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Science, university-firm R&D collaboration and innovation across Europe

Abstract
According to the National Innovation System (NIS) approach, the innovative capabilities of a firm are explained by its interactions with other national agents involved in the innovation process and by formal and informal rules that regulate the system.
This paper intends to verify how product and process innovation in the European food and drink industry are affected by: i) the NIS structure in terms of universities vs public research labs, faculties/department mix and size; ii) the NIS output in terms of WoS indexed publications vs the supply of graduates; iii) the NIS fragmentation and coordination and iv) the NIS scientific impact and specialisation.
The source of data on firm innovation is the EU-EFIGE/Bruegel-UniCredit dataset supplemented by information from the International Handbook of Universities, Eurostat and the bibliometric analysis of academic research quality.
The results obtained suggest that large size of public research institutions are detrimental to interactions between university and industry and the indicators used for public research assessment are not appropriate proxies of local knowledge spillovers.

Keywords

university–industry interaction, firm R&D collaboration, product and process innovation, academic research quality, university education

JEL: O3, I23, D22, R1

1. Introduction

The importance of public knowledge production for industrial innovation is broadly recognized in literature since the work of Mansfield (1991, 1995), Lundvall (1988), Freeman, Lundvall and Nelson (1988). Universities generally play the prominent role in science production among the public actors of the National Innovation Systems (NIS), which are composed by all agents involved in the innovation process, their actions, interactions and the formal and informal rules that regulate the system (Nelson, 1993).

The effect of university science production on industrial innovation has been investigated taking a production-function approach to the study of academic spillovers; in

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addition, a growing empirical literature regarding university–industry collaboration focuses on the firm-perceived benefits of such collaborations (see i.e., De Fuentes and Dutrénit, 2012), whereas in a rather heterogeneous field of study, firm data are used to determine the impact of university–industry collaboration in terms of outcome variables, such as innovation or proxy of innovative performance.

At any rate, the direct impact of university knowledge production on firm innovation is rarely investigated whereas it is implicitly recognized by the studies which have included academic research quality among the determinants of university–industry collaborations. Mansfield and Lee (1996) report the citations of academic researchers relevant for innovation in some high-tech industries; Jiang *et al*. (2010) explain the number of patents of incumbent firms in terms of co-autorships with university scientists and citations of scientific articles and Baba *et al*. (2009) analyse the impact on patents of collaborations with academic scientists differentiated according to their publication and patenting profiles.

The above-mentioned studies are generally conducted for advanced sectors, using patents as innovation proxy and assuming that the number of scientific publications on high-ranked journals is the indicator of academic research quality relevant for firms in the choice of R&D partners. For a low-tech sector, such as the food and drink (F&D) industry, the number of scientific publications on high-ranked journals may even display a negative effect on product innovation (Maietta, 2015).

This evidence suggests that local knowledge spillovers and scientific publications on high-ranked journals are university non-joint outputs since scholars tend to concentrate on academic publications because industry-oriented research may deteriorate their publication profiles relevant for carrier advancement.

Even if academic careers are still shaped by the traditional system of academic self-governance and national regulations, the international standard of American and British universities, where publications play a key role, is gradually being adopted across Europe (Robin and Schubert, 2013). Moreover (Chartier, 2007), for the agri-food research system, when the main knowledge producers is public, the cross-country convergence seems to be more pronounced not only in terms of scientific output indicators but also in terms of NIS structure. This is the case of the publically supported decentralised EU agri-food research system (Ruttan, 2001), where the Standing Committee on Agricultural Research (SCAR) (EEC Reg. No 1728/74) periodically monitors the NIS fragmentation, in terms of number of research organisations and research groups, and the coordination, in term of presence of medium-term strategy and importance of research council with multi-annual research programs.

The aims of this paper are to verify how firm R&D collaboration and product and process innovation in the European food and drink (F&D) industry are affected by: i) the NIS structure in terms of universities *vs* public research labs, faculties/department mix and size; ii) the NIS output in terms of WoS indexed publications *vs* the supply of graduates by university ISCED levels; iii) the assessment of the NIS structure in terms of fragmentation and coordination; iv) the assessment of the NIS output in terms of scientific impact and specialisation.

The methodology adopted consists in a simultaneous multi-equation approach that can address both the endogeneity of R&D decisions and the simultaneity between internal and external R&D investment. Being the dependent variables dummy, the simultaneous approach is a multivariate probit model. The dependent variables refer to the choice of investing in internal R&D, of investing in external R&D with universities/research labs and other firms/consultants and of innovating products and processes. The determinants of firm innovation are those customarily used in literature plus several specifications of variables reflecting the NIS structure, output and assessment. These are alternatively tested being highly correlated.

The source of data on firm innovation is the EU-EFIGE/Bruegel-UniCredit dataset which is a survey, carried out in 2010 which provides comparable cross-country data of manufacturing firms in seven European countries (Austria, France, Germany, Hungary, Italy, Spain and the United Kingdom) and covers quantitative as well qualitative information ranging from R&D, R&D collaborations and innovation. The sampling design has been structured following a three-dimension stratification: industry (11 NACE-CLIO codes), region (the NUTS-1 level of aggregation) and size class (10-19; 20-49; 50-250 and more than 250 employees). The university information is gathered from different sources: the International Handbook of Universities, multiple years, Eurostat (number of researchers) plus the bibliometric analysis of academic research quality (the number of WoS indexed publications and the number of citations per article) sourced from the EU AGRI MAPPING report.

The remainder of the paper is divided into five sections. The second section reviews different bodies of literature that address the issue discussed here. Sections three focuses on the specificities of the European public agri-food research system and of the European F&D industry. Section four describes the methodology and the sources of the data that have been used, and section five presents the results of the present analysis. Section six provides concluding remarks, and the robustness check follows in the appendix.

2. The National Innovation System (NIS) at a glance

In the literature, a common approach to take into account the economic performances at country level is the concept of National Innovation System (NIS) which aims at framing innovative activities and the way firms act within the institutional national context (Freeman, 1988; Lundvall, 1988; Nelson, 1993). It 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; indeed, in explaining the behaviour of nations in terms of innovation, the rules and regulations under which operate the agents of the innovation system play an important role.

According to Goto (2000), the NIS system consists of three sectors such as industry, universities, and the government, with each sector interacting with the others, while at the same time playing its own role. Indeed, the main institutions and agents within the NIS framework are those fostering and promoting learning and innovations such as universities, research institutes, innovative companies and entrepreneurship (Audretsch et al. 2015a, b); the government plays an important role, too, stimulating, fostering and shaping the complementary of these institutions and agents (McCann and Ortega-Argile´s 2016; Audretsch et al. 2016). Importantly, these activities take place within a specific national institutional context (Filippetti and Archibugi, 2011) and sectoral dimensions of patterns of innovation are country-specific (Malerba and Orsenigo, 1996, 1999) as well as firms' persistency in innovating (Cefis and Orsenigo, 2001). Accordingly, the innovation systems approach underlines that relationships and linkages between societal actors are central to their innovation behaviour, highlighting the importance of science – industry - government relations (see also the so-called Triple Helix literature Etzkowitz and Leydesdorff, 1998, 2000; Leydesdorff, 2000). More specifically, according to Filippetti and Archibugi (2011), the concept of NIS rests on three suppositions such as that countries exhibit systematic differences in term of economic performances, that the latter performances depend on different technological and innovation capabilities as well as on the development of institutions and finally that innovation policies are an effective tool in order to encourage the countries' performances.

Among the sector NIS applications, Hall et al. (2001, 2006) define the Agricultural Innovation Systems (AIS) as “a network of organisations, enterprises, and individuals focused on bringing new products, new processes, and new forms of organisation into economic use, together with the institutions and policies that affect the way different agents interact, share, access, exchange and use knowledge”. The AIS concept stresses the influence of institutions (companies, public research institutes and governmental entities) and infrastructures on learning and innovation, including all relevant organizations beyond agricultural research and extension systems (Klerkx et al., 2012).

The interaction between industry and science is one of the most prominent institutional interfaces for knowledge diffusion. Although knowledge transfer can occur through a variety of channels (see Schartinger et al., 2002), formal collaborations between firms and public research institutions play a crucial role (see Robin and Shubert, 2013); indeed, universities are cited by firms with publicly supported innovations as the most important source, although publicly financed laboratories get almost as many citations (see Beise and Sthal 1999). Firms are the units that play the most important role in the innovation system, innovate in an interaction with other firms and interact with knowledge infrastructure including universities and technological institutes. Therefore, it is crucial to analyse what takes place inside firms in terms of innovation and competence building and to analyse the interaction among firms including competition, co-operation and networking and how firms interact with knowledge infrastructure (Lundvall, 2005). The way in which firms carry out innovation activities and set their learning processes is affected by a number of specific national factors (Archibugi and Pianta, 1992; Archibugi and Michie, 1997; Lorenz and Lundvall, 2006), including the nature of the scientific and technological institutions, the education and training system, the financial system, the structure of the labour market, and the industrial specialization (Filippetti and Archibugi, 2011). As a consequence, how firms interact with universities may sharply vary across countries, as evidenced in literature (Menrad, 2004; Cardamone and Pupo, 2015). 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 program meat a local university (Maietta, 2015). Furthermore, institutional changes may contribute to reinforcing the relevance of certain NIS actors as local providers of external firm knowledge (Robin and Schubert, 2013). Firms with the ability to build links with university research may conduct more productive technological search (Fleming and Sorenson, 2004) and may be more likely to innovate (Feldman, 1994).

R&D activities can improve the technological opportunities in the region, providing an argument for public support for industrial R&D (Breschi and Lissoni, 2001; Rodriguez-Pose and Crescenzi, 2008; Laursen et al. 2011). Taking into account the quality of university faculty on the propensity of firms to support academic research and development activities, according to Mansfield and Lee (1996), shorter distances between the firm and the university facilitate interaction, lowering the costs of knowledge exchange (Cardamone et al., 2015; Giunta et al.; 2015); considering the relationship between the number of citations to universities in firms' patents, the greater this distance, the lower will be that firm's rate of exploitation of public science (Fabrizio, 2006).

In order to join the Bologna Process, the higher education system has been reformed across Europe and universities have started being financed according to their level of virtuosity, in order to promote academic excellence. "Formulas to allocate public funds to higher education institutions are now related to performance indicators such as graduation or completion rates" and "research funding has also increasingly been allocated to specific projects through competitive processes rather than block grants" (OECD 2008). The allocation of the resources from the government has been generally based on indicators which have been developed to accurately evaluate the performance of universities in research and teaching. This incentive system may favour large universities and is based on a model of university-firm collaboration tailored for countries whose firms are large or associated in firm networks which facilitate university-government-firm interactions. It may present a cost in terms of tacit knowledge spillovers and economic innovativeness for small-medium firms in weaker economic areas, where the main knowledge producer is public. For example, Maietta (2015) found that the number of citations on WoS-Scopus journals, which positively impact university-firm R&D collaboration, display a negative effect on product innovation of local F&D firms.

3. The F&D industry and the agri-food research sector in Europe

In the EU economy, the F&D industry employed 4.25 million people in 2011

(FoodDrinkEurope National Federations report) representing the largest EU manufacturing sector in terms of direct employment (15%). Moreover, throughout the economic downturn, the F&D industry continued to increase, while a sharp decrease was observed in other key manufacturing sectors, maintaining the characteristics of a stable, non-cyclical and robust sector. In the seven countries considered in the analysis, according to Eurostat data, the F&D industry accounts for 10.8% of manufacturing value added and 13.8% in terms of employment in 2011. As a key sector in the EU Member State economies, the F&D industry ranks first in France, Spain and the UK in terms of turnover and features in the top three manufacturing activities in several Member States. Germany, France, Italy, the UK and Spain are the largest EU F&D producers.

Table 1 below summarizes some descriptive statistics for the selected countries in our analysis.

[Table 1 around here]

Considering an indicator of the knowledge intensiveness of the industry such as R&D intensity, Tables 2, below, reports the R&D expenditures and personnel in the government, and higher education sectors, for the selected countries in the analysis, respectively taking into account the agricultural science sector. In 2007, R&D intensity in the EU-27 amounted to 1.85 % of GDP since the EU-27 dedicated EUR 228 billion to R&D, compared to EUR 269 billion spent by the United States and EUR 118 billion by Japan. Within the EU-27, four Member States — Germany, France, Italy and the United Kingdom — accounted for more than half of total EU-27 R&D expenditure. Germany alone, with EUR 61.5 billion, made up more than one quarter of the total. France, the United Kingdom and Italy followed, with EUR 39.3 billion, EUR 36.7 billion and EUR 16.8 billion respectively.

[Table 2 around here]

The agri-food research system in the EU as in other advanced economies is publically supported and decentralised (Ruttan, 2001) but in the last fifteen years, agri-food research in the EU is experiencing a decrease in public support. The countries which invested more in the agricultural sciences over 2007-'09 are, in decreasing order, Germany, Spain, the UK and Italy (Table 2), however an increasing trend can be observed only for Germany and Spain. The agri-food research sector in EU relies both on universities and public research institutes but there is a trend for a growing importance of universities with some exceptions, for example in France where public research institutes play a dominant role. Among the seven countries object of analysis, Italy and Austria show the largest relative weight of the higher education institution as sector receiving public funding in the agricultural sciences.

The Standing Committee on Agricultural Research (SCAR), established by the EEC Reg. No 1728/74, periodically monitors the agri-food research sector structure judging its fragmentation, in terms of number of research organisations and research groups, and its coordination, in term of presence of medium-term strategy and importance of research council with multi-annual research programs (Chartier, 2007). Also as a consequence of the SCAR suggestions, the EU agri-food research sector is object to a process of rationalisation and concentration with the merging of research entities and a better coordination consequent to the establishment of research councils, the setting-up of pluri-annual research programmes and the award of financial support through competitive programmes. Important changes have already taken place in the UK and generally in the North of Europe, have been planned within global changes of the national research system in Spain or having been discussed in Germany, Italy and Hungary. The agri-food research capacity is considered concentrated (a few research players) in France and rather fragmented (many research players) in Austria, Germany, Italy, Spain, Hungary and the UK. The level of coordination of the agri-food research sector, estimated according to the presence of medium-term strategy and the importance of research council with multi-annual research programmes, is poor in Germany, Italy and Hungary, good in the United Kingdom and fair in the remaining countries (Chartier, 2007).

Among the world leading countries in agricultural and veterinary sciences in terms of scientific papers indexed in the Scopus database over the 2003-2010 period, the UK ranks third, Germany sixth, France ninth, Spain tenth and Italy eleventh. Among the seven countries analysed, Spain is the most specialised in the agricultural and veterinary sciences, since its specialisation index[2] is higher than 1 whereas the UK presents the highest scientific impact as measured by the average citations per article (Roberge and Côté, 2012).

[Table 3 around here]

Table 3 reports the number of innovative enterprises with innovation cooperation during 2006-2008 in the manufacture of food products, beverages and tobacco products, sourced

[2] Specialization index (Roberge and Côté, 2012) is defined by:

$$SI = \frac{Xs/Xt}{Ns/Nt}$$

X = No. publications
N = World publications
s = research area
t = total research areas

from the Community Innovation Survey (Eurostat). The number of innovation cooperation is given separately for the seven countries analysed and for the EU-27. In the years analysed, universities were important F&D firm partners for innovation cooperation being generally more frequently chosen than other public research institutes and in Germany and Italy the first kind of partners, in absolute terms. Important national patterns emerge for Austria, Germany, Hungary, Italy and the UK, universities are more chosen than research labs, the contrary holds for Spain and they are equally chosen in France.

4. The empirical framework

4.1. The econometric approach

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 five simultaneous equations related to the following dependent variables: (the existence of) in-house R&D investment, R&D collaboration with universities or research labs, R&D collaboration with private firms or consultants, process innovation and product innovation. Among these, the variables of R&D collaboration with universities or research public labs, and R&D collaboration with private firms or consultants are also used as regressors. All these indicators are binary variables.

The simultaneous equations of the econometric model are jointly described by a multivariate probit model. The model follows a five-equation structure in which the estimation results of the second and third equations are used as regressors in the fourth and fifth equations, as follows:

$$\begin{cases} y^*_{1i} = \mathbf{x}'_{1i}\boldsymbol{\beta}_1 + \epsilon_{1i} \\ y^*_{2i} = \mathbf{x}'_{2i}\boldsymbol{\beta}_2 + \epsilon_{2i} \\ y^*_{3i} = \mathbf{x}'_{3i}\boldsymbol{\beta}_3 + \epsilon_{3i} \\ y^*_{4i} = \gamma_{24}\, y^*_{2i} + \gamma_{34}\, y^*_{3i} + \mathbf{x}'_{4i}\boldsymbol{\beta}_4 + \epsilon_{4i} \\ y^*_{5i} = \gamma_{25}\, y^*_{2i} + \gamma_{35}\, y^*_{3i} + \mathbf{x}'_{5i}\boldsymbol{\beta}_5 + \epsilon_{5i} \end{cases} \quad (1)$$

The five latent variables defined as follows: y_1* is *intra muros* R&D investment; y_2* are R&D collaborations with universities and/or research labs; y_3* are R&D collaborations with other firms and/or consultants; y_4* are product innovations and y_5* are process innovations; $\mathbf{x}_{ki}$ are vectors of exogenous variables, which influence those probabilities for firm i; $\boldsymbol{\beta}_k$ are parameter vectors; γ_{kl} are scalar parameters; and ε_{ki} are error terms, which are assumed to be jointly normal with unknown correlation coefficients, ρ_{kl}, and correlated with something else in the model. The covariate vectors $\mathbf{x}_{ki}$ are not restricted to containing the same variables of interest as long as there is at least one varying exogenous regressor[3] in each equation in system (1) (Wilde, 2000).

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

$$\begin{cases} y_{ki} = 1, & \text{if } y_{ki}^{*} > 0 \\ y_{ki} = 0 & \text{otherwise; } k = 1, \ldots, 5 \end{cases} \tag{2}$$

The dependant variables are equal to 1 when: *intra muros* R&D investment>0 for y_1, *extra muros* R&D expenditure with partner$_m$>0 for y_k where m = universities/research labs or other firms/consultants and k = 2, 3; and product and process innovation are present, respectively for y_4 and for y_5.

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

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

4.2 The data

In order to explore the university-industry research and development (R&D) collaboration and innovation, different sources of data have been used. At the heart of the project is the EFIGE[4] (European Firms in a Global Economy) database; it consists of a representative sample (at the country level for the manufacturing industry) of almost 15,000 surveyed firms[5] above 10 employees[6]) in seven European economies (Austria, France, Germany, Hungary, Italy, Spain and the United Kingdom). Data was collected in 2010, covering the years from 2007 to 2009. Given that the aim of the paper is focusing on the European F&D industry, using the NACE-CLIO classification, F&D firms have been extracted, resulting in a sample of 1520 firms.

The database contains quantitative and qualitative information on R&D and innovation, labour organisation, financing and organisational activities, and pricing behaviour. More specifically, firms are asked whether process, product and or other innovation were introduced during the previous three years (2007-2009). The questionnaire also collects information regarding whether R&D was in-house or acquired from external sources such as universities/research labs and other private firms/consultants. No distinction was made between universities and research labs but from Table 3 it is possible to argue that universities were more frequently chosen. Information on which percentage of the total turnover has the firm invested in R&D on average in the last three years (2007-2009), on whether the firm benefit from tax allowances and financial incentives for these R&D activities and on whether part of these financial incentives are provided by the public sector, are also available and have been used.

Size classes have been defined according to the following classification with respect to the number of employees: very small (10-19 employees); small (between 20 and 49 employees); medium (between 50 and 100 employees); large (between 100 and 150 employees) and very large (≥250 employees). Other firm characteristics included as regressors are the presence of skilled employees (that is graduates), age and gender of the current CEO or company head, age of the firms and its current legal form, and whether the

[4] The Efige project was supported by the Directorate General Research of the European Commission through its 7th Framework Programme and coordinated by Bruegel. For more details on the EFIGE dataset, see Altomonte and Aquilante (2012).

[5] Including around 3,000 in Germany (DE), France (FR), Italy (IT) and Spain (ES), some 2,200 firms in the UK (UK), and around 500 firms in Austria (AT) and Hungary (HU).

[6] The reference population is composed by firms with more than 10 employees; this is the reason because internationally active firms are more numerous in EFIGE sample with respect to domestic firms. The truncation of the sample requires a weighting system in order to guarantee balance.

firm, in the last three years, applied for a patent, registered an industrial design or a trademark and claimed copyright.

In order to explore whether the knowledge context in which the firm operates affects the university-firm R&D collaboration and firm product and process innovations, the following information was also gathered and used: the number of agriculture faculties; the average number of citations in agrifood science and the number of publications in the scientific area of "Food technology, human nutrition and consumer concerns" using the WoS production of European agri-food research over 1996-2004 from the EU AGRI MAPPING report[7]; the number of universities with agriculture as field of education (using Eumida[8]); the government sector R&D expenditure (average 2003-2009) in agriculture (expressed in million of euros) (using Eurostat); the number of scientists and engineers (annual average 2006-2008) in agriculture, forestry and fishing, mining and quarrying and low-technology manufacturing (using Eurostat); the number of graduates (average 2006-2009) in agriculture and veterinary by ISCED level (using Eurostat[9]); the number of engineering and science faculties (using the International Handbook of Universities[10]).

The analysis is also completed by the use of some indicators of the levels of fragmentation and of coordination the agri-food research sector. The level of fragmentation (number of research organisations and research groups) is equal to 1 if the research capacity is not considered fragmented, 2 if its defined rather fragmented and 3 if the capacity is considered highly fragmented in the EU AGRI MAPPING report. Analogously, the level of coordination (presence of medium-term strategy and importance of research council with multi-annual research programs), is equal to 1 if defined poor, 2 if defined fair and 3 if defined good in the EU AGRI MAPPING report.

The level of rurality of the province where the firm is located, which is sourced from OCDE, is used as a proxy of the distance between firms and universities or research labs since in more rural areas the presence of research institutions is scarce.

[7] The Agri-Food Research in Europe reports bibliometric mapping of agri-food research activities in 33 countries and survey of the research capacity in 14 countries. This report is part of the project "EU AGRI MAPPING" which has been awarded financial support by the European Commission through the contract FP6- 506087 under the 6th framework programme of the European Community for research, technological development and demonstration activities.

[8] The Research and Innovation DG launched a feasibility study in 2009 to create a European University Data Collection. This project (known as EUMIDA) aimed to build a complete census of European universities and included a pilot data collection with particular emphasis on those universities that are research-active. The final report was published in December 2010.

[9] For more details see: http://ec.europa.eu/eurostat/data/database.

[10] International Handbook of Universities, 19th edition.

4.3. The empirical specification and the variables

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

In-house R&D investment = f_1 (Public subsidies, skilled employees, protection of intellectual property dummies, CEO firm age and gender, firm age, firm size dummies, legal form dummies, country dummies, knowledge context and territory characteristics of the national innovation system).

R&D collaboration with partner$_m$ = f_k (R&D intensity, dummy for R&D acquired abroad, dummy for R&D subsidies, skilled employees, protection of intellectual property dummies, CEO firm age and gender, firm age, firm size dummies, legal form dummies, country dummies, knowledge context and territory characteristics of the national innovation system), where m = universities/research labs or other firms/consultants and k = 2, 3.

Innovation j = f_j (R&D collaboration with universities/research labs, R&D collaboration with private firms/consultants, R&D intensity, public subsidies, skilled employees, protection of intellectual property dummies, CEO firm age and gender, firm age, firm size dummies, legal form dummies, country dummies, knowledge context and territory characteristics of the national innovation system), where j = product or process.

Descriptive statistics of the variables are reported in Table n. 4 below. Among all the firms in the sample, 4% of the firms in the sample have R&D collaborations with a university or research lab, while 8% of them have R&D collaborations with private firms or consultants. Among all firms in the sample, 52% have introduced product innovation, and 44% have introduced process innovation. A higher presence of product than process innovation may be explained by the EU support to the protected designation of origin, protected geographical indication and traditional speciality guaranteed trademarks (Mancini and Consiglieri, 2016). The R&D intensity, which is measured as the percentage of the total turnover that the firm invested in R&D on average in the last three years (2007-2009), is around 2%; during the same time span, 12% of the firms undertook in-house R&D activities.

About the legal form, most firms are limited liability partnerships (Sarl, *société a responsabilité limitée*), 15% are public companies (Sa, *société anonyme*), 5% are proprietorships, 4% are cooperatives and the remaining ones are limited liability proprietorships (Eurl, *entreprise unipersonnelle à responsabilité limitée*) or other forms.

Nearly 12% of the firms received benefits from tax allowances and financial incentives for these R&D activities while 21% benefit, for the overall activity, from financial incentives provided by the public sector. Taking into account the human capital composition of the firms, the average age of the firms' CEOs is around 50 years while it seems that women still are not treated as equals to men when it comes to high stakes positions as only 10% of those CEOs are women. Relatively small is the fraction of the graduates within the workforce (less than 10%).

[Table 4 around here]

The key regressors in all equations are related to the "knowledge context" represented by the presence and the characteristics of higher education institutions and by the characteristics of the national innovation system. On average over the 2006-2008 time span, around 39,000 thousands of scientists and engineers operate in agriculture, forestry and fishing, mining and quarrying and low-technology manufacturing areas; the agri-food research system produces around 436 food articles. On average, 26 universities have agriculture as general field of studies and education objectives, being most of the academic research on agri-food topics performed by faculties of agricultural studies (on average around 10). The average number of engineering faculties is around 80 and that of science faculties is around 83. In the specific agriculture and veterinary subject, the system produces, on average over the 2006-2008 time span, 3,000 graduates considering the first stage of tertiary education (ISCED 5a).

The description is completed by some indicators of the national innovation system measuring how fragmented and coordinated is the NIS. The number of research organisations and research groups, measuring the level of fragmentation, is 1.02 indicating that the research system is on average not fragmented but poorly coordinated being equal to 0.67 the dummy relative to the presence of medium-term strategy and importance of research council with multi-annual research programs.

5. The empirical evidence

The marginal effects of the multivariate probit regressions are reported for various specifications (including different subsets of regressors and different dependent variables) in Tables 6–10. The standard errors (not reported) of the coefficients have been clustered around the rurality of country 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 five-equation framework (see Table 5).

[Table 5 around here]

Table 6 reports the marginal effects for Eq. (1) when the existence of *in-house* R&D investment has been used as dependent variable. The main results of the regressions for the entire period (Models 1-6) are mainly discussed. R&D subsidies is positive and highly statistical significant; receiving financial incentives to boost R&D activities induces *in-house* R&D investment. The number of universities, with agriculture as a field of education, and government R&D are not conductive to *in-house* R&D investment whereas larger size of R&D institutions, in terms of scientist number, and the number of years in EU are positive and highly significant determinants. Among the other NIS structure variables, the presence of engineering and science faculties favours R&D *in-house* whereas the presence of agriculture faculties does not. The number of articles on food according to the WoS database is positive and weakly significant, whereas the number of ISCED5 (a plus b) graduates in agriculture is always positive and highly significant. Both a fragmented and coordinated NIS structure are detrimental to firm *in-house* R&D investment.

[Table 6 around here]

Table 7 reports the marginal effects for Eq. (2) where R&D collaboration with universities and research labs has been used as dependent variable. R&D intensity and R&D subsidies are positive and statistically significant. The level of rurality, meaning a higher geographical distance for the firms from the research system, increases the likelihood of R&D collaboration with universities and research labs, as already observed in literature (Maietta, 2015). Firm R&D collaborators may be searched for among foreign universities or research labs; indeed, R&D acquired abroad increases the probability in R&D collaboration with universities and research labs. Firm R&D collaborators are more likely to be universities since the number of universities with agriculture as field of education is the only variable reflecting the NIS structure to be positive and highly significant being the number of agriculture faculties positive but only weakly significant. The number of WoS food articles is positive and highly significant whereas the number of ISCED5b graduates is highly significant but negative. Regarding the other NIS characteristics, coordination is positive and highly significant whereas specialisation is negative and significant.

[Table 7 around here]

Table 8 reports the marginal effects for Eq. (3) where R&D collaboration with other firms/consultants has been used as dependent variable. R&D subsidies is still positive and highly statistical significant; the number of universities increases the probability of collaborating with private firms or consultants, whereas public research labs are substitute partners of R&D collaborations with private firms or consultants. Scientific production, such as the number of food articles, appears to be beneficial for R&D collaboration with private firms.

[Table 8 around here]

Table 9 reports the marginal effects for Eq. (4) where product innovation has been used as dependent variable. Product innovation is strongly determined by whether the firm received financial incentives by the public sector. R&D collaboration with universities/research labs and other firms/consultants are not statistically significant. Firm age has a positive and statistically significant effect on product innovation. A higher number of universities as well as a high number of agriculture, engineering and science faculties favours product innovation; on the other hand, government R&D appears to be detrimental to product innovation. The WoS food articles are positive and highly significant. Among the education variables, the number of ISCED6 graduates is positive and statistically significant, in line with the idea that the supply of graduates from tertiary programs leading to the award of an advanced research qualification is an important channel for product innovation. The NIS coordination is positive and weakly significant.

[Table 9 around here]

Finally, Table 10 reports the marginal effects for Eq. (5) where process innovation has been used as dependent variable. Process innovation is strongly determined by R&D collaboration with other firms/consultants while R&D collaboration with universities/research labs is not statistically significant. R&D intensity is also positive and favours process innovation as well as receiving financial incentives by the public sector. Large size of R&D institutions has a detrimental effect on process innovation as well as a higher presence of engineering and science faculties. Specialisation is positive and highly significant.

[Table 10 around here]

Summing up the results from all the equations, considering the European F&D industry of the 2007-2009 period, the empirical evidence suggests that a higher number of universities favours R&D collaborations and product innovation, larger size of R&D centres prevents process innovation and government R&D is not conducive to product innovation. Still considering the NIS structure, engineering and science faculties are not conducive to process innovation but science faculties favour product innovation. With regard to the NIS output, results also show that WoS articles favour R&D collaborations and product innovation but do not influence process innovation; the supply of ISCED5 graduates favour process innovation whereas that of ISCED6 graduates favours product innovation. Taking into account the NIS assessment, a specialised knowledge production prevents product innovation but favours process innovation. A possible explanation is that most product innovation are protect designation of origin, protected geographical indication and traditional speciality guaranteed trademarks (Mancini and Consiglieri, 2016) which most rely on tacit knowledge transfer and multidisciplinary codified knowledge spillovers. University-firm R&D collaboration is hampered by both the scientific impact and highly specialised knowledge production.

In order to take into account firm heterogeneity, the multilevel approach, which handles the hierarchical structures of data, has been applied as a robustness check. This model gives proper attention to nesting and thus allows the evaluation of whether, and to what extent, in our case, regional aggregation matters in determining firm behaviour. In fact, the multilevel approach combines different levels of data aggregation since it takes into account the simultaneous existence of distinct level-one (firm) and level-two (region) equations. The multilevel regressions have been separately applied to the five equations, the results, which are reported in the appendix, confirm the main findings described here.

6. Concluding remarks

The objective of this paper is to determine the role that firm R&D collaborations with universities/research labs play among the determinants of product and process innovation and to determine how the national knowledge context where the firm is located explains the choice of innovating through R&D collaborations with universities/research labs and with other firms/consultants. The national knowledge context is represented through several indicators of structure and of output.

The conclusions of our study are that large size of public research institutions are detrimental to interactions between university and industry and that the parameters used for research output assessment are not always good proxies of local knowledge spillovers. Furthermore, surveys on firm innovations are necessary in order to evaluate the impact of the structure of public knowledge producers on firm innovation.

TABLES

Table 1 - Food and drink industry turnover, value added, employees and companies in 2011

Countries	Turnover (€ billion)	Value added (€ billion)	Number of employees (1.000)	Number of companies
Austria	12.6	4.7	58	3921
Germany	163.3	11.5	550	5960
France	157.2	29.3	500	10000
Hungary	8.3	2.0	97	6556
Italy	127.0	24.2	408	6300
Spain	83.8	20.0	446	30000
United Kingdom	87.6	23.7	370	6500

Source: FoodDrinkEurope National Federations, 2011

Table 2 - Total R&D expenditure by sectors of performance – Agricultural sciences sector

	2007	2008	2009	2007	2008	2009
	Expenditures			Personnel		
Government						
Austria	40.852	\\	44.646	1099	\\	1053
Germany	429.97	483.854	563.37	7041	7296	7035
France	\\	\\	\\	\\	\\	\\
Hungary	37.020	35.543	28.898	1828	1494	1279
Italy	280.4	282.1	176.6	4755	4674	4287
Spain	358.68	443.729	538.36	6628	7334	8778
United Kingdom	\\	381.38	347.62	2864	\\	2686
Higher education						
Austria	70.648	\\	90.436	1197	\\	1722
Germany	328.31	392.48	411.79	10766	10847	11005
France	\\	\\	\\	\\	\\	\\
Hungary	20.812	21.113	22.842	1619	1626	1710
Italy	225.7	220.9	223.3	5367	7051	8130
Spain	90.37	106.92	102.65	3884	4183	4237
United Kingdom	\\	140.27	133.46	3965	\\	3723

Source: Eurostat

Table n. 3 - Number of innovative enterprises with innovation co-operation during 2006-2008 in the manufacture of food products, beverages and tobacco products

Countries	Suppliers of equipment, materials, components or software	Clients or customers	Competitors or other enterprises of the same sector	Consultants, commercial labs, or private R&D institutes	Universities or other higher education institutions	Government or public research institutes
Austria	64	33	26	27	36	14
Germany	276	364	291	208	544	190
France	519	368	245	300	267	268
Hungary	83	69	34	32	49	18
Italy	105	38	49	172	196	40
Spain	249	77	47	126	160	166
United Kingdom	532	639	200	240	170	158
EU-7	1,828	1,588	892	1,105	1,422	854
EU-27	3,359	2,681	1,450	1,951	2,021	1,252

Source: Eurostat - CIS6

Table n. 4 - Variables and descriptive statistics

Variable	*Mean*	*Std. Dev.*
Firm characteristics		
R&D in-house	*0.12*	*0.32*
R&D collaboration with other firms/consultans	*0.08*	*0.27*
R&D collaboration with universities/research labs	*0.04*	*0.20*
Product innovation	*0.52*	*0.50*
Process innovation	*0.44*	*0.50*
Dummy for R&D acquired abroad	*0.01*	*0.10*
R&D intensity (%)	*2.14*	*6.07*
Dummy for R&D subsidies	*0.12*	*0.32*
Dummy for public subsidies	*0.21*	*0.40*
Skilled employees (%)	*8.07*	*11.76*
CEO age	*51.04*	*10.52*
CEO gender	*0.90*	*0.29*
Firm age	*41.79*	*37.67*
Size 10-19 employees	*0.34*	*0.47*
Size 20-49 employees	*0.40*	*0.49*
Size 50-100 employees	*0.10*	*0.31*
Size 100-250 employees	*0.08*	*0.27*
Proprietorship/Ownership dummy	*0.05*	*0.22*
Sa Dummy	*0.17*	*0.37*
Sarl dummy	*0.66*	*0.47*
Eurl dummy	*0.004*	*0.06*
Coop Dummy	*0.04*	*0.20*
Patent dummy	*0.06*	*0.23*
Industrial design dummy	*0.05*	*0.22*
Trademark	*0.22*	*0.42*
Copyright dummy	*0.04*	*0.19*
Territorial and university characteristics		
Rurality of the province where firm is located	*1.88*	*0.71*
No. Scientists (th)	*39.44*	*22.68*
No. Universities	*26.45*	*17.77*
No. Agriculture faculties	*10.41*	*7.56*
No. Science faculties	*83.70*	*71.92*
No. of Engeneering faculties	*80.63*	*56.11*
Government R&D (ml €)	*275.42*	*99.94*
No. years in UE	*34.20*	*15.60*
No. WoS food articles	*436.79*	*143.96*
No. Isced 5b graduates	*1720*	*1882.53*
No. Isced 5a graduates	*2964*	*1261.63*
No. Isced 6 graduates	*421*	*322.90*
Fragmented NIS	*1.02*	*0.54*
Coordinated NIS	*0.67*	*0.64*
Specialization index	*1.22*	*0.36*
Average citations	*8.02*	*1.59*

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

Coefficients	***Model #1***	***Model #2***	***Model #3***	***Model #4***	***Model #5***	***Model #6***
Rho21	*0.631****	*0.619****	*0.566****	*0.563****	*0.629****	*0.607****
Rho31	*0.770****	*0.782****	*0.752****	*0.753****	*0.769****	*0.754****
Rho41	*0.242**	*0.269***	*0.227*	*0.238*	*0.247**	*0.204*
Rho51	*0.178*	*0.161**	*0.156*	*0.155*	*0.185*	*0.148*
Rho32	*0.480****	*0.528****	*0.477****	*0.475****	*0.485****	*0.498****
Rho42	*0.182*	*-0.026*	*0.117*	*0.122*	*0.195*	*0.147*
Rho52	*0.146*	*-0.164*	*0.128*	*0.129*	*0.147*	*0.118*
Rho43	*0.067*	*0.199*	*0.048*	*0.066*	*0.079*	*0.044*
Rho53	*0.007*	*-0.064*	*-0.068*	*-0.068*	*0.002*	*-0.051*
Rho54	*0.381****	*0.372****	*0.383****	*0.382****	*0.380****	*0.383****

Table n. 6 - Multiprobit regression. Marginal effects for the dependent variable (existence of) in-house R&D investment

Variable	***Model #1***	***Model #2***	***Model #3***	***Model #4***	***Model #5***	***Model #6***
	dF/dX	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*
Dummy for R&D subsidies	*0.147****	*0.153****	*0.153****	*0.153****	*0.147****	*0.146****
Skilled employees (%)	*0.001**	*0.001**	*0.001**	*0.001**	*0.001**	*0.001**
CEO age	*0.001**	*0.001**	*0.001***	*0.001***	*0.001**	*0.0006*
CEO gender	*0.00****	*0.018*	*0.00****	*0.00****	*0.00****	*0.00****
Firm age	*-0.0004*	*-0.0005****	*-0.0005***	*-0.0005***	*-0.0004***	*-0.0003***
Size 10-19 employees	*-0.032***	*-0.034*	*-0.033*	*-0.034*	*-0.032*	*-0.022*
Size 20-49 employees	*0.002*	*0.0003*	*0.002*	*0.002*	*0.002*	*0.005*
Size 50-100 employees	*-0.006*	*0.004*	*0.002*	*0.002*	*-0.005*	*-0.004*
Size 100-250 employees	*0.046***	*0.044***	*0.043***	*0.043***	*0.045***	*0.047***
Proprietorship/Ownership dummy	*-0.599****	*-0.549****	*-0.592****	*-0.597****	*-0.635****	*-0.533****
Sa dummy	*0.007*	*0.014*	*-0.006*	*-0.008*	*0.007*	*0.014*
Sarl dummy	*-0.023*	*-0.017*	*-0.024*	*-0.025*	*-0.021*	*-0.032*
Eurl dummy	*-0.084*	*-0.082*	*-0.085*	*-0.086*	*-0.083*	*-0.084**
Coop dummy	*0.039*	*0.052**	*0.036*	*0.036*	*0.042*	*0.032*
Patent dummy	*-0.028*	*-0.039*	*-0.029*	*-0.029*	*-0.029*	*-0.027*
Industrial design dummy	*-0.002*	*0.005*	*0.012*	*0.014*	*-0.002*	*-0.0004*
Trademark dummy	*0.067****	*0.071****	*0.065****	*0.065****	*0.066****	*0.062****
Copyright dummy	*-0.005*	*-0.0003*	*-0.009*	*-0.008*	*-0.002*	*-0.002*
Rurality of the province where firm is located	*-0.010**	*-0.008*	*-0.008*	*-0.008*	*-0.010**	*-0.008*
France dummy	*0.221****					
Germany dummy	*0.036*					
Hungary dummy	*-0.044*					
Italy dummy	*0.021*					
Spain dummy	*-0.050***					
Uk dummy	*0.078*					
No. universities		*-0.001****				
Government R&D (ml €)		*-0.0005****	*-0.0005****	*-0.0005****	*-0.0005****	
No. scientists (th)		*0.002****				
N. years in UE		*0.003****	*0.004****	*0.004****	*0.0005*	*-0.0001*
N. agriculture faculties			*-0.006****	*-0.006****		
No. engineering faculties			*0.0004****			
No. science faculties				*0.0002****		
N. WoS food articles (100)					*0.00006**	
No. isced5a graduates (th)					*0.0002****	
No. isced5b graduates (th)					*0.0003****	
No isced6 graduates (th)					*0.0003*	
Fragmented NIS						*-0.291****
Coordinated NIS						*-0.125****
Specialisation index						*0.026*
Average citations						*0.008*

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

Table n. 7 - Multiprobit regression. Marginal effects for the dependent variable R&D collaboration with universities/research labs

Variable	***Model #1***	***Model #2***	***Model #3***	***Model #4***	***Model #5***	***Model #6***
	dF/dX	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*
R&D intensity (%)	*0.001**	*0.008**	*0.0009**	*0.0009**	*0.0009**	*0.0008**
Dummy for R&D acquired abroad	*0.036**	*0.37*	*0.043***	*0.043***	*0.037***	*0.042***
Dummy for R&D subsidies	*0.077****	*0.080****	*0.074****	*0.073****	*0.076****	*0.079****
Skilled employees (%)	*0.0004*	*0.0005**	*0.0004**	*0.0004**	*0.0005**	*0.0005**
CEO age	*0.00*	*-0.0004*	*-0.00008*	*-0.0007*	*0.00008*	*0.0001*
CEO gender	*0.00****	*0.019*	*0.00****	*0.00****	*0.00****	*0.00****
Firm age	*-0.00003*	*-0.00001*	*-0.00005*	*-0.00005*	*-0.0001*	*-0.0001*
Size 10-19 employees	*0.009*	*0.004*	*0.003*	*0.003*	*0.004*	*-0.001*
Size 20-49 employees	*0.009*	*0.007*	*0.006*	*0.006*	*0.007*	*0.006*
Size 50-100 employees	*0.025*	*0.026**	*0.019*	*0.019*	*0.026*	*0.023*
Size 100-250 employees	*0.008*	*0.005*	*0.007*	*0.007*	*0.005*	*0.003*
Proprietorship/Ownership dummy	*-0.301****	*-0.297****	*-0.273****	*-0.275****	*-0.320****	*-0.267****
Sa dummy	*-0.035**	*-0.018*	*-0.020*	*-0.019*	*-0.037**	*-0.030*
Sarl dummy	*-0.036**	*-0.027*	*-0.028*	*-0.028*	*-0.036**	*-0.024*
Eurl dummy	*-0.249****	*-0.259****	*-0.250****	*-0.252****	*-0.264****	*-0.238****
Coop dummy	*-0.001*	*0.002*	*0.005*	*0.006*	*-0.005*	*0.007*
Patent dummy	*-0.003*	*-0.004*	*-0.004*	*-0.004*	*-0.003*	*-0.004*
Industrial design dummy	*-0.006*	*-0.005*	*-0.008*	*-0.008*	*0.0008*	*0.001*
Trademark dummy	*0.027***	*0.027***	*0.026***	*0.026***	*0.026***	*0.026***
Copyright dummy	*0.043****	*0.046****	*0.038***	*0.038***	*0.037***	*0.037***
Rurality of the province where firm is located	*0.014****	*0.016****	*0.012****	*0.012****	*0.015****	*0.012****
France dummy	*-0.006*					
Germany dummy	*0.027*					
Hungary dummy	*0.048*					
Italy dummy	*0.030*					
Spain dummy	*0.025*					
Uk dummy	*0.047***					
No. universities		*0.0006****				
Government R&D (ml €)		*-0.00002*	*-0.00005*	*-0.00006*	*-0.00004*	
No. scientists (th)		*-0.0002*				
N. years in UE		*0.00006*	*-0.0001*	*-0.0001*	*0.0008**	*0.001****
N. agriculture faculties			*0.001**	*0.001*		
No. engineering faculties			*0.0006*			
No. science faculties				*0.00006*		
N. WoS food articles (100)					*0.00007****	
No. isced5a graduates (th)					*-0.00001**	
No. isced5b graduates (th)					*-0.00001****	
No isced6 graduates (th)					*0.00001*	
Fragmented NIS						*0.048**
Coordinated NIS						*0.047****
Specialisation index						*-0.033***
Average citations						*-0.010***

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

Table n. 8- Multiprobit regression. Marginal effects for the dependent variable R&D collaboration with private firms/consultants

Variable	***Model #1***	***Model #2***	***Model #3***	***Model #4***	***Model #5***	***Model #6***
	dF/dX	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*
R&D intensity (%)	*0.0007*	*0.009*	*0.0007**	*0.0007**	*0.0007*	*0.0006*
Dummy for R&D acquired abroad	*-0.002*	*-0.008*	*0.007*	*0.007*	*-0.001*	*0.010*
Dummy for R&D subsidies	*0.127****	*0.121****	*0.125****	*0.125****	*0.126****	*0.133****
Skilled employees (%)	*0.0005*	*0.0005*	*0.0005*	*0.0005*	*0.0005*	*0.0005*
CEO age	*-0.00006*	*0.00*	*-0.0001*	*-0.0001*	*-0.00002*	*0.0002*
CEO gender	*-0.022*	*-0.014*	*-0.018*	*-0.018*	*-0.022*	*-0.022*
Firm age	*0.0002*	*0.0001*	*0.0001*	*0.0001*	*0.0002*	*0.0002*
Size 10-19 employees	*0.021*	*0.007*	*0.003*	*0.004*	*0.019*	*0.007*
Size 20-49 employees	*0.033*	*0.021*	*0.017*	*-0.018*	*0.033*	*0.028*
Size 50-100 employees	*-0.019*	*-0.024*	*-0.031*	*-0.031*	*-0.018*	*-0.022*
Size 100-250 employees	*0.017*	*0.012*	*0.008*	*0.008*	*0.017*	*0.011*
Proprietorship/Ownership dummy	*-0.036*	*-0.026*	*-0.031*	*-0.031*	*-0.034*	*-0.024*
Sa dummy	*-0.023*	*0.011*	*-0.004*	*-0.003*	*-0.023*	*-0.024*
Sarl dummy	*-0.044*	*-0.023*	*-0.029*	*-0.028*	*-0.043*	*-0.027*
Eurl dummy	*-0.497****	*-0.482****	*-0.478****	*-0.481****	*-0.522***	*-0.480****
Coop dummy	*-0.006*	*0.003*	*0.008*	*0.009*	*-0.007*	*0.009*
Patent dummy	*0.027*	*0.025*	*0.029*	*0.029*	*0.027*	*0.028*
Industrial design dummy	*0.037***	*0.022*	*0.027*	*0.027*	*0.039***	*0.039***
Trademark dummy	*0.028*	*0.030*	*0.030*	*0.030*	*0.027*	*0.029*
Copyright dummy	*0.017*	*0.022*	*0.013*	*0.013*	*0.016*	*0.014*
Rurality of the province where firm is located	*0.004*	*0.004*	*-0.0007*	*-0.0006*	*0.004*	*0.001*
France dummy	*0.054*					
Germany dummy	*0.061*					
Hungary dummy	*0.047*					
Italy dummy	*0.080*					
Spain dummy	*0.061*					
Uk dummy	*0.148****					
No. universities		*0.001****				
Government R&D (ml €)		*-0.0001***	*-0.0001*	*-0.0001*	*-0.0003****	
No. scientists (th)		*-0.00009*				
N. years in UE		*0.0006*	*0.0003*	*0.0004*	*0.0005*	*0.0009*
N. agriculture faculties			*0.001*	*0.001*		
No. engineering faculties			*0.0001*			
No. science faculties				*0.0001*		
N. WoS food articles (100)					*0.0002****	
No. isced5a graduates (th)					*0.00*	
No. isced5b graduates (th)					*0.00*	
No isced6 graduates (th)					*0.00003*	
Fragmented NIS						*0.029*
Coordinated NIS						*0.035*
Specialisation index						*-0.010*
Average citations						*0.003*

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

Table n. 9 - Multiprobit regression. Marginal effects for the dependent variable product innovation

Variable	***Model #1***	***Model #2***	***Model #3***	***Model #4***	***Model #5***	***Model #6***
	dF/dX	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*
R&D collaboration with univerisities and research labs	*-0.087*	*0.067*	*-0.049*	*-0.047*	*-0.093*	*-0.070*
R&D collaboration with other firms/consultants	*0.102*	*-0.028*	*0.115*	*0.100*	*0.094*	*0.127*
R&D intensity (%)	*0.005*	*0.004*	*0.005*	*0.005*	*0.005*	*0.005*
Dummy for public subsidies	*0.071***	*0.071***	*0.072***	*0.071***	*0.073***	*0.070***
Skilled employees (%)	*0.00*	*0.0001*	*0.00002*	*-0.00001*	*-0.00001*	*-0.00006*
CEO age	*-0.002**	*-0.002*	*-0.002**	*-0.002*	*-0.002**	*-0.002*
CEO gender	*0.049*	*0.052*	*0.055*	*0.00****	*0.031*	*0.051*
Firm age	*0.0009***	*0.0009****	*0.0009****	*0.0009****	*0.0009****	*0.0009***
Size 10-19 employees	*0.008*	*-0.002*	*-0.001*	*-0.007*	*0.005*	*-0.012*
Size 20-49 employees	*0.043*	*0.038*	*0.034*	*0.031*	*0.042*	*0.035*
Size 50-100 employees	*0.063*	*0.062*	*0.058*	*0.054*	*0.063*	*0.057*
Size 100-250 employees	*0.095*	*0.092*	*0.089*	*0.086*	*0.094*	*0.087*
Proprietorship/Ownership dummy	*-0.070*	*-0.061*	*-0.059*	*-0.066*	*-0.070*	*-0.045*
Sa dummy	*-0.069*	*-0.050*	*-0.049*	*-0.052*	*-0.068*	*-0.062*
Sarl dummy	*-0.064*	*-0.048*	*-0.046*	*-0.052*	*-0.064*	*-0.020*
Eurl dummy	*-0.042*	*-0.035*	*-0.035*	*-0.039*	*-0.043*	*-0.035*
Coop dummy	*-0.182****	*-0.165****	*-0.167****	*-0.168****	*-0.180****	*-0.142***
Patent dummy	*0.130**	*0.134***	*0.135**	*0.135**	*0.137**	*0.136**
Industrial design dummy	*0.258****	*0.273****	*0.256****	*0.254****	*0.260****	*0.255****
Trademark dummy	*0.291****	*0.282****	*0.293****	*0.292****	*0.291****	*0.294****
Copyright dummy	*0.026*	*-0.005*	*0.024*	*0.025*	*0.029*	*0.032*
Rurality of the province where firm is located	*-0.001*	*-0.005*	*-0.005*	*-0.004*	*-0.001*	*-0.003*
France dummy	*-0.141****					
Germany dummy	*-0.156****					
Hungary dummy	*-0.027*					
Italy dummy	*-0.135****					
Spain dummy	*-0.205****					
Uk dummy	*0.044*					
No. universities		*0.003****				
Government R&D (ml €)		*-0.0006****	*-0.0008****	*-0.0008****	*-0.001****	
No. scientists (th)		*0.0005*				
N. years in UE		*0.0005*	*-0.00001*	*0.0002*	*0.0008*	*0.001*
N. agriculture faculties			*0.003***	*0.002**		
No. engineering faculties			*0.0007****			
No. science faculties				*0.0006****		
N. WoS food articles (100)					*0.0003****	
No. Isced5a graduates (th)					*-0.00001*	
No. Isced5b graduates (th)					*-0.00001*	
No isced6 graduates (th)					*0.0001****	
Fragmented NIS						*0.031*
Coordinated NIS						*0.109**
Specialisation index						*-0.151****
Average citations						*-0.029**
Sub_sector dummies	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*

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

Table n. 10 - Multiprobit regression. Marginal effects for the dependent variable process innovation

Variable	***Model #1***	***Model #2***	***Model #3***	***Model #4***	***Model #5***	***Model #6***
	dF/dX	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*
R&D collaboration with univerisities and research labs	*0.009*	*0.184*	*-0.001*	*-0.0006*	*0.004*	*0.009*
R&D collaboration with other firms/consultants	*0.202**	*0.223****	*0.267***	*0.268***	*0.202**	*0.243***
R&D intensity (%)	*0.013****	*0.014****	*0.014****	*0.014****	*0.014****	*0.014****
Dummy for public subsidies	*0.180****	*0.172****	*0.177****	*0.177****	*0.183****	*0.179****
Skilled employees (%)	*0.002***	*0.001***	*0.002***	*0.002***	*0.002**	*0.002***
CEO age	*0.001*	*0.001*	*0.001*	*0.001*	*0.001*	*0.001*
CEO gender	*0.083**	*0.115***	*0.095***	*0.083***	*0.00****	*0.084**
Firm age	*-0.0001*	*-0.0002*	*-0.00008*	*-0.00009*	*-0.00003*	*-0.0001*
Size 10-19 employees	*-0.165****	*-0.166****	*-0.177****	*-0.179****	*-0.169****	*-0.164****
Size 20-49 employees	*-0.090***	*-0.101***	*-0.106***	*-0.107***	*-0.094***	*-0.090***
Size 50-100 employees	*-0.025*	*-0.030*	*-0.038*	*-0.039*	*-0.031*	*-0.028*
Size 100-250 employees	*0.029*	*0.020*	*0.016*	*0.015*	*0.022*	*0.026*
Proprietorship/Ownership dummy	*-0.012*	*-0.036*	*-0.0006*	*0.00008*	*-0.011*	*-0.007*
Sa dummy	*-0.093***	*-0.057*	*-0.068*	*-0.063*	*-0.095***	*-0.097***
Sarl dummy	*-0.053*	*-0.044*	*-0.030*	*-0.027*	*-0.058*	*-0.039*
Eurl dummy	*0.273****	*0.296****	*0.277****	*0.275****	*0.266****	*0.276****
Coop dummy	*-0.055*	*-0.038*	*-0.025*	*-0.022*	*-0.046*	*-0.034*
Patent dummy	*0.062*	*0.058*	*0.065*	*0.065*	*0.063*	*0.064*
Industrial design dummy	*0.118**	*0.112**	*0.096*	*0.093*	*0.106*	*0.100*
Trademark dummy	*0.054***	*0.048***	*0.060****	*0.061****	*0.054***	*0.056****
Copyright dummy	*0.022*	*0.007*	*0.031*	*0.028*	*0.035*	*0.030*
Rurality of the province where firm is located	*-0.002*	*-0.007*	*-0.008*	*-0.008*	*-0.002*	*0.00002*
France dummy	*-0.126****					
Germany dummy	*-0.149****					
Hungary dummy	*-0.189****					
Italy dummy	*-0.022*					
Spain dummy	*0.052*					
Uk dummy	*-0.021*					
No. universities		*0.0008*				
Government R&D (ml €)		*0.0002*	*0.0005***	*0.0005***	*0.0003**	
No. scientists (th)		*0.0002****				
N. years in UE		*-0.002*	*-0.001****	*-0.002****	*-0.001**	*-0.001***
N. agriculture faculties			*0.002*	*0.002**		
No. engineering faculties			*-0.001****			
No. science faculties				*-0.001****		
N. WoS food articles (100)					*0.00004*	
No. isced5a graduates (th)					*0.00003***	
No. isced5b graduates (th)					*-0.00002****	
No isced6 graduates (th)					*-0.0002*	
Fragmented NIS						*0.062*
Coordinated NIS						*0.056**
Specialisation index						*0.176****
Average citations						*0.015*
Sub_sector dummies	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*

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

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APPENDIX

Table n. 6 bis - Multilevel regression for the dependent variable (existence of) in-house R&D investment

Variable	***Model #1***	***Model #2***	***Model #3***	***Model #4***	***Model #5***	***Model #6***
	dF/dX	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*
Dummy for R&D subsidies	*0.16****	*0.06**	*0.16****	*0.16****	*0.16****	*0.16****
France dummy	*0.17****					
Germany dummy	*-0.03***					
Hungary dummy	*-0.10****					
Italy dummy	*-0.06****					
Spain dummy	*-0.11****					
Uk dummy	*0.024***					
No. universities		*-0.002****				
Government R&D (ml €)		*-0.0005****	*-0.0006****	*-0.001****	*-0.001****	
No. scientists (th)		*0.002****				
N. years in UE		*0.003****	*0.005****	*0.005****	*0.00*	*0.00*
N. agriculture faculties			*-0.007****	*-0.007****		
No. engineering faculties			*-0.0006****			
No. science faculties				*0.0004****		
N. WoS food articles (100)					*0.0001**	
No. isced5a graduates (th)					*0.00003****	
No. isced5b graduates (th)					*0.00*	
No isced6 graduates (th)					*0.00*	
Fragmented NIS						*-0.24*
Coordinated NIS						*0.09*
Specialisation index						*-0.27*
Average citations						*0.005*
ML component (country code)						
Coeff.	*2.30e-35*	*1.74e-32*	*8.90e-33*	*2.3e-31*	*5.4e-35*	*0.013*
SE	*1.49e-34*	*3.15e-32*	*1.51e-32*	*2.8e-29*	*4.0e-34*	*0.11*

*** Significant at 1% level; ** Significant at 5% level; * Significant at 10% level.

Table n. 7 bis - Multi regression. Marginal effects for the dependent variable R&D collaboration with universities/research labs

Variable	***Model #1***	***Model #2***	***Model #3***	***Model #4***	***Model #5***	***Model #6***
	dF/dX	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*
Dummy for R&D acquired abroad	*0.08****	*0.08***	*0.08***	*0.08***	*0.07***	*0.08***
Dummy for R&D subsidies	*0.08****	*0.07****	*0.07****	*0.07****	*0.07****	*0.07****
France dummy	*-0.005****					
Germany dummy	*-0.006*					
Hungary dummy	*0.02*					
Italy dummy	*-0.009*					
Spain dummy	*-0.012**					
Uk dummy	*0.016***					
No. universities		*0.0008****				
Government R&D (ml €)		*0.00*	*-0.00007***	*-0.0001***	*-0.0001***	
No. scientists (th)		*0.00*				
N. years in UE		*-0.0004**	*-0.0006**	*-0.0005**	*0.00*	*0.0007****
N. agriculture faculties			*0.001***	*0.001***		
No. engineering faculties			*0.0001****			
No. science faculties				*0.0001****		
N. WoS food articles (100)					*0.0001****	
No. isced5a graduates (th)					*-8.90e-06***	
No. isced5b graduates (th)					*-0.00001****	
No isced6 graduates (th)					*0.00004***	
Fragmented NIS						*0.044*
Coordinated NIS						*0.04****
Specialisation index						*-0.042****
Average citations						*-0.009****
ML component (country code)						
Coeff.	*4.26e34*	*2.26e33*	*2.75e-33*	*2.2e-33*	*6.54e-35*	*8.0e-33*
SE	*1.02e-33*	*6.61e-33*	*5.09e-33*	*6.0e-33*	*2.84e-34*	*2.4e-32*

*** Significant at 1% level; ** Significant at 5% level; * Significant at 10% lev

Table n. 8 bis - Multi regression. Marginal effects for the dependent variable R&D collaboration with other firms/consultants

Variable	***Model #1***	***Model #2***	***Model #3***	***Model #4***	***Model #5***	***Model #6***
	dF/dX	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*
Dummy for R&D acquired abroad	*0.17****	*0.16****	*0.16****	*0.16****	*0.16****	*0.17****
Dummy for R&D subsidies	*0.11****	*0.11****	*0.011****	*0.11****	*0.11****	*0.11****
France dummy	*-0.015*					
Germany dummy	*0.018*					
Hungary dummy	*0.009*					
Italy dummy	*0.027***					
Spain dummy	*0.011*					
Uk dummy	*0.09****					
No. universities		*0.002****				
Government R&D (ml €)		*-0.0001****	*0.00*	*0.00*	*-0.0003****	
No. scientists (th)		*0.00*				
N. years in UE		*0.00*	*0.00*	*0.00*	*0.0003****	*0.0007***
N. agriculture faculties			*0.00*	*0.00*		
No. engineering faculties			*0.00*			
No. science faculties				*0.00*		
N. WoS food articles (100)					*0.0002****	
No. isced5a graduates (th)					*-0.00001**	
No. isced5b graduates (th)					*0.00*	
No isced6 graduates (th)					*0.00006***	
Fragmented NIS						*0.045*
Coordinated NIS						*0.036**
Specialisation index						*-0.03*
Average citations						*0.004*
ML component (country code)						
Coeff.	*2.41e-34*	*9.84e-34*	*0.0007*	*5.3e-29*	*5.1e-35*	*3.2e-35*
SE	*3.66e-34*	*6.71e-34*	*0.0608*	*1.4e-27*	*3.3e-34*	*1.8e-34*

*** Significant at 1% level; ** Significant at 5% level; * Significant at 10% leve

Table n. 9 bis - Multiprobit regression. Marginal effects for the dependent variable product innovation

Variable	***Model #1***	***Model #2***	***Model #3***	***Model #4***	***Model #5***	***Model #6***
	dF/dX	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*
R&D collaboration with univerisities and research labs	*0.02*	*0.02*	*0.02*	*0.01*	*0.02*	*0.02*
R&D collaboration with other firms/consultants	*0.10*	*0.11*	*0.10*	*0.10*	*0.09*	*0.11*
Dummy for public subsidies	*0.07****	*0.07****	*0.07****	*0.00***	*0.07****	*0.06***
France dummy	*-0.09*					
Germany dummy	*-0.09*					
Hungary dummy	*0.005*					
Italy dummy	*-0.08*					
Spain dummy	*-0.14***					
Uk dummy	*0.09*					
No. universities		*0.003****				
Government R&D (ml €)		*-0.0005****	*-0.001****	*-0.001****	*-0.001****	
No. scientists (th)		*0.0004**				
N. years in UE		*0.00*	*0.00*	*0.00*	*0.00*	*0.0*
N. agriculture faculties			*0.003***	*0.002***		
No. engineering faculties			*0.001****			
No. science faculties				*0.001****		
N. WoS food articles (100)					*0.0004****	
No. Isced5a graduates (th)					*-0.00001**	
No. Isced5b graduates (th)					*0.00*	
No isced6 graduates (th)					*0.0001****	
Fragmented NIS						*0.003*
Coordinated NIS						*0.11**
Specialisation index						*-0.15***
Average citations						*-0.03**
ML component (country code)						
Coeff.	*1.39e-35*	*1.54e-59*	*8.62e-34*	*3.7e-32*	*1.1e-34*	*1.8e-30*
SE	*3.97e-34*	*4.50e-58*	*2.62e-33*	*5.4e-32*	*1.3e-34*	*5.7e-30*

*** Significant at 1% level; ** Significant at 5% level; * Significant at 10% level.

Table n. 10 bis - Multiprobit regression. Marginal effects for the dependent variable process innovation

Variable	***Model #1***	***Model #2***	***Model #3***	***Model #4***	***Model #5***	***Model #6***
	dF/dX	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*	*dF/dX*
R&D collaboration with univerisities and research labs	*0.07*	*0.07*	*0.07*	*0.07*	*0.07*	*0.07*
R&D collaboration with other firms/consultants	*0.19****	*0.20****	*0.20****	*0.20****	*0.19****	*0.19****
Dummy for public subsidies	*0.16****	*0.16****	*0.16****	*0.16****	*0.16****	*0.16****
France dummy	*-0.11****					
Germany dummy	*-0.13****					
Hungary dummy	*-0.18*					
Italy dummy	*0.00*					
Spain dummy	*0.07****					
Uk dummy	*-0.004*					
No. universities		*0.00*				
Government R&D (ml €)		*0.00*	*0.00*	*0.00*	*0.0004****	
No. scientists (th)		*-0.002****				
N. years in UE		*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
N. agriculture faculties			*0.00*	*0.00*		
No. engineering faculties			*0.00*			
No. science faculties				*0.00*		
N. WoS food articles (100)					*0.0004****	
No. Isced5a graduates (th)					*-0.00003***	
No. Isced5b graduates (th)					*0.00*	
No isced6 graduates (th)					*-0.0002****	
Fragmented NIS						*0.01**
Coordinated NIS						*0.085****
Specialisation index						*0.15***
Average citations						*0.01****
ML component (country code)						
Coeff.	*1.15e-35*	*0.0177*	*0.0174*	*0.022*	*7.0e-33*	*3.2e-05*
SE	*2.41e-34*	*0.0120*	*0.0203*	*0.018*	*2.1e-32*	*3.2e-04*

*** Significant at 1% level; ** Significant at 5% level; * Significant at 10% level.