilities and human resources to absorb and integrate this external knowledge (Arza, 2010). However, these linkages do not require sophisticated knowledge resources such as those provided by PhDs. Therefore, the gains and losses of PhDs in firms will most likely have non-significant effects on this type of linkage. The other two types of linkages, namely the purchase of R&D services and university–industry collaboration in innovation, require personal interactions and the formalisation of knowledge, although there are some notable differences between them. The acquisition of R&D services requires a certain degree of interaction. However, firms tend to access the parts of their business that are less essential or, in other words, with a more standardised content of knowledge (Teirlinck and Spithoven, 2013). Hence, a relatively low degree of interaction is required, and there is less demand for R&D personnel in companies. Indeed, as explained later, this interaction and requirement of qualified personnel may occur less than in the case of cooperative relationships, where there is high potential for interaction and considerable uncertainty about the results of these collaborations (D'Este and Perkmann, 2011).

As just noted, cooperative processes between companies and universities involve interactions and a level of proximity whose fluidity is conditioned by the availability of skills and competencies in the companies themselves, to a greater degree than in the acquisition of R&D

services (Dyer and Singh, 1998; Kale et al., 2000; Teirlinck and Spithoven, 2013). The exploration, acquisition and application of external knowledge requires capabilities within companies in terms of management and R&D experience (Teirlinck and Spithoven, 2013). University–industry alliances can facilitate the transmission of tacit knowledge thanks to the trust that develops between actors (D`Este and Perkmann, 2011). The propensity of firms to use research cooperation largely depends on the number of staff with PhDs, especially in the case of smaller companies (Teirlinck and Spithoven, 2013). PhDs have a better understanding of both the cultural and institutional context of universities, as well as the skills and competencies of research groups. This greater understanding then reinforces trust in long-term collaborations (Attia, 2015; Canhoto et al., 2016; Teirlinck and Spithoven, 2013).

Ultimately, R&D staffing requirements may be different for collaborative R&D strategies than for strategies based on the procurement of R&D services. Teirlinck and Spithoven (2013) showed that PhDs are important for establishing R&D cooperation agreements between firms and universities but are not so important for R&D outsourcing. Apa et al. (2020) also showed that these collaborations, which frequently take place through structured research projects, require the participation of highly qualified researchers in companies. In summary, these differences suggest that the gains and losses of PhDs in firms will significantly affect innovation cooperation agreements with universities. In contrast, for R&D services, where the required level of absorptive capacity is lower, the effects are unclear. A gain of PhDs can encourage this type of relationship. If this gain has helped increase the knowledge base of the firms, the loss of PhDs may not have an effect on university–industry linkages. In any case, as explained in the introduction, there is no established theoretical framework to postulate well-founded hypotheses. We therefore consider our work to be largely of an exploratory nature.

3. Method and data

3.1. Data

This study uses data from the Spanish Panel on Technological Innovation Survey (PITEC). This survey is conducted annually by the National Statistical Institute (INE) in collaboration with the Spanish Science and Technology Foundation (FECYT) and the Foundation for Technological Innovation (COTEC). The survey follows the guidelines defined by the Organisation for Economic Cooperation and Development's Oslo Manual (OCDE, 2005). This survey can therefore be compared with similar European innovation surveys (Community Innovation Survey). Recent studies that have used this data set include those by Barge-Gil et al. (2020) and Santamaría et al. (2021).

To assess the impact of PhDs on cooperation with universities, we use data from the PITEC for the period 2006 to 2015. The panel comprises 12,283 firms drawn from industrial and service sectors. These firms were observed repeatedly throughout the period, offering highly representative data on Spanish firms. PITEC data are especially suitable for this analysis because they provide information on the qualifications of R&D staff. According the ISCED-UNESCO nomenclature, PITEC uses the following categories: holders of doctorates (ISCED level 6), holders of university degrees (ISCED level 5a), holders of other tertiary level diplomas (ISCED level 5b) and other personnel. In this research, we focus on doctorate holders (in full-time equivalent) devoted exclusively to R&D activities as a percentage of R&D employees. Based on this variable, we construct our main dependent variables, which take the value 1 if a gain or loss of PhD employees takes place. Table 1 displays the definition of the variables and descriptive statistics.

3.2. Descriptive statistics and analysis

The literature examines the factors influencing firms' decisions to hire PhD graduates, also studying how these decisions determine firms' performance. By contrast, little is known about the effect of drastic reductions in the number of PhDs. To study this phenomenon, we focus on the recruitment of PhDs by firms without PhD personnel. This analysis investigates how PhD employees potentially change the relationship between a firm and its use of external knowledge sources. We then focus on our main research objective, namely the effect of the loss of PhD personnel. We study whether an increase or decrease in PhD employees has a symmetrical or non-symmetrical effect on the university–industry relationships.

According to the literature, PhDs have specific characteristics

Table 1
Descriptive statistics.

Variables	Description	Mean	SD	Obs.
Loss of PhDs	Binary variable: 1 = firm reduces number of PhDs to 0 in periods t, t + 1 and t + 2	0.024	0.152	72,221
Gain of PhDs	Binary variable: 1 = firm increases number of PhDs from 0 in periods t, t + 1 and t + 2	0.025	0.157	72,221
Collaboration with universities	Binary variable: 1 = firm collaborates with universities	0.148	0.355	72,221
University as important source of innovation	Binary variable: 1 = firm values university as a highly important source of information for innovation	0.107	0.310	56,710
Technical and scientific papers as important source of innovation	Binary variable: 1 = firm values scientific and technical papers as a highly important source of information for innovation	0.088	0.283	56,710
Purchase of R&D services from universities	Purchase of R&D services from national and foreign universities as percentage of external R&D acquisition	4.463	18.523	72,221
Independent and control variables				72,221
Firm size (in log)	Number of employees	4.567	1.592	72,221
Previous subsidies	Binary variable: 1 = firm receives R&D subsidies from national government, regional government or EU, from t-2 to t	0.339	0.473	72,122
Firm age (in log)	Number of years since company was founded	3.114	0.697	72,221
OECD_0	Company operates in other activities not classified by the OECD (residual industries):	0.060	0.238	72,221
OECD_1	1 if company operates in high-technology industries	0.050	0.218	72,221
OECD_2	1 if company operates in medium-high-technology industries	0.183	0.386	72,221
OECD_3	1 if company operates in medium-low-technology industries	0.130	0.337	72,221
OECD_4	1 if company operates in low-technology industries	0.146	0.353	72,221
OECD_5	1 if company operates in knowledge-intensive services	0.256	0.437	72,221
OECD_6	1 if company operates in non-knowledge-intensive services	0.174	0.379	72,221

regarding their potential role in these relationships. Often, the most relevant change for a firm is to welcome a PhD graduate into its research team for the first time or to go from having at least one PhD to none. Therefore, we decided that the most critical line of analysis was to examine having PhDs in the firm and the inverse situation of reducing the number of PhDs to 0, rather than simply considering the increase or decrease in the total number of PhDs within the firm. In addition, the number of PhDs in firms is usually low. For example, in our data set, 40.1 % of firms with PhDs had at most one PhD graduate (in full-time equivalent). Consequently, this approach allowed us to observe with clarity qualitative changes due to the gain or loss of PhDs.

Table 2 shows the number of firms each year that experienced a reduction or increase in the number of PhDs. The loss of PhD employees was stable. Between 130 and 197 firms in the sample reduced their number of PhD employees to 0 at least one time during the period of observation. There were few changes, even during the years of the Great Recession (2008–2014). In total, 1707 firms (2.36 %) reduced the number of PhDs to 0 between 2006 and 2015. In the case of firms recruiting personnel from 0 in the study period, 1836 firms (2.54 %) firms hired PhDs. To limit the presence of confounding effects associated with repeatedly gaining or losing PhD employees, we imposed the restriction that the firm should experience this event only once and should have the same status for the next two years. Thus, for firms losing PhDs, the number of PhD employees should be 0 in t + 1 and t + 2, and for firms hiring PhDs, the number of PhDs should be positive in t + 1 and t + 2. After imposing this restriction, the number of firms in the analysis fell to 836 firms losing PhD employees and 367 firms gaining PhD employees.

The composition of R&D teams in firms gaining and losing PhDs is shown in Table 3. In the case of firms recruiting PhDs, the composition of the R&D team after recruiting PhDs was as follows: PhDs represented an average of 25.47 % of employees, employees with ISCED level 5a of education represented 43.55 % of R&D staff, and ISCED level 5b and other non-university employees represented 13.55 % and 17.43 %, respectively.

In the case of firms losing PhDs, it is worth studying the composition by level of education of the R&D staff in the year previous to the reduction. In t-1, PhD employees represented, on average, 33.89 % of the R&D staff. Employees with an education equivalent to ISCED level 5a represented 33.01 %, whilst ISCED level 5b and other non-university employees represented 14 % and 18.81 %, respectively. Observing the composition of R&D teams in both cases suggests that PhD employees are an important part of the R&D staff. To examine whether the events of losing or gaining PhDs are equally distributed among different types of firms or tend to be more common for certain types of firms, Tables 4 and 5 show the distribution of firms experiencing gains and losses in the number of PhDs by size and industrial sector.

In the case of size, the loss of PhDs seems to be more common in smaller firms, whereas gaining PhDs seems to occur more in larger firms. However, the differences between the two groups of firms are small. Regarding sectors by technology intensity, the data corresponding to firms gaining or losing PhDs do not reveal significant differences. As expected, the presence of PhDs in sectors with high technological intensity or knowledge-intensive business services (KIBS) is higher than in other sectors. To account for the influence of these variables, we include them as control variables in the estimates.

Finally, Table 6 shows the correlation matrix. In this matrix, we include two variables capturing the presence of PhDs in firms, as well as four variables capturing collaborations with suppliers and customers and the role they play as sources of information. The correlation between PhDs in firms (measured as whether or not the firm has PhDs on the payroll and the share of PhDs in R&D teams) and cooperation with universities is positive. In addition, the correlation between PhDs and cooperation with universities is stronger than the correlation for other types of partners or sources of information such as suppliers or customers. These results suggest that changes in the number of PhDs could have significant effects on linkages with universities.

3.3. Estimation of the impact of PhD losses

The main purpose of the empirical analysis is to examine how the reduction of the number of PhD personnel affects the relationships between firms and universities and the use of external sources of knowledge. The four types of relationships analysed in this study are collaboration with universities in innovation, the importance attributed to universities as a source of information for innovation, the importance of scientific journals and trade/technical publications as a source of information for innovation, and the purchase of R&D services from national and foreign universities.

This analysis raises some endogeneity concerns. First, the decision to reduce or increase the number of PhD employees could not be considered an exogenous shock. Instead, it was a decision caused by the interaction between the company and its employees. On the firm side, this decision could be triggered by factors related to finances, human resources, innovation strategy or some other area. On the employee side, it may be related to wages, labour conditions, job satisfaction, labour mobility or other such considerations. Given that the data do not provide enough information to disentangle this problem, an omitted variable problem may have affected the estimates. To mitigate this problem, at least partially, before analysing how firm–university linkages change when a firm loses PhD employees, we first examined the opposite situation. That is, we analysed the effect of hiring PhD personnel for the first time on the relationship between firms and their external sources of knowledge. By doing so, we examined the potential differences between the effects of recruiting and losing PhDs. This analysis also lends robustness to our estimates regarding the loss of PhDs. Second, the relationship between the gains or losses of PhD employees and firms' linkages with universities could be affected by a reverse causality problem. To alleviate this concern, we imposed a timing structure with two-lags between the dependent variables and the increase or reduction in the number of PhD employees. Some variables in PITEC follow the time structure proposed by the Community Innovation Survey, so they are measured in three-year windows. In this case, the explanatory variables were measured at the beginning of the period where the dependent variable was defined. Specifically, we assumed that the PhD gains or losses that took place at $t-2$ had an impact on university–industry linkages from *t-2* to *t*.

Given the binary nature of three out of the four dependent variables and the structure of the database (panel data), we use a logit model with fixed effects. This type of model is used frequently to eliminate the unobserved heterogeneity associated with time-invariant characteristics of firms. By implementing the fixed effects estimator, we remove any unobserved time-invariant firm-level heterogeneity.

$$DepVar = \beta_0 + \beta_1 PhDGain + \beta_2 Year + \beta_3 Z + \varepsilon_{it} \quad (1)$$

Here, *DepVar* are the dependent variables affected by the recruitment of PhD personnel. As noted above, we use four indicators to analyse the impact of the reduction in the number of PhDs: collaboration with universities, the university as a source of information, scientific journals and trade/technical publications as a source of information and the purchase of R&D from universities. For the two variables regarding the use of universities and scientific journals as sources of information for innovation, we followed the method of Laurser and Salter (2006). We coded these variables with 1 if the firm rates the source as highly important and 0 otherwise. We believe that this approach better captures whether the firms intensively use each of these sources of information. *PhDGain* is a dummy variable that takes the value 1 if a firm without PhD personnel in previous years hires one or more PhDs and retains them for at least the next two years. *Year* represents a set of dummy variables for the years of the period 2006 to 2013. Finally, *Z* is a vector of control variables consisting of the log of firm size measured in number of employees, previous subsidies and the log of the firm's age.

Table 2
Number of firms gaining/losing PhD employees by year.

Year	Number of firms reducing PhD employees	Percentage	Number of firms increasing PhD employees	Percentage	Number of firms reducing PhD employees to 0 and not recruiting for the next two years	Percentage	Number of firms increasing PhD employees from 0 and maintaining them for at least the next two years	Percentage
2006	197	2.99 %	232	3.52 %	123	1.93 %	83	1.32 %
2007	171	2.60 %	186	2.82 %	107	1.68 %	53	0.84 %
2008	165	2.51 %	201	3.05 %	110	1.73 %	43	0.68 %
2009	183	2.78 %	204	3.10 %	122	1.92 %	42	0.66 %
2010	172	2.61 %	174	2.64 %	112	1.76 %	36	0.57 %
2011	177	2.69 %	179	2.72 %	97	1.52 %	39	0.61 %
2012	179	2.72 %	151	2.29 %	97	1.52 %	31	0.49 %
2013	158	2.40 %	194	2.95 %	68	1.07 %	40	0.63 %
2014	175	2.66 %	133	2.02 %	n/a	n/a	n/a	n/a
2015	130	2.04 %	182	2.86 %	n/a	n/a	n/a	n/a
Total	1707	2.36 %	1836	2.54 %	836	1.20 %	367	0.53 %

Note: n/a: not applicable.

Table 3
Personnel by level of education in full-time equivalent (FTE) as percentage of total personnel in R&D staff (overall sample).

Firms recruiting PhDs			
Holders of doctorate in t	Holders of university degrees in t	Holders of other tertiary level diploma in t	Other workers in t
25.47	43.55	13.55	17.43
Firms losing PhDs			
Holders of doctorate in t-1	Holders of university degree in t-1	Holders of other tertiary level diploma in t-1	Other workers in t-1
33.89	33.01	14.28	18.81

Note: Because data in the PITEC are anonymised, we did not directly observe the number of R&D employees. Instead, we observed the share of R&D employees classified by education level. The values in this table were recovered by multiplying the percentage of full-time equivalent (FTE) employees by the total number of R&D employees (anonymised variable). This procedure gave the number of R&D employees by level of education. We then calculated the relative weight of each category with respect to the total number of R&D employees.

Table 4
Firms losing and recruiting PhDs by firm size.

N° of employees	Total sample	Firms recruiting PhDs	Firms losing PhDs
	Percentage of firms with PhD employees devoted to R&D activities	Percentage of firms recruiting PhDs	Percentage of firms losing PhD
0–20	13.97 %	0.50 %	1.39 %
21–50	13.94 %	0.67 %	1.36 %
50–200	14.35 %	0.50 %	1.26 %
201–500	11.86 %	0.34 %	0.95 %
> 500	16.27 %	0.71 %	0.96 %
Total	13.99 %	0.53 %	1.20 %

As mentioned earlier, the PITEC questionnaire follows the time structure proposed by the Community Innovation Survey. Therefore, some questions refer to the period from t-2 to t. Examples include collaboration with universities and the use of universities, scientific journals and trade/technical publications as a source of information. For variables measured annually, such as the purchase of R&D services from universities, the pre-hiring period is defined as t-1, which means considering the increase of PhD personnel at t-1. We show estimates where the dependent variables are measured from t-2 to t and estimates where the dependent variables are defined at t. We perform an estimation resembling the one stated in Eq. (2) to capture the impact of reducing the number of PhDs to 0 (PhDLoss)

Table 5
Firms losing and recruiting PhDs by industry sector, according to technological intensity.

	Total sample	Firms recruiting PhDs	Firms losing PhDs
Industry sectors by technological intensity	Percentage of firms with PhD employees devoted to R&D activities	Percentage of firms recruiting PhDs	Percentage of firms losing PhDs
High	35.28 %	0.78 %	1.66 %
Medium-High	15.86 %	0.71 %	1.34 %
Medium-Low	9.21 %	0.47 %	1.31 %
Low	9.81 %	0.41 %	1.12 %
KIBS	19.16 %	0.68 %	1.32 %
Non-KIBS	5.63 %	0.23 %	0.78 %
Other industries	13.32 %	0.50 %	1.05 %
Total	13.99 %	0.53 %	1.20 %

$$DepVar = \beta_0 + \beta_1 PhDLoss + \beta_2 T + \beta_3 Z + \varepsilon_{it} \tag{2}$$

The estimation described in Eq. (2) is therefore similar to the one described in Eq. 1. The difference is that the main explanatory variable is the reduction of PhD employees, not the increase. In this case, *PhDLoss* is a dummy variable that takes the value 1 if firms reduce their number of PhDs to 0 in two consecutive periods. As in the previous case, logit fixed effects controlling for time and lagged variables are included in the estimation.

Finally, to provide a better understanding of the effects of gaining and losing PhDs, we examine the effects not only in year t but also in the following two years (t + 1 and t + 2) for each case. We estimate how collaboration with universities and linkages with external sources change in t, t + 1 and t + 2 when firms hire PhD employees in t. We also estimate how these relationships with universities change in t, t + 1 and t + 2 when firms reduce the number of PhD employees to 0.[1]

4. Results and discussion

When describing the background, we listed the functions of PhD holders performing R&D as follows: generating new ideas for research

[1] To observe the firm at t + 1 and t + 2, we used a different wave of the survey. For example, for a PhD gain or loss reported for 2006, the results that corresponded to t were taken from the survey corresponding to 2008, when the firm was asked about its collaborations with universities from 2006 to 2008. At t + 1, we observed the firm's collaboration with universities in the survey corresponding to 2009, and so on. This restriction ensured that a firm experiencing a gain or loss in t did not recruit PhD employees for the next two years (i.e. until t + 2).

Table 6
Correlation matrix.

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. PhD (%)	1.00												
2. Dummy PhD	0.64	1.00											
3. Collaboration with universities	0.16	0.32	1.00										
4. Cooperation with suppliers	0.04	0.14	0.37	1.00									
5. Cooperation with customers	0.09	0.20	0.44	0.44	1.00								
6. Purchase of R&D services from universities	0.10	0.17	0.32	0.07	0.10	1.00							
7. Suppliers as important source of innovation	0.00	0.00	0.02	0.17	0.06	−0.02	1.00						
8. Customers as important source of innovation	0.03	0.07	0.10	0.10	0.22	0.03	0.19	1.00					
9. Universities as important source of innovation	0.13	0.21	0.38	0.11	0.14	0.26	0.03	0.07	1.00				
10. Technical and scientific papers as important source of innovation	0.14	0.20	0.17	0.08	0.12	0.09	0.11	0.12	0.22	1.00			
11. Firm size (in log)	−0.060	0.073	0.090	0.191	0.043	0.003	0.083	−0.046	−0.015	−0.025	1.00		
12. Previous subsidies	0.11	0.23	0.31	0.18	0.25	0.15	0.01	0.11	0.18	0.10	−0.05	1.00	
13. Firm age (log)	−0.08	−0.03	−0.05	0.06	−0.04	−0.05	0.05	−0.03	−0.05	−0.04	0.23	−0.10	1.00

Note: This table has been constructed using the total sample, which consists of 72,221 observations.

and developing innovative projects, monitoring and screening the external environment to incorporate knowledge generated outside the firm, and evaluating the applicability of available knowledge. Our results show that, based on these functions, hiring or losing PhDs affects the university–industry connections of firms, although these effects differ for different relationships between firms and universities and are not symmetrical for hiring versus losing PhDs.

First, the results of the estimates (Table 7) show a positive effect of hiring PhDs on collaboration with universities and the purchase of external R&D from universities. This finding supports previous research (Zellner, 2003; Stephan et al., 2005; Barge-Gil et al., 2020; Cantabene and Grassi, 2020) showing that PhDs working at firms and highly skilled R&D employees are crucial to channel knowledge from universities and research centres towards productive activity. This positive impact could be explained by the influence exerted by cognitive and relational social capital on university–industry collaborations (Steinmo and Rasmussen, 2018). The results also show a positive effect in period t + 1 on considering universities an important source of innovation. Recruiting PhDs has no significant effect on considering scientific journals and trade/technical publications an important source of innovation.

Second, the results presented in Table 8 reveal differences in the effects of the loss of PhDs on each type of relationship between firms and

Table 7
The effect of PhD increase.

	Model 1. Collaboration with universities			Model 2. University as source of innovation			Model 3. Scientific journals and trade/technical publications as source of innovation			Model 4. Purchase of R&D from universities as %		
	t	t + 1	t + 2	t	t + 1	t + 2	t	t + 1	t + 2	t	t + 1	t + 2
Gain of PhDs	0.529***	0.295	0.13	0.248	0.338*	−0.044	0.091	0.197	−0.099	−0.344	1.686**	1.439**
	(−0.171)	(−0.183)	(−0.199)	(0.190)	(0.204)	(0.228)	(0.218)	(0.241)	(0.273)	(0.773)	(0.757)	(0.733)
Firm size (in log)	0.412***	0.239***	0.127	0.037	−0.153	−0.245**	−0.079	−0.078	−0.051	0.436**	0.348*	0.035
	(−0.069)	(−0.079)	(−0.09)	(0.087)	(0.102)	(0.118)	(0.095)	(0.112)	(0.128)	(0.177)	(0.195)	(0.214)
Previous subsidies	0.454***	0.207***	0.016	0.134**	0.115	0.146*	0.030	0.028	0.039	3.440***	1.589***	0.125
	(−0.052)	(−0.057)	(−0.065)	(0.066)	(0.073)	(0.085)	(0.074)	(0.082)	(0.093)	(0.183)	(0.190)	(0.197)
Firm age (log)	−0.612***	−0.532***	−0.446**	−0.404**	−0.191	0.029	0.179	−0.136	−0.094	−2.014***	−2.327***	−1.853***
	(−0.137)	(−0.153)	(−0.177)	(0.162)	(0.186)	(0.220)	(0.175)	(0.198)	(0.233)	(0.448)	(0.478)	(0.510)
OECD_1	−0.704**	−0.298	−0.001	−0.356	−0.440	−1.020*	0.308	−0.551	0.013	1.395	0.512	0.327
	(−0.349)	(−0.367)	(−0.403)	(0.409)	(0.445)	(0.537)	(0.439)	(0.507)	(0.549)	(1.053)	(1.085)	(1.096)
OECD_2	−0.863***	−0.521	−0.116	−0.475	−0.428	−1.213**	−0.112	−0.516	−0.565	1.743*	−0.360	0.489
	(−0.313)	(−0.334)	(−0.366)	(0.368)	(0.411)	(0.505)	(0.455)	(0.510)	(0.568)	(0.902)	(0.929)	(0.943)
OECD_3	−0.736**	−0.458	0.058	−0.660	−0.584	−1.030*	0.624	−0.132	−0.090	1.401	0.372	0.418
	(−0.375)	(−0.399)	(−0.439)	(0.452)	(0.497)	(0.582)	(0.565)	(0.636)	(0.707)	(0.988)	(1.019)	(1.032)
OECD_4	−0.194	−0.012	0.388	−0.416	−0.680	−0.694	0.486	−0.354	−0.568	−0.799	0.085	0.228
	(−0.338)	(−0.366)	(−0.4)	(0.417)	(0.455)	(0.521)	(0.481)	(0.532)	(0.585)	(0.971)	(0.996)	(1.004)
OECD_5	−0.717**	−0.369	0.049	−0.463	−0.422	−0.360	0.426	0.012	−0.251	0.834	0.179	1.359
	(−0.296)	(−0.312)	(−0.336)	(0.336)	(0.367)	(0.445)	(0.389)	(0.437)	(0.477)	(0.823)	(0.843)	(0.853)
OECD_6	−0.799***	−0.521*	0.014	−0.857**	−0.494	−0.527	0.081	−0.158	−0.180	−0.251	−0.651	0.063
	(−0.079)	(−0.08)	(−0.082)	(0.345)	(0.374)	(0.447)	(0.396)	(0.437)	(0.468)	(0.789)	(0.809)	(0.817)
Constant										7.388***	9.966***	9.429***
										(1.604)	(1.707)	(1.811)
N	14,896	12,390	9221	10,167	8239	6558	9197	7228	5638	62,607	56,401	50,130

Notes: (i) *** (**,*) indicate a significant level of 1 % (5 %, 10 %). (ii) Standard errors in parentheses. (iii) All estimates include time dummies. (iv) Parameter estimates of Models 1 to 3 from conditional logit model. (v) Parameter estimates of Model 4 from fixed effects model. (vi) Gain of PhDs, firm size, previous subsidies and firm age in Models 1 to 3 measured at time t-2. (vii) Gain of PhDs, firm size, previous subsidies and firm age in Model 4 measured at time t-1. (viii) The differences in the number of observations between Model 4 and Models 1, 2 and 3 are caused by two factors. First, they have different time lag structures. Second, if observation values for the dependent variable do not change over time, they are dropped during estimation. For a more detailed explanation about the estimation procedure please refer to Allison (2009).

Table 8
The effect of PhD loss.

	Model 1. Collaboration with universities			Model 2. University as source of innovation			Model 3. Scientific journals and trade/technical publications as source of innovation			Model 4. Purchase of R&D from universities as %		
	t	t + 1	t + 2	t	t + 1	t + 2	t	t + 1	t + 2	t	t + 1	t + 2
Loss of PhDs	−0.106	−0.265*	−0.283*	−0.232	−0.210	−0.058	−0.104	−0.354	0.014	−0.448	0.119	−0.590
	(0.131)	(0.142)	(0.159)	(0.168)	(0.186)	(0.212)	(0.188)	(0.219)	(0.238)	(0.708)	(0.695)	(0.676)
Firm size (in log)	0.594***	0.420***	0.272**	0.060	−0.091	−0.187	−0.048	−0.109	0.013	1.283**	0.182	0.206
	(0.101)	(0.114)	(0.129)	(0.118)	(0.138)	(0.159)	(0.126)	(0.150)	(0.174)	(0.501)	(0.547)	(0.604)
Previous subsidies	0.490***	0.148*	−0.024	0.113	0.098	0.099	0.106	0.096	−0.056	4.535***	2.196***	0.767*
	(0.076)	(0.083)	(0.093)	(0.093)	(0.105)	(0.120)	(0.102)	(0.115)	(0.129)	(0.420)	(0.440)	(0.462)
Firm age (log)	−0.702***	−0.371*	−0.192	−0.111	−0.058	0.193	0.332	−0.159	−0.264	−3.245***	−2.117**	−0.193
	(0.176)	(0.193)	(0.222)	(0.204)	(0.231)	(0.272)	(0.215)	(0.242)	(0.279)	(0.950)	(1.013)	(1.086)
OECD_1	−0.629	0.243	0.144	0.450	−0.450	−0.169	−0.425	−1.119	−0.630	7.532***	3.294	−2.782
	(0.534)	(0.546)	(0.585)	(0.631)	(0.708)	(0.857)	(0.671)	(0.769)	(0.873)	(2.870)	(2.970)	(3.072)
OECD_2	−0.605	0.032	−0.185	0.287	0.335	−0.331	−0.776	−1.159	−1.507	6.704**	2.140	−0.427
	(0.517)	(0.526)	(0.561)	(0.613)	(0.684)	(0.879)	(0.748)	(0.841)	(0.973)	(2.756)	(2.856)	(2.956)
OECD_3	−0.052	0.553	0.978	0.830	0.375	−0.032	1.306	−0.338	0.096	6.847**	4.035	−0.437
	(0.659)	(0.675)	(0.739)	(0.828)	(0.902)	(1.018)	(0.997)	(1.088)	(1.309)	(3.084)	(3.203)	(3.288)
OECD_4	−0.631	0.007	0.426	−0.084	−0.770	−0.283	−0.136	−1.027	−1.203	1.711	0.823	−3.476
	(0.539)	(0.560)	(0.590)	(0.662)	(0.713)	(0.852)	(0.760)	(0.853)	(0.935)	(2.875)	(2.974)	(3.062)
OECD_5	−0.430	0.155	0.491	0.269	−0.021	0.298	−0.227	−0.583	−0.805	4.787*	3.833	2.518
	(0.481)	(0.492)	(0.517)	(0.539)	(0.578)	(0.755)	(0.602)	(0.678)	(0.768)	(2.524)	(2.605)	(2.719)
OECD_6	−0.238	0.483	0.767	0.049	−0.113	0.510	−0.591	−0.622	−0.705	5.164**	3.502	0.402
	(0.458)	(0.468)	(0.489)	(0.532)	(0.575)	(0.718)	(0.591)	(0.666)	(0.743)	−0.448	0.119	−0.590
Constant										6.717*	12.898***	10.177**
										(3.986)	(4.230)	(4.495)
N	7656	6416	5250	5524	4516	3598	4988	3873	3052	18,608	16,737	14,866

Notes: (i) *** (**,*) indicate a significant level of 1 % (5 %, 10 %). (ii) Standard errors in parentheses. (iii) All models include time dummies. (iv) Parameter estimates of Models 1 to 3 from conditional logit model. (v) Parameter estimates of Model 4 from fixed effects model. (vi) Loss of PhDs, firm size, previous subsidies and firm age in Models 1 to 3 measured at time t-2. (vii) Loss of PhDs, firm size, previous subsidies and firm age in Model 4 measured at time t-1. (viii) The differences in the number of observations between Model 4 and Models 1, 2 and 3 are caused by two factors. First, they have different time lag structures. Second, if observation values for the dependent variable do not change over time, they are dropped during estimation. For a more detailed explanation about the estimation procedure please refer to Allison (2009).

universities. At a 10 % significance level, not retaining PhDs has a negative effect on cooperation but no significant effect on the other types of relationships. We found no negative effect on the acquisition of R&D services from universities, and the parameters are clearly non-significant. These results suggest that the most complex linkages with universities, which require a greater degree of university–industry interaction, disappear once the firm lacks the knowledge provided by PhD researchers. These results are in line with the findings of Apa et al. (2020), who showed that collaboration requires the participation of people who are fully involved in formal projects. These individuals play a crucial role in communicating and assimilating knowledge provided by universities.

Other channels of knowledge transfer, such as acquiring external R&D, which require some absorptive capacity for the identification and use of external knowledge (Ferreras-Méndez et al., 2016) but not a high degree of scientific knowledge, are not affected by the loss of PhDs. In a context where strategies aimed at using external sources of knowledge are increasingly important, our results suggest that, once the incorporation of PhDs has helped firms formalise the acquisition of R&D services, firms continue to outsource R&D even without having PhDs on their R&D staff. This finding seems to be consistent with the results provided by Kobarg et al. (2018), who explained that the positive aspects of absorptive capacity are less important in a context of low complexity and ease of learning, such as acquiring external knowledge. The presence or absence of PhDs working in R&D within firms can strengthen or weaken the ability to absorb and exploit external knowledge. The identification, absorption and application of external sources of knowledge is a difficult task. If knowledge is codified, it may be more available and applicable for use by companies.

5. Conclusions

Human capital is a key component of innovation and economic growth. PhDs represent the highest level of education. The literature (Herrera et al., 2010; Hess and Rothaermel, 2011; Herrera and Nieto, 2015) shows that having PhD graduates in industry may have significant benefits for firms' innovation activities and performance. First, PhDs evaluate the applicability of existing knowledge and assess its possible introduction to the market. Second, PhDs monitor knowledge outside the firm with a view to incorporating it into the firm. In particular, they play an important role in university–industry relationships.

This paper analyses what happens with the connections between firms and universities when firms hire and lose PhD employees performing R&D. We consider four types of relationships: cooperation in innovation with universities, universities as a source of information for innovation, academic journals as a source of information and acquisition of R&D services from universities. The econometric analyses use data from the Technological Innovation Panel (PITEC) for the period 2006 to 2015. This panel provides data on the educational level of R&D employees.

Several conclusions emerge. First, the effect of hiring PhDs was estimated and then compared with the impact of losing PhDs. The results confirm a positive effect of hiring PhDs on collaboration with universities and on external acquisition of R&D from universities. The most relevant effects arise in the case of cooperation in innovation with universities and the acquisition of R&D services from universities. On the contrary, no significant effect of hiring PhDs was observed when considering scientific journals and trade/technical publications as a critical source of information for innovation. Second, the results show that the loss of PhDs by firms has a dual effect. The loss of PhDs negatively affects the most complex relationships, which require a high degree of interaction between firms and universities (e.g. cooperation in innovation). These relationships are the most affected. Other relationships such as acquiring R&D services from universities do not seem to be negatively affected. These results suggest that the presence of PhDs in firms undertaking research activities are important to transfer knowledge from universities into productive activity. Considering that engaging in relationships with universities has positive effects for firms in terms of their innovation performance, the loss of PhDs by firms may have long-term effects on their innovation capabilities.

Our results offer insights for the analysis of the role of highly skilled R&D workers and university–industry connections and innovation. First, like the results in the literature (Schartinger et al., 2002; Apa et al., 2020), our results show the importance of examining university–industry connections by considering the different types of relationships between universities and firms specifically instead of generally. These relationships vary greatly, and the role of human capital in firms in establishing these connections and taking advantage of them may differ substantially. Second, after controlling for the characteristics of the firms, our empirical analysis highlights the key role of individuals and the knowledge embodied in highly skilled researchers to explain cooperation strategies and innovation. This finding is in line with recent studies showing that inventor-specific skills are more important than firm-specific capabilities for explaining variance in the output of inventors, as well as emphasising the central role of human capital in theories of the firm and in explanations of innovation performance (Bhaskarabhatla et al., 2021).

The results also provide some business implications and guidance for managers. If firms want to engage in innovation cooperation with universities to increase their innovate capabilities, hiring and retaining highly skilled R&D workers such as PhD holders is a key factor to ensure that they can establish these connections successfully in the long term. Hiring PhDs temporarily allows for certain relationships such as acquiring R&D services, but it does not allow for the most complex and innovative relationships such as cooperation in R&D. These relationships require a substantial degree of absorptive capacity. PhDs provide this capacity, and they are able to generate ideas and new knowledge whilst formalising connections with other partners.

Finally, the results provide some recommendations for the design of R&D and innovation policies. Many countries have implemented innovation measures to help firms recruit PhDs to undertake R&D activities, at least temporarily, and these actions have been useful to increase the human capital of firms. However, sustainable, long-term innovation policies seem necessary to exploit the potential advantages of having PhDs in firms to foster university–industry relationships and the innovation capabilities of firms in general.

This research is not without limitations. First, we analysed university–industry connections, where, according to the literature and our empirical analysis, PhDs performing R&D play a key role. Nevertheless, firms establish relationships with other partners, such as competitors, suppliers and customers, where the role of highly skilled R&D workers may also be important. We consider this area a future line of research. Second, although the PITEC provides rich data, it offers no specific data on the causes of business decisions or the reasons for losing PhDs (i.e. dismissal vs. a decision to leave the firm). In addition, some non-observable factors and the potential reverse causality of some of the variables raise endogeneity concerns. We tried to minimise these concerns by exploiting the time dimension of our data with the use of lags and fixed effects models. We also estimated the effects of hiring PhDs to compare hiring PhDs with losing PhDs. The results confirm the existence of considerable differences.

CRediT authorship contribution statement

S. Afcha: Conceptualization, Methodology, Software, Writing – review & editing. **J. García-Quevedo:** Conceptualization, Supervision, Writing – original draft, Writing – review & editing. **F. Mas-Verdú:** Conceptualization, Writing – original draft, Writing – review & editing, Resources.

Data availability

The authors do not have permission to share data.

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