Determinants of R&D University-Firm Collaboration and Its Impact on Innovation: a Perspective from the Italian Food and Drink Industry

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Abstract

The objective of this paper is to examine R&D collaboration between firms, on the one hand, and universities or public research labs, on the other, with particular attention to the role such collaboration plays among the determinants of product and process innovation in the Italian food and drink industry.

The firm data are sourced from four waves of the Capitalia survey. The approach is a multivariate probit analysis in which the dependent variables are intra muros R&D investment, R&D collaboration with universities, public labs and private firms, process and product innovation. The independent variables consist of firm, territory and university characteristics.

The results of the analysis demonstrate that R&D university–firm collaboration determines process innovation and, to a lesser extent, product innovation. A firm's product innovation is positively affected by its geographical proximity to a university but negatively affected by the amount of its codified knowledge production.

Keywords: university–industry interaction, R&D collaborations, product and process innovation, academic research quality, geographical distance, university education

JEL codes: O3, D22, R1

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1. Introduction

The importance of university knowledge production for industrial innovation is implicitly recognised by the substantial number of studies that have identified the determinants of university–firm interactions in firms, universities and territory characteristics. Universities may transfer knowledge and technology to firms through market-mediated interactions, such as contract and collaborative research, or through unintended flows of knowledge, such as spillovers from university-based research (D'Este and Patel, 2007; D'Este and Iammarino, 2010). The relevance of the specific market-mediated channel of the knowledge transfer from university to industry depends on the degree of knowledge codification and interdependence in firm technology and appears to vary across disciplines and sectors (Bekkers and Bodas Freitas, 2008). Academic research quality and geographical proximity from firm to university (Mansfield, 1991, 1995) are also universally recognised to influence market-related university–firm interactions, mainly through contract and collaborative research (D'Este and Iammarino, 2010; Laursen *et al*., 2011; D'Este, *et al*., 2013) and licensing (Mowery and Ziedonis, 2015).

However, little research has focused on a more systematic investigation of the multiple patterns of knowledge and technology transfers from external sources to the firm allowing at the same time for the endogenous nature of R&D decisions (Crepon *et al*., 1998; Robin and Schubert, 2013) and simultaneity between *intra muros* (that is internal to the firm) and *extra muros* (that is acquired from external sources) R&D investment (Veugelers, 1997; Belderbos *et al*., 2004). Taking both the above points into account allows to shed new light on how different modes of external R&D expenditure impact both product and process innovation.

Finally, while there are already some contributions in the literature about whether academic research quality impacts firm innovative performance through the indirect channel of market-related university–firm interactions, there is no full-fledged contribution about the direct effects of academic research quality on innovation.

The present analysis employs the "National Systems of Innovation" (NSI) approach (Lundvall, 1988; Freeman; 1988; Nelson; 1993) as its conceptual framework, which assumes that the innovative capabilities of a firm depend upon its ability to communicate and interact with external sources of knowledge, such as other firms, customers and scientific institutions; as a consequence, how firms interact with universities may sharply vary across countries, as evidenced in literature (Cardamone and Pupo, 2015). Furthermore, the demand for knowledge and technology transfer for firms with sharply different absorptive capacities is different because firms with low absorptive capacity depend more on having local high-quality universities (Laursen *et al*., 2011) not only for industrial research but also for the expertise and training these universities offer the local labour market. This expertise is particularly relevant for small and medium-sized firms, which may not have the strength and/or capacity to compete in the national labour market. Institutional changes (Robin and Schubert, 2013) contribute to reinforce the relevance of certain NSI actors as local sources of external knowledge. The present paper intends to focus on the role that geographical proximity to universities plays in shaping firm R&D collaborations with universities, public research labs and other private firms and on the impact that these different relationships have on firm innovative performance.

The novel contributions of this paper include identifying the direct impact on firm innovation of university education (among the multiple channels of university–firm interaction) and of academic quality indicators and performing a joint analysis of the determinants of *intra muros* R&D investment, of R&D collaborations and of product and process innovation.

The analysis employs a representative sample of Italian food and drink (F&D) firms that have at least 10 workers and that are contained in the 7th (1995–1997), 8th (1998–2000), 9th (2001–2003) and 10th (2004–2006) waves of the Capitalia survey. A long period is necessary to ascertain the effects of collaboration between NSI actors and industry after accounting for cross-sectional and temporal heterogeneity. The approach adopted is a multivariate probit regression in which the dependent variables are *intra muros* R&D investment, R&D collaboration with universities, R&D collaboration with public labs, R&D collaboration with private firms, and process innovation and product innovation. The independent variables are firm, territory and university characteristics.

2. The determinants of university–industry collaborations and university–industry collaboration as a determinant of innovation

Several studies have analysed the determinants of university–industry collaboration and identified drivers that can be grouped as proximity, university, firm and territory characteristics.

Geographical proximity (Boschma, 2005) plays a fundamental role as a determinant of university–industry collaboration that has been recognised by different bodies of literature (D'Este *et al*, 2013) which assume that firms that are located nearby universities may frequently collaborate with universities and benefit from knowledge spillovers. Geographical proximity (Morgan, 2004) enables the transmission of tacit knowledge, which is personal and context-dependent; this tacit knowledge cannot be easily bought via the market and is difficult to communicate other than through personal interaction in the context of shared experiences. In particular, geographical proximity matters when knowledge spillovers are informal (Jaffe *et al*., 1993; Audretsch and Feldman, 1996). Geographical proximity is important when there is information asymmetry between researchers and research users, which arises when users cannot precisely evaluate the applicability of the transferred research until they attempt to translate it into new or improved products or processes. In the context of asymmetry, the transfer of knowledge is unlikely if researchers and research users do not have frequent interactions (Landry *et al*., 2007). The number of universities within the region in which a firm is located also affects the probability of interacting with a nearby university because it increases the range of options that are available to a firm (D'Este and Iammarino, 2010).

Conversely, codified knowledge, which is explicit and standardised, can be transmitted over longer distances and across organisational boundaries with little cost. The capability of shared codification creates non-spatial proximity: cognitive proximity, which is the extent to which two organisations share the same knowledge – and organisational proximity – is the result of the accumulation of experience between the same or similar actors (D'Este, Guy and Iammarino, 2013). When knowledge is transmitted through formal ties between researchers and firms, geographical proximity is not necessary because face-to-face contact does not occur by chance but is instead carefully planned (Audretsch and Feldman, 1996). Cognitive proximity is generally higher in research in the natural sciences than in research in the social sciences because social science knowledge is less codified than that of the natural sciences and is not based on a unified and established scientific methodology. Instead, it is idiosyncratic to specific disciplines, sub-disciplines and even research approaches. Thus, geographical proximity to universities may be more important for accessing social science research than for accessing natural science research (Audretsch *et al.,* 2005).

Among university characteristics, the determinants of university–industry collaboration that have been identified in the literature are academic research quality, university size and faculty/discipline composition, department size, intermediation and the age, seniority and gender of researchers.

Academic research quality (Mansfield, 1991) is expected to act as a catalyst for industrial labs that are interested in conducting joint research activities by attracting firms with cutting-edge technologies. Mansfield (1995) provides evidence that higher-quality universities make greater academic contributions to industrial innovation. Mansfield and Lee (1996) argue that firms prefer to work with local university researchers and with more distinguished university departments; however, the impact of academic quality and geographical proximity is not homogeneous across disciplinary fields. The effect of geographical proximity on businesses' choices with respect to university partners is more pronounced for applied research than for basic research. Firms that conduct basic research predominantly collaborate with high-quality departments. D'Este and Iammarino (2010) disentangle the effects of geographical proximity and university research quality on the frequency and distance of university–industry research collaborations. For engineering-related departments, proximity is key to explaining the frequency of collaborations with industry, whereas it is not important for basic-science related departments, for which the positive impact of research quality prevails. However, the relationship between academic research quality and distance of collaborations is curvilinear because collaborations with industry turn out to be geographically closer after a certain threshold of research quality is reached. Laursen *et al*. (2011) find that a firm's choices regarding collaborating with local high-quality universities depend on the firm's absorptive capacity: firms with low absorptive capacity choose to collaborate with a high-quality local university or, as second best, with a high-quality non-local university. For firms with high absorptive capacity, geographical proximity to a top university has no effect on collaboration choice. Petruzzelli (2011) demonstrates that the value of university–industry joint innovation, which is defined as the total number of citations a specific joint-patent received within five years of its issue date, is positively affected by university reputation, prior ties and geographical distance. Muscio and Nardone (2012) find that academic research quality positively impacts the private funding of university research activities, particularly with respect to food sciences departments. The age of a university, measured in years, is also used to control for reputation effects to explain the birth of knowledge-based start-ups located in close proximity to universities (Audretsch and Lehmann, 2005).

To account for the fact that academic institutions require a critical mass of researchers to improve their chances of interacting with firms, scholars have also introduced university and department size into the analysis, which is quantified as the number of researchers (or the percentage of time) devoted to research activities (Landry *et al.*, 2007; D'Este and Iammarino, 2010; Muscio and Nardone, 2012) or the R&D intensity of the higher education sector (Huynh and Rotondi, 2009).

The composition of the university faculty/discipline or the academic scientific specialisation are introduced into the analysis of university spillovers to capture the higher familiarity with networking for basic *versus* applied research, the different amount of tacit knowledge produced and the capability of technology transmission (Landry *et al*. 2007; D'Este and Iammarino, 2010; Audretsch *et al*., 2012; Bonnaccorsi *et al*., 2013). The latter is also proxied for by the presence of a technology transfer office set up to minimise the cognitive distance between business and academics (Muscio and Nardone, 2012) or by the regional location of the university for tacit-knowledge-intensive industries (Fitjar and Rodríguez-Pose, 2012).

Among the personal characteristics of scholars, age and professional status are taken into account because older scientists and full professors are expected to accept multiple offers of firm involvement, whereas younger scientists and research assistants are more likely to be involved with a local firm than with a nonlocal firm or to not be involved at all (Audretsch and Stephan, 1996; Landry *et al*., 2007; Giunta *et al*., 2015). Gender is also used as a control variable (Landry *et al.*, 2007).

The firm characteristics that are identified in the literature as drivers of university–industry R&D collaboration are size, age, ownership structure, public subsidies for the promotion of innovation and the multi-purpose nature of firm problems (Piga and Vivarelli, 2004; Medda *et al*., 2005; Huynh and Rotondi, 2009; Bodas Freitas *et al*., 2011; Laursen *et al.*, 2011). Among the territory characteristics of a firm that are important, firm location in industrial clusters (D'Este, Guy and Iammarino, 2013) and regional R&D intensity (Laursen *et al*., 2011) are also taken into account.

The result that proximity to a university is positively associated with innovation is well established in studies taking a production-function approach to the study of academic spillovers; in addition, a growing empirical literature regarding university–industry collaboration focuses on the firm-perceived benefits of such collaborations (see i.e., De Fuentes and Dutrénit, 2012), whereas relatively fewer studies analyse firm data to determine the impact of university–industry collaboration in terms of outcome variables, such as innovation performance. These latter studies also differ in the type of sample used (for example, only firms with R&D activities, only innovators or samples which include innovators and non-innovators), in the type and number of channels investigated, in the comparison with other external source of firm knowledge and whether they use simultaneous analyses or not.

Motohashi (2005), Robin and Schubert (2013) and Belderbos *et al*. (2014) analyse firms with innovative activities, Baba *et al*. (2009) analyse firms with patents and Jiang *et al*. (2010) analyse incumbent firms. Innovating firms are analysed by Brower and Kleinknecht (1996), Belderbos *et al*. (2004), Faems *et al*. (2005), and González-Pernía *et al*. (2014); innovators and non-innovators are investigated by Karlsson and Olson (1998), Becker and Dietz (2004), Amara and Landry (2005), Nieto and Santamaria (2007), Chen *et al*. (2011), and Fitjar and Rodríguez-Pose (2012).

The channels studied include the following: co-authorship (Jiang *et al*., 2010), co-patenting (Baba *et al*., 2009), labour mobility (Karlsson and Olson, 1998), citations (Mansfield and Lee, 1996; Jiang *et al*., 2010), R&D collaborations with universities or public research labs (Brower and Kleinknecht, 1996; Becker and Dietz, 2004; González-Pernía *et al.*, 2014; Belderbos *et al*.; 2014) and collaborations with universities or public research labs without distinguishing between informal technology consultancies and R&D contract and joint research (Karlsson and Olson, 1998, Belderbos *et al*., 2004; Amara and Landry, 2005; Faems *et al*., 2005; Motohashi, 2005; Nieto and Santamaria; 2007; Chen *et al*., 2011; Fitjar and Rodríguez-Pose, 2012; Robin and Schubert, 2013).

Most studies focus on product innovation (Brower and Kleinknecht, 1996; Karlsson and Olson, 1998; Becker and Dietz, 2004; Faems *et al*., 2005; Nieto and Santamaria, 2007; Chen *et al*., 2011; Belderbos *et al*.; 2014); innovation is studied by Mansfield and Lee (1996) and Amara and Landry (2005); and both product and process innovation are studied by Nieto and Santamaria (2007), Fitjar and Rodríguez-Pose (2012), Robin and Schubert (2013) and González-Pernía *et al*. (2014). Motohashi (2005) and Baba *et al*. (2009) analyse patents.

Veugelers (1997) analyses internal and external R&D expenditures, whereas multiple external sources of firm knowledge are studied by Belderbos *et al*. (2004) and Robin and Schubert (2013). Simultaneous systems are proposed by Becker and Dietz (2004) and Belderbos *et al*. (2004).

In summing up the literature review, the potential firm drivers of firm R&D collaborations include the following: property rights, public subsidies for innovation, size, age, and territorial location. The potential drivers of university–firm R&D alliances with respect to university characteristics include academic research quality, intermediation, faculty size and discipline composition, whereas with respect to scholars' characteristics, these drivers include age, seniority and gender. Furthermore, a simultaneous multi-equation approach can address the simultaneity between *intra muros* and *extra muros* R&D investment and the endogeneity of R&D decisions.

3. Methodology

3.1. The econometric approach

The econometric model consists of simultaneous equations that are jointly described by a multivariate probit model.

The model follows a six-equation structure in which the estimation results of the second, third and fourth equations are used as regressors in the first, fifth and sixth equations, as follows:

$$\begin{cases} y_{1i}^{*} = \gamma_{12}\, y_{2i}^{*} + \gamma_{13}\, y_{3i}^{*} + \gamma_{14}\, y_{4i}^{*} + \mathbf{x}_{1i}^{'}\boldsymbol{\beta}_{1} + \epsilon_{1i} \\ y_{2i}^{*} = \mathbf{x}_{2i}^{'}\boldsymbol{\beta}_{2} + \epsilon_{2i} \\ y_{3i}^{*} = \mathbf{x}_{3i}^{'}\boldsymbol{\beta}_{3} + \epsilon_{3i} \\ y_{4i}^{*} = \mathbf{x}_{4i}^{'}\boldsymbol{\beta}_{4} + \epsilon_{4i} \\ y_{5i}^{*} = \gamma_{54}\, y_{4i}^{*} + \mathbf{x}_{5i}^{'}\boldsymbol{\beta}_{5} + \epsilon_{5i} \\ y_{6i}^{*} = \gamma_{64}\, y_{4i}^{*} + \mathbf{x}_{6i}^{'}\boldsymbol{\beta}_{6} + \epsilon_{6i} \end{cases} \quad (1)$$

The six latent variables defined as follows: y_1* is *intra muros* R&D investment; y_2* are R&D collaborations with universities; y_3* are R&D collaborations with public research labs; y_4* are R&D collaborations with private firms; y_5* are product innovations and y_6* are process innovations; $\mathbf{x}_{ki}$ are vectors of exogenous variables, which influence those probabilities for firm *i*; $\boldsymbol{\beta}_k$ are parameter vectors; γ_{kl} are scalar parameters; and ε_{ki} are error terms, which are assumed to be jointly normal with unknown correlation coefficients, ρ_{kl}, and correlated with something else in the model. The covariate vectors $\mathbf{x}_{ki}$ are not restricted to containing the same variables of interest as long as there is at least one varying exogenous regressor[1] in each equation in system (1) (Wilde, 2000).

The realisation of the latent variables $y_{ki}*$, is not observed; however, the realisation of the binary variables, y_{ki}, is observed, and these are linked to the former according to the following rule:

$$\begin{cases} y_{ki} = 1, & \text{if } y_{ki}^* > 0 \\ y_{ki} = 0 & \text{otherwise; } k = 1, \ldots, 6 \end{cases} \quad (2)$$

The dependant variables are equal to 1 when: *intra muros* R&D investment>0 for y_1, *extra muros* R&D expenditure with partner$_m$>0 for y_k where m = universities, public research labs, private firms and k = 2, 3, 4; and product and process innovation are present, respectively for y_5 and for y_6.

The equations that refer to y_1, y_2, y_3 and y_4 have been included to identify the determinants of the *intra muros* and *extra muros* R&D investment that aims at introducing product or process innovation and to take into account the simultaneity of firm decisions relating to the type of *intra muros* and *extra muros* R&D investment. Furthermore, the common latent factor structure of the multivariate probit framework allows us both to control for the potential endogeneity of the R&D investment decision and to correct the potential sample selection. The resulting recursive multivariate probit model can be described as an instrumental variable framework for categorical variables (whose identification conditions have been described in footnote 1) and can be estimated using a simulated maximum likelihood method.

For the empirical model, the determinants of university–firm interaction that are listed at the end of section 2 have been used to describe firms' external relationships with universities, public research labs and private firms – except for scholars' characteristics, which have been used only for the equation relative to R&D collaboration with universities. The determinants of product and process innovation used in the empirical model are those that are customarily used in literature (Rama, 2008).

[1] In recursive multiple equation probit models with endogenous dummy regressors, no exclusion restrictions on the exogenous variables for parameter identification are required when there is sufficient variation in the data. The last condition is ensured by the assumption that each equation contains at least one varying exogenous regressor (Wilde, 2000).

3.2. The data and the variables

The firm data used in this paper are sourced from the "Survey of Italian manufacturing firms", which was formerly run by Mediocredito Centrale and is currently run by Capitalia, which are both Italian credit institutions. The analysis is built on four waves, which cover the 1995–1997 (7th), 1998–2000 (8th) 2001–2003 (9th) and 2004–2006 (10th) periods; each wave includes over 4,000 firms. The survey design includes all firms with at least 500 workers and a sample that is representative of Italian manufacturing firms employing between 10 and 500 workers, which is stratified by firm size, sector and geographical area.

In the Capitalia surveys, firms are asked whether process, product and/or other innovations were introduced during the previous three years. The questionnaire also collects information whether R&D was *intra muros* or acquired from universities, public research labs and other private firms, along with other firm characteristics, such as the presence of skilled employees (that is graduates). Information about whether the universities are regional was provided only in the last wave[2].

Using their ATECO classification, F&D firms have been extracted, which results in a pool of 1,744 firms for the 1995–2006 period. After checking ex-post representativeness, it was determined that the sample so derived is representative of Italian F&D firm by region.

Size classes have been defined following the AGRA (2004) classification with respect to turnover thresholds, which are expressed in constant 2006-based €: very small firms < 5 ml; small firms between 5 and 25 ml; medium-sized firms between 25 and 50 ml; large firms between 50 and 100 ml; and very large firms ≥ 100 ml.

Information about the municipality in which the firm is located, or, in its absence, of the province, as in Benfratello *et al*. (2008), has been used to identify the first three closest faculties of agriculture. The choice of focusing on these faculties is supported by the evidence that most university collaborations of F&D firms are with the regional faculty of agriculture; furthermore, a firm that has university collaborations is likely to have multiple university or public research lab partners (Bodas Freitas *et al*., 2011), and the probability that one of these partners is the regional faculty of agriculture is very high. Following Laursen *et al*. (2011), three distances in kilometres from the faculty's

[2] According to this information, 4 F&D firms had R&D collaborations with extra-regional universities for the 2004-2006 period.

main location for each firm are presented in the data set; as usual (D'Este *et al.*, 2013), these distances are measured as the crow flies[4]. The choice of the faculty's main location is made based on the evidence that research labs are located there, even if specific courses might sometimes be moved to peripheral towns. A fourth variable for geographical proximity is a dummy that takes the value of 1 if the closest faculty of agriculture is more than 150 km away; this value was chosen after testing at different thresholds.

With respect to the closest faculty of agriculture, the following information was also gathered: whether the faculty is extra-regional; whether it is public; the year in which it was established; its size in terms of researchers/professors (calculated annually)[5]; the annual composition of researchers/professors in terms of i) gender, ii) birth year, iii) carrier status (researchers, associate and full professors), and iv) scientific disciplines; the annual number of graduates (ISTAT, Statistiche sulla Ricerca Scientifica[6]); faculty reputation (measured annually), which was kindly offered by Censis for the 1998–2006 period; the presence of a 5-year food technologist degree programme[7]; and the presence of a food technologist 3-year degree programme (Ministero dell'Università e della Ricerca Scientifica, several years). The number of bachelor's degree biotechnologist courses is relative to the university regional supply (Ministero dell'Università e della Ricerca Scientifica, several years; ISTAT, several years; INEA, several years). Finally, the number of faculties by region has been calculated to capture agglomeration externalities and the social capital component of the university–firm interaction through the creation of networks between industry and government.

The academic research quality of each faculty of agriculture is measured by the grades provided by the Italian Evaluation of Research Quality, hereafter VQR, for the 2001–2003 and 2004–2010 periods. The VQR grade is a composite indicator of the quality of the research output produced by universities and/or public research labs under the supervision of the Higher Education Department during the evaluation period. Groups of Experts of Evaluation, which are coordinated by the National Agency for the Evaluation of Universities and Research Institutes, evaluated the research output using both bibliometric analysis and informed peer review. There is evidence that these two

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[4] http://distanzechilometriche.net/
[5] http://cercauniversita.cineca.it and http://www.cnvsu.it/
[6] http://www.cnvsu.it/
[7] After the reform ushered in with Decree n. 509/99, it consists of a 3-year general degree, followed by a 2-year specialized degree.

evaluation systems give similar grades for the same set of journal articles (Bertocchi *et al*., 2015).

Two measures of codified knowledge are built using the medians of the ISI-Scopus indexed scientific production, which is measured by the number of articles and citations in the populations of full professors of the Italian faculties of agriculture grouped by scientific discipline over the 2002–2012 period[8]. It was not possible to measure the scientific production of the faculty of agriculture for the 1995–2001 period because scholars' names for the 1995–1999 period are not available on the website. The use of the medians referred to the 2002–2012 period is based on the assumptions that the differences among scientific disciplines in median production of ISI-Scopus indexed journals have not changed materially with respect to the 1995–2001 period.

Other indicators that are used in this paper as proxies for society's perception of a faculty's reputation include the following annual grades supplied by Censis for the 1998–2006 period: the research project grade (which is based on the number of research projects financed by national and international institutions), and the international grade, which is based on the international mobility of scholars and students. This information is missing for the 1995–1997 period; thus, the two grades for 1998 have been used for the first period. For the remaining periods, the two grades are the average of the grades for the three corresponding years. These two indicators are used to compute the annual ranking of faculties that is published to assist high-school students in choosing a degree course.

A final indirect expression of meritocratic *versus* hierarchical institutions is the absence of gender segregation, proxied by the percentage of women who are full professors.

Territorial characteristics are sourced by Istat for the agricultural and food districts and by INEA (for several years) for regional R&D, which is measured as the amount of accredited funds at constant 2006-based prices normalised by the number of regional F&D firms. The latter is used as a proxy of regional R&D intensity.

Table 1 reports the descriptive statistics of the sample.

Table 1 here

[8] http://abilitazione.miur.it/

4. Results and Discussion

The results of the multivariate probit regression are reported for several variable specifications in tables 2–7. The standard errors (not reported) of the coefficients have been clustered around the regions in which the firm is located because the institutional setting is homogenous within the same region, as regional governments are responsible for implementing agri-food policies.

The likelihood ratio test (Monfardini and Radice, 2006), which was conducted on the hypothesis that the ρs are jointly null supports the multivariate six-equation framework against the univariate probit run separately for equation 1 plus a multivariate five-equation structure run for equations 2–6; the value of the statistics for the specification of variables relative to model 4 of tables 3–7 is equal to 13.53 with 5 degrees of freedom, compared with a critical value equal to 11.07 at the 5% significance level. The variance inflation factor (VIF) for each variable in models 1-5 is always lower than 10[9]; it is respectively equal to 5.7 for *Codified 1* in model 6 and to 22.12 for *Codified 2* in model 7, as a consequence model 6 is the preferred variable specification. For both models, *No. of graduates* is the only other variable with a VIF greater than 10 (equal to 10.7).

Table 2 here

The significance and high values of ρ_{32} and ρ_{42} (Table 2) show a high correlation between R&D university–firm collaborations and R&D public research labs–firm collaborations and between R&D university–firm collaborations and product innovation, respectively. The correlation among the errors of the equations is also significant and strong for ρ_{65} and is increasing in the final period. This result emphasises that firm innovation has become more complex in recent years and has involved both products and processes.

The marginal effects for equation 1 are skipped because less interesting. We mainly discuss the results of the regressions run for the entire period (models 1–7). Model 1 and model 4 are virtually identical, although model 4's Log likelihood value is higher and hence model 4 is chosen for further developments in the paper.

[9] A VIF greater than 10 is a sign of multicollinearity.

Table 3 here

Table 3 reports the marginal effects for equation 2.

The positive determinants of R&D collaboration with universities include the following: skilled employees, subsidies and firm age. *Intra muros* R&D intensity is positive and gains significance in the presence of faculty characteristics, whereas being a very small firm is negative and always highly significant. R&D university-firms collaboration is less likely in northern Italy, after taking into account faculty characteristics.

Regarding geographical proximity, the 1st, 2nd and 3rd distances from the faculties of agriculture are not significant, whereas when the distance from the closest faculty of agriculture is greater than 150 km, such proximity is highly significant. Isolated firms, which are more than 150 km away from the closest faculty of agriculture, have 0.04 more probability of R&D collaboration with a university, which may or may not be the closest faculty of agriculture. The former case might be explained by the so-called ‘stray dog syndrome’ (Howells *et al*., 2012), i.e., isolated firms tend to value any contact with universities more than less-isolated firms because of the difficulty of identifying and maintaining these contacts and because they are relatively unusual.

The amount of normalised regional accredited funds is negative and significant.

Among the university characteristics, the presence of an intermediation structure has no direct effects on firm R&D collaboration with universities. This result, not in accordance with Muscio and Nardone (2012), can be explained observing that the the majority of Italian universities set up technology transfer offices between 2000 and 2005, and the majority of these offices, during the years examined in the present study, remained understaffed and did not offer specialized services (Cardamone *et al*., 2015). The public status of the university is significant but negative because the private university research and industrial communities are more deeply connected and there are more interactions between them.

The number of faculties within the same region tends to express a negative and weakly significant effect, which is most likely simply because informal interactions with universities prevail in regions with more faculties.

Among the faculty characteristics, the size (the number of researchers or professors) is positive and significant only in the absence of academic research quality indicators; when the latter are added, the former becomes weakly significant. Among the training variables, the 5-year food technologist course is a channel for R&D university collaboration, whereas the 3-year food technologist course acts against these alliances. The interpretation of this result is that university education can act as a mechanism of university–firm interactions if graduates from local universities find jobs in local firms. Freshmen will likely choose the degree course with more local occupational chances; then, when employed in local firms they may preferentially turn to their Alma Mater for R&D collaborations.

Among the personal characteristics of scholars, the presence of female full professors induces R&D university collaboration because, on one hand, women have higher ability to cooperation (Kuhn and Villeval, 2013), sensitivity to social cues and context-dependency (Croson and Gneezy, 2009) and, on the other hand, the cost of knowledge exchange with meritocratic and non-hierarchical institutions is low. The fraction of the total scholars that are researchers acts negatively, as suggested by the literature. Both variables are associated with the faculty's age: younger faculties have more women among full professors and relatively few researchers; consistent with the foregoing, younger faculties tend to be less hierarchical and are not perceived as distant by firms.

Codified knowledge, as measured by the number of citations on ISI-Scopus indexed journals, and the VQR are positive and weakly significant. Having agriculture faculties a technical nature, this result is in accordance with what already found by D'Este and Iammarino (2010) for engineering-related departments.

Table 4 here

Table 4 reports the marginal effects for equation 3. The pattern is similar to that observed for *extra muros* R&D collaboration with universities, and the important differences consist of the following: a lower marginal impact of skilled employees and of the absolute value of the very small firms dummy, a negative and significant impact of the southern Italy dummy and a significant and positive impact of the non-standard jobs dummy.

Public labs compete with universities as firm partners in R&D collaborations because collaborations with public labs increase with the 1st distance from the closest faculty of agriculture and decrease with its age, its internationalisation and the number of regional faculties of agriculture; however, the regional funds support firm-public research labs alliances. Concurrently, public labs seem also to be co-partners of universities in firm

R&D collaborations because the presence of R&D collaborations with public labs is positively related to the research project grade of the closest faculty of agriculture.

Table 5 here

Table 5 reports the marginal effects for equation 4. The profile of the F&D firm choosing private firms as R&D partners is a company that has skilled employees and no R&D collaborations with universities and receives subsidies but is not located in southern Italy. *Intra muros* R&D intensity is weakly significant, and there is no size effect. Regional funds do not support this type of R&D network; among the faculty characteristics of the closest faculty of agriculture, university intermediation is detrimental.

Thus, public research seems complementary to private research – as has previously been found for Italy (Fantino *et al*., 2013) – for more knowledge-intensive F&D firms because *intra muros* R&D intensity is significant only for the variable relative to R&D collaboration with universities. For less knowledge-intensive F&D firms, public research is a substitute for private research because academic policies that are oriented towards the commercial exploitation of research results have realised a displacement effect on both the presence of *intra-muros* R&D investment (not reported here) and of R&D collaboration with private firms.

Table 6 here

Table 6 reports the marginal effects for equation 5.

Product innovation is strongly determined by *extra muros* R&D from private firms and subsidies. Skilled employees, R&D intensity and *extra muros* R&D from universities and public research labs are weakly significant. The dummies relative to very small firms and to co-ops are negative; however, the former becomes weakly significant after faculty characteristics are introduced because very small firms tend to be located closer to agriculture faculties. In other terms, if we observe firm innovative activities from an NSI perspective, product innovation appears less scale intensive, which is likely because a very-small firm size is counterbalanced by the behaviour of the public NSI actors. Location in agricultural districts appears weakly detrimental to product innovation.

Regarding geographical proximity, the 1st distance from the faculty of agriculture is highly significant and negative, whereas the 2nd and 3rd distances are not significant. Analogously, whether the distance from the closest faculty of agriculture is greater than 150 km is highly significant and negative: a firm that is within a radius of 150 km[11] of a faculty of agriculture has a probability of product innovation that is 0.20 times greater (after faculty characteristics have been accounted for) than a more distant firm.

Among university and faculty characteristics, the number of regional faculties of agriculture and the number of disciplines that are present in the closest faculty of agriculture are significant and positive. Size tends to be weakly significant and negative, which is most likely because larger faculties tend to promote the commercial exploitation of academic research results and may inhibit informal technology transfer, as found by Landry *et al*. (2007).

The indicators of research project grade and of codified knowledge are significant and negative: consultancies or informal collaboration may be too demanding for faculties that are involved in projects that are aimed at codified knowledge production and scholars tend to concentrate on academic publications because industry-oriented research may deteriorate their publication profile (Bonaccorsi *et al*., 2006); on the other hand, evidence of a trade-off between high-quality research and teaching performance has already been provided in literature (Barra and Zotti, 2014). The VQR grade is weakly significant and also negative.

By summing up, when innovation is produced by tacit knowledge, geographical distance from university matters, in this case most likely for university–industry–government networks, which, however, tend to exclude very small firms.

The marginal effects for equation 6 are reported in table 7.

Table 7 here

Process innovation is determined by *extra muros* R&D from private firms, *extra muros* R&D from universities or public research labs, subsidies and sales through distribution chain agreements; no size effect is significant. R&D intensity is weakly significant and becomes highly significant in the last sub-period. Firm size does not affect process innovation directly but only indirectly through the capabilities of *intra muros* R&D investment (not reported here) and *extra muros* R&D collaborations with

[11] This threshold has been selected by comparison with the alternative dummies for 50, 75, 100 and 200 kms, which produce weak or non-significant results. Conversely, if we multiply the marginal effect of the 1st distance variable in model 1 by 150, a comparable value of -0.15 is obtained.

universities and public research labs.

Geographical distances from a faculty of agriculture are generally not significant whereas the number of regional faculties of agriculture is significant and positive. The public status of the university is negative and significant with a strong impact.

The indicator of research project grade is significant and positive: projects financed at universities have effects on the process innovation of local firms. The amount of codified knowledge is not significant.

By summing up the results from all the equations, firm age explains the choice of a university as an R&D partner, whereas faculty age has a negative effect on the choice of public research labs; furthermore, the profile of the F&D firm that collaborates in R&D with public research labs is characterized by a lower investment in full-time research staff. Firms located in southern Italy tend not to collaborate with both public research labs and private firms. One possible explanation is that long co-location creates linkages between F&D firms and universities, and this long co-location reduces the risk of R&D collaborations. The other two important motivations include the presence of multidisciplinarity at universities, compared with the specialisation of public and private research labs, on the one hand, and the training channel, which has a stronger impact for university collaborations compared with that for public research labs, on the other.

Very small firms prefer, in decreasing order, private firms, public labs and universities as R&D partners; scale limits are overcome by these firms mainly through R&D collaborations with other private firms. The main reason behind this finding is that the R&D collaboration with private firms has a higher marginal effect in terms of probability of innovation than the R&D collaboration with universities or public research labs. However, the former is, on average, three times more as expensive as the latter.

R&D university–industry collaboration is a strong determinant of process innovation and is less important for product innovation, whereas product innovation is affected by informal university–industry collaboration, as proxied by the geographical distance variable.

Over the 2001–2006 period (Model 8), R&D collaborations decreased, particularly those with public research labs and, to a lesser extent, those with universities. Subsidies became the strongest innovation driver, and R&D intensity became significant for product and process innovation, whereas co-location with a faculty of agriculture loses significance for product innovation and R&D collaboration with universities or public research labs for process innovation. The choice of firms to collaborate with universities is weakly affected by the grade given to the faculty by the Italian Evaluation of Research Quality. Academic policies that aim at commercialising research output, which are pursed in this sub-period and proxied by the technology transfer office's age, negatively impact both product and process innovation.

5. Concluding remarks

The objective of this paper is to determine the role that firm R&D collaborations with universities, public research labs and other private firms play among the determinants of product and process innovation and to determine how geographical proximity to a university explains the choice of innovating through R&D collaborations with universities, public research labs and other private firms.

The results obtained show that local knowledge spillovers from universities can be important because a firm within a radius of 150 km from a university has a higher likelihood of product innovation than a more distant firm. However, local knowledge spillovers and codified knowledge appear to be university non-joint outputs because the direct impact of the ISI-Scopus indexed journal production on local firms' product innovation is negative. Expertise supplied by local universities acts as a channel for R&D collaborations with universities, public research labs and private firms.

The implications for public science and technology policy of the results obtained in this study shows that the NSI structure has effects on the size of local knowledge spillovers. The same amount of knowledge produced by the public research system – when areas of expertise offered by universities are those required by the local industry – can spill over throughout the local economy, through informal or market-mediated channels of interaction between firms and other NSI actors, more easily in the case of an NSI structure with a strong presence at universities, such as the Italian and the German public agri-food research system. The positive impact of geographical proximity on product innovation suggests that a territorially dispersed NSI structure increases local knowledge spillovers for a sector with a plethora of small firms whose technologies are not based on codified knowledge. However, the geographical distance from universities to local firms, which is relevant for knowledge externalities, is not particularly small (150 km), whereas the marginal effect of an additional faculty of agriculture is limited in magnitude. Note however that other intrinsic characteristics of new faculties (such as generally being less hierarchical academic institutions) have already been taken into account through other variables (women on full professors; researchers on total researchers/professors; discipline composition). A dispersed and polycentric NSI structure runs the risk of conflicting interests among different public players, such as universities and national and regional public research labs, with a resulting increase of the information asymmetry in the choice of firm R&D partners. Finally, the choice of both scientific disciplines and degree courses have an impact on the path of local development: some economic activities might be benefitted, whereas others, which do not use the codified knowledge produced by that specific scientific discipline or the expertise supplied by that specific course, might instead be sacrificed.

The third role played by universities conflicts with research and higher education in the absence of adequate resources (to be devoted to this specific aim) and of indicators of this type of output, which are taken into account to evaluate the advancement of scholars' careers.

From the university perspective, particularly in the case of large faculties, achieving high-quality teaching (by monitoring scholars' teaching performance through the information on the evaluation of degree courses and/or the graduate occupation) should be perceived not as a tool for local development externalities but mainly as a potential future source of private funding to augment university budgets. The same can be said about the gender glass ceiling whose elimination would increase the probability of university-firm collaboration.

From the firm perspective, it is clear that for tacit knowledge-intensive activities, in particular, a small size and an isolated location can still be problematic as it is related to difficulties in developing successful R&D collaborations and in choosing the appropriate R&D partner. Reducing information asymmetry should be undertaken by trustworthy third parties, such as regional development agencies, which are not biased towards regional public research labs.

A limitation of the present work and a direction for its future extension is that, because of data limitations, the analysis conducted herein excludes micro firms.

Tables

Table 1
Variables and descriptive statistics

Variables	Mean	Std. Dev.	Variables	Mean	Std. Dev.
Firm characteristics			***Regional public R&D***		
Dummy for R&D collaboration with universities	0.05	0.22	Accredited funds (constant 2006-based th.s €/No. F&D firms)	2.18	3.12
Dummy for R&D collaboration with public labs	0.05	0.22			
Dummy for R&D collaboration with universities or public research labs	0.09	0.28	***Distance from the faculties of agriculture***		
Dummy for R&D collaboration with private firms	0.09	0.29	1st distance (kms)	47.71	37.24
Dummy for *intra muros* R&D investment	0.27	0.44	2nd distance (kms)	108.94	74.40
Dummy for product innovation	0.34	0.48	3rd distance (kms)	144.71	81.40
Dummy for process innovation	0.49	0.50	Dummy for distance > 150 kms	0.02	0.15
R&D intensity (% turnover)	0.28	1.23			
Intra muros R&D intensity (% turnover)	0.24	1.34	***University characteristics***		
Extra muros R&D intensity from universities (% turnover)	0.01	0.07	No. regional bachelor biotechnologist courses	0.61	0.49
Extra muros R&D intensity from public labs (% turnover)	0.01	0.06	N. of regional faculties of agriculture	1.53	1.00
Extra muros R&D intensity from private firms (% turnover)	0.03	0.18	Dummy for public university	0.97	0.18
Skilled employees (%)	5.13	7.82	Dummy for technological transfer office	0.22	0.41
Sales through distribution chain agreement (%)	25.49	34.62	Technological transfer office's age	1.80	1.92
Subsidies dummy	0.48	0.50			
Non standard job dummy	0.24	0.49			
Co-op firm dummy	0.17	0.38	***Faculty characteristics***		
Firm age (years)	30.96	24.09	Dummy for extra-regional faculty of agriculture	0.12	0.32
Very small-sized firm dummy	0.31	0.46	Dummy for food technologist bachelor 3-year degree	0.54	0.50
Small-sized firm dummy	0.51	0.50	Dummy for food technologist bachelor 5-year degree	0.42	0.49
Medium-sized firm dummy	0.08	0.27	Faculty of agriculture's age (years)	50.00	24.93
Large-sized firm dummy	0.05	0.21	N. of researchers/professors	109.93	51.55
Meat processing dummy	0.16	0.36	N. of graduates	166.77	127.02
Fruit&vegetables processing dummy	0.12	0.33	Women on full professors (%)	10.74	9.85
Dairy products'manufacture dummy	0.18	0.38	Researchers on total researchers/professors (%)	34.56	10.39
Grain mil and starch products manufacture dummy	0.07	0.25	Average age of researchers/professors	48.19	4.68
Prepared animal feeds manufacture dummy	0.05	0.22	N. of scientific disciplines' groups	5.56	1.81
Beverage manufacture dummy	0.19	0.39	Industrial engineers on total scholars (%)	0.63	1.53
Oils and fats manufacture dummy	0.04	0.19	Biologists on total scholars (%)	8.53	10.79
Fish processing dummy	0.03	0.16	Chemicals on total scholars (%)	5.98	8.03
			Physicians on total scholars (%)	1.03	3.71
Temporal dummies			Geologists on total scholars (%)	1.11	2.08
Dummy 1998-2000	0.29	0.45	International grade	64.62	28.39
Dummy 2001-2003	0.29	0.46	Research project grade	82.46	16.49
Dummy 2004-2006	0.18	0.38	VQR grade	68.43	9.03
			Codified knowledge indicator (No. journal articles)	18.57	1.76
Territorial characteristics			Codified knowledge indicator (No. citations)	14.04	4.00
North dummy	0.52	0.50			
South dummy	0.35	0.48			
Dummy for food district	0.08	0.26			
Dummy for agricultural district	0.03	0.16			

Table 2
Snignificance and value of the correlation coefficients among the errors of the equations 1-6

Coefficients	*model 1*	*model 2*	*model*	*model 4*	*model 5*	*model 6*	*model 7*	*model 8*
rho21	-0.01	-0.01	-0.01	-0.01	0.02	0.03	0.03	-0.16 *na*
rho31	0.05	0.05	0.04	0.05	0.05	0.06	0.06	0.08 *na*
rho41	0.07	0.07	0.07	0.07	0.10	0.09	0.09	-0.21
rho51	0.06	0.06	0.06	0.07	0.06	0.06	0.06	-0.06
rho61	**0.09***	**0.09***	**0.10***	**0.10***	0.08	0.09	0.09	0.02
rho32	**0.50***	**0.50*****	**0.50*****	**0.50*****	**0.52*****	**0.54*****	**0.54*****	0.97 *na*
rho42	**0.48***	**0.47*****	**0.47*****	**0.47*****	**0.48*****	**0.50*****	**0.50*****	**0.56*****
rho52	-0.11	-0.12	-0.12	-0.11	-0.11	-0.11	-0.11	0.23
rho62	**-0.22*****	**-0.22*****	**-0.22*****	**-0.22*****	**-0.20*****	**-0.20*****	**-0.20*****	0.20
rho43	**0.29****	**0.28****	**0.28****	**0.29****	**0.32*****	**0.32****	**0.32****	**0.53*****
rho53	-0.06	-0.06	-0.06	-0.06	-0.05	-0.05	-0.05	0.20
rho63	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	0.21
rho54	**-0.13***	**-0.12***	**-0.12***	**-0.13****	**-0.12***	-0.11	-0.11	0.23
rho64	**-0.27*****	**-0.27*****	**-0.27*****	**-0.28*****	**-0.24*****	**-0.24*****	**-0.24*****	0.26
rho65	**0.44*****	**0.44*****	**0.44*****	**0.43*****	**0.44*****	**0.44*****	**0.44*****	**0.50**

na In the case of model 8 only, the software did not provide significance levels fo the ρs

Table 3

Multiprobit regression. Marginal effects for the dependent variable *extra muros* R&D collaboration with universities

Variables	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**
	model 1	***model 2***	***model 3***	***model 4***	***model 5***	***model 6***	***model 7***	***model 8***
Extra muros R&D intensity from public labs	-0.04	-0.04	-0.04	-0.04	-0.05	-0.05	-0.06	**-0.22****
Extra muros R&D intensity from private firms	-0.05	-0.05	-0.04	-0.04	-0.04	-0.04	-0.04	-0.05
Intra muros R&D intensity	**0.01***	**0.01***	**0.01***	**0.01***	**0.01****	**0.01****	**0.01***	**0.01*****
Skilled employees	**0.002*****	**0.002*****	**0.002*****	**0.002*****	**0.002*****	**0.002*****	**0.002*****	**0.003*****
Co-op firm	**-0.03***	**-0.03***	**-0.03***	**-0.03***	**-0.03****	**-0.03***	**-0.03***	-0.02
Subsidies	**0.04*****	**0.04*****	**0.04*****	**0.04*****	**0.04*****	**0.04*****	**0.04*****	**0.05*****
Non standard jobs	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01
Firm age	**0.0004****	**0.0004****	**0.0004****	**0.0004****	**0.0004****	**0.0004****	**0.0004****	**0.0006****
Very small-sized firm	**-0.10*****	**-0.10*****	**-0.10*****	**-0.10*****	**-0.09*****	**-0.09*****	**-0.09*****	**-0.08****
Small-sized firm	-0.04	-0.04	**-0.04***	**-0.04***	-0.03	-0.03	-0.03	-0.01
Medium-sized firm	-0.03	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02	-0.04
Large-sized firm	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.04	-0.01
North	0.00	0.00	0.00	0.00	**-0.05*****	**-0.05*****	**-0.05*****	-0.06
South	0.00	0.00	0.00	0.00	-0.02	-0.03	-0.03	0.02
Food district	-0.03	-0.03	-0.03	-0.03	-0.03	-0.02	-0.02	-0.01
Agricultural district	0.02	0.01	0.01	0.02	0.02	0.01	0.01	0.01
1st distance	0.00							
2nd distance		0.00						
3rd distance			0.00					
Distance > 150 kms				**0.04***	**0.04*****	**0.04*****	**0.04*****	0.03
Regional R&D - Accredited funds					**-0.004****	**-0.003****	**-0.003****	**-0.005***
Biotechnologist courses					0.01	0.01	0.01	-0.01
Food technologist bachelor 5-year course					**0.04****	**0.05*****	**0.05*****	0.04
Food technologist bachelor 3-year course					**-0.03****	**-0.03****	**-0.03****	-0.03
Extra-regional faculty of agriculture					0.00	0.01	0.01	**0.05***
Faculty of agriculture 's age					0.00	0.00	0.00	0.00
N. of researchers/professors					**0.001****	**0.001***	**0.001***	0.00
N. of graduates					0.00	**0.0002***	**0.0002***	0.00
Industrial engineers on total scholars					0.00	0.00	0.00	0.01
Biologists on total scholars					0.00	0.00	0.00	**0.006****
Chemicals on total scholars					**-0.002****	**-0.003****	**-0.003****	**-0.02*****
Physicians on total scholars					0.00	0.00	0.00	0.00
Geologists on total scholars					**0.01****	**0.01****	**0.01****	0.01
Women on full professors					**0.002****	**0.002****	**0.002****	**0.002*****
Researchers on total researchers/professors					**-0.002*****	**-0.003*****	**-0.003*****	0.00
Average age of researchers/professors					0.00	0.00	0.00	-0.01
N. of scientific macro-fields					0.00	0.00	0.00	0.00
N. of regional faculties of agriculture					**-0.01****	**-0.01***	**-0.01***	0.00
Public univerisity					**-0.14*****	**-0.14*****	**-0.14*****	-0.07
Technological transfer office					0.03	0.03	0.03	-0.02
International grade						0.00	0.00	
Research project grade						0.00	0.00	
Codified knowledge indicator (No. articles)						0.01		
Codified knowledge indicator (No. citations)							**0.01***	
VQR grade								**0.01***
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*** signficant at 1% level ** signficant at 5% level * signficant at 10% level

Table 4

Multiprobit regression. Marginal effects for the dependent variable *extra muros* R&D collaboration with public resea

Variables	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**
	model1	***model2***	***model3***	***model4***	***model5***	***model6***	***model7***	***model8***
Extra muros R&D int. from universities	-0.07	-0.07	-0.07	-0.07	-0.07	-0.08	-0.08	**-0.12*** **
Extra muros R&D int. from private firms	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.70
Intra muros R&D intensity	**0.01***	**0.01***	**0.01***	**0.01***	0.00	0.01	0.00	0.00
Skilled employees	**0.001****	**0.001****	**0.001****	**0.001****	**0.001****	**0.001****	**0.001****	**)0.003*****
Co-op firm	**-0.04****	**-0.04****	**-0.04****	**-0.04****	**-0.04****	**-0.04****	**-0.04****	-0.29
Subsidies	**0.04*****	**0.04*****	**0.04*****	**0.04*****	**0.03*****	**0.03****	**0.03****	**0.05*****
Non standard jobs	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	0.00
Firm age	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Very small-sized firm	**-0.04*****	**-0.04****	**-0.04****	**-0.04****	**-0.04****	**-0.07****	**-0.04****	-0.32
Small-sized firm	-0.01	0.00	-0.01	0.00	-0.01	-0.01	-0.01	0.04
Medium-sized firm	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	0.00
Large-sized firm	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	0.00
North	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.05
South	**-0.03***	**-0.04***	**-0.04***	**-0.04***	**-0.05*****	**-0.07*****	**-0.07*****	**-0.08*****
Food district	0.01	0.01	0.01	0.01	0.00	0.00	0.00	-0.05
Agricultural district	-0.02	-0.02	-0.03	-0.02	-0.02	-0.02	-0.02	0.01
1st distance	**.0003*****							
2nd distance		0.00						
3rd distance			**0.0001*****					
Distance > 150 kms				**0.05*****	**0.03****	**0.03****	**0.03****	0.05
Regional R&D - Accredited funds					**0.002***	**0.002****	**0.002****	**0.002***
Biotechnologist courses					0.00	0.00	0.00	**-0.24*****
Food technologist bachelor 5-year course					**0.03*****	**0.03*****	**0.03*****	**-0.17****
Food technologist bachelor 3-year course					-0.02	-0.01	-0.01	-0.04
Extra-regional faculty of agriculture					0.00	0.00	0.00	**-0.32*****
Faculty of agriculture 's age					**-0.001****	**-0.001*****	**-0.001*****	**0.003****
N. of researchers/professors					0.00	0.00	0.00	0.00
N. of graduates					0.00	0.00	0.00	0.00
Industrial engineers on total scholars					0.00	0.00	0.00	0.02
Biologists on total scholars					0.00	0.00	0.00	**0.01**
Chemicals on total scholars					**-0.002****	**-0.004*****	**-0.004*****	0.01
Physicians on total scholars					**0.002****	**0.002***	**0.002***	**0.04***
Geologists on total scholars					0.00	0.00	0.00	**0.06*****
N. of scientific macro-fields					0.00	0.00	0.00	0.00
N. of regional faculties of agriculture					**-0.01****	**-0.01****	**-0.01****	**-0.12****
Public univerisity					0.02	0.03	0.03	**-0.61*****
Technological transfer office					-0.01	-0.01	-0.01	**-0.04***
Technological transfer office's age								-0.02
International grade						**-0.001****	**-0.001****	
Research project grade						**0.001*****	**0.001*****	
Codified knowledge indicator (No. articles)						0.01		
Codified knowledge indicator (No. citations)							0.00	
VQR grade								0.00
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*** signficant at 1% level ** signficant at 5% level * signficant at 10% level

Table 5

Multiprobit regression. Marginal effects for the dependent variable *extra muros* R&D collaboration with private firms

Variables	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
	model1	*model2*	*model3*	*model4*	*model5*	*model6*	*model7*	*model8*
Extra muros R&D int. from universities	-0.25**	-0.26**	-0.26**	-0.26**	-0.24**	-0.24**	-0.24**	-0.22
Extra muros R&D int. from public labs	-0.15	-0.15	-0.15	-0.15	-0.13	-0.14	-0.14	-1.72**
Intra muros R&D intensity	0.01*	0.01*	0.01*	0.01*	0.01*	0.01*	0.01*	0.02***
Skilled employees	0.002**	0.002**	0.002**	0.002**	0.002**	0.002**	0.002**	0.004***
Co-op firm	-0.05**	-0.05**	-0.05**	-0.05**	-0.05**	-0.06***	-0.06***	-0.02
Subsidies	0.07***	0.07***	0.07***	0.07***	0.07***	0.07***	0.07***	0.11***
Non standard jobs	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Firm age	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Very small-sized firm	-0.07	-0.07	-0.07	-0.07	-0.06	-0.06	-0.06	-0.03
Small-sized firm	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.02
Medium-sized firm	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02
Large-sized firm	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07*
North	0.02	0.02	0.02	0.02	-0.02	-0.03	-0.03	0.01
South	-0.04**	-0.04**	-0.04**	-0.04**	-0.06*	-0.08**	-0.08**	-0.02
Food district	-0.02	-0.02	-0.02	-0.02	-0.01	-0.01	-0.01	0.00
Agricultural district	0.05	0.05	0.05	0.05	0.05	0.04	0.04	-0.05
1st distance	0.00							
2nd distance		0.00						
3rd distance			0.00					
Distance > 150 kms				0.02	0.00	0.01	0.01	0.04
Regional R&D - Accredited funds					-0.01**	-0.01**	-0.01**	-0.01**
Biotechnologist courses					0.03	0.03	0.03	0.06**
Food technologist bachelor 5-year course					0.05**	0.05**	0.05**	0.01
Food technologist bachelor 3-year course					-0.03	-0.03	-0.03	-0.07*
Extra-regional faculty of agriculture					0.00	0.00	0.00	0.01
Faculty of agriculture 's age					0.001*	0.00	0.00	0.002*
N. of researchers/professors					-0.001**	0.00	0.00	0.00
N. of graduates					0.00	0.00	0.00	-0.0003**
Industrial engineers on total scholars					-0.02*	-0.02*	-0.02*	-0.02*
Biologists on total scholars					-0.002***	-0.002***	0.00	-0.006*
Chemicals on total scholars					0.00	0.00	0.00	0.01**
Physicians on total scholars					0.00	0.00	0.00	-0.07***
Geologists on total scholars					0.01***	0.01***	0.01***	0.04**
N. of scientific macro-fields					0.00	0.01	0.01	0.02**
N. of regional faculties of agriculture					0.00	-0.01	-0.01	-0.04**
Public univerisity					-0.02	-0.03	-0.03	-0.17**
Technological transfer office					-0.04**	-0.03	-0.03	-0.04*
Technological transfer office's age								0.00
International grade						0.00	0.00	
Research project grade						0.00	0.00	
Codified knowledge indicator (No. articles)						0.00		
Codified knowledge indicator (No. citations)							0.00	
VQR grade								0.00
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*** signficant at 1% level ** signficant at 5% level * signficant at 10% level

Table 6

Multiprobit regression. Marginal effects for the dependent variable product innovation

Variables	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
	model1	*model2*	*model3*	*model4*	*model5*	*model6*	*model7*	*model8*
R&D collaborations with universities and public labs	0.13*	0.13*	0.13*	0.13*	0.13*	0.13*	0.13*	-0.05
R&D collaborations with private firms	0.20***	0.20***	0.20***	0.20***	0.19***	0.19***	0.19***	-0.04
R&D intensity	0.02*	0.02*	0.02*	0.02*	0.02*	0.02*	0.02*	0.02**
Skilled employees	0.002*	0.002*	0.002*	0.003**	0.003**	0.003**	0.003**	0.003**
Sales through distribution chain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co-op firm	-0.04**	-0.04**	-0.04**	-0.04**	-0.05**	-0.05**	-0.05**	-0.04
Subsidies	0.16***	0.16***	0.16***	0.16***	0.16***	0.17***	0.17***	0.34***
Non standard jobs	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05
Firm age	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Very small-sized firm	-0.08**	-0.09**	-0.09**	-0.09**	-0.08*	-0.07*	-0.08*	-0.07
Small-sized firm	-0.05	-0.05*	-0.05*	-0.05*	-0.04	-0.04	-0.04	-0.02
Medium-sized firm	0.05	0.04	0.04	0.04	0.06	0.06	0.06	0.08
Large-sized firm	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.10
North	-0.04*	-0.04*	-0.04*	-0.04*	-0.05	-0.06*	-0.06*	0.04
South	-0.02	-0.02	-0.01	-0.01	0.05	0.06	0.04	0.04
Food district	-0.04	-0.05	-0.05	-0.04	-0.06	-0.06	-0.06	-0.01
Agricultural district	-0.04	-0.05	-0.05	-0.06	-0.06*	-0.07	-0.07	-0.15***
1st distance	-0.001***							
2nd distance		0.00						
3rd distance			0.00					
Distance > 150 kms				-0.18***	-0.20***	-0.20***	-0.20***	-0.08
				-0.09***	-0.12***	-0.16***	-0.16***	
Regional R&D - Accredited funds					0.00	0.00	0.00	-0.01**
Biotechnologist courses					-0.02	-0.02	-0.01	0.04
Food technologist bachelor 5-year course					0.01	-0.03	-0.03	-0.01
Food technologist bachelor 3-year course					0.05*	0.05*	0.05*	0.01
Extra-regional faculty of agriculture					0.04	0.04	0.04	0.00
Faculty of agriculture 's age					0.00	0.00	0.00	0.00
N. of researchers/professors					0.00	-0.001*	-0.001*	0.00
N. of graduates					0.00	0.00	0.00	0.00
Industrial engineers on total scholars					0.01	0.01	0.01	0.00
Biologists on total scholars					0.00	0.00	0.00	-0.01*
Chemicals on total scholars					0.00	0.004***	0.004***	0.01
Physicians on total scholars					0.00	0.00	0.02**	0.00
Geologists on total scholars					0.00	0.00	0.00	0.00
N. of scientific macro-fields					0.02**	0.02**	0.03***	0.01
N. of regional faculties of agriculture					0.03**	0.03**	0.03**	0.00
Public univerisity					-0.04	-0.04	-0.04	-0.06
Technological transfer office					-0.02	0.00	0.00	0.05
Technological transfer office's age								-0.06***
International grade						0.00	0.00	
Research project grade						-0.001***	-0.002***	
Codified knowledge indicator (No. articles)						-0.03***		
Codified knowledge indicator (No. citations)							-0.02***	
VQR grade								-0.01*
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sub-sector dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*** signficant at 1% level ** signficant at 5% level * signficant at 10% level

Table 7

Multiprobit regression. Marginal effects for the dependent variable process innovation

Variables	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**	**dF/dx**
	model1	***model2***	***model3***	***model4***	***model5***	***model6***	***model7***	***model8***
R&D collaborations with universities and public labs	**0.25*** **	**0.25*** **	**0.24*** **	**0.25*** **	**0.24*** **	**0.24*** **	**0.24*** **	0.02
R&D collaborations with private firms	**0.29*** **	**0.29*** **	**0.29*** **	**0.29*** **	**0.27*** **	**0.26*** **	**0.26*** **	-0.06
R&D intensity	**0.02***	**0.02***	**0.02***	**0.02***	**0.02***	**0.02***	**0.02***	**0.04*** **
Skilled employees	-0.0001	-0.0001	0.00	0.00	0.00	0.00	0.00	0.00
Sales through distribution chain	**0.001*** **	**0.001*** **	**0.001*** **	**0.001*** **	**0.001*** **	**0.001*** **	**0.001*** **	0.00
Subsidies	**0.18*** **	**0.18*** **	**0.18*** **	**0.18*** **	**0.19*** **	**0.19*** **	**0.19*** **	**0.25*** **
Non standard jobs	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Co-op firm	0.02	0.02	0.02	0.02	0.02	0.02	0.03	-0.04
Firm age	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Very small-sized firm	-0.03	-0.03	-0.04	-0.03	-0.04	-0.04	-0.04	-0.06
Small-sized firm	0.01	0.01	0.01	0.01	0.01	0.01	0.00	-0.06
Medium-sized firm	0.05	0.05	0.05	0.04	0.04	0.04	0.04	-0.04
Large-sized firm	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.00
North	-0.03	-0.03	-0.03	-0.03	-0.05	0.00	-0.05	0.04
South	**-0.07***	-0.06	**-0.07***	-0.06	-0.01	0.03	0.00	-0.10
Food district	-0.03	-0.03	-0.03	-0.03	-0.03	**-0.04***	**-0.04***	-0.01
Agricultural district	0.01	0.02	0.01	0.01	-0.01	0.01	0.01	-0.05
1st distance	0.00							
2nd distance		0.00						
3rd distance			0.000					
Distance > 150 kms				-0.12	-0.11	-0.13	-0.11	-0.19
Regional R&D - Accredited funds					**0.01***	**0.01***	**0.01***	0.00
Biotechnologist courses					-0.02	-0.01	0.00	**-0.13****
Food technologist bachelor 5-year course					-0.03	-0.05	-0.05	**-0.16*** **
Food technologist bachelor 3-year course					0.07	0.03	0.00	-0.02
Extra-regional faculty of agriculture					0.04	-0.03	-0.03	-0.06
Faculty of agriculture 's age					0.00	0.00	0.00	0.00
N. of researchers/professors					0.00	0.00	0.00	0.00
N. of graduates					0.00	0.00	0.00	0.00
Industrial engineers on total scholars					0.01	0.01	0.01	-0.02
Biologists on total scholars					0.00	0.00	0.00	-0.01
Chemicals on total scholars					0.00	0.00	0.00	0.02
Physicians on total scholars					0.00	0.00	0.00	**0.01***
Geologists on total scholars					0.00	0.00	0.01	0.02
N. of scientific macro-fields					0.02	0.02	0.01	**0.04*** **
N. of regional faculties of agriculture					**0.02****	**0.02****	**0.02****	0.00
Public univerisity					**-0.24****	**-0.22****	**-0.22****	**-0.41*** **
Technological transfer office					0.02	0.03	0.01	0.01
Technological transfer office's age								**-0.05*** **
International grade						0.00	0.00	
Research project grade						**0.002****	**0.002****	
Codified knowledge indicator (No. articles)						0.00		
Codified knowledge indicator (No. citations)							0.00	
VQR grade								0.00
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sub-sector dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*** signficant at 1% level ** signficant at 5% level * signficant at 10% level

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