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Innovation Systems Research in the Italian Food Industry

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Abstract

The objective of the paper is to determine the role that R&D networking, through the collaboration of firms with universities, plays among the determinants of product and process innovation in the Italian food and drink industry and how geographical proximity to a university affects both R&D university-industry collaboration and innovation. The data are sourced from the 7th (1995-1997), 8th (1998-2000), 9th (2001-2003) and 10th (2004-2006) waves of Capitalia survey data. The approach is a triprobit analysis in which the dependent variables are R&D collaboration with a university, process and product innovation; the independent variables are firm, territorial and university characteristics.

Keywords: product and process innovation, university-industry interaction, geographical distance, food and drink industries

JEL Classification: O31, D21, R1

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Table of contents

1. Introduction

The roles of universities in society have been of interest to scholars in different scientific fields. Beginning in the mid-1960s, the objectives of universities have been considered to be the production and transmission of knowledge, mainly through the channels of research, teaching and consultancy (Sonka and Chicoine, 2004).

Recently, the role that universities play as incubators of new technology-based firms, through spin-off effects, attraction of external investments and technology transfer to firms that belong to high-tech clusters, has been discussed extensively (Mansfield, 1991; Rosenberg and Nelson 1994; Mansfield and Lee, 1996). According to the triple-helix model of university-industry-government relations (Etzkowitz and Leydesdorff, 2000; Etzkowitz, 2004), universities play a further crucial role in a pattern of technology-led local development through the creation of networks between industry and government; these networks foster the conditions for innovation. More precisely, the collaborative partnership between university and industry, which is facilitated by government programs, builds new forms of social capital, in the form of communication and trust, into the national research systems. Empirical evidence for the key role played by the collaboration between university and industry for the success of relatively small high-tech firm systems is found all over the world (e.g., Quadrio Curzio and Fortis, 2002). A further relevant aspect that is emphasised in literature is that the above-mentioned type of social capital can be particularly important in research transfer for certain groups of disciplines, such as the life sciences (Landry *et al*., 2007), and in the presence of cognitive gaps, which make geographical proximity a necessary condition for R&D collaboration (de Jong and Freel, 2010).

Traditional channels of technological transfer from universities to firms are training, through the supply of human capital (which consists of individuals who are highly specialised in terms of their technical and scientific skills), consultancy, and contract and joint research; these forms are more frequent than co-patenting or spin-out activities and may represent important channels of university-firm interaction (D’Este and Patel, 2007). The relative importance of these channels can be size- or sector-specific. For example, the expertise offered to the local labour market through training is especially relevant for local small and medium firms, which may not have the strength and/or capacity to compete in the national labour market. Training is particularly important for the interaction between university and firms in the food and drink industry (F&D) to conform to food safety law prescriptions and health safety requirements.

Academic research quality is a key variable that shapes the pattern of university-firm collaboration because innovative firms favour the research produced by high-quality research universities (Mansfield, 1991, 1995; Mansfield and Lee, 1996; Pavitt, 2001; Bruno and Orsenigo, 2003). Particularly, knowledge-acquisition activities of small- and medium-sized enterprises are assumed to benefit from geographical proximity to centres of research excellence because large firms, which generally devote more resources to in-house R&D, tend to collaborate with universities that sell the results of their research, regardless of the location and of the distance cost, and to rely on spillovers from distant institutions more often than small and medium firms, which have few or no resources invested in R&D and rely on local research institutions (Audretsch and Vivarelli, 1996; Piergiovanni *et al.*, 1997; Rodríguez-Pose and Refolo, 2003).

The aim of this paper is to assess the effect of universities on innovation in the Italian F&D industry with respect to the other determinants that are customarily used in the literature to explain the adoption of process and product innovation.

The choice of this sector is based on multiple reasons: a) the very significant presence of small firms with no R&D intensity and, hence, a potentially more important role for university-industry collaboration; b) the presence of cognitive gaps that are linked to knowledge of the effects of pedoclimatic conditions on local production; c) the demand for process innovation due to the public-good attributes of food products, such as food safety, makes this sector an interesting case-study of non-technology-based small firms whose absorptive capacity is poorly measured by their R&D expenditure.

The analysis is carried out using data from the time period 1995-2006 regarding F&D firms contained in the 7th (1995-1997), 8th (1998-2000), 9th (2001-2003) and

10th (2004-2006) waves of the Capitalia survey. A quite long period is necessary to determine the effects of collaboration between universities and industry. The approach adopted is a trivariate probit regression in which the dependent variables are the presence of R&D collaboration with a university, process innovation and product innovation, whereas the independent variables are firm, territorial and university characteristics.

The novel contributions of the paper include the identification of multiple channels of university-firm interaction (formal R&D collaboration, informal interaction and training), a joint analysis of university-firm collaboration and of product and process innovation, the proposal of a more accurate measure of the amount of codified knowledge produced by universities and its focus on a sector that is usually considered codified-knowledge extensive. The interest in this sector is justified by the increase in the number of faculties of agriculture during the period examined, in contrast with other European countries, such as the UK or Germany.

2. The Italian public agri-food research system

As in the other industrialised countries, a publically supported decentralised agri-food research system was developed in Italy. After the Second World War, the member states of the then European Economic Community decided to reduce farmer poverty, income-insecurity and dependency on third countries for food. To achieve this goal, the EEC members engaged in a strong common agricultural policy that aimed at maximisation of agricultural productivity, thereby securing an affordable food supply for the European population and providing farmers with adequate incomes.

A powerful instrument that was employed to attain these goals was the ensemble of research and development, education and extension: in each of the member states, agricultural knowledge systems were established, and they flourished following the dominant technologised and over-productive scientific paradigm. New technologies and innovative production systems were adopted by firms of the agri-food industries, partially because of the knowledge-based services supplied by the extension services (Werrij, 2010).

The resulting Italian public agri-food research system was very articulated and fragmented because the research activities were performed in labs and technology institutes under the control of different public departments (Higher Education, Agriculture, Public Health and Environment, for example)[1]. Generally the type of financing from the Higher Education Department is aimed at basic and applied research, whereas the Agriculture Department exclusively finances applied research. Regional governments in Italy have also financed public research since DPR 606/1976 introduced the concept of "research of regional interest"[2], after which regional administrations with special status, in particular, created their own public lab networks[3]. The competencies in the farming and agri-food industries were further decentralised to regional administrations by the law 491/1993 and the legislative decree 143/1997 and institutionalised by the Title V amendment to the Constitution in 2001. Almost all projects (99%) financed by the Italian regional governments are aimed at applied research (Ascione *et al*., 2006). Finally, some public financing to agri-food research topics stems directly from EU sources; the type of project financed is those that are aimed at satisfying the demand of civil society for food safety and quality and social and environmental sustainability (Ascione *et al*., 2006).

Although research projects about agri-food topics can be conducted in other faculties (veterinary studies, economics, sociology, political science, engineering and law faculties, for example), most of the academic research in the field is performed in faculties of agriculture (INEA, 2009), which employed 2,104 researchers and professors in 2011. The faculties of agriculture are highly dispersed throughout the nation. Their current number is 24 and each university is autonomous (law 168/1989). The Northern Italy hosts 9 faculties of agriculture,

[1] In 1998, 3,062 scholars were active in the field of public research for the F&D industry. 51% of them were employed by universities, 27% were employed by public labs under the control of the Department for Agriculture or the Department of Higher education and 11% were employed by regional public labs (INEA, 1999).

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

[3] The ordinary-status regional governments of Piemonte, Veneto, Emilia Romagna, Liguria, Toscana and Calabria also substantially support their own regional research in the field (INEA, 1998).

the Centre hosts 5 and the South has 10. Some of these faculties are very young because 5 were established in the 1980s and 4 were established in the 1990s. Italy also hosts the oldest faculty of agriculture in the world, which was founded in 1871 at the University of Pisa[4]. In 2011, the students of the faculties of agriculture accounted for 1.7% of the total students and PhD students in agri-food studies were 4.7% of total PhD students (INEA, 2009).

Technology transfer to firms is achieved through a regional development agency, one for each region, which generally conducts only applied research, starting from the basic research supplied by universities, except for some cases (e.g., in Liguria, whose development agency also conducts basic research).

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 carried out in 1999 by merging them into one institution (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 the Higher Education, were also restructured and unified under specific themes. A third important event for Italian public research occurred in the beginning of 1999, when an evaluation procedure for research activities by the Italian Evaluation of Research Quality through the CIVR periodic reports was established. This evaluation is the result of a general debate on the inadequate level and inefficacy of the Italian public research system, which led to the Bassanini law 59/97, which reformed the whole system by introducing coordination, evaluation and participative research planning (through the National Research Plans). The reform was completed by the law 297/99, which reordered and rationalised the significant number of subsidies to industrial research and explicitly introduced incentives for collaboration between public and private researchers. At the same time, to attract new students and decrease the dropout rate, Ministerial Decree 509/99 reformed the length of the degree programs by introducing a first 3-year degree that is

[4] The number of the faculties of agriculture is 0 in Liguria, Trentino Alto Adige and Valle d’Aosta, 1 in Abruzzo, Campania, Calabria, Basilicata, Friuli Venezia Giulia, Lazio, Marche, Molise, Piemonte, Sardegna, Umbria and Veneto, 2 in Lombardia, Puglia, Sicilia and Toscana and 4 in Emilia Romagna.

followed by a 2-year specialisation degree.

A higher-education evaluation system was properly 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 CNSVU (National Committee for the Evaluation of the University Sector), are publicly available and have been used in this paper; they also represent the basis for the ranking of faculties that is annually published by Italian newspapers (la Repubblica and Il Sole ventiquattrore).

The over-technologised and over-productive scientific paradigm of the agri-food research system, which originated in the 1970s, has been criticised by the consumerism and environmental movements, who asked for academic research projects that are targeted towards the realisation of environmentally sustainable production processes and attuned to present-day concerns[5]. At the same time, advances in the knowledge of several disciplines have increased the attention paid to the relation between food and human health. During 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 bachelor degrees (Santini, 2003). A further development of these years that is relevant for the university-industry interaction is the introduction in the bachelor programmes of compulsory pre-graduate student internships at agri-food firms; some of the students that were offered internships remain in the firms. Currently, similarly, after their PhD internships, some of the post-graduate students that are hosted in a firm that has an R&D department are employed by the guest firms.

The re-orientation of production-oriented research occurred with some difficulties (Werrij, 2010). First, the small-firm sized farming and agri-food industries hardly considered science and research as a pertinent strategic factor. Second, the disciplinary composition of the Italian faculties of agriculture has not substantially changed over the past decades; for example, the percentage of

[5] For example, the Subsidy Integrated Plans (PIA) of the National Operative Programme, which became operative in 2000, subsidises firms according to a grade given to firm applications that is calculated as the arithmetic mean of elementary grades for the innovativeness, quality of occupation increase and degree of attention paid to environment safeguards (Contó, 2005).

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). On the other hand, the budget for public agri-food research in Italy has increased throughout 1998-2008 (Sorrentino and Capozzi, 2010). At the same time, preliminary discussion about the allocation of regional plan funds for rural development research has involved not only representatives of the public research and extension systems and of the farming and agri-food industries but also consumer and environmental associations (Ascione *et al.*; 2006).

Whereas production-oriented research has been relatively less geographically targeted, the realisation of socially and environmentally sustainable production processes is necessarily more context-dependent and has yielded a renewed importance of geographical proximity for effective collaboration between firms and universities. Some examples of the new university research projects that have been financed, which are evidence for this aspect, are those that are aimed at identifying the effect of organic fertilisers on sustainable local cultivation systems and those aimed at identifying the local genotypes cultivated in geographical areas; this latter project is intended to inform the disciplinary regulation of typical products that are protected by a denomination of origin trademark or by a guaranteed origin certification of its historical production area[6] (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 quite long and overcome national borders, particularly in case of multinationals. For example, the maximum distance between the Faculty of Agriculture at the University of Naples Federico II and firms that finance R&D projects there is 1,000 km (Santini, 2003).

Generally speaking, because of cuts in public financing from national sources to Italian universities, the share of university budget sourced from R&D collaborations with private firms is increasing as a consequence of university incentives given to professors in the form of profit sharing, increase in research funds or career advancement; on average, this share was 16% in 2002 and 25% in

[6] Italy is the EU country with the greatest number of products of designated and guaranteed origin (De Devitiis and Maietta, 2013).

2009 (Netval, 2005, 2011). The R&D expenses from private for-profit firms as a fraction of the total R&D investment in Italy ranges from the 70% in the North of Italy in 2007 to 31% in the South, where universities and public labs finance 66% of the total R&D; a third of the total public R&D of the southern regions is spent in Campania (Istat, 2011).

The amount of R&D from Italian universities, devoted to the F&D industry was 440 ml € in 2008. It was much greater than the amount invested by F&D firms in the same year: on average, F&D firms invested 127 ml € annually over 1998-2008. Among EU countries, Italy ranks third, after Spain and Germany, in terms of the amount of R&D from universities and public research that was devoted to the F&D industry during the time period 1998-2008. The rate of increase of the public resources devoted in Italy to R&D for the F&D industry over 1998-2008 was greater than 30% (Sorrentino and Capozzi, 2010).

3. The Italian F&D industry

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

The use of the 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 expenditure in terms of industry innovation expenditures is very high for F&D because most innovation is carried out using equipment and capital goods (Rama, 2008). Registration of a trademark is one of the most important forms of innovation in this industry. Other non-R&D inputs to innovation are learning by doing and learning by interacting. Learning by interacting, with suppliers and with consumers, is important in the sector because of the food-quality concern. For example, the new pattern of socially responsible consumption, which asks for product and process innovation and is particularly aimed at the F&D industry, is an example of innovation that stems from the interaction with consumers generated by a non-R&D innovation input.

Public regulation is strong in the F&D sector because of some public-good attributes of food products, such as food and health safety. Public regulation generally alters incentives for innovation. In this sector, it induces the sort of innovation that respects food and health safety and food quality standards, together with the direct public support, through the European Union Common Agricultural Policy. This specific attribute of the F&D industry can enhance the innovation capacity of small-sized firms compared with the innovation capacity of small-sized firms of other sectors, thereby resulting in the percentage of innovative firms in the F&D industry being greater than that in other traditional sectors (Ferace and Mazzotta, 2011).

The respect of food and health safety and food quality standards makes innovation in the F&D industry the result of a multi-disciplinary activity in which different skills (biological, chemical, engineering, nutritional, economic and law-abiding) are necessary in the development of the path from the formulation of an idea to its industrial realisation.

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

Sectors	R&D expenditure (ml €)	*per worker*	*R&D intra-muros*	*R&D extra-muros*	*Physical capital*	*Immaterial capital*	*Development*	*Training*	*Mtkg*
			% Innovation expenditure for:						
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 1 reports the levels of R&D expenditure for the Italian F&D and other supplier-dominated sectors in 2004. The R&D investment per worker was not particularly high for the F&D industry. However, considering the innovation expenditures, two features distinguish the F&D industry: the values for the percentage of innovation expenditure for marketing and for R&D *extra-muros*, from public or private firms, are the greatest of all sectors. This latter figure reflects the development, as in other industrialised countries, of a publically supported decentralised agri-food research system (Ruttan, 2001) in which collaboration among firms and universities is more widespread than for other small and medium 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), formal and informal 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[7]. The percentage of Italian F&D firms with interactions with universities or public research labs is also greater than that in other European countries, such as Germany and France (Pasetto, 2011).

[7] In the period 2008-2010, 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. In the same period, with respect to a representative sample of firms with at least 10 employees, 13% of F&D firms had formal interactions with universities or public research labs, compared with an average of 10% for manufacturers as a whole (SRM, 2013). The percentage of F&D firms with formal interactions with universities or public research labs is greater in the South of Italy.

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. €

Table 2, which reports the distribution of Italian F&D firms and workers by size class, emphasises the dualistic structure of the sector, which is characterised by a very small number of medium- and large-sized firms and a very large number of micro firms. The huge percentage of micro firms in the F&D sector is explained by the presence of bakers' and confectionery shops, which are generally family firms, are 56% of the total F&D sector firms and employ an average of 4 workers (INEA, 2006).

The presence of micro firms in the F&D sector also explains why the average R&D intensity is very low, as a result of structural factors that shape the R&D intensity (Moncada-Paternò-Castello *et al*., 2010) within a sector.

4. The determinants of university-industry collaborations

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

Geographical proximity (Boschma, 2005) plays a fundamental role as a determinant of university-industry collaboration, which has been recognised by different bodies of literature: studies of localised knowledge spillovers, studies of the systemic nature of knowledge and innovation, from innovation systems to the triple-helix model, and studies of industrial clusters. The studies of localised knowledge spillovers are based on the knowledge production function framework, which 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 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 been largely estimated for nations (Jaffe, 1989; Acs *et al*., 1991; Anselin *et al*., 1997; Feldman and Florida, 1994) or regions (Varga, 2000; Acs *et al*., 2002; Fritsch, 2002; Greunz, 2002). Studies of the systemic nature of knowledge and innovation typically focus on the interaction 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 describes the university as the centre of a relationship with 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 have been made possible by studies of industrial clusters, which consider university-industry collaboration as the key factor for competitiveness and growth of local economic systems.

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

On the other hand, codified knowledge, which is explicit and standardised, can be transmitted over longer distances and across organisational boundaries at a low cost. The capability of shared codification creates non-spatial proximity: cognitive proximity, which is the extent to which two organisations share the same knowledge, and organisational proximity, which is due to the accumulation of experience between the same or similar actors. 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 instead is carefully planned (Audretsch and Feldman, 1996). Cognitive proximity is generally higher in natural sciences research than is social sciences research because social science knowledge is less codified than that of the natural sciences and is not based on a unified and established scientific methodology. Rather, it is idiosyncratic to very specific disciplines, sub-disciplines and even research approaches. Thus, geographical proximity to universities may be more important for accessing social science research than for accessing natural science research (Audretsch *et al.*, 2005).

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

Academic research quality (Mansfield, 1991) is expected to act as a catalyst for industrial labs that are interested in carrying out joint research activities by attracting firms with forefront technologies. Mansfield (1995) provides evidence that higher-quality universities have greater academic contributions to industrial innovation. Mansfield and Lee (1996) argue that firms prefer to work with local university researchers and with more distinguished university departments; however, the impact of academic quality and geographical proximity is not homogeneous across disciplinary fields. The effect of geographical proximity on businesses' choice of 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 highly relevant in explaining the frequency of collaborations with industry, whereas it is not important for basic-science related departments, for which a positive impact of research quality prevails. However, the relationship between academic research quality and distance of collaborations is curvilinear because beyond a certain threshold of research excellence, collaborations with industry turn out to be geographically closer. Petruzzelli (2011) demonstrates that the value of the university–industry joint innovation, which is defined as the total number of citations a specific joint-patent received within five years of the issue date, is positively affected by university reputation, prior ties and geographical distance. Muscio and Nardone (2012) find that academic research quality positively impacts the private funding of university research activities, particularly in the case of food sciences departments. The age of a university, as measured in years, is also used to control for reputation effects to explain the birth of knowledge-based start-ups located within close proximity to universities (Audretsch and Lehmann, 2005).

To take into account that academic institutions need a critical mass of researchers to improve their chance of interacting with firms, scholars have also introduced into the analysis the university and department size, which is quantified as the number of researchers (or the percentage of time) devoted to research activities (Bruno and Orsenigo, 2003; Landry *et al.*, 2007; D'Este and Iammarino, 2010; Muscio and Nardone, 2012) or the R&D intensity of the higher education sector (Huynh and Rotondi, 2009).

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

Among personal characteristics of scholars, age and carrier status are taken into account because older scientists and full professors are expected to accept multiple offers of firm involvement, whereas younger scientists and research assistants are more likely to be involved with a local firm than with a nonlocal firm or to be not 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 the size, ownership, public subsidies for the promotion of innovation and multi-purpose nature of university-firm collaboration (Piga and Vivarelli, 2004; Medda *et al*., 2005; Huynh and Rotondi, 2009; Bodas Freitas *et al*., 2011).

5. The issues that this paper addresses

Following the suggestion of the aforementioned studies, particularly that firms may be more willing to collaborate with universities in R&D when collaboration has multiple objectives, the determinants of university-industry collaboration are analysed together with the choice of both product and process innovation; firm and university characteristics are co-determinants of this multiple choice. The principal aim of the proposed analytical framework is to disentangle the effect of different channels of university-industry interaction.

Firm, university and territorial characteristics are used to simultaneously explain the choice of R&D university-industry collaboration and the choice of product and process innovation in a simultaneous model in which university-industry collaboration is an endogenous variable. The use of this model allows us to separate the effect on innovation of formal R&D collaboration, in the form of contract and joint research (the variable called R&D university-industry collaboration), from the effect of consultancies or informal collaboration (whose effect is captured by the geographical proximity to a university) and of other university characteristics, which are used as regressors in the equations relative to product and process innovation.

Thus, the first question addressed in this paper is the following: how does geographical proximity explain the choice of R&D university-industry collaboration and the choice of product and process innovation?

No effect of geographical proximity is expected for the variable university-industry collaboration because this collaboration is carefully planned, whereas geographical proximity is expected to be significant for product and/or process innovation to the extent they are based on a certain amount of personal and context-dependent tacit knowledge. If geographical proximity is significant, what is the distance from a university that enables innovation? Which type of innovation is more sensitive to geographical proximity?

The second question is the following: how does academic research quality affect university-industry collaboration and product and process innovation? Is firm perception of academic quality the same for these three choices? We use several indicators of academic research quality because the standard measure of reputation used in the literature (the number of citations of the faculty research staff) is unavailable for the entire period examined.

Complementary to the first two questions, the third question is as follows: how does codified knowledge affect product and process innovation? An indicator of codified knowledge is constructed using a weighted average of the faculty scientific production obtained using the annual scientific disciplinary composition of the faculty; the number of articles of the corresponding scientific discipline is taken to be the median of the scientific production of the population of Italian full professors over the 2002-2012 period.

The fourth question relates to the impact of training at universities on university-industry collaboration and whether the impact of university training on innovation is stronger than the impact of formal and informal university-industry collaboration.

6. Methodology

6.1. The data

The firm data used in the paper are sourced from the "Survey of Italian manufacturing firms", which was formerly run by Mediocredito Centrale and currently by Capitalia, which are two Italian credit institutions. The analysis is built on four waves, which cover the periods 1995-1997 (7^{th}), 1998-2000 (8^{th}) 2001-2003 (9^{th}) and 2004-2006 (10^{th}); each wave includes over 4000 firms. The survey design includes all firms with a minimum of 500 employees and a sample, which is representative of Italian manufacturing firms with between 10 and 500 employees, that is stratified by firm size, sector and geographical area.

In the Capitalia surveys, firms are asked whether innovation was introduced during the previous three years. The concept of innovation does not distinguish between radical and incremental innovation but only among process, product and other innovation. The questionnaire also collects information, together with other firm characteristics, about the presence of *extra-moenia* collaborations in R&D with universities and other public research labs. Only in the last wave, which is for the 2004-2006 period, was information about whether the universities are regional provided[8].

Using their ATECO classification, F&D firms have been extracted, thereby resulting in a pool of 1,744 firms for the 1995-2006 period. Ex-post representiveness has been checked: the sample so derived is representative of Italian F&D firm by region, as it is possible to observe from table A1 in the appendix.

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

Information about the municipality in which the firm is located, or, in its absence, of the province, as in Benfratello *et al*. (2008), has been used to identify

[8] According to this information, only 4 F&D firms had R&D collaborations with extra-regional universities.

the first three closest faculties of agriculture. The choice of focusing on these faculties is supported by the evidence that most of the university collaborations of F&D firms is with the regional faculty of agriculture; furthermore, a firm that has university collaborations is likely to have multiple university or public research lab partners (Bodas Freitas *et al.*, 2011) and the probability that one of these partners is the regional faculty of agriculture is very high. Consequently, three distances, as the crow flies[9], in kilometres for each firm are present in the data set. A fourth variable for geographical proximity is a dummy that takes the value 1 if the closest faculty of agriculture is more than 150 km away; this value was chosen after testing different thresholds.

With respect to the closest faculty of agriculture, further information was gathered: whether the faculty is extra-regional; whether it is public; its birth year; its annual size in terms of researchers/professors[10]; the annual composition of researchers/professors in terms of: i) gender, ii) birth year, iii) carrier status (researchers, associate and full professors), and iv) group of scientific disciplines; the annual number of graduates (ISTAT, Statistiche sulla Ricerca Scientifica[11]); the annual faculty reputation, which was kindly offered by Censis for the year 1998-2006; the presence of a food technologist bachelor 5-year course and the presence of a food technologist bachelor 3-year course (Ministero dell'Università e della Ricerca Scientifica, several years). The number of bachelor biotechnologist courses is relative to the university regional supply (Ministero dell'Università e della Ricerca Scientifica, several years; ISTAT, several years; INEA, several years).

The academic research quality is measured through the grades given by the Italian Evaluation of Research Quality, hereafter VQR, for the 2001-2003 and 2004-2010 periods. The VQR grade is a composite indicator of the quality of the research output produced by universities or public research labs under the supervision of the Higher Education Department in the evaluation period. Groups of Experts of Evaluation, which are coordinated by the National Agency for the Evaluation of University and Research, evaluated the research output using both

[9] http://distanzechilometriche.net/
[10] http://cercauniversita.cineca.it and http://www.cnvsu.it/
[11] http://www.cnvsu.it/

bibliometric analysis and informed peer review. There is evidence that these two evaluation system gave similar grades for the same set of journal articles (Bertocchi *et al*., 2013). Two other indicators of faculty reputation that are used in this paper are the following annual grades supplied by Censis for the period from 1998 to 2006: the research grade, which is based on the number of research projects financed by national and international institutions, and the international grade, which is based on the international mobility of scholars and students. This information is missing for the 1995-1997 period; thus, the two grades for 1998 have been used for the first period. For the remaining periods, the two grades are the average of the grades for the three corresponding years.

The mentioned indicator of codified knowledge is built using the medians of the ISI-Scopus indexed scientific production of the populations of full professors of the Italian faculties of agriculture grouped by scientific discipline over the 2002-2012 period[12]. It was not possible to measure the scientific production of the faculty of agriculture because scholars' names for 1996-1999 are not available on the website. The use of the medians referred to 2002-2012 is based on the assumptions that the differences among scientific disciplines in average production of ISI-Scopus indexed journals have not changed with respect to 1995-2001.

Table 3 reports descriptive statistics of the sample. It indicates that 5% of the firms in the sample have R&D collaboration with a university, whereas 9% of them have collaboration with private research labs. 34% have introduced product innovation, and 49% have introduced process innovation. The R&D intensity, which is measured as the average of the ratio of R&D expenditures to sales over the three years in each period, is very low, 0.28% of turnover. Half of the firms in the sample have a turnover between 5 ml and 25 ml €, almost one-third of firms have a turnover that is less than 5 ml € and the remaining firms have a turnover that is equal to or greater than 25 ml €. Two features that are peculiar to the sector examined are the relatively high presence of cooperatives (17% of firms) and distribution chain agreements (25.49% of sales occur through this channel).

Almost a quarter of firms in the sample use non-standard jobs[13] because of the introduction in Italy of flexibility legislation that lowered the cost for firms to use

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

[13] Open-ended part-time, fixed-term part-time and fixed-term full-time jobs.

high-skilled labour. Almost half of firms are subsidised[14], particularly those located in the South of Italy because of the legislation for disadvantaged areas.

The average distance from the closest faculty of agriculture is 47.71 km, whereas the third-closest one is only 144.71 km away, on average. Moreover, only 2% of F&D firms are more than 150 km away from a faculty of agriculture. The short distance between F&D firms and faculties of agriculture is partly because of the choice of a linear distance but mainly reflects a highly decentralised agri-food research system.

A faculty of agriculture is, on average, 50 years old, and it graduates 167 students per year and employs 110 researchers or professors. The employees are, on average, 48 years old, and a third of them are researchers. Women account for only 11% of full professors. This latter variable is used as a proxy for the absence of gender segregation. The choices that are related to the research and didactics mix differ from faculty to faculty, partly reflecting the regional productive structure (for example, in mountain regions, a forestry management bachelor course is often present); however, the average number of groups of scientific disciplines is 6. On average, biologists represent 8.53% of total scholars, chemicals account for 5.98%, physicians represent 1.03%, geologists are 1.11% and industrial engineers account for 0.63%. However, the presence of engineers is greater because food engineers are included in the very ample residual macro-area of food scientists.

On average, among la Repubblica-Censis indicators of faculty reputation, the average international grade is lower than the research grade. The median production of codified knowledge by full professors of the Italian faculties of agriculture throughout 2002-2012 is equal to 19 ISI-Scopus indexed journal articles. The average VQR grade of the Italian faculties of agriculture is 0.6843 (it has been multiplied by 100 to make its marginal effect comparable to that of the research grade).

During the period examined, regional governments (INEA, several years) annually devoted, on average, 2,180 €, at constant 2006-based prices and

[14] The data set provides information about whether the firm obtained any financial subsidy for applied research and technological innovation via Italian national laws, such as the laws 46/82 and 297/99, or EU and regional laws.

normalised per F&D firm, to agri-food research.

Table 3
Variables and descriptive statistics

Variables	Mean	Std. Dev.	Variables	Mean	Std. Dev.
Firm characteristics			***University characteristics***		
Dummy for R&D collaboration with university	0.05	0.22	No. regional bachelor biotechnologist courses	0.61	0.49
Dummy for R&D collaboration with public las	0.05	0.22	N. of regional faculties of agriculture	1.53	1.00
Dummy for product innovation	0.34	0.48	Dummy for public university	0.97	0.18
Dummy for process innovation	0.49	0.50	Dummy for technological transfer office	0.22	0.41
Dummy for R&D collaboration with private firms	0.09	0.29			
R&D intensity (% turnover)	0.28	1.23	***Faculty characteristics***		
Skilled employees (%)	5.13	7.82	Dummy for extra-regional faculty of agriculture	0.12	0.32
Sales through distribution chain agreement (%)	25.49	34.62	Dummy for food technologist bachelor 3-year degree	0.54	0.50
Subsidies dummy	0.48	0.50	Dummy for food technologist bachelor 5-year degree	0.42	0.49
Non standard job dummy	0.24	0.49	Faculty of agriculture's age (years)	50.00	24.93
Co-op firm dummy	0.17	0.38	N. of researchers/professors	109.93	51.55
Firm age (years)	30.96	24.09	N. of graduates	166.77	127.02
Very small-sized firm dummy	0.31	0.46	Women on full professors (%)	10.74	9.85
Small-sized firm dummy	0.51	0.50	Researchers on total researchers/professors (%)	34.56	10.39
Medium-sized firm dummy	0.08	0.27	Average age of researchers/professors	48.19	4.68
Large-sized firm dummy	0.05	0.21	N. of scientific disciplines' groups	5.56	1.81
Meat processing dummy	0.16	0.36	Industrial engineers on total scholars (%)	0.63	1.53
Fruit&vegetables processing dummy	0.12	0.33	Biologists on total scholars (%)	8.53	10.79
Milk processing dummy	0.18	0.38	Chemicals on total scholars (%)	5.98	8.03
Rice dummy	0.07	0.25	Physicians on total scholars (%)	1.03	3.71
Pet food dummy	0.05	0.22	Geologists on total scholars (%)	1.11	2.08
Beverage dummy	0.19	0.39	International grade	64.62	28.39
			Research grade	82.46	16.49
Territorial characteristics			VQR grade	68.43	9.03
North dummy	0.52	0.50	Food science dept.' VQR grade	68.80	22.16
South dummy	0.35	0.48	Codified knowledge indicator (No. journal articles)	18.57	1.76
Dummy for food district	0.08	0.26			
Dummy for agricultural district	0.03	0.16	***Regional public R&D***		
			Disbursements (constant 2006-based th. € /No. F&D firms)	1.44	2.83
Distance from the faculties of agriculture			Accredited funds (constant 2006-based th. €/No. F&D firms)	2.18	3.12
1st distance (km)	47.71	37.24			
2nd distance (km)	108.94	74.40	***Temporal dummies***		
3rd distance (km)	144.71	81.40	Dummy 1998-2000	0.29	0.45
Dummy for distance > 150 km	0.02	0.15	Dummy 2001-2003	0.29	0.46
			Dummy 2004-2006	0.18	0.38

6.2. The econometric approach

The econometric model consists of three simultaneous processes. The first one explains the decision of R&D collaboration with universities, the second one explains the decision of innovating firm products and the third one explains the decision of innovating firm processes. These three processes are jointly described by a trivariate probit model because the dependent variables (R&D collaboration with universities, product innovation and process innovation) are dummy variables.

The structure of the model follows a three-equation form in which the estimation result of the first equations is used as a regressor in the second and third equations, as follows:

$$\begin{cases} y_{1i}^{*} = \mathbf{x}_{1i}^{'}\boldsymbol{\beta}_1 + \epsilon_{1i} \\ y_{2i}^{*} = \gamma_{21}\, y_{1i}^{*} + \mathbf{x}_{2i}^{'}\boldsymbol{\beta}_2 + \epsilon_{2i} \\ y_{3i}^{*} = \gamma_{31}\, y_{1i}^{*} + \mathbf{x}_{3i}^{'}\boldsymbol{\beta}_3 + \epsilon_{3i} \end{cases} \quad (1)$$

y_{1i}*, y_{2i}* and y_{3i}* are latent variables: y_1* is the presence of R&D collaboration with university; y_2* is the presence of product innovation and y_3* is the presence of process innovation. $\mathbf{x}_{1i}$, $\mathbf{x}_{2i}$ and $\mathbf{x}_{3i}$ are vectors of exogenous variables, which influence those probabilities for firm *i*. $\boldsymbol{\beta}_1$, $\boldsymbol{\beta}_2$ and $\boldsymbol{\beta}_3$ are parameter vectors. γ_{21} and γ_{31} are scalar parameters. ε_{1i}, ε_{2i} and ε_{3i} are three error terms, which are assumed to be jointly normal with unknown correlation coefficients, ρ_{21}, ρ_{31} and ρ_{32}, and correlated with something else in the model, in particular, $E(x_{2i,}\ \varepsilon_{2i}) = \gamma_{21}$ and $E(x_{3i,}\ \varepsilon_{3i}) = \gamma_{31}$. The three covariate vectors $\mathbf{x}_1$, $\mathbf{x}_2$ and $\mathbf{x}_3$ are not restricted to contain the same variables of interest as long as there exists at least one varying exogenous regressor[15] in each equation in system (1) (Wilde, 2000).

The realisation of the three latent variables y_{1i}*, y_{2i}* and y_{3i}* is not observed; what is observed is the realisation of three binary variables, $y_{1i,}$ y_{2i} and y_{3i}, which are linked to the former according to the following rule:

$$\begin{cases} y_{ki} = 1, & \text{if } \ y_{ki}^{*} > 0 \\ y_{ki} = 0 & \text{otherwise; } \ k = 1, 2, 3 \end{cases} \quad (2)$$

The basic idea that underlies the model is that when trying to explain a

[15] In recursive multiple equation probit models with endogenous dummy regressors, no exclusion restrictions on the exogenous variables for parameter identification are needed if there is sufficient variation in the data. The last condition is ensured by the assumption that each equation contains at least one varying exogenous regressor (Wilde, 2000). Imposing an exclusion restriction on vectors $\mathbf{x}_1$, $\mathbf{x}_2$ and $\mathbf{x}_3$ implies that at least one element of $\mathbf{x}_1$ should not be present in $\mathbf{x}_2$ and $\mathbf{x}_3$.

firm's choices of innovation, both observed factors, which are represented by $\mathbf{x}_1$, $\mathbf{x}_2$ and $\mathbf{x}_3$ (firm, university and territorial characteristics) and unobserved factors, which are embedded in γ_{21} and γ_{31} and in the joint distribution of ε_1, ε_2 and ε_3, are important. γ_{21} and γ_{31} estimate the effect that y_1 has on y_2 and y_3, whereas the coefficients ρs measure the correlation among the error terms in the three equations due to any unobservable characteristics.

The equation that refers to y_1 has been included to identify the determinants of the R&D collaboration between a firm and a university that is aimed at introducing product or process innovation because the common latent factor structure of the trivariate probit framework allows us both to control for the potential endogeneity of the decision of R&D collaboration with universities and to correct the potential sample selection.

The coefficients ρs can be interpreted as conditional correlations because the estimated value of ρ_{21} and ρ_{31} can be interpreted, respectively, as the correlation between y_2 and y_1 and between y_3 and y_1 after the effect of y_1 has been accounted for. In other words, any residual correlation left between y_2 and y_1 and/or between y_3 and y_1 will not be due to an actual correlation between the two variables but rather due to unobservables that are not controlled for in the model, i.e., due to endogeneity. The resulting recursive trivariate probit model can be described as an instrumental variable framework for categorical variables (whose identification conditions have been described in footnote 16) and can be estimated using the simulated maximum likelihood.

For the empirical model, the literature mentioned in section 4 describes a firm's external relationships with universities as a function of the firm's property rights, the public subsidies for innovation, the firm size, the geographical location and university characteristics. The determinants of product and process innovation used in the empirical model are those that are customarily used in literature (Rama, 2008). The empirical specification is described as follows:

University-firm interaction = f_1 (R&D with public labs, R&D from private firms, Skilled employees, R&D intensity, Non-standard jobs, Co-op, Subsidies, Firm-size dummies, Years dummies, Territorial dummies, Geographical distance, University/faculty characteristics).

Product innovation = f_2 (University-firm interaction, R&D from private firms, Skilled employees, R&D intensity, Non-standard jobs, Co-op dummy, Sales through distribution chains, Subsidies, Firm-size dummies, Years dummies, Sub-sector dummies, Territorial dummies, Geographical distance, University/faculty characteristics).

Product innovation = f_3 (University-firm interaction, R&D from private firms, Skilled employees, R&D intensity, Non-standard jobs, Co-op dummy, Sales through distribution chains, Subsidies, Firm-size Dummies, Years dummies, Sub-sector dummies, Territorial dummies, Geographical distance, University/faculty characteristics).

7. Results and Discussion

The results of the trivariate probit regression are reported for several variable specifications in tables 4, 5 and 6 where the standard errors (not reported) of the coefficients have been clustered around the regions where the firm is located. The likelihood ratio test, which was conducted on the hypothesis that ρ_{21} and ρ_{31} are jointly null, supports the trivariate framework: the value of the statistics, for the specification of variables relative to model 4 of tables 4, 5 and 6, is equal to 19.65, with two degrees of freedom, compared with a critical value equal of 5.991 for the 5% significance level. An OV Hausman-type test (Kennedy, 2008) was also performed by using the predicted value of y_1 from its univariate probit regression as an additional regressor in the bivariate probit for the variables y_2 and y_3. The Wald test that the coefficient of the predicted value is null is equal to 5.46, with two degrees of freedom; the predicted value of y_1 is significant only for the process innovation equation.

The correlation among the errors of the equations is significant for ρ_{31} and ρ_{32}; the latter coefficient is equal to 0.43 over the whole period and it is increasing in the last period, when it is equal to 0.55. This result emphasises that in recent years, firm innovation has become more complex and involved both products and processes. ρ_{21} becomes weakly significant in the last sub-period, when ρ_{31} loses significance, thereby indicating a changed influence pattern of university-firm collaboration for both product and process innovation.

Table 4 reports the marginal effects for the trivariate probit regressions in which R&D university firm collaboration is the dependent variable. We first discuss the results of the regressions run for the entire period (models 1-7).

The positive determinants of R&D university-firm collaboration are the following: R&D collaboration with public labs, R&D collaboration with private firms, skilled employees, R&D intensity, subsidies and firm age. Being a very small-sized firm is a negative determinant. Firms that are more R&D intensive because they invest in *intra-muros* and *extra-muros* R&D with public labs or private partners also collaborate with universities. Public research is complementary to and not a substitute for private research, as was already found for Italy (Fantino *et al*., 2013).

With regard to geographical proximity, the 1^{st}, 2^{nd} and 3^{rd} distances from the faculties of agriculture are not significant, whereas the distance from the closest faculty of agriculture being greater than 150 km[16] is highly significant. The interpretation of these results is that isolated firms, which are more than 150 km away from a faculty of agriculture, choose to collaborate with the closest faculty, whereas less-isolated firms have more options to choose from for the expertise that they need.

The amount of normalised regional disbursement is negative and weakly significant for the entire period and significant for the last sub-period, thereby indicating a displacement effect of investment in regional R&D for agri-food sciences on university-firm collaboration. This effect is not surprising because very

[16] This value has been selected by comparison with the results of the dummies, which were alternatively tested, for 50, 75, 100 and 200 km. All these dummies are not significant.

recently, regional rural development plans have introduced specific aids for innovation networks.

Among the university characteristics, intermediation is not significant, whereas the public status of the university is significant but negative. The absence of significance of the technological transfer office variable confirms what was already found for Italian departments (Muscio and Nardone, 2012) and this result is less surprising in the case of the faculties of agriculture because of their technical nature.

The number of faculties within the same region can be used to capture the social capital component of the university-firm interaction through the creation of networks between industry and government. In the case of R&D collaboration between universities and firms, this social capital component tends to express a negative effect, most likely simply because more faculties have to split the regional funding. However, the variable loses significance after the introduction of the faculty reputation indicators.

Table 4

Triprobit regression. Marginal effects for the dependent variable R&D university-firm collaboration

Variables	dF/dx	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*	*model 9*
R&D collaborations with public labs	0.11***	0.11***	0.11***	0.11***	0.11***	0.10***	0.10***	0.13***	0.13***
R&D collaborations with private firms	0.05***	0.05***	0.05***	0.05***	0.05***	0.05***	0.05***	0.06***	0.06***
Skilled employees	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.002***	0.002***
R&D intensity	0.01***	0.01***	0.01***	0.01***	0.01***	0.01**	0.01**	0.002	0.002
Co-op firm	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.001	0.002
Subsidies	0.03***	0.02***	0.02***	0.02***	0.03***	0.03***	0.03***	0.02	0.02
Non standard jobs	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-0.003	0.00
Firm age	0.0005***	0.0004***	0.0004***	0.0004***	0.0004***	0.0004***	0.0004***	0.001***	0.001***
Very small-sized firm	-0.07***	-0.08***	-0.08***	-0.08***	-0.07***	-0.07***	-0.07***	-0.06***	-0.06***
Small-sized firm	-0.03*	-0.03*	-0.03**	-0.03**	-0.03*	-0.02	-0.03*	-0.02	-0.03*
Medium-sized firm	-0.02	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02	-0.04	-0.04
Large-sized firm	-0.03	-0.03	-0.03	-0.03	-0.03	-0.04	-0.04	-0.02	-0.02
North	0.01	0.01	0.01	0.01	0.01	-0.05**	-0.05**	-0.09*	-0.06
South	0.02	0.02	0.02	0.02	0.02	0.00	0.01	0.02	0.00
Food district	-0.04	-0.04	-0.04	-0.04	-0.04	-0.03	-0.03	-0.01	-0.01
Agricultural district	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01
1st distance	0.00								
2nd distance		0.00							
3rd distance			0.00						
Distance > 150 km				0.03	0.03**	0.04***	0.04***	0.02	0.03
Regional R&D - Disbursements					-0.004	-0.01	-0.01*	-0.01**	-0.01
Biotechnologist courses						0.00	0.00	-0.01	0.01
Food technologist bachelor 5-year course						0.03**	0.04**	0.03*	0.04**
Food technologist bachelor 3-year course						-0.02	-0.03**	-0.01	-0.04*
Extra-regional faculty of agriculture						0.00	0.00	0.06**	0.04
Faculty of agriculture 's age						0.00	0.00	-0.0001	0.00
N. of researchers/professors						0.001**	0.00	0.0000	0.00
N. of graduates						0.0002*	0.0002**	0.001**	0.00
Industrial engineers on total scholars						0.00	0.00	0.01*	0.01*
Biologists on total scholars						0.00	0.00	0.01***	0.003***
Chemicals on total scholars						0.00	0.00	-0.01***	-0.01***
Physicians on total scholars						0.00	0.00	0.01*	0.01**
Geologists on total scholars						0.01***	0.01***	0.02**	0.02**
N. of scientific macro-fields						0.00	0.00	-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**	0.00	0.00
Average age of researchers/professors						0.00	0.00	-0.01	-0.01
N. of regional faculties of agriculture						-0.01**	-0.01	0.02	-0.01
Public univerisity						-0.16***	-0.16***	-0.04	-0.06
Technological transfer office						0.01	0.01	-0.02	-0.02
International grade							0.001**		
Research grade							0.000		
Codified knowledge indicator							0.01*		
VQR grade								0.005**	
Food sceince dept.' s VQR grade									0.000
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N. obs.	1535	1535	1535	1535	1535	1535	1535	722	722
LogL	-1931	-1934	-1933	-1931	-1929	-1898	-1889	-899	-901
rho21	-0.07	-0.07	-0.07	-0.07	-0.07	-0.06	-0.06	0.16*	0.17*
rho31	-0.19**	-0.19**	-0.19**	-0.19**	-0.18**	-0.18**	-0.15**	0.13	0.14
rho32	0.43***	0.43***	0.43***	0.43***	0.43***	0.43***	0.44***	0.55***	0.55***
LR	110	109	110	107	108	107	107	88	88

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

Table 5

Trivariate probit 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	dF/dx
	model 1	*model 2*	*model 3*	*model 4*	*model 5*	*model 6*	*model 7*	*model 8*	*model 9*
R&D university-firm collaboration	0.10	0.11	0.11	0.11	0.11	0.11	0.10	-0.12	-0.13
R&D collaborations with private firms	0.13***	0.13***	0.13***	0.13***	0.13***	0.13***	0.13***	0.08*	0.09*
R&D intensity	0.02**	0.02**	0.02**	0.02**	0.02**	0.02**	0.02**	0.02*	0.02*
Skilled employees	0.003**	0.003**	0.003**	0.003**	0.003**	0.003**	0.003**	0.00	0.00
Sales through distribution chain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co-op firm	-0.04***	-0.04***	-0.04***	-0.05***	-0.05***	-0.05***	-0.05***	-0.04	-0.03
Subsidies	0.17***	0.17***	0.17***	0.17***	0.17***	0.18***	0.18***	0.33***	0.33***
Non standard jobs	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.05	0.05
Firm age	0.0001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Very small-sized firm	-0.09**	-0.10**	-0.09**	-0.10**	-0.09**	-0.08*	-0.08**	-0.08	-0.08
Small-sized firm	-0.06*	-0.06*	-0.06*	-0.06**	-0.06**	-0.05	-0.05	-0.02	-0.02
Medium-sized firm	0.04	0.04	0.04	0.04	0.04	0.06	0.06	0.09	0.09
Large-sized firm	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.11	-0.10
North	-0.03	-0.03	-0.03	-0.03	-0.03	-0.05	-0.06*	-0.10	-0.13
South	-0.02	-0.02	-0.02	-0.02	-0.02	0.04	0.04	0.07	0.08
Food district	-0.04	-0.05	-0.05	-0.04	-0.05	-0.06	-0.06	0.02	0.02
Agricultural district	-0.04	-0.06**	-0.06**	-0.07**	-0.07**	-0.07**	-0.08**	-0.19***	-0.17
1st distance	-0.001***								
2nd distance		0.00							
3rd distance			0.00						
Distance > 150 km				-0.16***	-0.15***	-0.18***	-0.18***	-0.04	-0.05
Reginal R&D - Disbursements					0.00	0.00	0.00	-0.01***	-0.01***
Biotechnologist courses						0.00	0.00	0.09	0.07
Food technologist 5-year course						0.02	0.01	0.08*	0.09*
Food technologist 3-year course						0.05**	0.05*	0.01	0.04
Extra-regional faculty of agriculture						0.04	0.05*	0.01	0.03
Faculty of agriculture 's age						0.00	0.00	0.00	0.00
No. of researchers/professors						-0.001*	-0.001*	-0.001	-0.001*
No. of graduates						0.00	0.00	0.00	0.00
Industrial engineers on total scholars						0.01	0.00	0.01	0.01
Biologists on total scholars						0.00	0.00	0.00	0.00
Chemicals on total scholars						-0.002*	0.004***	0.00	0.00
Physicians on total scholars						0.00	0.00	0.00	0.01
Geologists on total scholars						0.01	0.01	0.01	0.01
N. of scientific macro-fields						0.03***	0.03***	0.02	0.02
N. of regional faculties of agriculture						0.03***	0.03***	0.02	0.04***
Public univerisity						-0.04	-0.06	-0.11	-0.09
Technological transfer office						-0.02	-0.01	0.02	0.01
International grade							0.00		
Research grade							-0.002**		
Codified knowledge indicator							-0.03**		
VQR grade								0.00	
Food science dept.' VQR grade									0.00
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sub-sector dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. obs.	1535	1535	1535	1535	1535	1535	1535	722	722

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

Table 6

Trivariate probit 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	dF/dx
	model 1	*model 2*	*model 3*	*model 4*	*model 5*	*model 6*	*model 7*	*model 8*	*model 9*
R&D university-firm collaboration	0.21**	0.21**	0.21**	0.21**	0.21**	0.20**	0.19**	-0.03	-0.04
R&D collaborations with private firms	0.12**	0.12**	0.12**	0.12**	0.12**	0.11*	0.12**	0.10*	0.11*
R&D intensity	0.03***	0.03***	0.03***	0.03***	0.03***	0.03***	0.03***	0.03***	0.03***
Skilled employees	0.001	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Sales through distribution chain	0.0005**	0.0005**	0.0005**	0.0005**	0.0005**	0.0005**	0.0005**	0.001**	0.001**
Co-op firm	0.00	0.00	0.00	0.00	0.01	0.01	0.01	-0.03	-0.03
Subsidies	0.20***	0.20***	0.20***	0.20***	0.20***	0.21***	0.21***	0.24***	0.24***
Non standard jobs	0.02	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	0.00
Very small-sized firm	-0.06	-0.06*	-0.06	-0.06	-0.06	-0.06	-0.07	-0.06	-0.06
Small-sized firm	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.05	-0.05
Medium-sized firm	0.05	0.05	0.05	0.05	0.04	0.04	0.04	-0.01	-0.01
Large-sized firm	0.09	0.08	0.09	0.09	0.08	0.08	0.08	0.01	0.01
North	-0.02	-0.02	-0.02	-0.02	-0.02	-0.07*	-0.06	-0.07	-0.08
South	-0.07**	-0.07*	-0.08*	-0.07*	-0.06	-0.02	-0.01	-0.10*	-0.11
Food district	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.04	0.02	0.02
Agricultural district	0.01	0.01	0.00	0.01	0.01	-0.02	0.00	-0.10***	-0.10***
1st distance	0.00								
2nd distance		0.00							
3rd distance			0.00						
Distance > 150 km				-0.10	-0.12	-0.11	-0.11	-0.19	-0.20
Regional R&D - Accredited funds					0.01*	0.01*	0.01*	0.00	0.00
Biotechnologist courses						-0.01	0.00	-0.09	-0.10**
Food technologist 5-year course						-0.02	-0.03	-0.06	-0.05
Food technologist 3-year course						-0.01	0.00	-0.02	-0.01
Extra-regional faculty of agriculture						-0.02	-0.02	-0.07	-0.07
Faculty of agriculture 's age						0.00	0.00	0.00	0.00
No. of researchers/professors						0.00	0.00	0.00	0.00
No. of graduates						0.00	0.00	0.00	0.00
Industrial engineers on total scholars						0.00	0.00	-0.01	-0.01
Biologists on total scholars						0.00	0.00	-0.01***	-0.01***
Chemicals on total scholars						0.00	0.00	0.01	0.01
Physicians on total scholars						0.00	0.00	0.02**	0.02**
Geologists on total scholars						0.01**	0.01**	0.02	0.03
N. of scientific macro-fields						0.02**	0.02**	0.05***	0.05***
N. of regional faculties of agriculture						0.02*	0.02*	0.01	0.02
Public univerisity						-0.26***	-0.25***	-0.42**	-0.42**
Technological transfer office						0.02	0.01	0.00	0.00
International grade							0.00		
Research grade							0.002**		
Codified knowledge indicator							0.00		
VQR grade								0.00	
Food science dept.' VQR grade									0.00
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sub-sector dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

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

Among the faculty characteristics, age is not significant. The size (the number of researchers or professors) is significant and positive only in absence of academic research quality indicators; when the latter are added, the size becomes insignificant. The number of disciplines is not significant for R&D collaboration because firms look for very specific competencies when they select universities as R&D partners. The competencies looked for in the R&D collaborations refer mainly to those offered by geologists. Among the training variables, the 5-year food technologist course is a channel for R&D university collaboration, whereas the 3-year food technologist course acts against these alliances.

Among the personal characteristics of scholars, the absence of gender segregation (the presence of female full professors) induces R&D university collaboration; it can be interpreted as the expression of meritocratic and less-hierarchical institutions. The fraction of the total scholars that are researchers acts negatively, as suggested by the literature. The average age of scholars is never significant.

Finally, we introduce the indicators of research quality into the regressions: the international grade is significant, whereas the amount of codified knowledge is weakly significant. The VQR grade is significant, whereas the VQR of the food science department is not significant. Also notice that because the VQR and the international grades are expressed on a comparable scale, the marginal effect of the VQR grade is five times the marginal effect of the international grade. It is also interesting to observe that the marginal effect of R&D collaboration with private firms (0.06) is not much greater than the marginal effect of the presence of a food technologist 5-year course (0.04), thereby confirming that training can be an important channel for R&D collaboration and can be even stronger than the presence of subsidies (whose marginal effect is 0.03).

Tables 5 reports the marginal effects of the trivariate probit for product innovation dependent variable.

Product innovation is determined by subsidies, R&D intensity, R&D *extra moenia* from private firms and skilled employees. Very-small-sized and small-sized firms are less innovative. Firms that are located in agricultural districts are less product-innovative, while a location in a food district is nor beneficial neither detrimental to product innovation. The R&D university-firm collaboration variable is not significant.

With regard to geographical proximity, the 1st distance from the faculty of agriculture is highly significant and negative, whereas the 2nd and 3rd distances are not significant. Analogously, whether the distance from the closest faculty of agriculture is greater than 150 km is highly significant and negative: a firm that is within a radius of 150 km[17] far from a faculty of agriculture has 0.18 (after faculty characteristics have been accounted for) more probability of product innovation than a more-distant firm.

In the last sub-period, higher regional investment in R&D for agri-food sciences has discouraged product innovation, most likely acting in the same direction of the specialisation in agricultural districts that privileges the agricultural component of local economic systems instead of the processing industry.

Among university and faculty characteristics, the number of regional faculties of agriculture and the number of disciplines that are present in the closest faculty of agriculture are highly significant and positive. Size tends to be weakly significant and negative, most likely because larger faculties tend to promote the commercial exploitation of academic research results and may inhibit informal technology transfer, as found by Landry *et al.* (2007). Among disciplines, no clear predominance emerges.

Both the indicators of research grade and of codified knowledge are significant and negative: consultancies or informal collaboration may be too demanding for faculties that are involved in projects that are aimed at codified knowledge production, and scholars tend to concentrate on academic publications because industry-oriented research may deteriorate their publication profile (Bonaccorsi *et al.*, 2006). The VQR grade is not significant.

It is interesting to notice that for product innovation, the geographical distance from the faculty of agriculture and the number of faculties of agriculture within the same region are significant, whereas R&D collaboration with university is not. The amount of codified knowledge produced by the closest faculty of agriculture is

[17] This value has been selected by comparison with the results of the dummies, alternatively tested, for 50, 75, 100 and 200 km. All these dummies are not significant except for the dummy relative to a distance higher than 100 km which is 4% significant with a marginal effect equal to -0.09.

negative, thereby confirming that when innovation is produced by tacit knowledge and university-industry-government networks, geographical distance from university matters.

The marginal effects for process innovation are reported in table 6. Process innovation is determined by subsidies, R&D *extra moenia* from universities or private firms, R&D intensity and sales through distribution chain agreements; no size effect is significant. For more knowledge-intensive firms, the marginal impact of R&D *extra moenia* from universities is equal to 0.12.

Geographical distances from the faculty of agriculture are not significant. Regional accredited funds in R&D for agri-food sciences have weakly encouraged process innovation.

The number of regional faculties of agriculture is weakly significant and positive, whereas the number of disciplines that are present in the closest faculty of agriculture is significant and positive. The presence of a technology transfer office is not significant.

The indicator of research grade is significant and positive: the projects financed at universities have effects on process innovation of local firms. The amount of codified knowledge is not significant: it is not immediately relevant for process innovation because it is a channel of knowledge transfer, which may be followed by technology transfer. One instrument of technology transfer may be university-firm collaboration that focuses on research users' needs.

In summary, according to the results of our analysis, the manner in which geographical proximity to a university affects R&D collaboration with a university depends on the F&D firm location because geographical distance increases the information asymmetry between researchers and research users. Firms that are more R&D intensive because they invest in *intra-muros* and *extra-muros* R&D with public or private partners also collaborate with universities, particularly with those with a higher reputation in terms of academic research quality. R&D university-industry collaboration is a determinant of process but not of product innovation, whereas product innovation is affected by informal university-industry collaboration, as proxied by the geographical distance variable.

As a consequence, it is possible to argue that product innovation in the Italian

F&D industry is a tacit knowledge-intensive activity because co-location with a faculty of agriculture within a radius of 150 km increases the probability of product innovation; the impact of an extra faculty of agriculture is significant but quite limited in magnitude. Large and more-qualified faculties tend to be less involved in consultancies and informal collaborations. On the other hand, process innovation appears as a codified-knowledge-intensive activity because it is determined by R&D university collaboration without the requirement of co-location with a faculty of agriculture.

In 2001-2006, subsidies become the strongest innovation determinant, whereas co-location with a faculty of agriculture loses significance for product innovation and R&D university-collaboration becomes weakly significant for process innovation. However, the choice of firms to collaborate with universities is affected by the grade given by the Italian Evaluation of Research Quality to the entire faculty and not that relative to the food science department.

8. Concluding remarks

The objective of this paper is to determine the role that collaboration of firms with universities plays among the determinants of product and process innovation in the Italian food and drink industry and how geographical proximity to a university explains the choice of innovating through R&D collaboration with universities.

The results demonstrate that isolated firms, which are more than 150 km away from a university, choose to collaborate with the closest university, whereas less-isolated firms have more options to choose from to obtain the expertise that they need and their choice is not affected by geographical proximity. Product innovation is affected by geographical proximity to university because a firm within a radius of 150 km from a university has 0.18 more probability of product innovation than a more-distant firm. Process innovation is not affected by geographical proximity to a university.

The academic research quality indicator that is relevant for university-industry collaboration is the grade given by the Italian Evaluation of Research Quality to the entire faculty and not to the department of food science. The amount of codified knowledge negatively affects product innovation, whereas the number of university projects that are financed by national and international sources positively affects process innovation.

Training can be an important channel for R&D collaboration, even stronger than the presence of subsidies, and it is a direct channel of technology transfer for product innovation.

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Appendix

Table A1
Regional distribution of F&D firms with >= 10 workers

Regions	Population*	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

* own elaboration on Istat - Census of Industry 2001