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Determinants of university–firm R&D collaboration and its impact on innovation: A perspective from a low-tech industry

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ABSTRACT

The main aim of the paper is to examine the drivers of university–firm R&D collaboration while at the same time assessing the determinants of innovation in a low-tech industry. This includes analysing firm R&D collaborations with partners different from universities.

The paper relies on a unique data-set where firm data were sourced from the Capitalia survey, covering the 1995–2006 years, and the university data were gathered from a number of sources.

Result from a multivariate probit model reiterate that university–firm R&D collaboration affects process innovation. Evidence of a more novel kind suggests that product innovation is positively affected by geographical proximity to a university but is negatively affected by the amount of its codified knowledge production. Degree programmes in fields useful for local firms favour R&D collaborations. Academic policies that aim to commercialise research output negatively impact both product and process innovations of local firms.

1. Introduction

University knowledge production is important for industrial innovation. Knowledge may be transferred to firms through unintended flows that generate spillovers from university-based research or through market-mediated interactions, such as contract and collaborative research (D'Este and Iammarino, 2010; D'Este and Patel, 2007). The relevance of the specific market-mediated channel of the knowledge transfer from university to industry varies across disciplines and sectors depending on the degrees of knowledge codification and interdependence in firm technology (Bekkers and Bodas Freitas, 2008). Academic research quality and geographical proximity from firm to university (Audretsch and Stephan, 1996; Mansfield, 1991, 1995) are also universally recognised as influencing market-related university–firm interactions, mainly through contract and collaborative research (D'Este and Iammarino, 2010; D'Este et al., 2013; Laursen et al., 2011) and licensing (Mowery and Ziedonis, 2015).

However, little research has focused on a systematic investigation of the impact on firm product and process innovations of various channels of knowledge and technology transfers from universities, public research labs and private firms. Although there are some contributions in the literature regarding whether academic research quality indirectly affects firms' innovative performance through university–firm interactions (Baba et al., 2009; Mansfield and Lee, 1996; Zucker et al., 1998), the direct impact of academic research quality indicators on firms' product and process innovations has not yet been quantitatively measured.

The primary objective of the paper is the identification of the channels through which university–firm R&D collaboration impacts upon firm product and process innovations and how the "knowledge context" in which the firm operates (in terms of research, education and technology transfer-related activities at local universities) affects this relationship. The paper's secondary objectives include focusing on a sector that is typically considered to be codified knowledge extensive, performing a joint analysis of the determinants of firm R&D investment and innovation and identifying the direct impact on firm innovation of academic research quality and degree programmes. The impact of university education on patent production is recognised for high-tech sectors in studies in which analyses are performed by aggregating the

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graduation fields that are relevant for a specific industry (Leten et al., 2014). The paper, by relying on disaggregated graduation fields, provides novel evidence on this issue.

The conceptual framework of the analysis is the “National Systems of Innovation” (NSI) approach, which assumes that a firm’s innovative capabilities depend upon its ability to communicate and interact with external knowledge sources such as other firms, customers and scientific institutions that can act as knowledge providers (Freeman, 1988; Lundvall, 1988; Nelson, 1993). A firm’s absorptive capacity shapes its demand for knowledge and technology transfer because firms with low absorptive capacity depend more on local high-quality universities (Laursen et al., 2011) for industrial research and for the expertise and training that are offered to the local market for skilled labour. This latter acts as a medium for the diffusion of academic knowledge spillovers (Beise and Stahl, 1999) which may particularly benefit small and medium-sized firms with a lower capacity to compete in the national labour market. In the specific case of family-run firms, owners’ children often choose to attend a degree programme at a local university. Furthermore, institutional changes may contribute to reinforcing the relevance of certain NSI actors as local providers of external firm knowledge (Robin and Schubert, 2013).

The novel contribution of the paper is that it disentangles and quantifies the direct and indirect impacts of research, education and technology transfer-related activities at local universities on firm innovative inputs and outputs. Local university structure and behaviour characterise the “knowledge context” in which the firm mainly operates and gathers information for R&D outsourcing. The local university is represented, in the paper, by the closest faculty of agricultural studies, along with being knowledge spillovers from technical universities more geographically bounded (Beise and Stahl, 1999).

The present analysis employs a representative sample of Italian food and drink (F&D) firms that have at least 10 workers and that are included 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 time heterogeneity. A complementary and very rich panel data-set has been built to describe the local university characteristics, which have been found to impact university–firm collaborations. The empirical approach is a multivariate probit system that allows for simultaneity between *intra moenia* and *extra moenia* R&D investments (Belderbos et al., 2004; Veugelers, 1997) and the endogenous nature of R&D decisions (Crépon et al., 1998; Robin and Schubert, 2013).

The remainder of the paper is divided into six sections. The second section reviews different bodies of literature that address the issue discussed here. Sections 3 and 4 focus on the specificities of the Italian public agri-food research system and of the Italian F&D industry in the European context, respectively. Section 5 describes the sources of the data and the methodology that have been used, and section six presents the empirical results. Section seven provides concluding remarks.

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

The paper brings together two strands of literature: the former is focused on the identification of drivers of university–firm R&D collaboration and the latter is related to the determination of the impact of university–firm R&D collaboration on innovations.

Within the former body of literature, a number of studies have analysed the determinants of university–industry collaboration that can be grouped into the categories of proximity, university, firm and territory characteristics.

Following D’Este et al. (2013), geographical proximity plays a fundamental role as a determinant of university–industry collaboration that has been recognised by different bodies of literature, including studies on localised knowledge spillovers, the systemic nature of knowledge and innovation (from innovation systems to the triple-helix model), and industrial clusters. The studies on localised knowledge spillovers are based on the knowledge production function framework that was proposed by Griliches (1979) and first implemented by Griliches and Pakes (1984) and Jaffe (1986, 1989). Following this conceptual framework, knowledge output, which is proxied by patent applications and/or innovation citations, is produced according to a Cobb–Douglas technology using R&D efforts, namely, business and university R&D expenditures. The “Griliches (1979) – Jaffe (1989) knowledge production function” has typically been estimated for nations (Acs et al., 1991; Anselin et al., 1997; Feldman and Florida, 1994; Jaffe, 1989) or territorial regions (Acs et al., 2002; Fritsch, 2002; Greunz, 2002; Varga, 2000). Studies on the systemic nature of knowledge and innovation typically focus on the interactions and networks among actors aimed at the production, diffusion and use of knowledge. The innovation systems approach privileges the firm as the core agent of the network, whereas the triple-helix model places the university at the centre of a relationship among firms and the government. The empirical analysis in the original formulation for both approaches is based on national data. A sub-national level of analysis has been made possible through studies on industrial clusters that consider university–industry collaboration as the key factor for the competitiveness and growth of local economic systems.

The bodies of literature discussed above assume that firms that are located near universities may frequently collaborate with them and benefit from knowledge spillovers. Geographical proximity (Morgan, 2004) enables the transmission of tacit knowledge, which is personal and context-dependent. This 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 and in the event of 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 (Audretsch and Feldman, 1996; Jaffe et al., 1993; Landry et al., 2007). In the context of asymmetry, the transfer of knowledge is unlikely if researchers and research users do not have frequent interactions. 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 (Boschma, 2005): cognitive proximity, which is the extent to which two organisations share the same knowledge, and organisational proximity, the result of the accumulation of experience between the same or similar actors (D’Este et al., 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 lower in social science research than in natural science research because social science knowledge is less codified than natural science knowledge and is not based on a unified and established scientific methodology. Thus, geographical proximity to universities may be more important for accessing social science research than for accessing natural science research (Audretsch et al., 2005). The amount of tacit knowledge also varies along the life cycle of a research project in that it is generally higher in its earliest phase, which requires a relatively high degree of affinity between the firm and the university (Broström, 2010).

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 impacts of academic quality and geographical proximity are 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 non-linear 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 firm choices regarding collaborating with local high-quality universities depend on the firm 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. 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. Academic reputation is also proxied by university age, measured in years (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 introduced university and department size into the analysis, which are quantified as the number of researchers (or the percentage of time) devoted to research activities (D'Este and Iammarino, 2010; Landry et al., 2007; 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 of basic *versus* applied research, the different production of tacit knowledge and the capability of technology transmission (Audretsch and Lehmann, 2005; Audretsch et al., 2012; Bonaccorsi et al., 2013; D'Este and Iammarino, 2010; Landry et al., 2007). The latter is also proxied by the existence of an intermediation structure, such as a technology transfer office, that is established to minimise the cognitive distance between business and academics (Muscio and Nardone, 2012), or by the university's regional location 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 non-local firm or to not be involved at all (Audretsch and Stephan, 1996; Landry et al., 2007). 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, *intra* and *extra muros* R&D, ownership structure and innovation subsidies (Huynh and Rotondi, 2009; Laursen et al., 2011; Medda et al., 2005; Motohashi, 2005; Piga and Vivarelli, 2004). Among the territory characteristics, location in industrial clusters (D'Este et al., 2013) and regional R&D intensity (Laursen et al., 2011) may influence university–firm collaboration.

Within the strand of literature related to the impact of university–firm interactions on innovation, the finding that proximity to a university is positively associated with innovation is well established in studies based on a production-function approach to investigating academic spillovers (Fritsch and Franke, 2004). Relatively fewer papers quantify the impact of university–industry collaboration in terms of outcome variables such as firm innovation. These latter studies differ in the types of samples (for example, only firms with R&D activities, only innovators or samples that include innovators and non-innovators), in the use of simultaneous equation models, in the analysis of product and/or process innovations, in the type and number of university–firm interaction channels and in the comparison with other external sources of firm knowledge.

Estimates related to innovating firms only may suffer from sample selection bias if university–industry collaboration is an important means of innovation for firms that would otherwise not innovate because they had no other innovation strategies, such as *intra moenia* R&D or some form of external knowledge acquisition. Samples of innovators and non-innovators are used by Amara and Landry (2005), Becker and Dietz (2004), Chen et al. (2011), Fitjar and Rodríguez-Pose (2012), Karlsson and Olsson (1998) and Nieto and Santamaria (2007).

To take into account the endogenous nature of R&D decisions, a simultaneous equation approach is suggested for modelling internal and external R&D expenditures (Veugelers, 1997), R&D collaborations with different partners (Belderbos et al., 2004) and internal and external R&D expenditures and innovation (Becker and Dietz, 2004). Both product and process innovation are analysed by Fitjar and Rodríguez-Pose (2012), González-Pernía et al. (2014), Nieto and Santamaria (2007) and Robin and Schubert (2013). R&D collaborations with universities or public research labs are most frequently investigated (Becker and Dietz, 2004; Belderbos et al., 2015; Broiwer and Kleinknecht, 1996 González-Pernía et al., 2014), whereas citations are less frequently studied (Beise and Stahl, 1999; Jiang et al., 2010; Mansfield and Lee, 1996).

The presence of multiple university–firm interaction channels (Arvanitis et al., 2008; Jang et al., 2010; Karlsson and Olsson, 1998) and firm R&D partners (Belderbos et al., 2004; González-Pernía et al., 2014; Monjon and Waelbroeck, 2003; Robin and Schubert, 2013) enriches the analysis of university–firm collaboration safeguarding it from omitted variable bias because the impacts are typically numerous and difficult to separate from other firm activities (Arvanitis et al., 2008).

The nature of knowledge flows between a firm and its partners and the consequent innovation-related benefits may differ according to the interaction channel, the firm's R&D partner and the project phase. Furthermore, firms' R&D partners complement or substitute each other, in the latter case mostly because academic researchers may be time constrained and less available to engage in technology-development projects.

Firms choose universities as R&D collaboration partners in cases of multi-purpose problems and learning-focused projects in areas involving new science and producing long-term benefits, such as strengthening their absorptive capacities and radical innovation; the motivation is that these projects are more likely not to be aborted prematurely (Amara and Landry, 2005; Arvanitis et al., 2008; Bodas Freitas et al., 2011; Broström, 2010; De Fuentes and Dutrénit, 2012; Fitjar and Rodríguez-Pose, 2012; Hall et al., 2003; Kaufmann and Tödling, 2001; Thether and Tajar, 2008). Distant universities are firms' R&D partners (De Fuentes and Dutrénit, 2014), but generally not in the earliest phase of the project (Broström, 2010); foreign universities usually partner highly innovative firms, at the frontier of the academic knowledge in their industry, when these latter need to acquire new forms of academic knowledge (Monjon and Waelbroeck, 2003). Smaller firms prefer to interact with local public research labs for applied research (De Fuentes and Dutrénit, 2014), whereas private research labs are generally firms' R&D partners in cases of incremental innovation (Thether and Tajar, 2008). Short-term benefits, such as those associated with quality control, usually accrue from informal interactions to imitators or firms adopting incremental innovation (De Fuentes and Dutrénit, 2012; Monjon and Waelbroeck, 2003). In the specific case of the F&D industry, firms collaborate with universities and public research labs to access new ideas and government funding, develop internal expertise and reduce time to market with new technologies, particularly for process innovation and new market penetration. Informal contacts and training courses are also important knowledge transfer channels (Avermaete et al., 2004; Kelly et al., 2008; Minarelli et al., 2015).

To disentangle the impact on firm innovation of R&D collaborations with universities, other variables that are customarily used in the literature as innovation determinants must be controlled for. These variables include firm age, size, R&D intensity, workforce skills, territorial location, innovation subsidies (Arvanitis et al., 2008; Avermaete et al., 2004; Benfratello et al., 2008; Brouwer and Kleinknecht, 1996), retail involvement in innovation (Stewart-Knox and Mitchell, 2003) and cooperative status (Huiban and Bouhsina, 1998).

Summing up the literature review, very few studies adopt a simultaneous multi-equation approach which models *intra muros* and *extra muros* R&D investment and innovation adoption decisions. No study jointly analyses the determinants of university–firm R&D collaboration and of product and process innovations while controlling for (various indicators of) academic research quality. These are the considerations upon which the paper relies in order to bring about novel evidence in this field.

3. The Italian public agri-food research system

A conceptual framework that is appropriate for analysing the specific factors that influence firm innovative capabilities in the F&D industry (Menrad, 2004) is the NSI approach, as proposed by Freeman (1988), Lundvall (1988) and Nelson (1993). Within this approach, national boundaries are relevant for a firm's innovation performance because of differences in government policies and in common social and cultural values that shape institutions in an innovation system.

As with other European countries, agri-food research in Italy is conducted primarily in public sector institutions, experiment stations and laboratories run by universities and departments (agriculture, higher education, public health, environment, productive activities and foreign affairs). Italian regional governments have also financed public research since DPR 606/1976 introduced the concept of "research of regional interest".[1] Following this policy, regional administrations created their own public lab networks.[2]

The Italian national agri-food research system appears to be one of the more fragmented among European countries. It is poorly coordinated, with a strong presence of universities and a weak presence of private research labs. The German national agri-food research system is also considered rather fragmented and decentralised, with the particular characteristic that universities of applied sciences are typically run by the federal governments with an orientation towards diffusion. By contrast, the French national agri-food research system is concentrated, mission-oriented (with missions being defined at the national level) and fairly coordinated. In particular, it is characterised by the very low importance of universities and the absence of links between research and higher education in the agri-food industry instead delivered by colleges. Alternatively, in the Netherlands, the national agri-food research system is well coordinated and rather concentrated, and universities are growing in importance (Chartier, 2007; Menrad, 2004; Robin and Schubert, 2013).

Most of the Italian academic research on agri-food topics is performed by faculties of agricultural studies[3] (INEA, 2009), which employed 2111 scientists in 2000 and numbered 24 before the last university reform.[4] Each university is autonomous (Law 168/1989)[5] but is under the control of the Higher Education Department. The number of scientists employed by equivalent university institutes in Germany numbered 812 in 2000 (Menrad, 2004), and the total number of equivalent faculties is 10 (Chartier, 2007). Some of the Italian faculties of agricultural studies, which are highly dispersed throughout the country, are very young: 5 were established in the 1980s, and 4 were established in the 1990s. Yet Italy also hosts the oldest faculty of agricultural studies in the world, which was founded in 1871 at the University of Pisa.

Technology transfer to firms is achieved through regional development agencies, one for each region, which generally conduct only applied research, beginning with the basic research supplied by universities.

The huge number of labs and technology institutes has created problems of coordination and communication among labs and between labs and firms. For this reason, a reform of the public research labs under the control of the Department for Agriculture was undertaken in 1999 by merging them into one funding agency (CRA). In the same year, the activities of the main Italian non-university public research institute (CNR), which is under the control of the Department of Higher Education, were also restructured and unified under specific themes. A third important event for Italian public research occurred at the beginning of 1999, when the Italian Evaluation of Research Quality established an evaluation procedure for research activities through periodic reports. This evaluation was the result of a general debate on the Italian public research system; the resulting Bassanini Law 59/1997 reformed the entire system by introducing coordination, evaluation and participative research planning (through National Research

[1] The average share of university budgets sourced from regional administrations was 2% in 2003 and 12% in 2011 (Netval, 2005, 2013).

[2] Law 491/1993 and Legislative Decree 143/1997 further decentralised competencies in the farming and agri-food industries to regional administrations. The amendment to Title V of the Constitution institutionalised this decentralisation of powers in 2001.

[3] In 1998, 51% of scholars who were active in the field of public research on agri-food topics were employed by universities, 27% by public labs under the control of the Department for Agriculture or the Department of Higher Education and 11% by regional public labs (INEA, 1999).

[4] Law 240/2010 abolished faculties and transferred teaching to departments.

[5] University statutes and internal regulations address external fundraising and technology transfer activities that represent the only sources of external income because of limitations on student fees.

Plans). Law 297/1999 completed this reform by reordering the significant number of subsidies to industrial research and explicitly introducing incentives for collaboration between public and private researchers. Concurrently, to attract new students and decrease the dropout rate, Ministerial Decree 509/1999 reformed the length of the degree programmes[6] by introducing a 3-year degree that can be followed by a 2-year specialisation degree.

A higher education evaluation system was formally introduced by Law 537/1993. To assess the quality of the tertiary education system, the Department of Higher Education began to collect a large amount of data for the purpose of developing qualitative and quantitative indicators. These data, which are summarised in annual reports by the National Committee for the Evaluation of the University Sector (CNSVU), are publicly available and have been used in this paper. They also represent the basis for faculty ranking that is published annually by Italian newspapers (*la Repubblica* and *Il Sole ventiquattrore*) to assist high-school students in choosing a degree programme (Magistà, 2013).

Beginning in the 1980s, Italian academic research and education put greater emphasis on content related to processing industries through new research lines and the birth of specialised graduation fields (Santini, 2003). An additional development during these years, that is relevant for university–industry interactions, was the introduction into degree programmes of compulsory pre-graduate student internships at agri-food firms. These internships directly connected universities and firms or indirectly connected these entities when students, who were offered internships, remained at the firms.

With respect to disciplines, the composition of the Italian faculties of agricultural studies has not changed substantially over the past decades; for example, the percentage of researchers in the biotechnology fields is only 4% of the total research personnel, whereas the percentage of researchers in the traditional agronomy and livestock production fields is 30% (Pennacchi, 2008). Conversely, the budget for public agri-food research in Italy has increased throughout the 1998–2008 period (Sorrentino and Capozzi, 2010). At the same time, preliminary discussion regarding the allocation of regional plan funds for rural development research has involved representatives not only from the public research and extension systems and the farming and agri-food industries but also from consumer and environmentalist associations (Ascione et al., 2006).

The realisation of socially and environmentally sustainable production processes is necessarily geographically targeted and context dependent and has yielded a renewed importance of geographical proximity in effective collaboration between firms and universities. Some examples of the new university research projects that have been financed, which provide evidence of this aspect of collaboration, are those that aim to identify the effect of organic fertilisers on sustainable local cultivation systems and those that aim to identify the local genotypes cultivated in geographical areas[7] (Andreakis et al., 2004; Sacchi et al., 2010). Of course, for non-geographically targeted production processes, the distance between agri-food firms and universities can be substantial and can overcome national borders, particularly in the case of multinationals.

Generally speaking, because of cuts in public financing from national sources to Italian universities, the share of university budgets sourced from R&D collaborations with private firms is increasing[8] as a consequence of university incentives given to professors in the form of profit sharing, research funds or career advancement (Fantino et al., 2012).

In 2007, the R&D expenses for private for-profit firms as a fraction of the total R&D investment in Italy ranges from 70% in northern Italy to 31% in southern Italy, where universities and public labs finance 66% of the total R&D (ISTAT, 2011). The amount of R&D from universities and public research labs that was devoted to the F&D industry was equal to 440 ml € in 2008, whereas, on average, F&D firms spent 127 ml € annually in R&D over the 1998–2008 period (Sorrentino and Capozzi, 2010). Italy ranks third in Europe, after Spain and Germany, in terms of the amount of R&D from universities and public research labs that was devoted to the F&D industry during the 1998–2008 period (Sorrentino and Capozzi, 2010).

4. The Italian F&D industry

The Italian F&D sector makes an interesting case study of tacit-knowledge-based small firms whose absorptive capacity is poorly measured by their R&D expenditures. In fact, the sector is characterised by (a) the significant presence of small firms with no R&D intensity and, therefore, a potentially more important role for university–industry collaboration; (b) the presence of cognitive gaps that are linked to knowledge regarding the effects of pedo-climatic conditions on local production; and (c) the demand for innovation based on the public good attributes of food products, such as food safety.

The F&D industry has traditionally been considered a low-tech industry on the basis of R&D intensity, which was 0.33% in 2010 for Italy. The average R&D expenditure for Italian F&D firms was 32,000 € over the 2001–2003 period and 35,000 € in the 2004–2006 period. Although the level of *intra-muros* R&D intensity is low, it is increasing (ISTAT, various years).

The use of R&D intensity as an indicator of the knowledge intensiveness of the F&D industry has been criticised recently (Rama, 2008) because F&D uses advanced technology that is developed by high-tech sectors, such as the chemical, pharmaceutical and biotechnology sectors, which strongly invest in R&D. Furthermore, investment expenditures in terms of industry innovation expenditures are high for F&D because most innovation is embodied in equipment and capital goods (Rama, 2008). Registering a trademark is one of the most important forms of innovation in this industry[9]. Other non-R&D inputs to innovation are learning by doing and learning by interacting. Interacting with suppliers and consumers is important in this sector because of the concern for food quality. The recent demand for socially responsible consumption, which is particularly aimed at the F&D industry, is an example of innovation that stems from interactions with consumers and is generated by a non-R&D input.

Public regulation is strong in the F&D sector because of certain public good attributes of food products, such as food safety and health concerns. Public regulation generally alters the incentives for innovation. In this sector, it induces the type of innovation that is in line with food safety, health enhancement and food quality standards (Ranieri and Silvestri, 2006; Scordamaglia, 2006). This specific attribute of the F&D industry, together with the direct public support from the European Union (EU) Common Agricultural Policy, can enhance the innovation capacity of small firms compared with the same capacity of small firms in other sectors.

[6] Some universities had already experienced 3-year degrees following Law 341/1990.

[7] This project is intended to inform the disciplinary regulation of products that are protected by a denomination of origin trademark or by a guaranteed origin certification authenticating their historical production areas.

[8] On average, this share was 16% in 2002 and 25% in 2009 (Netval, 2005, 2011).

[9] Among EU countries, Italy has the greatest number of products with a designated and/or guaranteed denomination of origin trademark (De Devitiis and Maietta, 2013).

Table 1
Innovation expenditure in the Italian supplier-dominated sectors in 2002–2004.

Sectors	R&D expenditure (ml €)		% Innovation expenditure for:						
		Per worker	R&D *intra-muros*	R&D *extra-muros*	Physical capital	Immaterial capital	Development	Training	Mk tg
Food and drink	1016	6.9	14.3	3.6	66.5	3.0	1.5	2.0	9.1
Textiles	548	5.6	31.8	1.8	53.0	5.3	3.6	1.5	3.0
Apparel	128	3.4	22.5	0.8	55.8	10.6	3.7	3.9	2.7
Leather and footwear	233	5.9	27.8	0.2	62.2	0.3	6.6	1.1	1.8
Wood	222	6.9	14.6	1.1	69.3	7.0	3.2	2.1	2.7
Paper	364	9.1	14.5	1.7	80.1	1.0	1.5	0.5	0.7
Printing	706	12.0	7.1	2.4	74.2	5.3	3.7	1.2	6.1

Source: Istat, Rilevazione sull'innovazione nelle imprese.

Table 2
F&D firms, workers, turnover, labour unit cost and firm investment by size class in Italy in 2009.

Firm size class	No. Firms	%	No. Workers	%	Turnover	%	Unit labour cost	Investment per firm
Micro (1–9)	50531	87.5	154315	36.0	16070284	14.3	23.3	38
Small (10–49)	6360	11.0	115562	27.0	28280920	25.2	30.7	174
Medium (50–249)	738	1.3	73204	17.1	31998713	28.5	40.8	1151
Large (>250)	120	0.2	85282	19.9	35967056	32.0	44.7	9656
Total	57749	100.0	428363	100.0	112316973	100.0	34.3	87

Source: ISTAT; size class defined in number of workers, value in th. €.

Farace and Mazzotta (2015), for example, find that the percentage of innovative firms in the F&D industry is greater than that in other traditional sectors.

The respect for food safety and food quality standards makes innovation in the F&D industry the result of multidisciplinary activity in which different skills (biological, chemical, engineering, nutritional, economic and legally compliant) are necessary to develop the path from the formulation of an idea to its industrial realisation.[10]

Table 1 reports R&D expenditures for the Italian F&D and other supplier-dominated sectors (Pavitt, 1984) in 2004. R&D investment per worker was not particularly high in the F&D industry. However, one feature distinguishes the F&D industry with respect to innovation expenditures: the value for the percentage of *extra-muros* R&D expenditure is the greatest for all sectors. This figure may reflect the development of a publically supported decentralised agri-food research system (Ruttan, 2001), as in other industrialised countries, in which collaboration among firms and universities is more widespread than it is for other small and medium-sized firms in the traditional sectors (Istituto Guglielmo Tagliacarne, 2004). In more recent years, despite an average R&D investment per worker that is lower than the average investment of all manufacturers (Monducci, 2011), interactions of Italian F&D firms with the scientific community have also been greater than those of other supplier-dominated industries and of manufacturers as a whole.[11] The percentage of Italian F&D firms (with at least 10 workers) that interact with universities and/or public research labs is greater than that in other European countries, including Germany and France (Pasetto, 2011). Table 2, which reports the distribution of Italian F&D firms and workers by size class, emphasises the sector's dualistic structure, which is characterised by a very small number of medium-sized and large firms and a very large number of micro-sized firms. The huge percentage of micro-sized firms in the F&D sector is explained by bakeries and confectioneries, which are generally family-run firms, represent 56% of the total F&D sector firms and employ an average of 4 workers (INEA, 2006). The presence of micro-sized firms in the F&D sector also indicates that average R&D intensity is low because of structural factors that shape R&D intensity (Moncada-Paternò-Castello et al., 2010) within the sector.

According to 2011 Eurostat data, Italian F&D firms represent 12% of all EU F&D firms with at least 10 workers. Looking at the distribution in size classes of EU F&D firms with at least 10 workers, small firms are relatively more widespread only in Germany,[12] whereas the distribution of EU F&D firms with at least 10 workers by subsector shows that the distribution of Italian F&D firms is similar to that of other Mediterranean countries, such as Spain.

A bipolar structure with a plethora of small firms and a few very large companies also characterises the F&D sector of other countries, such as Germany. Small firms are strongly present in other sectors as well, such as EU wood, leather and textiles (Pagano and Schivardi, 2003), making the results from this study interesting from a broader perspective.

5. The empirical framework

5.1. The data

The firm data used in this paper are sourced from the "Survey of Italian manufacturing firms". This survey was formerly conducted by Mediocredito Centrale and is currently conducted 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 more than 4000 firms. The survey design includes all firms with at least 500 workers and a sample that is representative of Italian manufacturing firms that employ between 10 and 500 workers and that 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 regarding

[10] Some examples of F&D innovation include health-enhancing food and drink products (Ziggers, 2005) and the use of ozonated water to decrease the amount of chemicals required for equipment sterilisation (Baregheh et al., 2012).

[11] In the 2008-2010 period, according to ISTAT data, 3% of F&D firms had formal interactions with universities or public research labs compared with an average of 2% for manufacturers as a whole.

[12] In 2011, small firms accounted for 66% of the national F&D firms with at least 10 workers in Germany and 62% in Italy.

whether R&D was *intra muros* or acquired from external sources such as universities,[13] public research labs and other private firms along with other firm characteristics, such as the presence of skilled employees (that is graduates), non-standard jobs[14] and subsidies.[15]

Using their ATECO classification, F&D firms have been extracted, resulting in a pool of 1744 firms for the 1995–2006 period. After checking ex post representativeness, it was determined that the derived sample is representative of Italian F&D firm by region, as shown in Table A1 in Appendix A.

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) have been used to identify the three closest faculties of agricultural studies. The choice to focus on these faculties is supported by the evidence that most university collaborations with F&D firms are with the regional faculty of agricultural studies. Furthermore, a firm that has university collaborations is likely to have multiple university or public research lab partners (Avermaete et al., 2004; Bodas Freitas et al., 2011), and the probability that one of these partners is the regional agricultural studies faculty is very high. The choice of three universities follows Laursen et al. (2011). For each firm, three distances in kilometres from each of the three relevant faculties have been downloaded.[16] As usual (D'Este et al., 2013; Laursen et al., 2011), these distances between the firm and the faculty main location are measured as the crow flies. The choice of the faculty's main location is based on the evidence that research labs are located there, even if specific courses might sometimes be held in peripheral towns. A fourth variable for geographical proximity is a dummy that takes the value of 1 if the closest faculty of agricultural studies is more than 150 km away; this value was chosen after testing at different thresholds.[17]

With respect to the closest agricultural studies faculty, 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 (computed annually)[18]; 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, various years); the presence of a food technologist 3-year degree programme and a food technologist 5-year degree programme[19] (Ministero dell'Università e della Ricerca Scientifica, various years); the presence and the birth year of the university technology transfer office, which were kindly offered by Netval and are used as proxies of academic policies that are oriented towards the commercial exploitation of research results; the Italian Evaluation of Research Quality, hereafter, VQR grades for the 2001–2003 and 2004–2010 periods; and the research project and the international mobility grades (measured annually), which were kindly offered by Censis for the 1998–2006 period.

The academic research quality of each agricultural studies faculty is measured by the VQR grade. 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 evaluation systems give similar grades for the same set of journal articles (Bertocchi et al., 2015).

The VQR evaluation is unavailable for the 1995–2000 period; alternatively, a battery of indicators of academic research quality and of society's perception of a faculty's reputation has been used for the entire period. These latter have been added because less innovative firms may adopt reputation indicators not based on academic research quality which is the criterion of leader firms, at the forefront in their industry, to select universities as R&D partners.

Academic research quality is proxied by two indicators of codified knowledge production, the numbers of ISI-Scopus articles and citations. The two indicators 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[20] of the Italian agricultural studies faculties, grouped by scientific discipline over the 2002–2012 period. No other measure of scientific production was operational because scholars' names for the 1995–1999 period are unavailable on the website. The use of the medians that referred to the 2002–2012 period is based on the assumption that the differences among scientific disciplines in the median production of ISI-Scopus indexed journals have not changed materially with respect to the 1995–2001 period.

Society's perception of a faculty's reputation is proxied by the research project and the international mobility grades (which are used to compute the annual faculty rankings), the faculty's age and the percentage of women who are full professors, which is an indirect expression of meritocratic *versus* hierarchical institutions. The research project grade (which is based on the number of research projects financed by national and international institutions) and the international mobility grade (hereafter, international grade), which is based on the international mobility of scholars and students, have been supplied for the 1998–2006 period. 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.

Related to the university regional supply are the number of biotechnologist degree programmes (Ministero dell'Università e della Ricerca Scientifica, various years; ISTAT, various years; INEA, various years) and the number of faculties, which is introduced to capture agglomeration externalities and the social capital component of university–firm interactions through the creation of networks between industry and government.

Territorial characteristics are sourced from ISTAT (2005) for the agricultural and food districts and by INEA (various 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.

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[13] Only the last wave provided information about whether the universities are regional. For the 2004–2006 period, 4 F&D firms had R&D collaborations with extra-regional universities.

[14] These are defined as open-ended part-time, fixed-term part-time and fixed-term full-time jobs.

[15] Any financial subsidy for applied research and technological innovation via Italian national laws, such as laws 46/1982 and 297/1999, or EU and regional laws.

[16] http://distanzechilometriche.net/.

[17] Alternatively, focusing on the faculty of the same province/region in which the firm is located was not operational because two regions and most provinces do not host an agricultural studies faculty, and the geographical distance from the faculty would be not computable in such cases.

[18] http://cercauniversita.cineca.it and http://www.cnvsu.it/.

[19] Since the reform that was ushered in with Ministerial Decree 509/1999, the programme consists of a 3-year degree followed by a 2-year specialisation degree.

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

5.2. The variables

Literature recommends that the empirical framework should take into account the interdependencies between innovations and external collaborations in R&D while addressing simultaneity between innovations and (internal and external) R&D investment decisions and the simultaneity between different forms of external collaborations in R&D.

In order to allow for this, the econometric model of the paper consists of six simultaneous equations related to the following dependent variables: (the existence of) *intra muros* R&D investment, R&D collaboration with universities, R&D collaboration with public labs, R&D collaboration with private firms, process innovation and product innovation. Among these, the variables of R&D collaboration with universities, R&D collaboration with public labs and R&D collaboration with private firms are also used as regressors. All these indicators are binary variables.

The empirical specification of the six equations can be summed up as follows:

Intra muros R&D investment = f_1 (R&D collaboration with universities, R&D collaboration with public research labs, R&D collaboration with private firms, skilled employees, non-standard jobs, co-op dummy, subsidies, firm-size dummies, year dummies, territory characteristics, geographical distance, and university/faculty characteristics).

R&D collaboration with partner$_m$ = f_k (*extra muros* R&D intensity from partner$_n$, *extra muros* R&D intensity from partner$_o$, *intra muros* R&D intensity, skilled employees, non-standard jobs, co-op dummy, subsidies, firm-size dummies, year dummies, territory characteristics, geographical distance, and university/faculty characteristics[21]),where *m, n, o* = universities, public research labs, private firms and $m \neq n \neq o$ and k = 2, 3, 4.

Product innovation = f_5 (R&D collaboration with universities and/or public research labs,[22] R&D collaboration with private firms, R&D intensity, skilled employees, non-standard jobs, co-op dummy, sales through distribution chains, subsidies, firm-size dummies, year dummies, sub-sector dummies, territory characteristics, geographical distance, and university/faculty characteristics).

Product innovation = f_6 (R&D collaboration with universities and/or public research labs, R&D collaboration with private firms, R&D intensity, skilled employees, non-standard jobs, co-op dummy, sales through distribution chains, subsidies, firm-size dummies, year dummies, sub-sector dummies, territory characteristics, geographical distance, and university/faculty characteristics).

Table 3 reports the descriptive statistics of the variables, which indicate that 5% of the firms in the sample have R&D collaborations with a university, the same percentage have R&D collaborations with a public research lab and 9% of firms have R&D collaborations with private firms that are, on average, three times as expensive than the two previous ones. R&D collaborations decrease in the last sub-period, particularly those with public research labs and, to a lesser extent, those with universities. Among all firms in the sample, 34% have introduced product innovation, and 49% have introduced process innovation. R&D intensity, which is measured as the average ratio of R&D expenditures to sales over the three years in each period, is low at 0.28% of turnover. Two features that are idiosyncratic to the sector examined are the relatively high presence of cooperatives (17% of firms) and the distribution chain agreements (25.49% of sales occur through this channel). Nearly a quarter of the firms in the sample use non-standard jobs because of the introduction in Italy of flexibility legislation that lowered the cost for firms of this form of labour. Nearly half of the firms are subsidised, particularly those located in southern Italy because of legislation that assists disadvantaged areas. The average distance from the closest faculty of agricultural studies is 47.71 km, whereas the third-closest faculty is only 144.71 km away, on average. The short distance between F&D firms and agricultural studies faculties is partly because the study chose to use linear distance but mainly reflects the presence of a highly decentralised agri-food research system based on agricultural studies faculties. Only 2% of F&D firms are more than 150 km from an agricultural studies faculty; generally, very small firms are located closer to these faculties.

Intermediation structures, when they are present, are recent. The first two technology transfer offices of the universities included in the data set were established only in 2001. The average agricultural studies faculty is 50 years old, graduates 167 students per year and employs 110 researchers or professors. The gender glass ceiling is present in that women account for only 11% of full professors, but it is absent in young faculties, which also employ relatively few researchers. The choices that are related to the combination of research and didactics differ from faculty to faculty, partly reflecting the regional productive structures sine faculties are specialised in the same technical fields as local firms. However, 0.63% only refers to industrial engineers because food engineers are included in the (not reported) ample residual macro-area of food scientists.

Regional governments devoted, as a period average, 2180 € per F&D firm, at constant 2006-based prices, to agri-food research. The amount increased over the years.

The key regressors in all equations are related to the “knowledge context” represented by the closest agricultural studies faculty. First of all, the geographical distances from the three closest faculties have been alternatively tested, in models 1–4 of Tables 4–10, in order to choose the appropriate specification of this variable for each equation. The description of the “knowledge context” begins by adding the following key independent variables related to the closest agricultural studies faculty only: food technologist 3-year and 5-year degree programmes, the society’s perception of a faculty’s reputation indicators and the intermediation structure indicators (technological transfer office or technological transfer office’s age) in model 5 of Tables 4–10. The description is completed by the three academic quality indicators, which have been alternatively tested in models 6–8 of Tables 4–10.

5.3. The econometric approach

Following what has been said at the outset of § 5.2, the econometric model consists of six simultaneous equations that are jointly modelled as a multivariate probit system. 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:

$$\begin{cases} y^*_{1i} = \gamma_{12}y^*_{2i} + \gamma_{13}y^*_{3i} + \gamma_{14}y^*_{4i} + x'_{1i}\beta_1 + \epsilon_{1i} \\ y^*_{2i} = x'_{2i}\beta_2 + \epsilon_{2i} \\ y^*_{3i} = x'_{3i}\beta_3 + \epsilon_{3i} \\ y^*_{4i} = x'_{4i}\beta_4 + \epsilon_{4i} \\ y^*_{5i} = \gamma_{54}y^*_{4i} + x'_{5i}\beta_5 + \epsilon_{5i} \\ y^*_{6i} = \gamma_{64}y^*_{4i} + x'_{6i}\beta_6 + \epsilon_{6i} \end{cases}, \quad (1)$$

[21] Scholars’ characteristics are included in the university-firm R&D collaboration equation only since the literature suggests that these characteristics may impact university-firm collaboration.

[22] This specification is preferred in the two innovation equations since the two variables R&D collaboration with universities and R&D collaboration with public research labs are weakly or not significant when used separately because they are strongly collinear.

Table 3
Variables and descriptive statistics.

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

Table 4
Significance and value of the correlation coefficients among the errors of the Eqs. (1)–(6).

Coefficients	Model 1	Model 2	Model 3	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[a]
Rho31	0.05	0.05	0.04	0.05	0.05	0.06	0.06	0.08[a]
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[a]
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

[a] In the case of model 8 only, the software did not provide significance levels for the rhos.

Table 5
Multiprobit regression. Marginal effects for the dependent variable (existence of) *intra muros* R&D investment.

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
R&D collaborations with universities	0.55***	0.55***	0.55***	0.55***	0.54***	0.54***	0.54***	0.53***
R&D collaborations with public labs	0.49***	0.49***	0.50***	0.50***	0.50***	0.50***	0.50***	1.01***
R&D collaborations with private firms	0.41***	0.41***	0.41***	0.41***	0.40***	0.40***	0.41***	0.48***
Skilled employees	0.003**	0.003**	0.003**	0.003**	0.003**	0.003**	0.003**	0.004***
Co-op firm	−0.08***	−0.08***	−0.08***	−0.08***	−0.09***	−0.09***	−0.09***	−0.07**
Subsidies	0.06***	0.06***	0.06***	0.06***	0.06***	0.06***	0.06***	0.10***
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	−0.11***	−0.10***	−0.10***	−0.11***	−0.10***	−0.10***	−0.10***	−0.07
Small-sized firm	−0.06*	−0.06	−0.06	−0.06*	−0.05	−0.05	−0.06	−0.02
Medium-sized firm	−0.03	−0.03	−0.03	−0.03	−0.02	−0.02	−0.03	0.00
Large-sized firm	0.04	0.04	0.04	0.04	0.05	0.05	0.04	−0.02
North	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.05
South	−0.02	0.00	−0.01	−0.02	−0.05	−0.03	−0.03	−0.08
Food district	−0.02	−0.02	−0.02	−0.02	−0.02	−0.02	0.02	0.05
Agricultural district	−0.01	0.01	0.01	0.00	0.01	0.00	0.00	−0.12
1st distance	0.000							
2nd distance		−0.0002**			0.00	0.00	0.00	0.00
3rd distance			−0.0001*					
Distance > 150 km				0.03				
Regional R&D – Accredited funds					0.00	0.00	0.00	−0.001***
No. biotechnologist degree programmes				0.04	0.04	0.04	0.01	
Food technologist degree 5-year programme				−0.02	−0.02	−0.01	0.05	
Food technologist degree 3-year programme				−0.01	−0.01	−0.01	−0.10**	
Extra-regional faculty of agricultural studies				0.02	0.03	0.03	−0.04	
Faculty of agricultural studies' age					−0.0001	0.00	0.00	0.00
No. researchers/professors					0.0003	0.00	0.00	0.00
No. graduates					0.0001	0.00	0.00	0.00
Industrial engineers on total scholars					0.01**	0.01**	0.01**	0.03***
Biologists on total scholars					0.00	0.00	0.00	0.00
Chemicals on total scholars					0.00	0.00	0.00	0.00
Physicians on total scholars					0.00	0.004***	0.01**	0.01
Geologists on total scholars					0.00	0.00	0.00	0.01
No. scientific macro-fields					−0.02***	−0.02**	−0.02**	−0.01
No. regional faculties of agricultural studies				0.00	0.01	0.00	−0.04***	
Public univerisity					−0.03	−0.02	−0.02	−0.14*
Technological transfer office					−0.08**	−0.08**	−0.07**	−0.05
Technological transfer office's age								0.00
International grade						0.00	0.001**	
Research project grade						0.00	0.00	
Codified knowledge indicator (No. articles)					−0.02*			
Codified knowledge indicator (No. citations)						−0.01*		
VQR grade								0.00
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. observations	1531	1531	1531	1531	1531	1531	1531	719
LogL	−3176.0	−3178.6	−3177.2	−3175.6	−3115.4	−3101.8	−3101.6	−1421.4

*** Signficant at 1% level.
** Signficant at 5% level.
* Signficant at 10% level.

Table 6
Multiprobit regression. Marginal effects for the dependent variable 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 km				0.04*	0.04***	0.04***	0.04***	0.03
Regional R&D – Accredited funds					−0.004**	−0.003**	−0.003**	−0.005*
No. biotechnologist degree programmes					0.01	0.01	0.01	−0.01
Food technologist degree 5-year programme					0.04**	0.05***	0.05***	0.04
Food technologist degree 3-year programme					−0.03**	−0.03**	−0.03**	−0.03
Extra-regional faculty of agricultural studies					0.00	0.01	0.01	0.05*
Faculty of agricultural studies' age					0.00	0.00	0.00	0.00
No. researchers/professors					0.001**	0.001*	0.001*	0.00
No. 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
No. scientific macro-fields					0.00	0.00	0.00	0.00
No. regional faculties of agricultural studies					−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
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)						0.01		
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 7
Multiprobit regression. Marginal effects for the dependent variable R&D collaboration with public research labs.

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	0.0003***							
2nd distance		0.00						
3rd distance			0.0001***					
Distance > 150 km				0.05***	0.03**	0.03**	0.03**	0.05
Regional R&D – Accredited funds					0.002*	0.002**	0.002**	0.002*
No. biotechnologist degree programmes					0.00	0.00	0.00	−0.24***
Food technologist degree 5-year programme				0.03***	0.03***	0.03***	−0.17**	
Food technologist degree 3-year programme				−0.02	−0.01	−0.01	−0.04	
Extra-regional faculty of agricultural studies				0.00	0.00	0.00	−0.32***	
Faculty of agricultural studies' age					−0.001***	−0.001***	−0.001***	0.003**
No. researchers/professors					0.00	0.00	0.00	0.00
No. 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***
No. scientific macro-fields					0.00	0.00	0.00	0.00
No. regional faculties of agricultural studies				−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.

where y_{1i}^*, y_{2i}^*, y_{3i}^*, y_{4i}^*, y_{5i}^* and y_{6i}^* are 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; $\boldsymbol{x}_{ki}$ are vectors of exogenous variables, which influence those probabilities for firm i; β_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 $\boldsymbol{x}_{ki}$ are not restricted to containing the same variables of interest as long as there is at least one varying exogenous regressor 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:

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

The binary 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 innovations >0 for y^*_5 and y^*_6, respectively.

The equations that refer to y_1, y_2, y_3 and y_4 have been included to identify the determinants of the presence of *intra* and *extra muros* R&D investment that aims at introducing product or process innovations and to take into account the simultaneity of firm decisions relating to the types of *intra* and *extra muros* R&D investments. Furthermore, the common latent factor structure of the multivariate probit framework allows to control for the potential endogeneity of the R&D investment decision and to correct potential sample selection.

The resulting recursive multivariate probit model can be estimated using a simulated maximum likelihood method.[23]

[23] No exclusion restrictions on the exogenous variables, in recursive multiple equation probit models with endogenous dummy regressors, 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 (Wilde, 2000).

Table 8
Multiprobit regression. Marginal effects for the dependent variable 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 km				0.02	0.00	0.01	0.01	0.04
Regional R&D – Accredited funds					−0.01**	−0.01**	−0.01**	−0.01**
No. biotechnologist degree programmes				0.03	0.03	0.03	0.06**	
Food technologist degree 5-year programme				0.05**	0.05**	0.05**	0.01	
Food technologist degree 3-year programme				−0.03	−0.03	−0.03	−0.07*	
Extra-regional faculty of agricultural studies				0.00	0.00	0.00	0.01	
Faculty of agricultural studies' age					0.001*	0.00	0.00	0.002*
No. researchers/professors					−0.001**	0.00	0.00	0.00
No. 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**
No. scientific macro-fields					0.00	0.01	0.01	0.02**
No. regional faculties of agricultural studies				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.

6. The empirical evidence

The results of the multivariate probit regressions are reported for various specifications (including different subsets of regressors) in Tables 4–10. 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 given that regional governments are responsible for implementing agri-food policies.

The likelihood ratio test, which was conducted on the hypothesis that the ρs are jointly null, is highly significant and supports the multivariate six-equation framework. The value of the statistics for the specification of variables relative to model 4 of Tables 5–10 is equal to 178.28 with 15 degrees of freedom, compared with a critical value of 30.58 at the 1% significance level. As all the correlation coefficients relative to Eq. (1) are, at the best, weakly significant, a second test, suggested by Monfardini and Radice (2006), was conducted on the multivariate six-equation framework against the univariate probit run separately for Eq. (1) plus a multivariate five-equation structure run for Eqs. (2)–(6).[24]

The significance and high values of ρ_{32} show a high correlation between R&D university–firm collaborations and R&D public research lab-firm collaborations. The correlation among the errors of the equations is also significant and strong for ρ_{65} and increases in the final period.

Table 5 reports the marginal effects for Eq. (1). The results of the regressions for the entire period (models 1–7) are mainly discussed. Model 1 and model 4 are virtually identical, although model 4's log likelihood value is higher. Hence, model 4 is chosen for further development in the paper. Regarding geographical proximity, the 2nd and 3rd distance variables from the agricultural studies faculties are negative and are significant and weakly significant, respectively. Being closer to more agricultural studies faculties induces *intra muros* R&D investment; however, the distance

[24] The value of the statistics for the specification of variables relative to model 4 of Tables 5–10 is equal to 13.53 with 5 degrees of freedom, compared with a critical value of 11.07 at the 5% significance level.

Table 9
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/or 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**
Sales through distribution chain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Skilled employees	0.002*	0.002*	0.002*	0.003**	0.003**	0.003**	0.003**	0.003**
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 km				−0.18***	−0.20***	−0.20***	−0.20***	−0.08
Regional R&D – Accredited funds					0.00	0.00	0.00	−0.01**
No. biotechnologist degree programmes					−0.02	−0.02	−0.01	0.04
Food technologist degree 5-year programme					0.01	−0.03	−0.03	−0.01
Food technologist degree 3-year programme					0.05*	0.05*	0.05*	0.01
Extra-regional faculty of agricultural studies					0.04	0.04	0.04	0.00
Faculty of agricultural studies' age					0.00	0.00	0.00	0.00
No. researchers/professors					0.00	−0.001*	−0.001*	0.00
No. 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
No. scientific macro-fields					0.02**	0.02**	0.03***	0.01
No. regional faculties of agricultural studies					0.03**	0.03**	0.03**	0.00
Public univeristy					−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.

variables lose significance after faculty characteristics are introduced. More precisely, the presence of a technology transfer office appears to have a displacement effect on *intra muros* R&D investment, particularly in the case of faculties with more disciplines.

Table 6 reports the marginal effects for Eq. (2).

Regarding geographical proximity, the 1st, 2nd and 3rd distance variables from the agricultural studies faculties are not significant. However, when the distance from the closest faculty is greater than 150 km, this proximity is highly significant. Isolated firms that are more than 150 km away from the closest agricultural studies faculty have a 0.04 greater probability of R&D collaboration with a university, which may or may not be the closest agricultural studies faculty. The former case might be explained by the so-called "stray dog syndrome" (Howells et al., 2012), in which isolated firms tend to value any contact with universities more than less-isolated firms do because of the difficulty of identifying and maintaining these contacts and because they are relatively unusual. Another possible explanation is that for more distant firms, the absence of universities at a closer distance prevents them from collaborating with any universities via direct interactions or through informal contacts with academics that could act as spearheads for other collaborations (Arvanitis et al., 2008) that are knowingly planned and not necessarily local.

Among university characteristics, the presence of an intermediation structure has no direct effects on firm R&D collaboration with universities. This result, which is apparently not in accordance with Muscio and Nardone (2012), can be explained by observing that the introduction of the technology transfer offices was too recent, and the diffusion of administrative practices that leverage new opportunities for university–industry interactions takes a minimum amount of time to demonstrate a direct effect. However, an indirect effect is evident in that the presence of a transfer technology office produces a displacement effect on the existence of *intra muros* R&D investment (Table 5) and R&D collaboration with private firms (the latter effect is less robust; see Table 8). The public status of the university is significant but negative because of the many interactions between the private university research and industrial communities that are more deeply connected.

Table 10
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/or 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***
Sales through distribution chain	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.00
Skilled employees	−0.0001	−0.0001	0.00	0.00	0.00	0.00	0.00	0.00
Co-op firm	0.02	0.02	0.02	0.02	0.02	0.02	0.03	−0.04
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
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 km				−0.12	−0.11	−0.13	−0.11	−0.19
Regional R&D - Accredited funds					0.01*	0.01*	0.01*	0.00
No. biotechnologist degree programmes					−0.02	−0.01	0.00	−0.13**
Food technologist degree 5-year programme					−0.03	−0.05	−0.05	−0.16***
Food technologist degree 3-year programme					0.07	0.03	0.00	−0.02
Extra-regional faculty of agricultural studies					0.04	−0.03	−0.03	−0.06
Faculty of agricultural studies' age					0.00	0.00	0.00	0.00
No. researchers/professors					0.00	0.00	0.00	0.00
No. 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
No. scientific macro-fields					0.02	0.02	0.01	0.04***
No. regional faculties of agricultural studies					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

Among the education variables, the food technologist 5-year programme is a channel for R&D university collaboration, whereas the 3-year programme acts against these alliances. The interpretation of this result is that university education can act as a mechanism for university–firm interactions if graduates from local universities find jobs in local firms. Freshmen will likely choose a graduation field with more local occupational chances. Then, when they are employed in local firms, they may preferentially turn to their alma maters for R&D collaboration if they experienced a good relationship with their lecturers and thesis supervisors.

Among scholars' personal characteristics, the presence of female full professors induces R&D university collaboration because, on one hand, women have greater ability to cooperate, sensitivity to social cues and context dependency (Croson and Gneezy, 2009; Kuhn and Villeval, 2013). On the other hand, the cost of knowledge exchange with meritocratic and non-hierarchical institutions is lower.

Codified knowledge, as measured by the number of citations in ISI-Scopus indexed journals, and the VQR are positive and weakly significant. Along with having agricultural studies faculties a technical nature, this result is in accordance with the findings of D'Este and Iammarino (2010) for engineering-related departments.

Table 7 reports the marginal effects for Eq. (3).

Public research labs compete with universities as firm R&D partners because collaborations with public research labs increase with the shortest distance from an agricultural studies faculty and decrease with its age, its internationalisation and the number of regional agricultural studies faculties. Concurrently, public labs appear to be partners of universities with more research projects in that the existence of R&D collaboration with public labs is positively related to the research project grade of the closest agricultural studies faculty.

Table 8 reports the marginal effects for Eq. (4). Among the characteristics of the closest agricultural studies faculty, university intermediation appears to be detrimental (in the absence of codified knowledge indicators) to R&D collaboration with private firms.

Table 9 reports the marginal effects for Eq. (5). Product innovation is strongly determined by R&D collaboration with private firms whereas R&D collaboration with universities and/or public research labs is weakly significant. Regarding geographical proximity, the 1st distance variable from the agricultural studies faculty is highly significant and negative, whereas the 2nd and 3rd distance variables are not significant. Analogously, whether the distance from the closest faculty is greater than 150 km is highly significant and negative. A firm that is within a radius of 150 km[25] of an agricultural studies faculty has a probability of product innovation that is 0.20 times greater (after accounting for faculty characteristics) than the probability for a more distant firm. This result may express the effect of informal contacts or direct interactions with academics and of university–industry–government networks that are beneficial for product innovation. The research project grade and codified knowledge indicators are significant and negative and the VQR grade is weakly significant and negative. Consultancies or informal collaboration may be too demanding for faculties that are involved in projects and in codified knowledge production and scholars tend to concentrate on academic publications because industry-oriented research may deteriorate their publication profiles (Bonaccorsi et al., 2006). The negative sign (only weakly significant) of the faculty size impact confirms that larger faculties promote the commercial exploitation of their academic research results and inhibit informal technology transfer (Landry et al., 2007).

The marginal effects for Eq. (6) are reported in Table 10. Process innovation is determined by R&D collaboration with private firms and R&D collaboration with universities and/or public research labs, confirming what already evidenced in literature (González-Pernía et al., 2014).

Geographical distance from a faculty of agricultural studies is generally not significant, whereas the public status of the university is negative and significant with a strong impact, which means that only geographical proximity to a private agricultural studies faculty matters for process innovation.

The research project grade indicator 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.

Summing up the results from all of the equations, firm age contributes to explaining the choice of a university as an R&D partner, and faculty age has a negative effect on the choice of a public research lab. Thus, long co-location contributes to explaining the linkages between F&D firms and universities together with the education channel, which exerts a stronger impact for collaboration with universities than for collaboration with public research labs. When graduates are employed in local firms, they have fewer links with public research labs; a possible explanation is that their turnover is higher in firms that collaborate in R&D with public research labs because these firms tend to use non-standard jobs.

Very small firms collaborate in R&D with private firms but encounter problems in the choice of public R&D partners, particularly of universities. The motivations are the “problem solving” approach to innovation, focused on new product development, of these firms and their difficulties in identifying scientific competences which are often fragmented and competing for fund-raising (Ranieri and Silvestri, 2006).

Over the 2001–2006 period, geographical distance loses significance for product innovation and R&D collaborations with universities and/or public research labs for process innovation. Academic policies that aim at commercialising research output, which are proxied by the technology transfer office’s age, negatively impact both product and process innovation.

After comparing the product and process innovations of the Italian F&D firms, the latter appears to be based on codified knowledge because of the stronger impacts of R&D collaborations and R&D intensity in the last sub-period, whereas the former appears to be based on tacit knowledge because of the impact of direct interactions or informal contacts with academics, as proxied by the geographical distance from the closest faculty of agricultural studies.

7. Concluding remarks

The main objective of the paper is to identify how university–firm R&D collaboration impacts firm product and process innovations and how the “knowledge context” in which the firm operates (in terms of research, education and technology transfer-related activities at local universities) affects this relationship.

The results obtained show that knowledge spillovers from local universities can be important because a firm within a radius of 150 km from a university has a higher likelihood of product innovation than does 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. Degree programmes, in fields useful for local firms, act 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 show that the NSI structure influences the nature and the size of local knowledge spillovers. The same amount of knowledge produced by the public research system—when the areas of expertise offered by universities are those required by the local industry—can spill over throughout the local economy and connect the research and industrial communities through the education channel in the case of NSI based on universities, such as the German and Italian public agri-food research systems. The positive impact of geographical proximity on product innovation suggests that a territorially dispersed NSI structure produces local knowledge spillovers for a sector with a plethora of small firms that use tacit-knowledge-based technologies. However, the geographical distance from local universities to firms, which is relevant for knowledge externalities, is not particularly small (150 km), whereas the marginal impact of an additional agricultural studies faculty is limited in magnitude. Note, however, that other intrinsic characteristics of new faculties (which probably are less hierarchical academic institutions) were already taken into account through other variables (women as full professors; researchers as a percentage of 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 research labs, with a resulting increase in the information asymmetry in a firm’s choice of R&D partners. Finally, the choice of both scientific disciplines and graduation fields influences the path of local development; some economic activities might benefit, whereas others that do not use the knowledge produced by that specific scientific discipline or the expertise supplied by that specific graduation field 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 should be perceived as a potential future source of private funding to augment university budgets. The same can be said about the gender glass ceiling, the elimination of which would increase the probability of university–firm collaboration.

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

From the firm perspective, very small size and an isolated location are related to difficulties in choosing a public R&D partner. Reducing information asymmetry should be undertaken by trustworthy third parties, such as regional development agencies.

A limitation of the present work and a direction for its future extension is that because of data limitations, the analysis excludes micro-sized firms (with less than 10 workers). As the paper evidenced that firm size does not directly matter for process innovation and R&D collaboration with private partners, it could be interesting to test whether this also holds in case of micro-sized firms.

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Appendix A

Table A1
Regional distribution of F&D firms with ≥10 workers.

Regions	Population[a]	Sample
Piemonte	8	8
Valle d'Aosta	0	0
Lombardia	15	15
Trentino Alto Adige	3	2
Veneto	10	11
Friuli Venezia Giulia	3	2
Liguria	2	2
Emilia Romagna	14	13
Toscana	6	6
Umbria	2	2
Marche	3	3
Lazio	5	3
Abruzzo	3	4
Molise	1	1
Campania	8	9
Puglia	6	7
Basilicata	1	1
Calabria	2	1
Sicilia	5	6
Sardegna	3	5
Total	100	100

[a] Own elaboration on Istat – Census of Industry 2001.

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