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The effects of university academic research on firm's propensity to innovate at local level: evidence from Europe

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Abstract
Universities have become key elements in building regional innovation systems. However, even though academic research is important when firms choose universities as collaboration partners, a still open question in the literature is whether only top-tier universities are relevant for firm innovativeness. This paper investigates the effect of the volume of scientific publications on firm's propensity to develop new product and processes and to what extent academic research has to be excellent in order to enhance local industrial innovation, taking into account that education may act as a channel of local university-based knowledge spillovers. Using data on manufacturing firms in seven European countries covering the period 2007–2009, a multivariate probit model is estimated to relate firm's propensity to develop innovation to the level of provincial academic research and education. Results show that academic research has a direct impact on the firm's propensity to develop innovation. Research at the second-tier university impacts product innovation more than that at first-tier one. Furthermore, the research output of the first-tier university exerts a detrimental effect on the development of process innovation whereas the research output of third- and lower-tier universities is beneficial. Research excellence, although very important, is not sufficient to explain university-based knowledge spillovers. It may be the case that academic research may enhance radical innovation of relatively few firms working on cutting-edge research, whereas less advanced academic research may be directly useful to incremental innovation of most local firms.

Keywords Product and process innovation · Firm R&D collaboration · Scopus publications · Academic ranking of world universities · Regional innovation systems

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1 Introduction

Considerable attention has been paid to the role of universities in regional economic development and innovation. Regional knowledge networks and modes of engagement between universities and the business community have increasingly been encouraged by public policies. The most recent development in the field has also formally identified a new mission in addition to the two traditional roles of teaching and research. Researchers use the terms "third mission" (Laredo 2007) or "knowledge transfer" (Bekkers and Freitas 2008) to identify a new set of activities through which higher education institutions interact with their communities. The university-based knowledge spillovers over the local economy that have been paid considerable attention in the literature relate to the creation of new firms (Acosta et al. 2011; Bonaccorsi et al. 2014a) and to the university-firm collaboration, through the commercialisation of academic knowledge, involving patenting and licensing of inventions as well as academic entrepreneurship (Laursen et al. 2011; De Fuentes and Dutrénit 2016). Therefore, universities have become key elements in building regional innovation systems (Caniëls and van den Bosch 2010). For example, the establishment of new companies, based on technologies derived from university research, is a well recognized driver of regional economic development (Hayter et al. 2017). Incubators developed by higher education institutions are effective in supporting new entrepreneurial initiatives (Auricchio et al. 2014). Innovative start-ups are also an effective way to facilitate technology transfer from universities to the economy (Boh et al. 2015). See Maietta (2015), for a description of the channels through which university-firm research and development (R&D) collaboration impacts firms' product and process innovations. Among the several contributions that universities can make in order to speed up local economic development, education and knowledge creation through academic research play an important role (Leten et al. 2014). Although this knowledge can be easily transferred at low cost (i.e., downloaded from the Internet) and therefore is not tied to a firm's location, proximity to high-output universities may be important for accessing research networks (Audretsch and Lehmann 2005). Indeed, a conclusion has been reached especially by the literature dealing with technologically advanced sectors: the number of scientific publications in high-ranked journals is a relevant indicator of academic research quality to assist firms in their choice of R&D partners.

However, some authors have questioned whether the kind of new knowledge and technology produced by regional universities is helpful to local firms (Bonaccorsi 2017), particularly in the case of firms with low absorptive capacity in mature and low-tech sectors. Regional-level studies on the impact of academic knowledge spillovers do not always highlight positive effects of universities on regional innovation in Europe (Ghinamo 2012). This weak evidence could be explained by the absence in Europe of a specialised public research infrastructure. Indeed, there is a scarce match between the regional knowledge base and the needs of industry—i.e. problems with the orientation of public sector research to industry needs (Prokop and Stejskal 2018). Even though academic research quality is important when firms choose universities as R&D collaboration partners, a still open question in the literature is therefore whether only top-tier universities are relevant for regional development. From industry perspectives, academic research excellence may even present some comparative disadvantages, and second and third-tier universities may also be important for industry innovation (Mansfield and Lee 1996). Indeed, lower-tier universities can probably better solve the problem of firms not interested in cutting-edge research. In this case, firms might not look for star universities (Hong and Su 2013). In this direction, Barra et al. (2019) recently analysed whether academic excellence, recognized at international level-measured by indicators of top publications and citations-can enhance innovation of firms, showing that top-10 publications of second-tier universities exhibit the highest positive association with product innovation of science-based sectors, but negative associations with top-10 publications of first- and second-tier universities are evidenced for process innovation in this macro-sector.

Moreover, the indirect effect (e.g. due to formal university-firm interaction) of university-firm collaboration on firm innovativeness is well-documented (Lööf and Heshmati 2002; Belderbos et al. 2004; Baba et al. 2009; Eom and Lee 2010; Protogerou et al. 2017). However, part of the literature has also underlined the importance of informal activities, rather than patenting and academic entrepreneurship, which are even considered significantly more valuable by many companies and also involve more academics (Perkmann et al. 2013). Informal relationships between universities and firms are indeed alternative and important channels of technology transfer (Bönte and Keilback 2005). This direct impact of academic research on firm-level innovation has not been extensively investigated and the few existing papers suggest a trade-off between publications vs. informal collaborations with the industry (Maietta 2015; Maietta et al. 2017; Barra et al. 2019).

Furthermore, changes occurred over the last decades in the European higher education institutions are not of secondary importance. Indeed, as a result of the convergence process started by the Bologna Declaration (see the "Appendix" for a brief summary of the structural changes in higher education system in Europe), the European higher education system has been substantially reformed and the role that universities play in enhancing regional innovation systems has been potentially reinforced.[1] However, the amount of academic duties has been growing due to the new administrative work, linked to teaching and research quality requirements, to the increasing number of students (Viola 2014) and to the general advent of mass university education (Perotti 2007). The relationship between teaching and research has also loosened because of the reduction of tenured and tenure tracked positions. As a consequence, the Humboldtian tradition of a strong connection between research and teaching, which is widespread in continental Europe, might be weakened as an instrument of knowledge spillovers from academic research to firms.[2] European universities have also faced changing funding regimes with the introduction of national systems of funding conditional on evaluation of research output or national assessment exercises (see again the "Appendix" for a brief summary of the differences, in terms of the funding regimes, among the European countries for which the empirical analysis of the paper is done). The introduction of a performance-based research funding system increased university competition for prestige and enhanced research productivity, but run also into costs. Because of the reliance on the academic elite in their design and implementation, they may suppress scientific novelty, innovation and intellectual diversity. Teaching quality has decreased, because of a trade-off between teaching quality and grades given by the national assessment exercise (Barra and Zotti 2016). More importantly given the context

[1] Morevoer, universities and public research labs are also recommended to adopt a common code of practice for their activities. This is to avoid that discrepancies between national systems may hamper transnational knowledge transfer (European Commission 2008).

[2] In Germany, for instance, it has been debated whether the teaching load should be reduced if researchers publish regularly in international journals (Plümper and Radaelli 2004).

examined in this paper, the interaction with industry and application of research activities, with economic benefits such as firm innovation, could be discouraged (Moscati et al. 2010; Maietta 2015). These unintended consequences might lead to an internationally approved ivory tower of scholarship, and damage societies over the long term (Hicks 2012, 2013).[3]

The primary objective of the paper is to analyse how the "knowledge context" in which the firm operates-in terms of research and education activities at local universities-affect the university-firm relationship. More specifically, we investigate the impact of the volume of scientific publications at local universities on firm's propensity to develop new product and processes. Furthermore, the second aim of the paper is to measure to what extent academic research has to be excellent in order to enhance local industrial innovation. We argue that although academic research is an important determinant of university-firm collaboration, however a still debated question in the literature is whether only top-tier universities are relevant for knowledge transfer from university to industry. Thirdly, the paper aims at disentangling and quantifying the direct channels through which academic research drives product and process innovation, once we control for the formal university-firm collaboration (mainly via contract and collaborative research). To conclude, the paper's final objective is to explore whether education act as a channel of local university-based knowledge spillovers. The local university is represented by the higher education institutions located in the same province (NUTS3 level) where the firm is located. The volume of research is represented by the number of publications while education activities are proxied by the number of national and international students of the universities within the province where the university is located. Local first (second and third) tier universities are defined as the universities, located in the same province where the firm is located, with the highest (second and third highest) number of publications to explore whether the firm's propensity to develop innovation depends only on star universities or whether also lower-tier institutions may play a role at local level. Importantly, this paper deviates from Barra et al. (2019) in two main specifications. Instead of focusing the whole discussion about research excellence, this paper put the emphasis on publication counts as a primarily measure of quantity. Moreover, while in Barra et al. (2019) a definition of what constitutes a "first tier university" based on an international comparison of reputation is used, this paper, instead, considers the largest (in term of publications) university in a province as "first tier". The drawback of such definition of academic research volume is that a university that would be first tier in a rural province may be "lower tier" in an urban region, where there are several other universities. However, what makes important and worthwhile examining the impact of the volume of academic research at local universities on the capacity of local firms to develop new products and processes is the following idea. It is true that tying with partners of high academic production is generally preferred to close geographical location (Laursen et al. 2011). However, distant universities are generally not chosen as firm R&D partners in the earliest phase of the projects (Broström 2010).

[3] The roots of the Bologna Process date back to 1998/1999 and the target date for the implementation of the European Higher Education Area was 2010. However, the empirical data used in this paper are related to the years 2007–2009, respectively 2010. Related to the period under investigation one might wonders whether the reform processes indeed have time to significantly impact the outcomes of university industry collaboration by 2007–2009. However, the Bologna's perspective broadened and follow-up meetings have affected the higher education systems of the participating countries such that some progress in the implementation of this reform process, although with differences in the speed of implementation between individual countries, could have already produced some results.

The source of data on company innovation is the European Firms in a Global Economy (EFIGE) dataset from an extensive survey carried out in seven European countries in 2010. Information on universities is collected at the NUTS 3 level since this geographic unit enables to capture the spillover effects of public research (Bonaccorsi 2014). It is gathered from a range of sources: European University Data Collection (EUMIDA), European Tertiary Education Register (ETER), Scopus by Elsevier, and the Academic Ranking of World Universities (ARWU). We use a simultaneous multi-equation approach that addresses both the endogeneity of R&D decisions and the simultaneity of internal and external R&D investment. Since the dependent variables are ordinal, the simultaneous approach is a multivariate probit model. Our dependent variables reflect the choice of: investing in internal R&D; investing in external R&D in university/research labs and other firms/consultants; and innovating products and processes. The determinants of firm innovation are those that have been used successfully in preceding studies (e.g. Maietta 2015) alongside several specifications of variables reflecting the university scientific composition and output.

The remain of the article is organized as follows. Section 2 reviews the related literature and develops the study hypotheses. Section 3 describes the methodology and the sources of the data. Section 4 presents the results of our analysis. Robustness check is provided in Sect. 5, while Sect. 6 concludes with a discussion and implications.

2 Literature review and hypotheses

Knowledge spillovers from universities to firms is channelled through research published in scholarly journals. Scientific research results in knowledge that could lead to firms' innovation activities (Bercovitz and Feldman 2007; Autant-Bernard 2001) and it could also be disseminated within the regional environment leading to an improvement of local economies (Goldstein and Renault 2004). Academic research has a positive impact on the regional distribution of innovation (Del Barrio-Castro and García-Quevedo 2005) through new product development, industry formation, job creation and access to advanced professional and management services (Walshok 1997). Indeed, a positive relationship between the scientific productivity of European universities and their entrepreneurial effectiveness such as contract research, patent activities, and spin-off creation has been found (Van Looy et al. 2011). Among the main channels through which university research impacts industrial R&D, there are published papers and reports, public conferences and meeting as well as informal information exchange and consulting (Cohen et al. 2002). Positive and significant effects of university scientific research are found indicating that firms benefit from scientific research of local universities.[4] The presence of a critical mass of academic research

[4] Industry specific findings show that for chemical and mechanical industries, the positive impact of universities on local technological performance is transmitted through the production of skilled labour in science and engineering. In electrical and pharmaceutical industries, scientific publications by researchers from local universities generate an additional positive effect on technological performance (Leten et al. 2014). The degree of knowledge codification depends also on the scientific area of research such that geographical proximity to universities may be more important for accessing social science research than for accessing natural science research (Audretsch et al. 2005). Indeed, while research related to natural sciences is more codified, in the case of research produced by the social sciences and the humanities, which is not based on a unique and established methodology, university department proximity can be still relevant for firm locational choices (Calcagnini et al. 2016) being direct contacts between entrepreneurs, researchers and/or graduates very important.

(such as the number of university publications in peer reviewed journals) creates opportunities for firms to link up to strong local scientific networks of university researchers, collaborate with university research groups and university spin-offs (Leten et al. 2014). Looking at publications as a source of ideas seems to be a particularly important element for the innovative process. Indeed, the probability of a firm to develop R&D project is positively affected by its willingness to acquire knowledge. This is the screening of publications such as reading scientific articles in order to identify competences in universities and select the right researchers (Fontana et al. 2006). However, if local collaboration may stimulate more innovation when involving a high-output partner (Nishimura and Okamura 2010), these externalities are not always widespread either because limited in the geographic space or in the scientific place (Autant-Bernard 2001). Indeed, knowledge codified in publications is more localized than knowledge codified in academic patents since its effect on knowledge-intensive firms is confined within the boundaries of the province where the universities are located (Bonaccorsi et al. 2014b). The first study hypothesis is the following:

H1 The volume of research affect the firm's propensity to innovate at local level.

The relationship between the reputation of faculty and the contribution to industry is not as strong as expected in all industries, the impact of academic quality and geographical proximity not being homogeneous across disciplinary fields. Indeed, firms seem more likely to look for a high-quality faculty or department, paying less attention to where the university is located, when basic research is considered. On the other hand, when applied R&D research is considered, firms seem to prefer working with a lower ranked university located closer to firm R&D laboratories. This behaviour may be explained by the fact that more face-to-face interaction between academics and firm employees is needed for applied research, while this interaction is less binding for basic research. Moreover, the differences between top- and second-tier universities may be more evident for basic research than for applied R&D, and beyond a certain threshold of academic quality, firms may no longer consider the additional cost attached to this collaboration worthwhile, as some top tier universities may impose more stringent conditions than those imposed by less prestigious universities. Indeed, some firms could decide to invest in supporting research at leading universities also to obtain access to promising students and graduates.

In general, by building relationships with highly ranked universities, firms gain more credibility in the market for their products' quality; therefore, improved reputation and legitimacy would mostly drive the decision to collaborate with prestigious universities. Firms make their decision to support R&D applied research according to the reputation of the university as well as to the presence of star scientists (Karlsson and Andersson 2006) based on the motivation that prestigious universities will make available the best technology to firms more cheaply and quickly (Mansfield 1991). Adams (2005) underlined that firms more interested in funding cutting-edge research will collaborate with top-tier universities regardless of the distance between them. Laursen et al. (2011) find that co-location with top tier universities promotes collaboration and that firms decide to collaborate with a university partner giving preference to its academic quality over the geographical location. Their findings show that firms first choose to collaborate with local top-tier universities and, second, with a non-local, but highly ranked, university rather than cooperating with a local second-tier institution. Szücs (2018) analyses the impact of university– firm collaboration on the number of granted patents, patent citations and indicators of patent novelty, considering the Webometrics university ranking. A positive impact, also increasing with the universities' academic quality, has been found.

However, although it is true that top-tier departments were more often cited by firms, universities with adequate to good and marginal faculties, according to the US National Academy of Science rating, also obtained good citations (Mansfield and Lee 1996). The evidence of a localized effect of academic research is offered by Calcagnini et al. (2016). They analyse the distance of innovative new firms' location from the closest university, measuring academic research according to the marks given by the national performance-based research funding system. A positive effect is evidenced only for the social science area, where knowledge is less codified and needs a direct interaction to be transmitted. Analogously, Maietta (2015) finds that firms which are closer to an academic institution develop more product innovation. However, bibliometric and research assessment indicators of the closest university exert a negative direct impact on firm product innovation. Barletta et al. (2017) also find evidence a negative association between the research groups' scientific productivity, defined as the number of Scopus publications per researcher, and the research groups' technology transfer activities. Maietta et al. (2017) find that the number of national Scopus publications presents a positive marginal effect on university-firm collaboration and product innovation but does not impact process innovation. Furthermore, the impact of national academic rankings on university spin-offs is not statistically significant (Fini et al. 2017). Based on these arguments, the following hypothesis may be formulated:

H2 Research production at local second and third tier universities has the same of even greater knowledge spillover than that at local top-tier universities.

Academic research production is recognised as an important determinant of university-firm interaction, mainly via contract and collaborative research (Laursen et al. 2011) and licensing (Mowery and Ziedonis 2015). Along this line, a few papers have underlined the effect of knowledge transfer from universities on firm product and process innovation and of university-firm collaboration on firm innovativeness (Lööf and Heshmati 2002; Belderbos et al. 2004; Baba et al. 2009; Eom and Lee 2010; Protogerou et al. 2017) and most of them focus on whether academic research indirectly affect firm's innovative outputs through formal university-firm interaction. The direct impact of academic research on firm-level innovation, instead, has not been extensively investigated[5] (Maietta 2015; Maietta et al. 2017; Barra et al. 2019). Nevertheless, informal types of cooperation for innovation, such as those which are not based on contractual agreements, like informal communication between employees from cooperating firms (Bönte and Keilbach 2005), may play an important role in the exchange of technical knowledge. For instance, a research team of one firm may ask researchers working in a R&D department of another firm for technical information and may provide in turn technical information to those researchers, although legally binding contracts do not exist and firms are not engaged in joint R&D (again, see Bönte and Keilbach 2005). We follow this definition regarding informality as it also coincides with previous definitions established in other studies related to university-firms collaboration that label as informal the lack of formalised agreements, as well as define informal

[5] The empirical literature on informal cooperation for innovation is quite scarce also because this form of collaboration is difficult to be quantified and various forms of undefined arrangements exist.

activities those providing ad hoc advice and networking with practitioners (Bonaccorsi and Piccaluga 1994; Olmos-Peñuela et al. 2014).[6] Academic engagement that also involves informal relationships has a long tradition, particularly at universities with a technical orientation of education and third-mission activities. More importantly, informal participation in collaborative activities may be pursued as an alternative resource mobilisation by highly motivated and successful individuals who are, however, not necessarily affiliated to higher quality research institutions, where fewer resources are available (Perkmann et al. 2013). These considerations led to the formulation of the following hypothesis:

H3 Informal relationship between universities and firms is an alternative and important channel of technology transfer.

Finally, spillovers to local business via university links are present due to the local generation of a skilled workforce (Faggian and McCann 2006). Graduates are a critical mechanism through which the knowledge produced in the higher education system gets transferred into the labour market (Marinelli 2013), and employers seem increasingly to be demanding workers with a graduate qualification (Wößmann 2008). Graduates may also decide to start up new firms that boost the dynamics of the local economic environment (Florax 1992; Goldstein et al. 1995). Indeed, more skilled and educated workers have a higher chance of being involved in the implementation of new technologies (Wozniak 1987), and so the skill composition of the labour force affects the technology used by firms. High quality human capital, as measured by the number of university graduates, explains local entrepreneurship in high-tech industries (Acosta et al. 2011) and has a positive effect on the creation of knowledge-intensive firms (Bonaccorsi et al. 2014b).

It is also true, however, that the education role played by universities may conflict with research and third mission in the absence of adequate resources (to be devoted to this specific aim) and of indicators of this type of output, which need to be taken into account to evaluate the advancement of scholars' careers. Achieving high-quality teaching by monitoring scholars' teaching performance could be perceived as a potential future source of private funding to augment university budgets but could also decrease the probability of university-firm collaboration. Indeed, the possibility of a trade-off between university missions, particularly between academic excellence, as measured by the number of publications in high-ranked journals, versus local knowledge spillovers useful for economic growth, has been suggested in the literature (Moscati et al. 2010; Perotti 2010) and may also dumper the quality of the teaching. As academic jobs typically involve multiple tasks, incentives based on the performance in a specific task, such as research output, could reduce workers' effort in another, such as teaching. These considerations led to the formulation of the following hypothesis:

H4 The role of education as a channel of university-based local knowledge spillovers may have been weakened due to a possible trade-off between university missions.

[6] Overall, other studies establish different definitions of what kind of activities could be included as informal. For example, from the point of view of the university, Landry et al. (2010) identify the following knowledge transfer activities: to send technical reports to knowledge users outside the scholarly milieu, to give presentations in a technical seminar organized by firms or other types of organizations, to participate in industry expert groups or expert committees involved in efforts to directly apply research knowledge, etc. (Landry et al. 2010: 1389).

3 The empirical framework

3.1 The econometric approach

Our econometric model consists of five simultaneous equations related to dependent binary variables which are jointly described by a multivariate probit model. The model is based on a five-equation structure in which the estimation results of the second and third equations are used as regressors in the fourth and fifth equations, as follows:

$$y^*_{1i} = \mathbf{x}'_{1i}\boldsymbol{\beta}_1 + \varepsilon_{1i} \tag{1}$$

$$y^*_{2i} = \mathbf{x}'_{2i}\boldsymbol{\beta}_2 + \varepsilon_{2i} \tag{2}$$

$$y^*_{3i} = \mathbf{x}'_{3i}\boldsymbol{\beta}_3 + \varepsilon_{3i} \tag{3}$$

$$y^*_{4i} = \gamma_{24}\, y^*_{2i} + \gamma_{34}\, y^*_{3i} + \mathbf{x}'_{4i}\boldsymbol{\beta}_4 + \varepsilon_{4i} \tag{4}$$

$$y^*_{5i} = \gamma_{25}\, y^*_{2i} + \gamma_{35} y^*_{3i} + \mathbf{x}'_{5i}\boldsymbol{\beta}_5 + \varepsilon_{5i} \tag{5}$$

These are the five latent variables. y^*_1 is *intra muros* R&D investment; y^*_2 is R&D collaborations with universities and/or research labs; y^*_3 is R&D collaborations with other firms and/or consultants; y^*_4 is product innovations and y^*_5 is process innovations. $\mathbf{x}_{ki}$ is vectors of exogenous variables, which influence those probabilities for firm *i*. $\boldsymbol{\beta}_k$ is parameter vectors. γ_{kl} is scalar parameters which describe a structural relation between y_k and y_l and therefore allow for causal interpretations. Finally ε_{ki} are error terms, which are assumed to be jointly normal with the unknown correlation coefficient, ρ_{kl}. The latter measures how far the unobserved factors influence y_k and y_l, if $\rho_{lk}=0$ cannot be rejected. This implies that the equations need not to be estimated as a system and can be estimated separately.

The latent variables y^*_{ki} are not observed. However, the binary variables, y_{ki}, are observed, and these are linked to the former according to the following rule:

$$\begin{cases} y_{ki} = 1, & \text{if} \quad y^*_{ki} > 0; \\ y_{ki} = 0 & \text{otherwise}; \quad k = 1, \ldots, 5 \end{cases} \tag{6}$$

Basically, our model includes three reasons why we might observe y_k (where $k=2, 3$) and y_4 (or y_5) to be correlated. First, a causal relation due to the influence from y_k on y_4 (or y_5) through the parameter γ_{k4} (or γ_{k5}). Second, y_k and y_4 (or y_5) may depend on correlated observed variables (the $\mathbf{x}_k$'s. Third, y_k and y_4 (or y_5) may depend on correlated unobserved variables (the ε_k's) (Arendt and Holm 2006). The common latent factor structure of the multivariate probit framework makes possible both to correct the potential sample selection and to control for the potential endogeneity of the R&D investment decision. Indeed, the coefficient ρ_{lk} can be interpreted as the degree of endogeneity of y_k to u_l where $k=2, 3$ and $l=3, 4$ (Monfardini and Radice 2008). The resulting multivariate probit model can be described as an instrumental variable framework for categorical variables and can be estimated using the simulated maximum likelihood method.

This method uses the Geweke-Hajivassiliour-Keane smooth recursive conditioning simulator to evaluate the multivariate normal distribution. The simulated probabilities are unbiased and bound within the (0, 1) interval (Cappellari and Jenkins 2003). All the equations in (1) can be estimated separately as single probit models but the estimated coefficients are inefficient because the correlation between the error terms is neglected and the simultaneity is not taken into account (Maddala 1983).

The estimation of a multivariate probit model with endogenous binary regressors requires some consideration for the identification of the model parameters. Maddala (1983) proposes that the exogenous covariates in the reduced form equations should contain at least one regressor not included in the structural equations. However, Wilde (2000) shows that no exclusion restrictions on the exogenous variables are required for parameter identification, when there is sufficient variation in the data. This last condition is ensured by the assumption that each equation contains at least one varying exogenous regressor, an assumption which is rather weak in economic applications. Given the assumption of joint normality, the multivariate probit model is identified by functional form. Wilde's contribution makes it clear that theoretical identification does not require availability of any additional instruments for the endogenous variables. However, the presence of equation-specific regressors in formally identified models may improve convergence and make the estimation results more robust to distributional misspecifications (Monfardini and Radice 2008).

3.2 The data and the descriptive statistics of the variables

The source of company information is the EFIGE database. The dataset consists of a representative sample for the manufacturing industry of surveyed firms with more than 10 employees in Austria, France, Germany, Hungary, Italy, Spain and the United Kingdom. The sampling design has been structured following a three dimension stratification: industry (NACE Rev. 2 codes), region (NUTS 1 level) and size class (10–19; 20–49; 50–99; 100–249 and more than 250 employees). The database contains quantitative and qualitative information on R&D and innovation. More specifically, firms are asked whether product and/or process innovation had been introduced during the years 2007–2009. The questionnaire also collects information regarding whether the R&D was *intra muros* or acquired from external sources such as universities/research labs and other firms/consultants. Other information used here includes the amount of R&D expenditure and whether the firm benefits from tax allowances and financial incentives for R&D investment or other activities. Size classes have been used with respect to the number of employees, along with other firm characteristics, such as the presence of skilled employees (that is graduates), age and gender of the current Chief Executive Officer (CEO) or company head. The age of the firm and its current legal form, firm NUTS3 location and whether the firm, in the three years, applied for a patent, registered an industrial design or a trademark and claimed a copyright have been also included.

The second source of data is represented by the EUMIDA and ETER databases. These projects aimed to build a complete census of European universities (Bonaccorsi 2014) and included a pilot data collection with particular emphasis on research-active universities. For each university, the data contain the number of national and international students, the presence of Ph.D. degrees, as well as information regarding the fields of education and the year in which the university was funded. Further information on the field of education is also sourced from the EU Agri Mapping project (Chartier 2007). All the information at the university level has been averaged out or summed up at the NUTS3 level and then matched with firm-level characteristics.

Thirdly, the main indicator of academic research used in this study is sourced from Scopus, one of the largest database of peer-reviewed literature. We specifically hand collected, for each university, the overall number of publications in scientific journals, book and conference proceeding in the field of science, technology, medicine, social sciences, and art and humanities in the year 2007.[7] Scopus has been chosen among other sources of information. Indeed, it provides good tools to track, analyse and visualize research output of an institution using both the institution name and its English translation. Furthermore, Scopus publications may well represent the internationalization degree of the national academic research output. The number of publications associated with each university has been then summed up at the NUTS3 level and matched with company-level characteristics. This allow us to assign to each firm in the dataset the indicator of academic research corresponding to the sum of publications of all the universities by the NUTS3 where the firm is located.

Fourthly, we use the ARWU database, also known as the Shanghai academic ranking of the universities, which ranks universities according to research output criteria. Among them, there is the number of papers published in Nature and Science and papers indexed in Science Citation Index-Expanded and Social Science Citation Index. It has been used in this paper to obtain an indicator of academic research output normalized by the output level of the university reaching the highest research output in the world in 2008, the intermediate year of the period under study.

Finally, information on total patents, which are used as proxy of technology level, by NUTS3 and by selected technology fields, is sourced from the Organisation for Economic Co-operation and Development (OECD) Patent Database.

Table 1, identifies and defines the variables used in our analysis, the characteristics of the sample and provides their descriptive statistics.

3.3 The empirical specification

The empirical specification of the five equations is as follows:

Intra muros R&D $=f_1$ (*R&D subsidies*, *Skilled employees*, *CEO age*, *CEO gender*, *Firm age*, firm size dummies, firm legal form dummies, intellectual property dummies, *Rurality of the province*, country dummies or university characteristics and output).

R&D collaboration with partner$_m = f_k$ (*Intra muros R&D intensity*, *extra muros* R&D intensity with partner $\neq m$, *R&D acquired abroad*, *R&D subsidies*, *Skilled employees*, *CEO age*, *CEO gender*, *Firm age*, firm size dummies, firm legal form dummies, intellectual property dummies, *Rurality of the province*, country dummies or university characteristics), where $m=$ universities/research labs or other firms/consultants and $k=2, 3$.

Innovation $j=f_j$ (*R&D collaboration with universities/research labs*, *R&D collaboration with private firms/consultants, R&D intensity, Subsidies, Skilled employees*, *CEO age*, *CEO gender*, *Firm age*, firm size dummies, firm legal form dummies, intellectual property

[7] As the empirical data used in the analysis are related to the years 2007–2009, we collect the number of publications at the baseline year assuming that a certain amount of time is required before academic research will affect the firm's propensity to innovate.

Table 1 Variables and descriptive statistics

Variables	Description of the variables	Mean	SD	Min	Max
Firm characteristics					
Intra muros R&D	Dummy variable taking the value of one in case the firm undertaken any intra-muros R&D activities	0.482	0.499	0	1
R&D collaboration with other firms/cons	Dummy variable taking the value of one in case the firm undertaken any R&D activities with other firms	0.089	0.285	0	1
R&D collaboration with univ/res labs	Dummy variable taking the value of one in case the firm undertaken any R&D activities with universities/research labs	0.048	0.215	0	1
Product innovation	Dummy variable taking the value of one in case the firm carried out any product innovation	0.490	0.499	0	1
Process innovation	Dummy variable taking the value of one in case the firm carried out any process innovation	0.439	0.496	0	1
R&D acquired abroad	Dummy variable taking the value of one in case the firm undertaken any R&D activities abroad	0.018	0.0135	0	1
R&D intensity (%)	Percentage of the total turnover that the firm has invested in R&D	3.586	7.714	0	100
Intra muros R&D intensity (%)	Intra muros R&D intensity	3.207	7.278	0	100
Extra muros R&D with other firms/cons. (%)	Extra muros R&D intensity with firms/consultants	0.125	0.966	0	50
Extra muros R&D with univ./research labs (%)	Extra muros R&D intensity with universities/research labs	0.251	1.661	0	70
R&D subsidy	Dummy variable taking the value of one in case the firm received financial incentives for R&D activities	0.161	0.368	0	1
Subsidies	Dummy variable taking the value of one in case the firm received financial incentives provided by the public sector	0.182	0.386	0	1
Skilled employees (%)	Percentage of graduates in firm workforce	9.453	13.498	0	100
CEO age	Age of the firm CEO	51.982	10.218	24	76
CEO gender	Dummy variable taking the value of one in case the firm CEO is male	0.923	0.265	0	1
Firm age	Firm age in the year in which the firm has been surveyed	34.529	30.625	0	368
Very small firm size	Dummy variable taking the value of one in case the firm has betweeen 10 and 19 employees	0.318	0.465	0	1
Small firm size	Dummy variable taking the value of one in case the firm has betweeen 20 and 49 employees	0.412	0.492	0	1

Table 1 (continued)

Variables	Description of the variables	Mean	SD	Min	Max
Medium firm size	Dummy variable taking the value of one in case the firm has betweeen 50 and 99 employees	0.120	0.325	0	1
Large firm size	Dummy variable taking the value of one in case the firm has betweeen 100 and 249 employees	0.081	0.272	0	1
Very large firm size (Reference group)	Dummy variable taking the value of one in case the firm has more than 249 employees	0.068	0.252	0	1
Proprietorship/ownership dummy	Dummy variable taking the value of 1 in case the firms is a proprietorship (entreprise individuelle / en nom personnel)	0.016	0.128	0	1
Sa dummy	Dummy variable taking the value of 1 in case the firm is a public company (société anonyme)	0.123	0.329	0	1
Sarl dummy	Dummy variable taking the value of 1 in case the firm is a limited liability partnership (société a responsabilité limitée)	0.731	0.443	0	1
Eurl dummy	Dummy variable taking the value of 1 in case the firm is a limited liability sole proprietorship (entreprise unipersonnelle à responsabilité limitée)	0.002	0.052	0	1
Coop dummy	Dummy variable taking the value of 1 in case the firm is a cooperative	0.019	0.137	0	1
Sas dummy (Reference group)	Dummy variable taking the value of 1 in case the legal form of the firm is a public limited company (société par actions simplifiée)	0.106	0.308	0	1
Patent	Dummy variable taking the value of 1 in the case the firm has applied for a patent	0.131	0.338	0	1
Design	Dummy variable taking the value of 1 in the case the firm has registered an industrial design	0.079	0.270	0	1
Trademark	Dummy variable taking the value of 1 in the case the firm has registered a trademark	0.127	0.333	0	1
Copyright	Dummy variable taking the value of 1 in the case the firm has claimed copyright	0.043	0.203	0	1
Territorial and university characteristics					
Rurality of the province	Variable taking the value of 0 if the region/province where the firm is located is predominantly urban, the value of 1 if intermediate urban and the value of 2 if predominantly rural (sourced from OECD)	1.843	0.762	1	3
University age	Average by NUTS3 of university age	64.870	132.730	0	876

Table 1 (continued)

Variables	Description of the variables	Mean	SD	Min	Max
Medical school	Sum by NUTS3 of the university dummy taking the value of 1 if the university has a hospital	0.628	1.217	0	8
Agriculture	Sum by NUTS3 of the university dummy taking the value of 1 if Agriculture is a field of education	0.427	0.871	0	7
Humanities and arts	Sum by NUTS3 of the university dummy taking the value of 1 if Humanities and Arts is a field of education	1.474	2.990	0	20
Business and law	Sum by NUTS3 of the university dummy taking the value of 1 if Social Sciences, Business and Law is a field of education	1.398	2.988	0	21
Engineering	Sum by NUTS3 of the university dummy taking the value of 1 if Engineering, Manufacturing and Construction is a field of education	1.404	2.412	0	13
Ph.D	Sum by NUTS3of the university dummy taking the value of 1 if Ph.D. programmes are offered	1.597	3.092	0	25
National students	Sum by NUTS3 of the university number of national students	26,861	55,309	0	264,679
International students	Sum by NUTS3 of the university number of international students	1595	5011	0	54,315
Academic research	Number of Scopus publications of local universities (sum of university values by the NUTS3 where the firm is located)—year 2007	1292.63	2584.57	0	10,504
First-tier university	Number of Scopus publications of the first university located in the NUTS3 where the firm is located—year 2007	695.90	1183.01	0	7578
Second-tier university	Number of Scopus publications of the second university located in the NUTS3 where the firm is located—year 2007	284.53	693.69	0	6171
Lower-tier universities (1)	Number of Scopus publications of all universities other than the first-tier one located in the NUTS3 where the firm is located—year 2007	595.63	1610.45	0	6729
Lower-tier universities (2)	Number of Scopus publications of all universities other than the first- and second-tier ones located in the NUTS3 where the firm is located—year 2007	313	957.90	0	4303
Shanghai index	Value of the Shanghai index associated with local universities (sum of university values by the NUTS3 where the firm is located)—year 2008	17.045	33.807	0	181.645
Shanghai index of first-tier university	Value of the Shanghai index associated with the first-tier university located in the NUTS3 where the firm is located—year 2008	9.766	16.995	0	66

Table 1 (continued)

Variables	Description of the variables	Mean	SD	Min	Max
Shanghai index of second.-tier university	Value of the Shanghai index associated with the second-tier university located in the NUTS3 where the firm is located—year 2008	4.340	10.852	0	61.8
Shanghai index of lower-tier univer. (1)	Value of the Shanghai index associated with all universities other than the first-tier one located in the NUTS3 where the firm is located—year 2008	7.275	19.337	0	123.445
Sahnagai index of lower-tier univer. (2)	Value of the Shanghai index associated with all universities other than the first- and second-tier ones located in the NUTS3 where the firm is located—year 2008	2.956	9.559	0	88.245
Supplier-dominated	Dummy variable taking the value of one in case the firm belongs to the Supplier-dominated Pavitt macro-sector	0.522	0.499	0	1
Scale-intensive	Dummy variable taking the value of one in case the firm belongs to the Scale-intensive Pavitt macro-sector	0.155	0.362	0	1
Specialised-suppliers	Dummy variable taking the value of one in case the firm belongs to the Specialised-suppliers Pavitt macro-sector	0.280	0.449	0	1
Science-based	Dummy variable taking the value of one in case the firm belongs to the Science-based Pavitt macro-sector	0.040	0.196	0	1
Total patents	Number of total patents in the NUTS3 where the firm is located	90.371	292.480	0	3955.744
Biotech patents	Number of Biotech patents in the NUTS3 where the firm is located	4.850	15.499	0	220.90
Inform and Comm tech patents	Number of Inform and Comm patents in the NUTS3 where the firm is located	21.242	102.211	0	1237
Nanotech patents	Number of Nanotech patents in the NUTS3 where the firm is located	0.647	3.219	0	52.50
Medical patents	Number of Medical patents in the NUTS3 where the firm is located	4.974	11.703	0	173.30
Pharmaceutical patents	Number of Pharmaceutical patents in the NUTS3 where the firm is located	7.390	26.475	0	314.50
Unemployment rate	Unemployment rate of individuals between 15 and 74 years old in the NUTS2 where the firm is located—year 2008	6.974	3.207	2	17.7
Non-academic spin-offs	Dummy variable taking the value of one in case the firm has affiliates of which owns a share of at least 10%	0.176	0.381	0	1
Number of patents	Number of patents owned by universities in the NUTS3 where the firm is located (only Italy)—years 2007–2009	57.153	122.219	0	440
Number of patents of first-tier university	Number of patents owned by first-tier universities in the NUTS3 where the firm is located (only Italy)—years 2007–2009	30.312	65.516	0	226

Table 1 (continued)

Variables	Description of the variables	Mean	SD	Min	Max
Number of patents of second-tier university	Number of patents owned by second-tier universities in the NUTS3 where the firm is located (only Italy)—years 2007–2009	13.141	32.494	0	111
Number of patents of lower-tier univer. (1)	Number of patents owned by all universities other than the first-tier one in the NUTS3 where the firm is located (only Italy)—years 2007–2009	22.062	59.930	0	214
Number of patents of lower-tier univer. (2)	Number of patents owned by all universities other than the first- and scond-tier ones in the NUTS3 where the firm is located (only Italy)—years 2007–2009	8.920	28.636	0	103
Academic research (Top-25)	Number of top-25 publications of universities in the NUTS3 where the firm is located (from GRBS)—years 2007–2010	4863.32	8994.31	0	55,167
First-tier university (Top-25)	Number of top-25 publications of first-tier universities in the NUTS3 where the firm is located (from GRBS)—years 2007–2010	3100.287	4876.842	0	30,625
Second-tier university (Top-25)	Number of top-25 publications of second-tier universities in the NUTS3 where the firm is located (from GRBS)—years 2007–2010	996.4625	2558.66	0	16,664
Lower-tier universities (1) (Top-25)	Number of top-25 publications of all universities other than the first-tier one in the NUTS3 where the firm is located (from GRBS)—years 2007–2010	1766.325	4931.678	0	29,783
Lower-tier universities (2) (Top-25)	Number of top-25 publications of all univ. other than the first- and second-tier ones in the NUTS3 where the firm is located (from GRBS)—years 2007–2010	766.5701	2618.288	0	18,805

Table 2 Significance and value of the correlation coefficients among the errors of the Eqs. (1)–(5)

Coefficients	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Rho21	**0.052****	**0.053****	**0.054****	**0.053****	**0.053****	**0.053****	**0.053****
Rho31	**0.090*****	**0.090*****	**0.091*****	**0.090*****	**0.090*****	**0.090*****	**0.090*****
Rho41	**0.239*****	**0.239*****	**0.238*****	**0.238*****	**0.239*****	**0.239*****	**0.239*****
Rho51	**0.167*****	**0.167*****	**0.167*****	**0.167*****	**0.167*****	**0.167*****	**0.167*****
Rho32	**0.148*****	**0.148*****	**0.149*****	**0.149*****	**0.149*****	**0.148*****	**0.148*****
Rho42	**0.022****	**0.023****	**0.023****	**0.022****	**0.023****	**0.023****	**0.023****
Rho52	**0.025*****	**0.024*****	**0.025*****	**0.025*****	**0.024*****	**0.025*****	**0.025*****
Rho43	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Rho53	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Rho54	**0.194*****	**0.194*****	**0.194*****	**0.194*****	**0.194*****	**0.194*****	**0.194*****

Bold values indicate coefficients of the variables statistically significant

*, **, ***Significance at 10%, 5% and 1%, respectively

dummies, *Rurality of the province*, industrial sector dummies, country dummies or university characteristics), where j = product or process.

As Table 1 shows, almost 5% of our firms have R&D collaborations with a university or research lab. Among all firms in the sample, 49% have introduced product innovation, and 44% have introduced process innovation. R&D intensity, measured as the percentage of the total turnover that the firm has invested in R&D on average in the three years is around 3.6%. Over the same time span, 48% of the firms undertook *intra muros* R&D activities.

Several specifications of variables reflecting university characteristics and output have been tested alternately. The baseline specification is Model 1, which includes only national dummies. Model 2 tests the role of average university composition (proxied by the average age of the universities, the presence of medical schools, the type of faculties in the university, and the presence of Ph.D. programmes). Model 3 and Model 4 analyse the university outputs in terms, respectively, of the number of national and international students, the academic research indicator and the number of total patents also split in different sectors (biotechnology, informatics and commercial technology, nanotechnology, medical and pharmaceutical). Model 5 tests the effect of scientific composition and academic output through the age of the universities, the presence of medical schools, the type of faculties, the presence of Ph.D. programmes, the number of national and international students, the academic research indicator and the number of total patents. Model 6, as explained in Sect. 4.2, analyses the academic research indicator of the first-tier university vs that of all the other universities in the province. Finally, Model 7 analyses the academic research indicator of the first- and second-tier universities vs that of all the remaining universities in the province.

Industrial sectors vary in terms of sources, paces and rates of technological change which modulate firm requirement to be engaged in innovation networks and the extent and character of such networking. As a consequence, we grouped firms in the four Pavitt classes (Pavitt 1984) to analyse the academic research indicator of the first-tier university vs that of all the other universities in the province also by Pavitt macro-sector.

Table 3 Multiprobit regression. Marginal effects for the dependent variable (existence of) intra muros R&D investment

Variables	Model 1 dF/dx	Model 2 dF/dx	Model 3 dF/dx	Model 4 dF/dx	Model 5 dF/dx	Model 6 dF/dx	Model 7 dF/dx
R&D subsidy dummy	**0.472*****	**0.473*****	**0.473*****	**0.473*****	**0.473*****	**0.473*****	**0.473*****
Skilled employees	**0.003*****	**0.003*****	**0.003*****	**0.003*****	**0.003*****	**0.003*****	**0.003*****
Ceo age	−0.00009	−0.0001	−0.0001	−0.0001	−0.0001	−0.0001	−0.0001
Ceo gender	−0.0006	0.000004	0.0002	−0.00007	0.0007	0.0007	0.0009
Firm age	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Very small firm size	**−0.150*****	**−0.150*****	**−0.150*****	**−0.151*****	**−0.151*****	**−0.151*****	**−0.151*****
Small firm size	**−0.090*****	**−0.089*****	**−0.089*****	**−0.090*****	**−0.090*****	**−0.089*****	**−0.090*****
Medium firm size	−0.027	−0.027	−0.026	−0.027	−0.026	−0.026	−0.026
Large firm size	0.004	0.004	0.003	0.003	0.003	0.003	0.003
Proprietorship/own dummy	**−0.084*****	**−0.083*****	**−0.080*****	**−0.080*****	**−0.079*****	**−0.079*****	**−0.079*****
Sa dummy	0.004	0.003	0.002	0.001	0.002	0.002	0.001
Sarl dummy	0.009	0.009	0.011	0.011	0.011	0.011	0.011
Eurl dummy	**−0.021*****	**−0.022*****	**−0.017****	**−0.018****	**−0.018****	**−0.018****	**−0.019****
Coop dummy	**−0.040*****	**−0.038*****	**−0.033*****	**−0.033****	**−0.033*****	**−0.034*****	**−0.033*****
Patent	**0.231*****	**0.231*****	**0.229*****	**0.230*****	**0.229*****	**0.229*****	**0.229*****
Design	**0.115*****	**0.116*****	**0.115*****	**0.114*****	**0.114*****	**0.114*****	**0.114*****
Trademark	**0.081*****	**0.081*****	**0.082*****	**0.082*****	**0.082*****	**0.082*****	**0.082*****
Copyright	0.017	0.017	0.019	0.019	0.018	0.018	0.019
Rurality of the province	0.007	0.009	0.009	0.009	0.012	0.012	0.012
France dummy	0.010	0.021	0.013	0.009	0.027	0.026	**0.028***
Germany dummy	0.016	0.020	0.014	0.013	0.017	0.016	0.018
Hungary dummy	**−0.237*****	**−0.225*****	**−0.226*****	**−0.230*****	**−0.237*****	**−0.236*****	**−0.235*****
Italy dummy	**0.026*****	**0.032*****	**0.023*****	**0.022*****	**0.025****	**0.024****	**0.026****
Spain dummy	**−0.072*****	**−0.072*****	**−0.082*****	**−0.087*****	**−0.071*****	**−0.071*****	**−0.070*****
Uk dummy	**0.023*****	**0.034*****	**0.028*****	**0.026*****	**0.036*****	**0.035*****	**0.037*****
University age		0.00001			0.00002	0.00002	0.00002

Table 3 (continued)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
Medical school		0.008			−0.004	−0.003	−0.006
Agriculture		−0.006			−0.007	−0.007	−0.008
Humanities		−0.005			−0.003	−0.004	−0.004
Business and law		0.006			**0.007***	0.008	**0.008***
Engineering		−0.001			**−0.012****	**−0.012****	**−0.012****
Ph.D		−0.0003	−0.002	−0.001	0.005	0.005	0.004
National students (th.)			−0.0002	−0.0002	−0.0002	−0.0002	−0.0001
International students (th.)			−0.0003	−0.0007	−0.001	−0.001	−0.001
Academic research (th.)			**0.010****	0.009	**0.010*****		
First-tier university (th.)						**0.010****	**0.010*****
Second-tier university (th.)							−0.006
Lower-tier universities (1) (th.)						**0.010*****	
Lower-tier universities (2) (th.)							**0.020****
Total patents (th)			**0.010***		**0.010****	**0.010***	0.010
Biotech patents (th)				−0.4			
Inform and Comm tech patents (th)				0.02			
Nanotech patents (th)				−0.2			
Medical patents (th)				**0.6****			
Pharmaceutical patents (th)				0.4			

Bold values indicate coefficients of the variables statistically significant

*, **, ***Significance at 10%, 5% and 1%, respectively

Multicollinearity among the regressors is assessed by computing the variance inflation factor (VIF). The empirical specification is based on a sample of 14,744 observations.

4 The empirical evidence

4.1 The drivers of innovation and of firm R&D collaboration

The marginal effects of the multivariate probit regressions are reported for various specifications in Tables 3–7 (Models 1 to 7). The standard errors of the coefficients have been clustered around the country in which the firm is located. The likelihood ratio test, which was conducted on the hypothesis that the ρ s are jointly null, is highly significant and supports the multivariate five-equation framework. The correlation coefficients (see Table 2) are significant for the internal R&D investment in that the presence of *intra muros* R&D is correlated with product and process innovation. The two equations related to external collaborations are also correlated and the two equations related to product and process innovation.

Table 3 reports the marginal effects for Eq. (1), for *intra muros* R&D investment. The dummy for R&D subsidies is positive and highly statistically significant. The dummies for very small and small firm size and sole proprietorship are negatively correlated with in-house R&D. As expected, skilled employees are positively correlated with in-house R&D.

Among the university characteristics, the age of the universities is not conducive to *intra muros* R&D investment. The type of faculties becomes significant after that the education variables and the academic research indicator are added. Both the academic research indicator and the number of total patents are conducive to *intra muros* R&D investment.

Table 4 reports the marginal effects for Eq. (2) (R&D collaboration with universities/research labs). The *intra-muros* R&D intensity has a negative and significant effect on the probability of building a collaboration with universities/research labs. This suggests substitution between *intra-muros* R&D investment and *extra-muros* R&D investment with universities. The *extra-muros* R&D intensity with other firms/consultants has a positive but weakly significant effect. The R&D subsidy dummy is positive and highly significant. Foreign universities/research labs may be chosen as company R&D partners because the dummy for R&D acquired abroad is positive and significant. The dummy for very small firm size is highly significant and negative. Applying for a patent and registering a trademark are positive and highly significant determinants. They, indeed, guarantee appropriability of jointly developed innovation taking into account that competitors may even collaborate with the same local research institution.

With regards to the university characteristics, age is positive and statistically significant suggesting that older universities are more involved in R&D collaboration with firms because of longstanding established networks between firms and universities. The number of total patents is negative and statistically significant probably because of rivalry between university-firm co-patents and the patents produced by other firms in the province. The number of international students seems to be detrimental to university-firm collaboration (even though not robust). It could be due to the fact that universities with international students are relatively more involved in codified knowledge teaching and research, and less focused on applied industrial research. The academic research indicator is not significant underlining no effect of the average academic research output on university-firm collaboration. It might happen that local firms, using cutting-edge technology, prefer to collaborate

Table 4 Multiprobit regression. Marginal effects for the dependent variable R&D collaboration with universities/research labs

Variables	Model 1 dF/dx	Model 2 dF/dx	Model 3 dF/dx	Model 4 dF/dx	Model 5 dF/dx	Model 6 dF/dx	Model 7 dF/dx
Intramuros R&D	**−0.0006****	**−0.0006****	**−0.0006****	**−0.0007****	**−0.0006****	**−0.0006****	**−0.0006****
Extramuros R&D with firms	**0.003***	**0.003***	**0.003***	**0.003***	**0.003***	**0.003***	**0.003***
Dummy for R&D acquired abroad	**0.098*****	**0.098*****	**0.099*****	**0.099*****	**0.099*****	**0.099*****	**0.099*****
R&D subsidy dummy	**0.063*****	**0.062*****	**0.062*****	**0.062*****	**0.062*****	**0.062*****	**0.062*****
Skilled employees	**0.0003*****	**0.0004*****	**0.0004*****	**0.0004*****	**0.0004*****	**0.0004*****	**0.0004*****
Ceo age	−0.0001	−0.0001	−0.0001	−0.0001	−0.0001	−0.0001	−0.0001
Ceo gender	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Firm age	0.00006	0.00006	0.00006	0.00006	0.00005	0.00005	0.00005
Very small firm size	**−0.014*****	**−0.014****	**−0.015*****	**−0.015*****	**−0.015*****	**−0.015*****	**−0.015*****
Small firm size	−0.001	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002
Medium firm size	0.005	0.004	0.004	0.004	0.004	0.004	0.004
Large firm size	**0.009***	0.009	0.008	0.008	0.009	0.009	0.009
Proprietorship/own dummy	**−0.083*****	**−0.083*****	**−0.083*****	**−0.083*****	**−0.083*****	**−0.082*****	**−0.082*****
Sa dummy	**−0.027*****	**−0.026*****	**−0.026*****	**−0.025*****	**−0.026*****	**−0.026*****	**−0.026*****
Sarl dummy	**−0.015*****	**−0.015*****	**−0.015*****	**−0.015*****	**−0.015*****	**−0.015*****	**−0.015*****
Eurl dummy	**−0.296*****	**−0.297*****	**−0.297*****	**−0.299*****	**−0.297*****	**−0.297*****	**−0.298*****
Coop dummy	−0.005	−0.005	−0.005	−0.005	−0.005	−0.005	−0.005
Patent	**0.029*****	**0.029*****	**0.029*****	**0.029*****	**0.029*****	**0.029*****	**0.029*****
Design	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Trademark	**0.014*****	**0.014*****	**0.014*****	**0.014*****	**0.014*****	**0.014*****	**0.014*****
Copyright	0.009	0.009	0.009	0.009	0.009	0.009	0.009
Rurality of the province	0.003	0.003	0.002	0.002	0.003	0.003	0.002
France dummy	**−0.042*****	**−0.041*****	**−0.045*****	**−0.043*****	**−0.042*****	**−0.041*****	**−0.041*****
Germany dummy	**−0.010****	**−0.012***	**−0.012****	**−0.011****	−0.010	−0.010	−0.010
Hungary dummy	**−0.012****	**−0.013***	**−0.013****	**−0.012****	**−0.016***	**−0.016***	**−0.016***
Italy dummy	**−0.030*****	**−0.030*****	**−0.031*****	**−0.031*****	**−0.032*****	**−0.031*****	**−0.031*****

Table 4 (continued)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
Spain dummy	**−0.019*****	**−0.015****	**−0.021*****	**−0.019*****	**−0.017****	**−0.016****	**−0.016****
Uk dummy	**−0.022*****	**−0.023*****	**−0.023*****	**−0.021*****	**−0.022*****	**−0.022*****	**−0.021*****
University age		**0.00001****			**0.00001*****	**0.00002****	**0.00002****
Medical school		**−0.004***			**−0.007***	**−0.008***	**−0.008***
Agriculture		0.001			0.0007	0.001	0.001
Humanities		0.00002			−0.0002	0.0001	0.0001
Business and law		−0.0001			−0.0003	−0.0007	−0.0007
Engineering		−0.0001			−0.0003	−0.0002	−0.0001
Ph.D		−0.0001	−0.0001	−0.0005	**0.001***	0.001	0.001
National students (th.)			0.00001	0.00002	0.00008	0.00008	0.00009
International students (th.)			**−0.0005*****	−0.0005	**−0.0008****	**0.0007***	−0.0007
Academic research (th.)			−0.0003	0.0006	0.0006		
First-tier university (th.)						−0.0009	−0.0007
Second-tier university (th.)							0.0003
Lower-tier universities (1) (th.)						0.002	
Lower-tier universities (2) (th.)							0.003
Total patents (th)			**−0.010*****		**−0.010*****	**−0.010*****	**−0.010*****
Biotech patents (th)				0.2			
Inform and Comm tech patents (th)				**−0.07*****			
Nanotech patents (th)				**0.2****			
Medical patents (th)				0.08			
Pharmaceutical patents (th)				**−0.3*****			

Bold values indicate coefficients of the variables statistically significant

*, **, ***Significance at 10%, 5% and 1%, respectively

Table 5 Multiprobit regression. Marginal effects for the dependent variable R&D collaboration with other firms/consultants

Variables	Model 1 dF/dx	Model 2 dF/dx	Model 3 dF/dx	Model 4 dF/dx	Model 5 dF/dx	Model 6 dF/dx	Model 7 dF/dx
Intramuros R&D	**−0.001*****	**−0.001****	**−0.001****	**−0.001****	**−0.001****	**−0.001****	**−0.001****
Extramuros R&D with univ	**0.028*****	**0.028*****	**0.028*****	**0.028*****	**0.028*****	**0.028*****	**0.028*****
Dummy for R&D acquired abroad	**0.261*****	**0.261*****	**0.260*****	**0.260*****	**0.261*****	**0.261*****	**0.261*****
R&D subsidy dummy	**0.065*****	**0.064*****	**0.064*****	**0.064*****	**0.064*****	**0.064*****	**0.064*****
Skilled employees	**0.0004*****	**0.0004*****	**0.0004*****	**0.0004*****	**0.0004*****	**0.0004*****	**0.0004*****
Ceo age	−0.0002	−0.0002	−0.0002	−0.0002	−0.0002	−0.0002	−0.0002
Ceo gender	**0.011****	**0.011****	**0.011****	**0.011****	**0.011****	**0.011****	**0.011****
Firm age	−0.00003	−0.00004	−0.00003	−0.00003	−0.00003	−0.00003	−0.00003
Very small firm size	0.002	0.002	0.003	0.003	0.002	0.002	0.002
Small firm size	0.008	0.008	0.009	0.009	0.009	0.009	0.009
Medium firm size	0.011	0.011	0.012	0.012	0.012	0.012	0.012
Large firm size	**0.016***	**0.016***	**0.016***	**0.016***	**0.016***	**0.016***	**0.016***
Proprietorship/own dummy	−0.029	−0.030	**−0.032***	−0.031	**−0.031***	**−0.032***	**−0.033***
Sa dummy	−0.008	−0.007	−0.007	−0.007	−0.007	−0.007	−0.007
Sarl dummy	−0.015	−0.016	−0.015	−0.015	−0.015	−0.016	−0.016
Eurl dummy	**−0.026*****	**−0.025*****	**−0.024*****	**−0.024*****	**−0.024*****	**−0.024*****	**−0.024*****
Coop dummy	0.005	0.004	0.004	0.004	0.004	0.003	0.003
Patent	0.009	0.009	0.010	0.010	0.010	0.009	0.009
Design	**0.048*****	**0.047*****	**0.047*****	**0.048*****	**0.047*****	**0.047*****	**0.047*****
Trademark	**0.027*****	**0.027*****	**0.027*****	**0.027*****	**0.027*****	**0.027*****	**0.027*****
Copyright	**0.020****	**0.020****	**0.020****	**0.020****	**0.020****	**0.020****	**0.020****
Rurality of the province	0.0007	0.0002	0.001	0.001	0.001	0.001	0.001
France dummy	−0.010	−0.010	−0.013	−0.012	−0.010	−0.013	−0.013
Germany dummy	**0.015*****	**0.022*****	**0.016*****	**0.015*****	**0.020*****	**0.018*****	**0.018*****
Hungary dummy	**−0.044*****	**−0.038*****	**−0.041*****	**−0.042*****	**−0.037*****	**−0.035*****	**−0.035*****
Italy dummy	**0.038*****	**0.045*****	**0.043*****	**0.042*****	**0.046*****	**0.042*****	**0.043*****

Table 5 (continued)

Variables	Model 1 dF/dx	Model 2 dF/dx	Model 3 dF/dx	Model 4 dF/dx	Model 5 dF/dx	Model 6 dF/dx	Model 7 dF/dx
Spain dummy	0.003	**0.012***	**0.009****	**0.008****	**0.013***	**0.012****	**0.012***
Uk dummy	**0.041*****	**0.048*****	**0.043*****	**0.041*****	**0.048*****	**0.045*****	**0.045*****
University age		**0.00001*****			**0.00001*****	−5.80e−06	−5.90e−06
Medical school		**−0.003***			−0.0001	0.003	0.003
Agriculture		**−0.008****			**−0.006***	**−0.007***	**−0.008***
Humanities		−0.0008			−0.0008	−0.002	−0.002
Business and law		0.0003			0.001	0.002	0.002
Engineering		−0.0004			−0.0006	−0.0009	−0.0006
Ph.D		**0.003****	**0.002*****	0.0008	0.002	0.002	0.002
National students (th.)			**−0.0001*****	**−0.0001****	**−0.0001***	**−0.0001***	−0.0001
International students (th.)			0.0001	0.0005	0.0003	0.0001	0.0001
Academic research (th.)			−0.0003	−0.0002	0.0001		
First-tier university (th.)						0.005	**0.006***
Second-tier university (th.)							−0.010
Lower-tier universities (1) (th.)						−0.005	
Lower-tier universities (2) (th.)							−0.002
Total patents (th)			**0.009****		**0.008*****	**0.010*****	**0.010****
Biotech patents (th)				−0.08			
Inform and Comm tech patents (th)				0.002			
Nanotech patents (th)				0.1			
Medical patents (th)				−0.02			
Pharmaceutical patents (th)				−0.03			

Bold values indicate coefficients of the variables statistically significant

*, **, ***Significance at 10%, 5% and 1%, respectively

Table 6 Multiprobit regression. Marginal effects for the dependent variable product innovation

Variables	Model 1 dF/dx	Model 2 dF/dx	Model 3 dF/dx	Model 4 dF/dx	Model 5 dF/dx	Model 6 dF/dx	Model 7 dF/dx
R&D collab. with univ/res labs	**0.093***	**0.093***	**0.092***	**0.092***	**0.093***	**0.093***	**0.093***
R&D collab. with other firms/cons	**0.091***	**0.090***	**0.091***	**0.091***	**0.091***	**0.091***	**0.091***
R&D intensity	**0.009***	**0.009***	**0.009***	**0.009***	**0.009***	**0.009***	**0.009***
Subsidy dummy	**0.060***	**0.061***	**0.061***	**0.061***	**0.061***	**0.061***	**0.061***
Skilled employees	**0.002***	**0.002***	**0.002***	**0.002***	**0.002***	**0.002***	**0.002***
Ceo age	**−0.0009***	**−0.0009***	**−0.0009****	**−0.0009****	**−0.0009***	**−0.0009***	**−0.0009***
Ceo gender	**0.031***	**0.031***	**0.031***	**0.031***	**0.031***	**0.031***	**0.031***
Firm age	**0.0003***	**0.0003****	**0.0003***	**0.0003***	**0.0003***	**0.0003***	**0.0003***
Very small firm size	**−0.076****	**−0.075****	**−0.076****	**−0.076****	**−0.076****	**−0.076****	**−0.076****
Small firm size	−0.035	−0.035	−0.036	−0.036	−0.036	−0.036	−0.036
Medium firm size	−0.011	−0.011	−0.012	−0.012	−0.011	−0.011	−0.011
Large firm size	0.014	0.014	0.013	0.013	0.013	0.013	0.013
Proprietorship/own dummy	0.021	0.021	0.024	0.024	0.024	0.023	0.023
Sa dummy	0.017	0.015	0.017	0.016	0.015	0.015	0.015
Sarl dummy	−0.004	−0.003	−0.003	−0.003	−0.003	−0.003	−0.003
Eurl dummy	**0.035***	**0.035***	**0.035***	**0.035***	**0.035***	**0.035***	**0.035***
Coop dummy	**−0.086****	**−0.085****	**−0.084****	**−0.085****	**−0.084****	**−0.084****	**−0.084****
Patent	**0.241***	**0.241***	**0.240***	**0.240***	**0.240***	**0.240***	**0.240***
Design	**0.175***	**0.174***	**0.174***	**0.175***	**0.174***	**0.174***	**0.174***
Trademark	**0.166***	**0.166***	**0.167***	**0.167***	**0.167***	**0.167***	**0.167***
Copyright	**0.106***	**0.107***	**0.107***	**0.107***	**0.108***	**0.108***	**0.108***
Rurality of the province	0.012	0.010	0.010	0.010	0.009	0.009	0.009
France dummy	**−0.096***	**−0.098***	**−0.101***	**−0.100***	**−0.100***	**−0.101***	**−0.101***
Germany dummy	**−0.125***	**−0.123***	**−0.123***	**−0.122***	**−0.122***	**−0.122***	**−0.123***
Hungary dummy	**−0.093***	**−0.073***	**−0.089***	**−0.086***	**−0.075***	**−0.075***	**−0.075***
Italy dummy	**−0.063***	**−0.054***	**−0.063***	**−0.062***	**−0.055***	**−0.057***	**−0.057***

Table 6 (continued)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
Spain dummy	**−0.109*****	**−0.118*****	**−0.116*****	**−0.113*****	**−0.120*****	**−0.120*****	**−0.120*****
Uk dummy	0.0009	0.008	0.004	0.007	0.009	0.008	0.007
University age		**−0.00006****			**−0.00005****	**−0.00006****	**−0.00006****
Medical school		**0.014****			**0.011***	**0.012***	**0.013***
Agriculture		−0.011			−0.010	−0.010	−0.010
Humanities		−0.004			−0.004	−0.004	−0.004
Business and law		0.003			0.003	0.003	0.003
Engineering		−0.0008			−0.004	−0.004	−0.004
Ph.D		0.0005	0.001	0.002	0.003	0.003	0.003
National students (th.)			**−0.0002****	**−0.0002***	**−0.0001***	**−0.0001***	**−0.0002***
International students (th.)			−0.001	−0.001	−0.0005	−0.0006	−0.0006
Academic research (th.)			**0.006****	**0.007***	**0.006****		
First-tier university (th.)						**0.008****	**0.007***
Second-tier university (th.)							**0.010****
Lower-tier universities (1) (th.)						0.004	
Lower-tier universities (2) (th.)							0.0003
Total patents (th.)			−0.010		−0.010	−0.010	−0.010
Biotech patents (th)				0.4			
Inform and Comm tech patents (th)				−0.01			
Nanotech patents (th)				−0.2			
Medical patents (th)				−0.07			
Pharmaceutical patents (th)				−0.2			

Bold values indicate coefficients of the variables statistically significant

*, **, ***Significance at 10%, 5% and 1%, respectively

with more distant universities. While local and more productive universities prefer to collaborate with distant large firms on richly supported cutting-edge research projects. Alternatively, for more applied research, it could be that firms prefer to collaborate with close universities even if they produce less Scopus publications.

Table 5 reports the marginal effects for Eq. (3) (R&D collaboration with other firms/consultants). The *intra-muros* R&D intensity has a negative effect on the probability of building a collaboration with other firms/consultants. This suggests substitution (and not complementarity) between *intra-muros* R&D and *extra-muros* R&D investments with other firms. Whereas the *extra-muros* R&D intensity with universities or research labs has a positive effect. The dummy for R&D subsidies is still positive and highly statistically significant and in addition the dummy for R&D acquired abroad is positive and significant with a high marginal effect. The dummy for sole proprietorship is negative and significant. The presence of medical schools and of agriculture faculties is not conducive to R&D collaboration with other firms or consultants.

Table 6 reports the marginal effects for Eq. (4) (product innovation). R&D intensity is positive and statistically significant. R&D collaborations with universities/research labs and with other firms/consultants are also positive and highly significant. The age of a firm has a positive and statistically significant effect on product innovation. CEO age appears to be significantly detrimental to product innovation, whereas being a male CEO is conducive to product innovation. The dummy for very small firm size is highly significant and negative. Cooperatives are less likely to innovate their products.

The university age is negative and statistically significant suggesting higher knowledge spilllovers of younger universities. The presence of a medical school favours product innovation. The number of national students is detrimental to product innovation, probably due to the fact that as more national students are enrolled, academics have to deal with additional teaching hours, leaving little time for third mission activities. More specifically, most local national students are enrolled in 3-year general degrees, but generally the connection between academic research and teaching at first-level degrees is weak. On the other hand, the connection between academic research and teaching at 2-year specialization degrees is higher but the mobility of these graduates is not locally confined. Finally, the pressure to publish on international journals to reach a good research assessment may have decreased the quality of teaching up to the point of weakening the role of education as a channel of local knowledge spillovers.

The academic research indicator is always positive and statistically significant meaning an important direct effect on product innovation. This variable may catch the effect of academic knowledge spillovers through informal relationships and doctors employed by firms.

Finally, Table 7 reports the marginal effects for Eq. (5) (process innovation). Process innovation is strongly determined by R&D collaboration both with universities/research labs and with other firms/consultants. R&D intensity and skilled employees are positive and highly significant. Process innovation is also favoured by public incentives. Very small and small firms are less likely to innovate their processes as well as proprietorship. Regarding the university characteristics, the presence of the faculty of humanities is detrimental to process innovation whereas the presence of the faculty of business and law is beneficial. The academic research indicator is not statistically significant.

Table 7 Multiprobit regression. Marginal effects for the dependent variable process innovation

Variables	Model 1 dF/dx	Model 2 dF/dx	Model 3 dF/dx	Model 4 dF/dx	Model 5 dF/dx	Model 6 dF/dx	Model 7 dF/dx
R&D collab. with univ/res labs	0.072**	0.072**	0.072**	0.072**	0.072**	0.072**	0.072**
R&D collab. with other firms/cons	0.116***	0.116***	0.116***	0.116***	0.116***	0.116***	0.116***
R&D intensity	0.004***	0.004***	0.004***	0.004***	0.004***	0.004***	0.004***
Subsidy dummy	0.102***	0.102***	0.102***	0.102***	0.101***	0.102***	0.102***
Skilled employees	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*
Ceo age	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001*
Ceo gender	0.051***	0.052***	0.051***	0.051***	0.052***	0.052***	0.052***
Firm age	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Very small firm size	−0.165***	−0.164***	−0.165***	−0.165***	−0.164***	−0.164***	−0.164***
Small firm size	−0.103**	−0.103**	−0.103**	−0.104**	−0.103**	−0.103**	−0.103**
Medium firm size	−0.050	−0.050	−0.050	−0.050	−0.050	−0.050	−0.050
Large firm size	−0.012	−0.011	−0.012	−0.011	−0.011	−0.011	−0.011
Proprietorship/own dummy	−0.088***	−0.086***	−0.088***	−0.088***	−0.086***	−0.085***	−0.085***
Sa dummy	−0.017	−0.018	−0.018	−0.018	−0.018	−0.018	−0.018
Sarl dummy	−0.015	−0.015	−0.015	−0.015	−0.015	−0.015	−0.015
Eurl dummy	0.118***	0.115***	0.118***	0.117***	0.116***	0.116***	0.116***
Coop dummy	−0.047**	−0.047**	−0.047**	−0.048**	−0.046**	−0.046**	−0.045**
Patent	0.069***	0.069***	0.069***	0.069***	0.069***	0.069***	0.069***
Design	0.024	0.024*	0.024*	0.024	0.024*	0.024*	0.024*
Trademark	0.049***	0.049***	0.049***	0.049***	0.049***	0.049***	0.049***
Copyright	0.069**	0.068**	0.069**	0.069**	0.068**	0.068**	0.068**
Rurality of the province	0.003	0.007	0.004	0.003	0.007	0.007	0.007
France dummy	−0.180***	−0.158***	−0.175***	−0.177***	−0.158***	−0.154***	−0.153***
Germany dummy	−0.169***	−0.165***	−0.172***	−0.171***	−0.167***	−0.165***	−0.163***
Hungary dummy	−0.210***	−0.200***	−0.206***	−0.203***	−0.201***	−0.202***	−0.202***
Italy dummy	−0.082***	−0.072***	−0.084***	−0.080***	−0.072***	−0.067***	−0.067***

Table 7 (continued)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
Spain dummy	**−0.028*****	**−0.016****	**−0.029*****	**−0.026*****	**−0.016****	**−0.015****	**−0.014****
Uk dummy	**−0.088*****	**−0.078*****	**−0.091*****	**−0.087*****	**−0.077*****	**−0.074*****	**−0.073*****
University age		0.00001			0.00001	0.00003	0.00003
Medical school		−0.0004			0.0004	−0.003	−0.005
Agriculture		0.003			0.004	0.006	0.005
Humanities		**−0.009*****			**−0.009*****	**−0.004*****	**−0.004*****
Business and law		**0.010*****			**0.011*****	**0.009****	**0.009*****
Engineering		−0.004			−0.005	−0.004	−0.004
Ph.D		0.001	−0.004	−0.001	0.001	0.001	0.0009
National students (th.)			0.00006	−0.00005	−0.00003	−0.00003	0.00002
International students (th.)			0.001	0.0005	−0.0003	−0.0001	−0.00004
Academic research (th.)			0.001	0.001	−0.0003		
First-tier university (th.)						**−0.006****	**−0.005*****
Second-tier university (th.)							−0.009
Lower-tier universities (1) (th.)						0.005	
Lower-tier universities (2) (th.)							**0.010****
Total patents (th.)			0.005		**0.008***	0.006	0.005
Biotech patents (th)				0.1			
Inform and Comm tech patents (th)				**0.1*****			
Nanotech patents (th)				**−0.9*****			
Medical patents (th)				−0.2			
Pharmaceutical patents (th)				−0.1			

Bold values indicate coefficients of the variables statistically significant

*, **, ***Significance at 10%, 5% and 1%, respectively

4.2 Academic research and local knowledge spillovers

So far, the empirical evidence suggests that academic research has an important direct effect on the firm's propensity to develop product innovation. In order to explore whether this result is mainly driven by the local first-tier university or whether also lower-tier universities play a role, we disaggregate the total number of publications. First of all, we differentiate local universities according to their research output. The local first-tier university is defined as the university with the highest number of Scopus publications. The local second-tier university is defined as the university with the second highest number of Scopus publications. Finally, local third-tier universities are all the other universities co-located in the firm NUTS3. The first-tier university is assigned the sum of its Scopus publications, and second-tier university is assigned the sum of its Scopus publications. Third-tier universities are assigned the sum of all Scopus publications of the other universities co-located in the firm NUTS3. We also grouped the publications of all the other universities apart from the first-tier one naming them *Lower-tier universities* (1) and the publications of all the other universities apart from the first- and second-tier (*Lower-tier universities* (2)).

This give us the possibility to explore whether the firm's propensity to develop innovation depends only on the activities of first-tier universities or whether also lower-tier institutions in the province where the firm is located play an important role. It is important to underline that we construct a measure of academic research that is based on a local rather than an international comparison. This is to capture the possibility that local universities, where a more face-to-face interaction between academics and firms is possible, can probably better solve the problem of firms not interested in cutting-edge research.

The main results are generally confirmed, therefore we report only the models with countries dummies and all the university characteristics (Tables 3 to 7, Model 6). When a first-tier university is present in the same province where the firm is located, then the firm is more likely to invest in *intra-muros* R&D (Table 3, Model 6) and to develop product innovation (Table 6, Model 6). Interestingly, the publications of the first-tier university are negative and statistically significant, having a detrimental effect on the development of process innovation (Table 7, Model 6). The explanation may be that first-tier universities prefer to interact with firms on product innovation activities which may generate valuable economic benefits, like patents, whereas this is not the case for process innovation (Duguet and Lelarge 2012). Lower-tier universities also positively contribute to increase the investment in *intra-muros* R&D (Table 3, Model 6).

Results in presence of first-, second- and third-tier universities (again for the main specifications) are summarised in Tables 3–7, Model 7. The empirical evidence shows that the academic production of both first-tier and lower-tier universities increases the likelihood that the firm invest in *intra-muros* R&D (Table 3, Model 7). The publications of the first two-tier universities have a positive marginal effect on firm's propensity to develop product innovation (Table 6, Model 7). This evidence underlines that benefits from high output departments are especially associated with downstream related activities—i.e. successful market introduction of new products (Bishop et al. 2011). The publications of third- and further-tier universities increases firm's propensity to develop process innovation (Table 7, Model 7). The publications of the first-tier university are again negative and statistically significant, having a detrimental effect on the development of process innovation (Table 7, Model 7).

Table 8 Multiprobit regression. Marginal effects for all the dependent variables

Variables	Model 3 dF/dx	Model 4 dF/dx	Model 5 dF/dx	Model 6 dF/dx	Model 7 dF/dx
Intra muros R&D investment					
Unemployment rate	**–0.006*****	**–0.006*****	**–0.006*****	**–0.006*****	**–0.006*****
Academic research (th.)	**0.010*****	**0.010*****	**0.010*****		
First-tier university (th.)				**0.020*****	**0.020*****
Second-tier university (th.)					0.008
Lower-tier universities (1) (th.)				**0.010*****	
Lower-tier universities (2) (th.)					0.010
R&D collaboration with universities/research labs					
Unemployment rate	–0.0004	–0.0005	–0.0004	–0.0004	–0.0004
Academic research (th.)	–0.0009	–0.0004	0.00005		
First-tier university (th.)				–0.001	–0.0007
Second-tier university (th.)					–0.002
Lower-tier universities (1) (th.)				0.001	
Lower-tier universities (2) (th.)					0.003
R&D collaboration with other firms/consultants					
Unemployment rate	–0.001	–0.001	–0.001	–0.001	–0.001
Academic research (th.)	–0.0005	–0.0002	0.00009		
First-tier university (th.)				**0.006***	**0.006****
Second-tier university (th.)					–0.010
Lower-tier universities (1) (th.)				**–0.007***	
Lower-tier universities (2) (th.)					–0.002
Product innovation					
Unemployment rate	**–0.005****	**–0.004****	**–0.004****	**–0.005****	**–0.005****
Academic research (th.)	**0.009*****	**0.010*****	**0.010*****		
First-tier university (th.)				**0.010*****	**0.010*****
Second-tier university (th.)					0.010
Lower-tier universities (1) (th.)				0.006	
Lower-tier universities (2) (th.)					0.003
Process innovation					
Unemployment rate	**–0.002*****	**–0.002*****	**–0.002****	**–0.002****	**–0.002****
Academic research (th.)	0.004	0.004	0.003		
First-tier university (th.)				–0.001	0.00001
Second-tier university (th.)					0.003
Lower-tier universities (1) (th.)				**0.008***	
Lower-tier universities (2) (th.)					**0.010****

Bold values indicate coefficients of the variables statistically significant

*, **, ***Significance at 10%, 5% and 1%, respectively

5 Robustness check

In order to make our results more reliable and to further examine whether academic research may enhance firms innovation, several robustness checks are performed.

Table 9 Multiprobit regression. Marginal effects for all the dependent variables

Variables	Model 3 dF/dx	Model 4 dF/dx	Model 5 dF/dx	Model 6 dF/dx	Model 7 dF/dx
Intra muros R&D investment					
Unemployment rate	**–0.006*****	**–0.006*****	**–0.006*****	**–0.006*****	**–0.006*****
Academic research (th.)	**0.013*****	**0.011****	**0.017*****		
First-tier university (th.)				**0.023*****	**0.020*****
Second-tier university (th.)					0.009
Lower-tier universities (1) (th.)				**0.011*****	
Lower-tier universities (2) (th.)					0.010
R&D collaboration with universities/research labs					
Unemployment rate	–0.0004	–0.0006	–0.0004	–0.0004	–0.0004
Academic research (th.)	–0.001	–0.0005	–0.00008		
First-tier university (th.)				–0.001	–0.0008
Second-tier university (th.)					–0.002
Lower-tier universities (1) (th.)				–0.001	
Lower-tier universities (2) (th.)					0.003
R&D collaboration with other firms/consultants					
Unemployment rate	–0.001	–0.001	–0.001	–0.001	–0.001
Academic research (th.)	–0.0005	–0.0003	–0.0001		
First-tier university (th.)				**0.006***	**0.006****
Second-tier university (th.)					**–0.010***
Lower-tier universities (1) (th.)				**0.007***	
Lower-tier universities (2) (th.)					–0.002
Spin-offs					
Unemployment rate	**–0.002****	**–0.003****	**–0.002****	**–0.002****	**–0.002****
Academic research (th.)	0.004	0.004	0.005		
First-tier university (th.)				**0.013*****	**0.010*****
Second-tier university (th.)					–0.008
Lower-tier universities (1) (th.)				–0.002	
Lower-tier universities (2) (th.)					0.001

Bold values indicate coefficients of the variables statistically significant

*, **, ***Significance at 10%, 5% and 1%, respectively

Firstly, we broaden the approach followed in the paper by considering the relationship between local economy and academic entrepreneurship. More specifically, one important aspect that has been taken into account in the literature on technology transfer is the role played by local conditions such as the unemployment rate. For instance, Horta et al. (2016) show that the rate of academic spin-off creation is positively associated with the skilled unemployment rate supporting the so-called recession push effect according to which when paid skilled jobs are less available, skilled entrepreneurs may be pushed toward self-employment. Although we do not have information on academic spin-off, we follow the

Horta et al. (2016) intuition and consider the effect of the regional (NUTS 2 level) rate of unemployment of individuals between 15 and 74 years old collected from the European Statistical Office (EUROSTAST) in 2008 (the intermediate year of the period under study) on the firm's propensity to develop innovations. Results (only the main specifications and the main variables proxing the research output of universities are reported[8]), summarized in Table 8, Models 3–7, are confirmed. Interestingly, the empirical evidence shows that the level of unemployment is negatively related to the firm's propensity to develop new product and processes.

We also examine the effect of the regional rate of unemployment on the firm's probability of having as affiliates firms of which they own a share or at least 10% (as proxy of non-academic spin-offs).[9] Results (again only the main specifications and the main variables proxing the research output of universities are reported[10]) are summarized in Table 9, Models 3–7,[11] and show that the academic research indicator is not significant indicating the presence of no direct effects of the average research output on the firm's propensity to establish spin-offs (Table 9, Models 3–5). However, when we differentiate local universities according to their research output (Table 9, Models 6–7), interestingly, the empirical evidence shows that especially the publications of the first-tier university are positive and statistically significant related to the likelihood of firms to create spin-offs. The rate of unemployment is confirmed to be negative and statistically significant, suggesting that a higher unemployment rate at the regional level will reduce the probability of spin-off creation. This result could be read in line with the idea that individuals are not incentivated to be pushed towards self-employment due to the risks brought by the lack of market demand and purchasing power of economies in which a substantial part of the population is unemployed.

Secondly, with regard to the definition of local first-tier universities, the total number of Scopus publications may not be the best measure to take into consideration and a different result could be reached if the focus is only on publications that are strongly relevant to the manufacturing industry. An additional research output with industrial relevance could be, for instance, the number of patents owned by the university. Unfortunately, we do not have information on university patents for all the European countries included in our analysis. However, data on patents owned by Italian universities are instead available. Therefore, we repeat the analysis using the sub-sample of Italian firms in the dataset and use the number of patents owned by Italian universities, collected from the Italian Public Research Institutes (PATIRIS), as a proxy of research excellence. More specifically, we collect, for each university, the number of patents owned by the universities in the years 2007–2009. Then, the number of patents have been summed up at the NUTS3 level and matched with company-level data. Results, summarized in Table 10, Models 3–7, (again only the main specifications and the main variables proxing the research output of universities are reported[12])

8 Results for all the specifications and all the variables are available on request.

9 More specifically, firms are asked "Has the firm any affiliates, i.e. firms of which you own a share of at least 10%". We build a dummy variable taking the value of 1 in case the firm has either national or international affiliates of which owns a share of at least 10% and 0 otherwise.

10 Results for all the specifications and all the variables are available on request.

11 With respect to the model described in Eq. (1), now we have four latent variables. y_1* is *intra muros* R&D investment; y_2* is R&D collaborations with universities and/or research labs; y_3* is R&D collaborations with other firms and/or consultants; y_4* is spin-offs. Again, $\mathbf{x}_{ki}$ is vectors of exogenous variables, which influence those probabilities for firm *i*.

12 Results for all the specifications and all the variables are available on request.

Table 10 Multiprobit regression. Marginal effects for all the dependent variables

Variables	Model 3 dF/dx	Model 4 dF/dx	Model 5 dF/dx	Model 6 dF/dx	Model 7 dF/dx
Intra muros R&D investment					
Academic research (th.)	0.0002	**0.0004*****	0.0001		
First-tier university (th.)				0.0006	**0.0009***
Second-tier university (th.)					**0.001***
Lower-tier universities (1) (th.)				– 0.0001	
Lower-tier universities (2) (th.)					**– 0.004****
R&D collaboration with universities/research labs					
Academic research (th.)	– 0.00001	0.00005	0.00001		
First-tier university (th.)				0.00003	0.0001
Second-tier university (th.)					0.0003
Lower-tier universities (1) (th.)				– 0.00001	
Lower-tier universities (2) (th.)					– 0.0007
R&D collaboration with other firms/consultants					
Academic research (th.)	– 0.00005	0.00004	– 0.0001		
First-tier university (th.)				0.0005	**0.0006***
Second-tier university (th.)					0.0002
Lower-tier universities (1) (th.)				– 0.0006**	
Lower-tier universities (2) (th.)					– 0.002
Product innovation					
Academic research (th.)	**0.0003*****	**0.0005*****	0.0002		
First-tier university (th.)				0.0009*	**0.001***
Second-tier university (th.)					0.0004
Lower-tier universities (1) (th.)				– 0.0001	
Lower-tier universities (2) (th.)					– 0.001
Process innovation					
Academic research (th.)	0.0003	0.0001	0.0001		
First-tier university (th.)				0.0006	0.0006
Second-tier university (th.)					– 0.0003
Lower-tier universities (1) (th.)				– 0.00009	
Lower-tier universities (2) (th.)					0.0003

Only the sub-sample of Italian firms has been used in the empirical analysis. The number of patents owned by the universities is used as a proxy of research excellence. The volume of research is represented by the number of patents owned by the universities within the province where the university is located. Local first (second and third) tier universities are defined as the universities, located in the same province where the firm is located, with the highest (second and third highest) number of patents

Bold values indicate coefficients of the variables statistically significant

*, **, ***Significance at 10%, 5% and 1%, respectively

show that academic patents have a direct impact on the firm's propensity to develop product innovation (Table 10, Models 3–4). More specifically, when disentangling the contribution of the first-tier university from lower-tier institutions in term of patent production, the empirical evidence shows that academic patents at the first-tier university impacts product

Table 11 Multiprobit regression. Marginal effects for all the dependent variables—Pavitt macro-sectors

Variables	Supplier-dominated		Scale-intensive		Specialised-suppliers		Science-based	
	Model 6	Model 7	Model 6	Model 7	Model 6	Model 7	Model 6	Model 7
	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
Intra muros R&D investment								
First-tier university (th.)	0.01	0.01	**0.03****	**0.03****	**0.02****	**0.02***	−0.005	0.0001
Second-tier university (th.)		−0.01		0.02		0.009		−0.01
Lower-tier universities (1) (th.)	0.007		**0.02*****		0.007		0.01	
Lower-tier universities (2) (th.)		0.02		0.02		0.005		0.03
R&D collaboration with universities/research labs								
First-tier university (th.)	0.003	0.002	**−0.02***	**−0.02***	−0.001	−0.0002	0.001	**0.01****
Second-tier university (th.)		0.01		0.01		−0.01		−0.08
Lower-tier universities (1) (th.)	−0.001		**0.01*****		0.0002		**0.02***	
Lower-tier universities (2) (th.)		**−0.008****		**0.01****		0.007		**0.08****
R&D collaboration with other firms/consultants								
First-tier university (th.)	0.0007	0.001	0.007	0.005	**0.01*****	**0.01*****	−0.005	0.004
Second-tier university (th.)		−0.01		0.01		**−0.01**		**−0.07***
Lower-tier universities (1) (th.)	**−0.008***		−0.001		−0.01		−0.01	
Lower-tier universities (2) (th.)		−0.006		−0.01		**−0.01*****		0.02
Product innovation								
First-tier university (th.)	**0.01****	0.009	0.002	0.001	0.005	0.002	0.0001	0.02
Second-tier university (th.)		0.01		0.01		0.02		−0.1
Lower-tier universities (1) (th.)	−0.001		0.01		−0.005		0.03	
Lower-tier universities (2) (th.)		−0.01		0.007		−0.02		**0.1****
Process innovation								
First-tier university (th.)	0.0009	0.0009	**−0.01*****	**−0.01***	**−0.01*****	**−0.01****	**−0.06*****	**−0.06*****
Second-tier university (th.)		0.002		0.01		−0.02		−0.005
Lower-tier universities (1) (th.)	0.002		0.01		0.009		−0.01	

Table 11 (continued)

Variables	Supplier-dominated		Scale-intensive		Specialised-suppliers		Science-based	
	Model 6	Model 7	Model 6	Model 7	Model 6	Model 7	Model 6	Model 7
	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
Lower-tier universities (2) (th.)		0.002		0.01		**0.02*****		−0.02

Bold values indicate coefficients of the variables statistically significant

*, **, ***Significance at 10%, 5% and 1%, respectively

Table 12 Multiprobit regression. Marginal effects for all the dependent variables

Variables	Model 3 dF/dx	Model 4 dF/dx	Model 5 dF/dx	Model 6 dF/dx	Model 7 dF/dx
Intra muros R&D investment					
Academic research (th.)	0.0008	−0.00008	0.0006		
First-tier university (th.)				0.0005	0.0004
Second-tier university (th.)					0.001
Lower-tier universities (1) (th.)				0.0009	
Lower-tier universities (2) (th.)					0.0006
R&D collaboration with universities/research labs					
Academic research (th.)	−0.0003	−0.0004	−0.0002		
First-tier university (th.)				−0.00006	0.00008
Second-tier university (th.)					−0.001
Lower-tier universities (1) (th.)				−0.0004	
Lower-tier universities (2) (th.)					0.001
R&D collaboration with other firms/consultants					
Academic research (th.)	0.0003	0.0003	0.0003		
First-tier university (th.)				0.0009	0.0009
Second-tier university (th.)					−0.0008
Lower-tier universities (1) (th.)				−0.0006	
Lower-tier universities (2) (th.)					−0.0003
Product innovation					
Academic research (th.)	**0.001*****	**0.002****	**0.001****		
First-tier university (th.)				0.002	0.002
Second-tier university (th.)					−0.001
Lower-tier universities (1) (th.)				0.001	
Lower-tier universities (2) (th.)					**0.004****
Process innovation					
Academic research (th.)	0.0001	0.0003	−0.00005		
First-tier university (th.)				**−0.001***	**−0.001****
Second-tier university (th.)					0.002
Lower-tier universities (1) (th.)				0.001	
Lower-tier universities (2) (th.)					0.0008

The volume of research is represented by the number of top-25 of the universities within the province where the university is located. Local first (second and third) tier universities are defined as the universities, located in the same province where the firm is located, with the highest (second and third highest) number of top-25 publications

Bold values indicate coefficients of the variables statistically significant

*, **, ***Significance at 10%, 5% and 1%, respectively

innovation more than that at lower-tier one (Table 10, Model 7) even though the result is only slightly statistically significant.

Thirdly, we are aware that industrial sectors vary in terms of sources, paces and rates of technological change, which modulate firm requirements to be engaged in innovation networks, and the extent and character of such networking, university-based knowledge spillovers may be industry-specific (Bonaccorsi et al. 2013). Therefore, we also analyse the academic research indicator of the first-tier university vs that of all the other universities in the province by Pavitt macro-sector. Results (only for the main specification and the main variables proxing the research output of universities[13]) are confirmed and presented, for all the dependent variables of the multiprobit regression and for each Pavitt macro-sector in Table 11, Models 6–7. More specifically, publications of both first- and lower-tier universities positively affect the university-firm collaboration when science-based firms are taken into account. Academic research at first-tier universities influences product innovation only of supplier-dominated industries. Furthermore, almost independently from the specific Pavitt classification, results confirm that publications has a detrimental effect on process innovation.

Fourthly, concerning the proxies of academic productivity, it could be argued that the volume of publications does not properly account for the quality of the research. Although including quality indicators of academic research is not the aim of the paper, in order to take into account this issue we consider a further source of data such as the Global Research Benchmarking System (GRBS) data set, which is based on Scopus publications in 251 subject categories covering all science and technology fields. The data set includes universities that have published at least 50 papers in at least one subject category in the period 2007–2010 (Bonaccorsi et al. 2017).[14] From this data set, we sourced the total number of publications found in titles that are within the top 25 of that subject area based on the source-normalized impact per paper (SNIP) in 2010. This is a proxy of a selected volume of scientific publications (see Barra et al. 2019 where several indicators of academic quality have been considered among the contextual drivers of innovation). The number of publications associated with each university has been again summed up at the NUTS3 level and matched with company-level characteristics. The main results (again only the main specifications and the main variables proxing the research output of universities are reported[15]), summarized in Table 12 (Models 3–7), are confirmed. Indeed, the empirical evidence shows again that the academic research indicator is positive and statistically significant representing an important direct effect on product innovation (Table 12, Model 3–5). The publications of third-and further-tier universities increase firm's propensity to develop product innovation while the publications of the first-tier universities are again negative and statistically significant having a detrimental effect on the development of process innovation (Table 12, Models 6–7).

Finally, as previously discussed, in order to measure the research output of the academic institutions, we have used the number of publications, at the university level, collected from Scopus. However, to obtain an indicator of academic research output normalized by the output level of the university reaching the highest research output in the world, we also use the ARWU ranking. It is the first developed indicator of university world ranking and, among its components, it is possible to select one specifically referring to research output. Indeed, universities are ranked by several indicators of academic or research performance, including alumni winning Nobel Prizes and Fields Medals (proxy of the quality of education), staff winning Nobel Prizes and Fields Medals and highly cited researchers (proxies of the quality of the Faculty), papers published in Nature and Science and papers

[13] Results for all the specifications and all the variables are available on request.

[14] Although this source of data allows us to use an alternative proxy of academic production, it has to be specificed that the period covered (2007–2010) does not perfectly correspond with our SCOPUS data collection (2007).

[15] Results for all the specifications and all the variables are available on request.

Table 13 Multiprobit regression. Marginal effects for all the dependent variables

Variables	Model 3 dF/dx	Model 4 dF/dx	Model 5 dF/dx	Model 6 dF/dx	Model 7 dF/dx
Intra muros R&D investment					
Shanghai index	**0.0009****	**0.0007***	**0.001*****		
Shanghai index of first-tier university				**0.001***	**0.002****
Shanghai index of second-tier university					0.001
Shanghai index of lower-tier univer. (1)				**0.001*****	
Shanghai index of lower tier univer. (2)					0.001
R&D collaboration with universities/research labs					
Shanghai index	0.00009	**0.0001***	**0.0001****		
Shanghai index of first-tier university				0.00001	– 0.0001
Shanghai index of second-tier university					– 0.003
Shanghai index of lower-tier univer. (1)				**0.0003***	
Shanghai index of lower tier univer. (2)					**0.0007*****
R&D collaboration with other firms/consultants					
Shanghai index	– 0.00001	– 0.00001	0.00001		
Shanghai index of first-tier university				0.0002	0.0009
Shanghai index of second-tier university					– 0.0002
Shanghai index of lower-tier univer. (1)				– 0.0002	
Shanghai index of lower tier univer. (2)					0.0001
Product innovation					
Shanghai index	**0.0005*****	**0.0006*****	**0.0006*****		
Shanghai index of first-tier university				**0.0006****	**0.0009***
Shanghai index of second-tier university					0.0005
Shanghai index of lower-tier univer. (1)				**0.0006***	
Shanghai index of lower tier univer. (2)					0.001
Process innovation					
Shanghai index	0.006	– 0.00002	– 0.00006		
Shanghai index of first-tier university				**– 0.0005***	**– 0.0008*****
Shanghai index of second-tier university					0.0001
Shanghai index of lower-tier univer. (1)				0.0004	
Shanghai index of lower tier univer. (2)					0.00003

indexed in Science Citation Index-Expanded and Social Science Citation Index (proxies of the research output), and the per capita academic performance of an institution (proxy of the per capita performance). We focus on the ranking based on the research output criteria. According to this indicator, the highest scoring institution is assigned a score of 100, and other institutions are calculated as a percentage of the top score.[16] However, the Shanghai

[16] The University of Oxford (United Kingdom) reaches the highest value (66) meaning that it produces 66% of the Harvad University, to which the score of 100 is assigned in 2008. Vienna University of Technology has the highest value in Austria (28.3), the University of Munich in Germany (52.7), Universidad de Barcelona in Spain (49.9), Loránd Budapest University in Hungary (25.1), Rome La Sapienza University in Italy (53.5), Pierre and Marie Curie University in France (58.2).

index ranks the universities up to the 500th position and we do not have any information on the specific ranking of institutions ranked above. Therefore, we have imputed the corresponding number of publications, previously collected from Scopus, to each university which is ranked above the 500th position. Then, we calculate the normalized output for each of these universities as the ratio of its Scopus publications to those of the university with the ARWU world highest score for research output criteria assigned in 2008. Again, all the information at university level have been summed up at the NUTS3 level and then matched with company-level characteristics.

Results (as the main findings are confirmed, we report only the main specification and the main variables proxing the research output of the universities[17]) are summarised, for all the dependent variables of the multiprobit regression in Table 13, Models 3–7. The empirical evidence shows that the Shanghai index enhances the firm's propensity to invest in *intra muros* R&D, to invest in R&D collaboration with universities or research labs as well as to develop product innovation (Table 13, Models 3–5). These results highlight that the number of Scopus publications is not the indicator of academic research firms use in their choice of R&D partners since the Shanghai index is significant.

When we disaggregate the contribution of the first- and lower-tier universities, the empirical evidence confirms that academic research, as measured by the Shanghai index, of the third- and lower-tier universities is significant in the equation related to R&D university-firm collaboration (Table 13, Model 6 and 7). This result could be explained by the fact that lower-tier institutions might better meet firm's needs. Especially when cutting-edge research is not involved, they are more likely to solve firm problems guaranteeing a more productive interaction between academics and the firm's research teams. Further results are that academic research of the first-tier university, as measured by the Shanghai index, exerts a positive effect on firm's propensity to develop product innovation whereas it is detrimental to the development of process innovation.

6 Concluding remarks

6.1 Conclusion

The aim of the paper is to empirically test the validity of four hypotheses. More specifically, we firstly examine whether the volume of academic research may enhance firm innovation differentiating local universities by research output level (H1). Secondly, we investigate whether research production at local second and third tier universities has the same of even greater knowledge spillover than that at local top-tier universities (H2). Thirdly, we explore if academic research may represent an alternative and important direct channel of technology transfer via informal relationship (H3). Finally, we also examine whether the role of education as a channel of university-based local knowledge spillovers may have been weakened due to a possible trade-off between university missions (H4).

In support of H1, results show that academic research has a direct impact on the firm's propensity to develop innovation. When disentangling the contribution of the first-tier university from lower-tier institutions, the empirical evidence also shows that research at the

[17] Results for all the specifications and all the variables are available on request.

second-tier university impacts product innovation more than that at first-tier one. Furthermore, the research output of the first-tier university exerts a detrimental effect on the development of process innovation whereas the research output of third- and lower-tier universities is beneficial. In favour of H2, this confirms that second-and third-tier universities may generate more knowledge spillovers than first-tier universities since their publications are associated with more innovation of local firms (Barra et al. 2019), being in line with the literature that suggests the possibility of a trade-off between university academic production and local knowledge spillovers useful for economic growth (Moscati et al. 2010; Perotti 2010). Results hold also when publications within the top 25 of that subject area as well as a different indicator of academic research output based on an international university ranking have been used. The empirical evidence validates the idea that beyond a certain threshold, firms may no longer consider the additional cost attached to collaboration with the local first-tier university worthwhile, as some first-tier universities may impose more stringent conditions than those imposed by lower-tier universities (see also Hong and Su 2013). This is also consistent with the idea that a trade-off exists between publications and informal collaboration with the industry (as previously suggested by Maietta 2015 and Maietta et al. 2017). More specifically, supporting H3, results show that the academic research indicator is positive and statistically significant meaning an important direct effect on product innovation, catching the effect of academic knowledge spillovers through informal relationships, informal contacts or direct interactions between academics and firms. Furthermore, informal participation in collaborative activities may be lower in first-tier universities since academics working in lower-tier universities have higher incentive to build these collaborations with firms to fund their own research activities (see Perkmann et al. 2013). Finally, in favour of H4, education does not seem to act as a channel of local knowledge spillovers suggesting that the pressure to publish on international journals to reach a good research assessment may have decreased the quality of teaching up to the point of weakening the role of education as a channel of local knowledge spillovers.

6.2 Discussion and implications

Several limitations as well as future lines of research can be derived from our analyses.

A first limitation of the analysis is related to data constraints. Indeed, the empirical evidence is based on data that exclude micro-sized firms (with less than 10 workers). Secondly, as argued in the theoretical background highlighted in Sects. 1 and 2, the role of education as a channel of university-based local knowledge spillovers may have been weakened as a consequence of the changes occurred over the last decades in the European universities. We proxy the education activities with the number of national and international students of the universities within the province where the university is located. We are aware that the number of students does not fully and perfectly represent the amount of teaching workload of universities. Indeed, knowledge spillovers from universities to firms may also operate through an upgrading of human capital stock in the area where the university is located. Incorporating in the empirical model the university graduates for all the European higher education institutions may help in disentangling education as a channel of local university-based knowledge spillovers. An additional limitation is related to the definition of local first-tier universities as the total number of publications are not the only measure of the volume of a university's research production. More work is needed to consider different proxies in terms of research output with industrial relevance. Finally, the use of Scopus publications has also potential limitations. It could indeed be possible that some papers that are particularly important for local firms could have been published in regional or national academic journals, which are not necessarily included in Scopus. And given that an important goal of the paper is to examine the role of publications on local innovation, this could be an important shortcoming, being particularly relevant in social sciences and humanities, where academic knowledge is often published in outlets that are not included in Scopus, or even in books and non-academic reports.

Our research opens the way to future interesting extensions. One immediate extension would be to test the role played by the context in which the firm operates-in terms of the quality of institutions—and assess the connection between regional quality of government and the university-firm relationship.

Several implications can also be derived from our analysis.

Firstly, our results suggest the importance of research carried out also by the lower-tier university. Therefore policies that aim at fostering academic research in Europe can be beneficial to raise the overall level of absorptive capacity innovation systems. But this should not be done reducing the resources devoted to lower-output institutions given their importance in sustaining local-level opportunities. On the other hand, in order to force first-tier universities to interact with local firms, incentives for university-firm collaboration may be increased in case of collaboration between the first-tier university and a local firm.

Secondly, a trade-off between university missions, particularly between academic production, as measured by the number of publications in academic journals versus local knowledge spillovers due to a change in the incentive structure may exists. Indeed, acts conducive to knowledge spillovers may not be particularly rewarded in academia when career advancement is predominantly dictated by scholar research quality. Consequently, researchers, mainly those employed in virtuous universities, will be more focused on high-ranked journal publications to increase their own reputation. In such circumstances, consultancies or informal collaboration may be too time demanding, and scholars may tend to concentrate on less industry-oriented academic publications. The empirical evidence partly supports this hypothesis showing that the volume of academic research, especially in lower tier universities, has an important direct impact on the firm's propensity to develop innovation.

In conclusion, research production, although very important, is not sufficient to explain university-based knowledge spillovers. It may be the case that academic research may enhance radical innovation of relatively few firms working on cutting-edge research, whereas less advanced academic research may be directly useful to incremental innovation of most local firms. Scientific research and its market exploitation may be helpful to each other since academic researchers cooperating in firms' projects acquire resources that are useful for future research. This incentive may motivate particularly high-performing academics working in lower ranked institutions, where fewer financial resources are available, as these scholars are more likely to be involved in collaborative research and industry networking (Perkmann et al. 2013).

Appendix: Structural changes in higher education system in Europe

In 1998 at University of Sorbonne-Paris, the Ministers for Education of Germany, France, Italy and UK made an agreement for promoting similarity of higher education architecture in Europe, based upon a system of two cycles. On 19 June 1999 in Bologna, this agreement, named the "Bologna Declaration", was reinforced and jointly signed by 29 countries for promoting a European Higher Education Area by 2010, usually named the “Bologna Process" (Enders et al. 2011).

The aim of the “Bologna Process" was the harmonisation of national degree university structures as a part of the construction of the new Europe. Important channels are the increased student and teacher mobility, the adoption of a common scheme of academic titles and cooperation in designing models for quality assessment. In order to control for the proliferation of official university qualifications (Perotti 2007), a framework of readable and comparable degrees was adopted. A system of credits—such as the European Credit Transfer and Accumulation System (ECTS)—was also established (Enders et al. 2011). Ten years later, 46 countries have joined the Bologna Process. Some results of the implementation of this process have been the homogenisation of the length of study programmes and the growing openness of higher education institutions to their outside social and economic environment. Indeed, the reform attempted to guarantee to each university the freedom to create degree courses responsive to the needs of the local context, within the limits of the established degree classes, and new professional identities were designed (Romano 2010). Furthermore, the need for comparability and mutual recognition of university degrees and diplomas among member-countries has fostered a restructuring of academic programmes (due to the division into cycles, the use of credits, etc.). This is a result that academics, often hostile to innovations (Ballarino and Perotti 2012; Perotti 2007; Romano 2010), would have not otherwise undertaken. On the other hand, the amount of academic duties has been growing due to the new administrative work, linked to teaching and research quality requirements. A higher workload is also due to the increasing number of students, as a consequence of the introduction of short-cycle degrees (Viola 2014) and to the general advent of mass university education (Perotti 2007). Moreover, the number of fixed-term contracts for both teaching and research has increased, including the growing recruitment of academic staff from external professional fields (Cavalli and Moscati 2010).

European universities have also faced changing funding regimes with the introduction of national systems of funding conditional on evaluation of research output, or performance-based research funding systems. National evaluation systems spread rapidly with significant differences across countries in the assessment procedure—peer review-based research assessment, metrics-based assessment or some combination of the two—and in the share of funding allocated through the national assessment exercise.

The rationales of performance-based research funding systems are numerous. Among others, first the increasing productivity with output-based evaluation, replacing traditional systems with market-like incentives. Second, the greater accountability and devolution, through higher university autonomy and self-governance (Hicks 2012).

The amounts of money directly allocated as a result of evaluation is small since input indicators and historical allocation remain dominant. However, it is possible that a performance-based research funding system entrains other parts of the research funding system. This will happen if grant review is not double-blind. Additionally, the probability of project funding is increased if the applicant is located in a higher-ranking department (Hicks 2012). As a consequence, the effect of a performance-based research funding system on universities is strong through public judgements of relative prestige. The result of the national assessment exercise is also published in newspapers and widely used. Furthermore, academic ranking is used by students, especially at the graduate level, to decide on their destinations, and by firms when looking for partners in research collaborations.

Performance-based research funding systems and academic ranking increase university competition for prestige and may enhance research productivity, but run into costs. Because of the reliance on the academic elite in their design and implementation, they may suppress scientific novelty, innovation and intellectual diversity. The contribution of universities to national and cultural identity is lowered, since the push into international and English language literature forces scholars to adopt the perspective of American academics who dominate such literature (Hicks 2012).

The United Kingdom distributes funds to higher education institutions through three main funding streams such as teaching, research and knowledge transfer. Teaching funds are allocated based on a formula that takes into account costs as well as student's participation and success rate. Research is mainly funded via a competitive research assessment. Finally, fundings for knowledge transfer are partly formula-based and then also distributed with the support of an innovation agency that co-funds projects between business and academia. The UK was the first country in Europe to introduce in 1986 a national assessment exercise (RAE) on the university research output (Hicks 2012). The main goal was increasing selectivity in the allocation of public resources moving away from a system where university funding was allocated on a historical basis (Geuna and Piolatto 2016). In Italy a general redifintion of the higher education funding system took place in 1993 when a new public funding system was set up based on the ordinary financing fund (FFO), a global lump sum that the Italian central government transfers to each university and that can be managed by universities autonomously. The FFO was allocated according to a mixed model based on historical data (at the beginning counting for more than 80 percent of the total FFO allocation) and a formula-based adjustment component which was introduced to offset the historically-based funding allocation. The formula-based component, initially based mainly on input indicators such as student numbers, now takes into account output indicators for teaching and research and it was introduced to encourage universities to improve the quality of their services. Indeed, an increased part of the FFO has been distributed according to performance indicators related to teaching activities, research activities and efficiency of institutional organization. Moreover, important changes have been implemented towards more performance-based funding mechanisms on the basis of a metric informed peer review exercise called VQR which was coordinated by the Italian national agency for the evaluation of the research (ANVUR) making Italy the only other European country (along with United Kingdom) using a national assessment of university research performance with the aim of allocating a part of the public grants. The UK and Italy are, indeed, the only countries that have implemented a performance-based research funding system that potentially evaluates all public research institutions' staff in order to allocate research funding (Geuna and Piolatto 2016). In Spain, institutional funding is generally allocated in the form of block funding. Research institutions do not receive a variable/competitively allocated organisational level research funding. Organisational level funding of universities is mainly based on education metrics and on the payment of salaries for the teachers and researchers. Recently, also Spain has introduced formula-based funding models and/or contract funding encompassing more competitive power in recent years. With respect to Italy and United Kingdom, the difference is that Spain has developed these models in a decentralized situation, where regional authorities have higher education responsibility such that each region has adopted its own formula-funding. Instead, Italy and United Kingdom have introduced these models in a situation in which the central State Administration still plays a major role, so there is a unique formula valid for allocating resources to all higher education institutions (Agasisti and Pérez-Esparrells 2010). Public funding is very strong in German universities, whereas private funding is more important in the Universities of Applied Science. However, recently, moderate tuition fees have been introduced by some German Landers,which are responsible for the German higher education system. The funding of education and research at university is devolved to a large extent to the sixteen states (Länder) which are highly autonomous in matters of education policy based on several procedures such as an incremental, discretionary and non-competitive part which is mainly based on the previous' year funding and corrected for inflation, an indicator-based part of the annual budget consists of both a teaching and a research component as well as state-wide pacts and individual target agreements as a complementary steering instruments. In France a national agency was established in 2008 to undertake, at national level, the evaluation of research in both research organisations and universities. This organisation has been replaced in 2013 by the High Council of the Evaluation of Research and Higher Education (HCERES). The main objective of HCERES is the evaluation of all French research teams and research centres. The evaluations provided are based on a peer-review assessment, but is not exclusively based on publication and citation analysis. Among the main criteria of the evaluation there is the quality of research, participation in national and/or international research networks or programmes, research grants obtained at national and international level. The main consequence of this evaluation system is the allocation of funding to the research teams by the Ministry of Higher Education and Research and by the research organisations. In Austria the financing structure of the higher education system changed considerably with the University Act of 2002 which bases competitive organisational and block funding to universities on three-year performance contracts. Competitive funding to higher education institutions outlined in these performance contracts considers separate budget areas, namely (1) budgets for teaching, (2) budgets for research and advancement of the arts, and (3) budgets for large scale infrastructures. In Hungary, the organisational funding allocation is mostly based on educational metrics such as number of full-time students, the type of education, level of education. Research support is calculated based on the number of teachers and researchers, state financed Ph.D. students, qualified staff out of teachers and teachers that get qualified (see Jonkers and Zacharewicz 2016)for a more detailed analysis of the research performance based funding systems in Europe).

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