First, second and third tier universities: academic excellence, local knowledge spillovers and innovation in Europe

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Abstract

This paper aims to study the drivers of innovation and of university-industry collaboration in the European manufacturing sector, specifically focusing on the extent to which academic excellence may enhance the capacity of firms to develop new products and processes. It shows that academic research has an important direct impact on the firm's propensity to develop innovation, apart from the indirect effect of academic excellence on partner choice in university-industry R&D collaboration. The results also suggest that the research at lower tier universities has an impact on business innovation and that there is a strong case in favour of public funding also to less prestigious academic institutions.

Keywords: University–industry interaction; R&D collaboration; Product and process innovation; Academic excellence; Regional innovation systems

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1. Introduction

The literature on the national innovation systems underlines with considerable force that general strength in national scientific education and research is a prerequisite for innovation capacity in the newer science-based industries. It is also essential for the adaptation and diffusion of industrial and agricultural technologies in countries where resource endowment or the stage of economic development differ substantially from that where the technology was initially developed (Acs et al., 2016). Since universities play a central role in national and regional innovation systems, particularly in Europe, any reform which affects universities has important implications for the national and regional innovation systems.

In recent decades many changes occurred in the European higher education institutions. Since the late 1990s, the role of universities in strengthening industrial competitiveness in the European Union (EU) has struck a chord in public debate and is now an issue in mainstream policy (European Commission, 2007, 2010), as outlined by the Bologna Declaration whose objective is to make the European higher education institutions more competitive and attractive, and the EU's Lisbon Strategy, which seeks to reform the still fragmented European higher education institutions into a more powerful and integrated system.

As a result of the convergence process started by the Bologna Declaration, the European higher education system has been reformed through the adoption of a first level general degree, followed by a second level specialized degree (Enders et al., 2011). Further aspects of this reform relate to the societal requirement that higher education institutions actively contribute to satisfy the demand by students and by the productive system for certified skills that are ready to be used on a professional basis. This necessity is satisfied through the supply of a student-centred didactics, the direct involvement of universities in their own graduates' job-placement and a shared governance attempt that is the entrance of external members onto academic governing boards. New services are now offered: open-days for high-school students, on-line action plans, laboratory work and tutorships in study choice, company internships and apprenticeships for pre- and post-graduate students, professional doctorates, observatories on job placement of graduates, career and recruitment agency services (Moscati et al., 2010).

Important pillars of the Lisbon Strategy[2] of economic growth, based on knowledge (EU Report Europe 2020), are education, research, innovation and the modernisation of higher education institutions. The introduction of quasi-market logics into higher education institutions is seen by

[2] The Lisbon Strategy, also known as the Lisbon Agenda or Lisbon Process, was an action and development plan devised in 2000, for the economy of the European Union.

European policy makers as the instrument to bring universities closer to society and the local economy needs (Perotti, 2010). As a consequence, universities have also begun to be financed according to their productivity and academic excellence (Agasisti et al., 2016). “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). In line with the Lisbon Strategy, many European countries have implemented reforms, aiming to reinforce cooperation between universities, research institutions and industry, through contracting-out or collaborative projects, and to increase the commercialization of research. Since discrepancies between national systems may hamper transnational knowledge transfer, EU universities and public research labs are recommended to adopt a common code of practice for knowledge transfer activities (European Commission, 2008).

Even if specific country pathways are distinguishable in how these reforms have been implemented (Moscati et al., 2010; Regini, 2015; Perotti, 2010), the role that universities play in enhancing regional innovation systems is potentially reinforced as academic institutions have generally gained autonomy throughout the EU. University statutes and internal regulations address the hiring of research and teaching staff, didactics supply criteria, student number, tuition within the existing limitations, external fundraising and technology transfer activities. Competition for scholars, students, public and private funds is strong not only among universities but also among disciplinary groups and departments within the same university and the way the ‘third mission’ is perceived may vary accordingly not only within the same university but also within the same department (Cavalli and Moscati, 2010; Moscati et al., 2010).

From the scholars’ perspectives, third mission activities are time-consuming and can be detrimental for the achievement of academic research excellence (Giuliani and Arza, 2008) as reflected in university rating and ranking.

From the industry perspectives, academic research excellence may even present some comparative disadvantages, and second and third tier universities may also be important for industry innovation. Mansfield and Lee (1996) ask a sample of major firms in seven high-tech industries to cite five academics whose research contributed most to the firm’s innovation. Top tier departments were more cited by firms, but universities with adequate-to good and marginal faculties, according to the US National Academy of Science rating, also obtained good citations because “less prestigious universities may have a comparative (indeed, an absolute) advantage”.

Studies that focus on the effect of academic knowledge spillovers on regional innovation do not seem to reflect the presence of positive effects of universities on regional innovation in Europe

(Ghinamo, 2012). This weak evidence is explained by the needs of a specialized rather than general public research infrastructure since academic research could be valuable input for firms' innovative processes only if carefully tailored to the technological needs of the local economy.

Perotti (2010) suggests a different explanation that is the existence of a potential trade-off between university missions, particularly between academic excellence, as measured through the number of publications in high-ranked journals, vs. local knowledge spillovers useful for economic growth. The resulting net effect on the local economy among different forces under specific contingencies (such as sectors, regions, company sizes and property types) could turn out not to be positive. The adoption of the international standard of American and British universities, where publications play a vital role in academic careers, has represented a sharp improvement in the academic tradition of self-governance for career advancement within national regulations (Corsi, 2007). However, academic excellence may present a cost for the local economy which is not clear and has not been investigated by policy makers throughout Europe.

The present study seeks to contribute to the relatively small amount of literature on the university third mission through the contemporaneous identification of determinants of Research and Development (R&D) investment and of innovation by firms in the manufacturing sector (Acosta et al., 2015; Maietta, 2015; Maietta et al., 2017); the study is based on a large set of comparable data across countries collected at a NUTS 3 level since this geographic unit enables capture the spillover effects of public research (Bonaccorsi, 2014). Among the drivers of university-industry collaboration, we specifically focus on whether university reputation enhances the capacity of firms to develop new products and processes through this channel. The impact of academic excellence on business innovation is investigated also for those firms who do not collaborate in R&D with an academic institution. The final question of the paper is whether research at local first tier universities has higher knowledge spillovers than that at local second and third tier universities.

We use a simultaneous multi-equation approach that addresses both the endogeneity of R&D decisions and the simultaneity of internal and external R&D investment. Firms' R&D decisions are potentially endogenous to firms' size in that large firms enjoy easier access to external finance and internal funds by cumulated profits (Garcia-Quevedo et al., 2014). Since the dependent variables are ordinal, the simultaneous approach is a multivariate probit model. Our dependent variables reflect the choice of: investing in internal R&D; investing in external R&D in university/research labs and other firms/consultants; and innovation in products and processes. The determinants of company innovation are those that have been used successfully in preceding studies (e.g. Maietta, 2015) alongside several specifications of variables reflecting the university scientific composition, output and reputation.

The source of data on company innovation is the EU-EFIGE/Bruegel-UniCredit dataset from an extensive survey carried out in 2010. These data provide comparative transnational data on manufacturing firms in seven European countries and cover quantitative as well qualitative information including data on R&D and in particular on R&D collaborations and innovation. Information on universities is gathered from a range of sources: EUMIDA (European University Data Collection), ETER (European Tertiary Education Register), the Academic Ranking of World Universities (ARWU) by Shanghai Jiao Tung University, commonly known as the Shanghai index, as well as the OECD patent database.

Section 2 underlines the characteristics of the higher education system in Europe. Section 3 reviews the literature regarding the influence of university reputation on the success of cooperative agreements with firms. Section 4 describes the methodology and the sources of the data and Section 5 presents the results of the analysis. Robustness check is provided in Section 6, while Section 7 concludes.

2. Structural changes in higher education systems in Europe

In 1998 at University of Sorbonne-Paris, the Ministers for Education of Germany, France, Italy and UK made an agreement for promoting similarity of higher education architecture in Europe, based upon a system of two cycles. On 19 June 1999 in Bologna, this agreement, named the “Bologna Declaration", was reinforced and jointly signed by 29 countries for promoting a European Higher Education Area by 2010, usually named the “Bologna Process". The framework of the EU would not allow for an education policy aimed at harmonising the higher education policies of the member states, since the competencies of the Commission do not extend this far but the increasing awareness that higher education was the pivot on which human capital hinge, incited the national governments to use policy methods outside the Union’s framework to better ensure and strengthen the competitiveness of higher education (Enders et al., 2011).

The aim of the “Bologna Process" was the harmonisation of national degree university structures as a part of the construction of the new Europe, through increased student and teacher mobility, the adoption of a common scheme of academic titles and cooperation in designing models for quality assessment. In order to control for the proliferation of official university qualifications (Perotti, 2007), a framework of readable and comparable degrees was adopted and a system of credits – such as the European Credit Transfer and Accumulation System (ECTS) - was established (Enders et al., 2011). Ten years later, 46 countries have joined the Bologna Process. Some results of the implementation of this process have been the homogenisation of the length of study programmes and the growing openness of higher education institutions to their outside social and economic environment since the reform attempted to guarantee to each university the freedom to create degree courses responsive to the needs of the local context, within the limits of the established degree classes, and new professional identities were designed (Romano, 2010). Furthermore, the need for comparability and mutual recognition of university degrees and diplomas among member-countries has fostered, in the respect of diversity when increasing similarity, a restructuring of academic programmes (due to the division into cycles, the use of credits, etc.) which academics, often hostile to innovations (Ballarino and Perotti, 2012; Perotti, 2007; Romano, 2010), would not otherwise have undertaken. On the other hand, the amount of academic duties has been growing due to the new administrative work, linked to didactics and research quality requirements, and to the increasing number of students, as a consequence of the introduction of short-cycle degrees (Viola, 2014) but also of the general advent of mass university education (Perotti, 2007). Furthermore, the relationship between teaching and research has loosened because of the reduction of tenured and tenure tracked positions, the growing number of fixed-term contracts for both teaching and research, including the growing recruitment of academic staff from external professional fields (Cavalli and Moscati, 2010). As a consequence, the Humboldtian tradition of a strong connection between research and teaching, which is widespread in continental Europe, has weakened as an instrument of knowledge spillovers accruing to firms[3].

European universities have also faced changing funding regimes with the introduction of national systems of funding conditional on evaluation of research output, or performance-based research funding systems. The UK was the first country in Europe to introduce in 1986 a national assessment exercise on the quality of university research (Hicks, 2012) with the goal of increasing selectivity in the allocation of public resources moving away from a system where university funding was allocated on a historical basis (Geuna and Piolatto, 2016). National evaluation systems spread rapidly to other countries with significant differences across countries in the assessment procedure - peer review-based research assessment, metrics-based assessment or some combination of the two - and in the share of funding allocated through the national assessment exercise. The UK and Italy are the only countries that have implemented a performance-based research funding system that potentially evaluates all public research institutions' staff in order to allocate research funding (Geuna and Piolatto, 2016).

The rationales of performance-based research funding systems are numerous: increasing productivity with output-based evaluation, replacing traditional systems with market-like

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

incentives; stronger service orientation; greater accountability and devolution, through higher university autonomy and self-governance (Hicks, 2012).

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

Performance-based research funding systems and international ranking increase university competition for prestige and may enhance research excellence, but run into costs. Because of the reliance on the academic elite in their design and implementation, they tend to suppress scientific novelty, innovation and intellectual diversity, to lessen the contribution of universities to national and cultural identity, since the push into international and English language literature forces scholars to adopt the perspective of American academics who dominate such literature, to potentially decrease didactic quality, because of a trade-off between teaching quality[4] and the grades given by the national assessment exercise (Barra and Zotti, 2016), and to discourage interaction with industry and application of research activities with economic benefits such as business innovation (Moscati et al., 2010; Hicks, 2012; Maietta, 2015). These unintended consequences seem likely to lead to an internationally approved ivory tower of scholarship, and damage societies over the long term (Hicks, 2012; 2013).

3. Does research need to be excellent in order to enhance industrial innovation?

Considerable attention has been paid to the role of universities in regional economic development and innovation. Regional knowledge networks and modes of engagement between universities and the business community are becoming increasingly prevalent (Huggins et al. 2008); excellence in research (supporting the region's economic base), excellence in education (i.e. students staying in the region and contributing to its growth) and excellence in collaboration with public and private actors are progressively called into question (Power and Malmberg, 2008). Indeed, there are several contributions that universities can make in order to speed up local

[4] The commissions of qualitative evaluation of the degree programs generally control quality of teaching with respect to parameters related to the number of regular graduates (Romano, 2010).

economic development; among them, both knowledge creation and regional innovation through research and technology transfer are examples of relevant channels. Many studies on the contribution of universities to local development focus on the technology transfer channel, highlighting the importance of higher education institutions' services, such as university-industry collaboration, for boosting firm innovation activities. Many are the factors that have been identified as important determinants of university-industry collaboration. Among them, university characteristics could play an important role such as university or department size (von Tunzelmann et al., 2003; D'Este and Iammarino, 2010), scientific discipline composition and specialization (Landry et al., 2007) and academic research quality (D'Este and Iammarino, 2010). Features of the individual company also play an important role such as *intra* and *extra muros* R&D investment (Medda et al., 2005; Piga and Vivarelli, 2004), size (Motohashi, 2005) and innovation subsidies (Piga and Vivarelli, 2004). Furthemore, location of the firms and the proximity to universities have been discussed in order to examine whether firms that are located near universities may frequently collaborate with them and benefit from knowledge spillovers (among others, see D'Este and Iammarino, 2010; Fritsh and Franke, 2004; D'Este et al., 2013). See Maietta (2015) and Muscio and Nardone (2012) for a more detailed discussion on the determinants of university–industry collaboration.

Among the drivers, discussed above, of the university-industry relationship, part of the literature has focused the attention on the importance of the quality of academic research and on the reputation of the higher education institution when firms choose universities as R&D collaboration partners. In other words, a still open question in the literature is whether a university has to be recognized as a top tier institution in order to be a powerful attractor for industry cooperation, and consequently to be relevant for regional development. Although, as suggested by Bonaccorsi (2016) academic excellence is necessary but not sufficient, it could be argued that higher-quality universities make greater academic contributions to industrial innovation, specifically when cutting-edge research is involved, even though empirical evidence seems not to be completely exhaustive, with conflicting and ambiguous results. The idea is that by building relationships with highly ranked universities, firms gain more credibility on the market for the their products' quality; therefore, improved reputation and legitimacy would mostly drive the decision to collaborate with prestigious universities. Overall, academic scientific productivity is in general positively related to industry engagement (Schartinger et al., 2002; Fontana et al., 2006) and firms generally prefer to collaborate with top tier universities rather than second tier universities (Laursen et al., 2011). Firms base their decision to support R&D applied research according to the reputation of the university as well as to the presence of star scientists (Karlsson and Anderson, 2006; Athey et al., 2007) also on the basis of the fact that prestigious universities will make available the best technology to firms (Effelbein, 2006). The quantity of academic research as well, as its quality, do count in building a university-industry partnership and they are considered among the main drivers of innovation performances of firms; high quality researchers or academic institutions have a higher probability of being involved in knowledge transformation as well as the fact that firms which cooperate with highly rated universities generate more innovation (Sachwald, 2015). Adams (2005) underlined that firms which are more interested in funding cutting-edge research would collaborate with top tier universities regardless of the distance between them. Mora Valentin et al. (2004) show that the good reputation of research organizations has a positive influence on the success of agreement with firms. Laursen et al. (2011) find that co-location with top tier universities promotes collaboration and that firms decide to collaborate with a university partner giving preference to its academic quality over the geographical location. Their findings show that firms firstly choose to collaborate with local top tier universities and secondly with a non-local, but probably highly-ranked, university rather than cooperating with a local second tier institution. According to them, an explanation could be related to the fact that second tier universities are more specialized in teaching activities which dos not attract firms as much as research intensive activities do. Moreover, the potential benefit of collaborating with a second tier university may not be well balanced by the cost involved in building this collaboration; when facing budget constraints, firms will prefer a partnership with a highly ranked institution.

However, the impacts of academic quality on the university-industry relationship turned out to be more complex when both geographical locations of firms and academic institutions and different industry sectors are taken into account. Abramovsky et al. (2007) show that firms locate their R&D laboratories in places with a high concentration of highly ranked universities, when the pharmaceutical and chemical industry is taken into account; while, considering other industrial sectors (i.e., motor vehicles), the location of such activities is in places with both a high concentration of top and low ranked universities. When firms have been asked to cite researchers whose work contributed in an important way to the development of new products and processes, part of them are related to world leading universities in science and in technology but less prestigious universities are also well represented. Indeed, the relationship between the reputation of the faculty and the contribution to industry is not as strong as expected in all the industries boosting the idea that also modestly-ranked universities might have an important role as much as highest-ranked institutions and that second tier universities are a precious source of research for the industry (Mansfield, 1995; Mansfield and Lee, 1996). A trade-off between quality of the department and geographical proximity is also possible as the impact of academic quality and geographical proximity is not homogeneous across disciplinary fields. Indeed, Mansfield (1995) and Mansfield and Lee (1996) provide evidence that firms seems more likely to look for a high quality faculty or deparment, paying less attention to where the university is located, when basic research is considered; on the other hand, when applied R&D research is taken into account, firms seem to prefer working with a marginal quality university but closer located to the firm's R&D laboratories. This behaviour could be explained by the fact that a more face-to-face interaction between academics and firm's employees is needed for applied research, while this interaction is less binding for basic research; moreover, the differences between top and second tier universities may be more evident for basic research than for applied R&D. It is true, therefore, that the university-industry collaboration is positively related to university quality; it is also true, however, that beyond a certain threshold of academic quality, firms may no longer consider it worthwhile the additional costs attached to this collaboration. Indeed, some firms could decide to invest in supporting research at leading universities also to obtain access to promising students and graduates while some other firms might not be prone to start these collaborations as some top tier universities may impose too restringent conditions than those imposed by less prestigiuos universities. D'Este and Iammarino (2010) found that university departments carrying out research of higher scientific excellence are more likely to be involved in R&D collaboration with firms. However, results are not homogenous when considering different disciplines; indeed, for engineering-related departments, proximity is key to explaining the frequency of collaborations with industry, whereas it is not important for basic-science related departments, for which the positive impact of research quality prevails. They argue that the university-industry relationship that involves top-ranked universities is less constrained by geographical distance compared to low-ranked universities, since the choice to collaborate with academic excellent departments is driven by the search for very talented scholars regardless of the distance. Hong and Su (2013) show that although prestigious universities are less likely to attract industrial partners, they are more likely to attract non-local industrial partners in line with the idea that when a university has a high prestige, the effect of geographic proximity will decrease. This could be explained by the fact that second tier universities can probably better solve the problem of firms when there are not many firms involved in cutting-edge research. In this case, indeed, firms might not look for elite universities and therefore non-elite universities have a higher chance of being selected for collaboration. Once a local solution is not available and the firms could internalize the cost of a distant partnership, then firms will choose prestigious universities.

The main literature, as discussed above, focuses the attention on the effect of academic research quality on the firm's decision to collaborate with universities. However, apart from the latter, academic excellence of research institutions may also directly enhance a company's ability to develop new products and processes through other channels, particularly important for local and not large-sized firms, such as informal relationships, consultancy activities and training of good Ph.D. students, who might be working in firm research laboratories. With exception of Mansfield (1991; 1995) who underlined that academic research provides company scientists and engineers the necessary technique to carry out innovation activities more cheaply and quicky, only few studies focused on mechanisms other than expressly supported R&D activities at some universities. More recently, the number of indexed publications and the performance-based research grade of the local university (Maietta, 2015) as well as the specilisation index based on the number of indexed publications (Maietta et al., 2017) present a negative marginal effect on the probability of developing innovation in the food sector. A possible explanation is that lower fundings are allocated to universities, being in turn increasingly linked to the assessment of academic research quality; as a consequence, researchers will be more focused on high ranked journal publications in order to increase their own and their faculty's reputation. In such circumstances, consultancies or informal collaboration may be too demanding and scholars prefer to concentrate on prestigious publications because industry-oriented research may deteriorate the publication profile relevant for career advancement.

In conclusion, it cannot be ignored that the presence of good researchers at academic institutions, as well as being involved in frontier research, increase the chance of building collaboration with firms that probably will turn in innovative outputs. However, being a low tier university does not mean being cut off from the possibility of collaborating with industry and therefore also raise funding from industry; low tier universities may indeed be particularly active in directly contacting local medium- and large-sized firms in search for collaboration. Finally, it is also true that research excellence, although very important, is not enough to explain the university-industry partnership and that also a certain level of organization with the research team is needed to interact with the external environment productively. Moreover, knowledge spillovers from research institutions depend also from company internal and contextual factors on which universities do not have control (see Bonaccorsi, 2016, on this point). It could be the case that academic research quality may enhance radical innovation of relatively few firms, working on cutting-edge research, whereas less advanced academic research may be directly useful to incremental innovation of most local firms.

Policywise, further work is required in order to evaluate not only the indirect impact of academic research quality on the firm's innovation through the decision of firms to collaborate in R&D with universities, but also the direct effect of academic research quality on the likelihood of firms to innovate.

4. The empirical framework

4.1. The econometric approach

Our econometric model consists of five simultaneous equations related to the following dependent variables: (the existence of) *intra muros* R&D investment; R&D collaboration with universities and/or research labs; R&D collaboration with other firms and/or consultants; process innovation; product innovation. The variables of R&D collaboration with universities/research public labs, and R&D collaboration with private firms/consultants are potentially endogenous dichotomous variables since they may have a causal effect on product and process innovations. However, all these variables are also inter-related due to both observed and unobserved variables. The equations for the R&D decision variables are modelled as treatment equations. The two innovation equations are structural or outcome equations with the R&D decisions variables as explanatory factors.

All these indicators are binary variables and 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:

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

The five latent variables are 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 which describe a structural relation between y_k and y_l and therefore allow for causal interpretations; and ε_{ki} are error terms, which are assumed to be jointly normal with the unknown correlation coefficient, ρ_{kl}. The latter measures how far the unobserved factors influence y_k and y_l, if ρ_{lk}=0 cannot be rejected, this implies that the equations need not to be estimated as a system and can be estimated separately.

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

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

Basically, our model includes three reasons why we might observe y_k (where $k = 2, 3$) and y_4 (or y_5) to be correlated: 1) a causal relation due to the influence from y_k on y_4 (or y_5) through the parameter γ_{k_4} (or γ_{k_5}); 2) y_k and y_4 (or y_5) may depend on correlated observed variables (the $\mathbf{x}_k$'s) and 3) y_k and y_4 (or y_5) may depend on correlated unobserved variables (the ε_k's) (Arendt and Holm, 2006). The common latent factor structure of the multivariate probit framework makes it possible both to correct the potential sample selection and to control for the potential endogeneity of the R&D investment decision since the coefficient ρ_{lk} can be interpreted as the degree of endogeneity of y_k to u_l where $k = 2, 3$ and $l = 3, 4$ (Monfardini and Radice, 2008). The resulting multivariate probit model can be described as an instrumental variable framework for categorical variables and can be estimated using the simulated maximum likelihood method.

This method uses the Geweke-Hajivassiliour-Keane smooth recursive conditioning simulator to evaluate the multivariate normal distribution; the simulated probabilities are unbiased and bound within the (0, 1) interval (Cappellari and Jenkins, 2003). All the equations in (1) can be estimated separately as single probit models but the estimated coefficients are inefficient because the correlation between the error terms is neglected and the simultaneity is not taken into account. Only in the case of independent error terms ε_{ki} it is possible to deal with the above model as independent equations (Maddala, 1983).

The estimation of a multivariate probit model with endogenous binary regressors requires some consideration for the identification of the model parameters. Maddala (1983) proposes that the exogenous covariates in the reduced form equations should contain at least one regressor not included in the structural equations but Wilde (2000) shows that no exclusion restrictions on the exogenous variables are required for parameter identification, when there is sufficient variation in the data. This last condition is ensured by the assumption that each equation contains at least one varying exogenous regressor, an assumption which is rather weak in economic applications. Given the assumption of joint normality, the multivariate probit model is identified by functional form. Wilde's contribution makes it clear that theoretical identification does not require availability of any additional instruments for the endogenous variables. However, the presence of equation-specific regressors in formally identified models may improve convergence and make the estimation results more robust to distributional misspecifications (Monfardini and Radice, 2008). We use R&D subsidies, which change the user cost of R&D capital, as an extra-regressor in the reduced-form equations as suggested by Hombert and Matray (2015).

4.2. The data

In order to explore company innovation and R&D collaboration, different sources of data have been used. The source of company information is the EFIGE (European Firms in a Global Economy) database; moreover, we also exploit the EUMIDA (European University Data Collection) and ETER (European Tertiary Education Register) datasets, the Academic Ranking of World Universities (ARWU) by Shanghai Jiao Tung University, commonly known as the Shanghai index, as well as the OECD patent database.

The EFIGE dataset consists of a representative sample at country level for the manufacturing industry of almost 15,000 surveyed firms with more than 10 employees in seven European countries: Austria, France, Germany, Hungary, Italy, Spain and the United Kingdom. The sampling design has been structured following a three dimension stratification: industry (11 NACE-CLIO codes), region (NUTS 1 level) and size class (10-19; 20-49; 50-99; 100-249 and more than 250 employees). The data cover the years 2007-2009. The database contains quantitative and qualitative information on R&D and innovation. More specifically, firms are asked whether process and product innovation had been introduced during the previous three years (2007-2009). Product innovation is defined as the "introduction of a good which is either new or significantly improved with respect to its fundamental characteristics. The innovation should be new to the firm, but not necessarily to the market" whereas process innovation is defined as the "adoption of a production technology which is either new or significantly improved. The innovation should be new to the firm, but the firm has not necessarily to be the first to introduce the new process". The questionnaire also collects information regarding whether the R&D was *intra muros* or acquired from external sources such as universities/research labs and other firms/consultants. Other information used here includes the amount of R&D expenditure and whether the firm benefits from tax allowances and financial incentives for R&D investment or other activities. Size classes have been used with respect to the number of employees, along with other firm characteristics, such as the presence of skilled employees (that is graduates), age and gender of the current Chief Executive Officer (CEO) or company head, age of the firm and its current legal form, and whether the firm, in the last three years, applied for a patent, registered an industrial design or a trademark and claimed a copyright.

The second source of data is represented by the EUMIDA (European University Data Collection) and ETER (European Tertiary Education Register) databases. These projects aimed to build a complete census of European universities (Bonaccorsi, 2014) and included a pilot data collection with particular emphasis on research-active universities, containing data for each university such as the number of national and international students, Ph.D.s, as well as information regarding the fields of education and the year in which the university was funded. Further information on the field of education is also sourced from the EU Agri Mapping project (Chartier, 2007). All the information at the university level has been averaged out or summed up at the NUTS 3 level and then matched with firm level characteristics.

Thirdly, the indicator of academic excellence used in this study is sourced from the Academic Ranking of World Universities (ARWU), also known as the Shanghai academic ranking of the universities. It has been chosen, among the others, because it is the first developed indicator of university world ranking and, among its components, it is possible to select one specifically referring to research output. Universities are ranked by several indicators of academic or research performance, including alumni winning Nobel Prizes and Fields Medals (proxy of the quality of education), staff winning Nobel Prizes and Fields Medals and highly cited researchers (proxies of the quality of the Faculty), papers published in Nature and Science and papers indexed in Science Citation Index-Expanded and Social Science Citation Index (proxies of the research output), and the per capita academic performance of an institution (proxy of the per capita performance). We focus on the ranking based on the research output criteria; according to this indicator, the highest scoring institution is assigned a score of 100, and other institutions are calculated as a percentage of the top score. The Shanghai index ranks the universities up to the 500^{th} position. Therefore we have imputed a value of 3 to each university which is ranked above the 500^{th} position as we do not have any information on the specific ranking of those institutions. Again, all the information at university level have been summed up at NUTS 3 level and then matched with company-level characteristics.

Finally, information on total patents, which are used as proxy of technology level, by NUTS 3 and by selected technology fields, is sourced from the OECD Patent Database.

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

[Table 1 around here]

4.3. The empirical specification and the descriptive statistics of the variables

The empirical specification of the five equations is as follows:

Intra muros R&D investment = f_1 (Dummy for R&D subsidies, skilled employees, CEO age and gender, age of firm, firm size dummies, firm legal form dummies, intellectual property dummies, rurality level of the province or region, country dummies or university's characteristics).

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

Innovation $j = f_j$ (R&D collaboration with universities/research labs, R&D collaboration with private firms/consultants, R&D intensity, public subsidies, skilled employees, age and gender of CEO, age of firm, firm size dummies, firm legal form dummies, intellectual property dummies, rurality level of the province, industrial sector dummies, country dummies or university's characteristics), where *j* = product or process.

As Table 1 shows, almost 5% of our firms have R&D collaborations with a university or research lab, while 9% have R&D collaborations with other firms or consultants. Among all firms in the sample, 49% have introduced product innovation, and 44% have introduced process innovation. R&D intensity, measured as the percentage of the total turnover that the firm has invested in R&D on average in the three years (2007-2009) is around 3.6%; over the same time span, 48% of the firms undertook *intra muros* R&D activities.

The description is completed by some indicators which measure the characteristics of higher education institutions. On average, 63% of the universities offer medicine as a field of studies; the average number of national students is around 27,000 while international students are almost 1,600 on average. Regarding the indicator of academic excellence, the average Shanghai scoring is around 23. The average Shangai index of the first tier university is 10 while when first and second tier universities are taken into account, their average value is around 15. The average value of the ranking associated with all universities other than the first tier one is around 12 and other than the first and second tier one is around 8. The highest values is 66 which corresponds to the University of Oxford (United Kingdom). Vienna University of Technology has the highest value in Austria (28.3), the University of Munich in Germany (52.7), Universidad de Barcelona in Spain (49.9), Loránd Budapest University in Hungary (25.1), Rome La Sapienza University in Italy (53.5), Pierre and Marie Curie University in France (58.2). For comparison, the highest Shanghai ranking is assigned to the Harvad University in United States, meaning that, for instance, the University of Oxford produces 66% of the Harvad University research output.

Several specifications of variables reflecting the university's characteristics, output and world excellence have been tested alternately. The baseline specification is Model 1, which includes only national dummies. Model 2 tests the role of average university composition (proxied by the average age of the university, the presence of medical schools, the type of faculties in the university, and the presence of Ph.D. programmes). Models 3 and Model 4 analyse the university outputs in terms, respectively, of the number of national and international students, the Shanghai index and the number of total patents also slit in different sectors (biotechnology, informatics and commercial technology, nanotechnology, medical and pharmaceutical). Model 5 tests the effect of composition, reputation and output through the age of the university, the presence of medical schools, the type of faculties, the presence of Ph.D. programmes, the number of national and international students, the Shanghai index and the number of total patents. Model 6, as explained later on, analyses the Shanghai index of the first tier university vs that of all the other universities in the province, whereas Model 7 analyses the Shanghai index of the first and second tier universities vs that of all the remaining universities in the province. Multicollinearity among the regressors is assessed by computing the variance inflation factor (VIF).

5. The empirical evidence

The marginal effects of the multivariate probit regressions are reported for various specifications in Tables 3–7 (Models 1 to 5). The standard errors of the coefficients have been clustered around the country in which the firm is located. The likelihood ratio test, which was conducted on the hypothesis that the ρs are jointly null, is highly significant and supports the multivariate five-equation framework. The correlation coefficients (see Table 2) are significant for the internal R&D investment in that the presence of intra muros R&D is correlated with product and process innovation. The two equations related to external collaborations are also correlated and the two equations related to product and process innovation.

[Table 2 around here]

Table 3 reports the marginal effects for Equation 1, for *intra muros* R&D investment. The dummy for R&D subsidies is positive and highly statistically significant, while very small and small firm size and proprietorship are negatively correlated with in-house R&D. British and Italian firms are more likely to invest in *intra muros* R&D while Hungarian and Spanish firms are less likely to do so (relative to Austria), with the other country dummies being insignificant. As expected, skilled employees are positive correlated with in-house R&D.

Among the university characteristics, the age of the university is not conducive to *intra muros* R&D investment whereas the type of faculties becomes significant after that the education variables and the Shangai index are added. The presence of international students has a negative impact on *intra muros* R&D, while both the Shanghai index and the number of total patents are conducive to *intra muros* R&D investment.

[Table 3 around here]

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

With regards to the university's characteristics, age is positive and statistically significant, suggesting that older universities are more involved in R&D collaboration with firms since university age is a proxy for reputation and because of longstanding established networks between firms and universities. The number of total patents is negative and statistically significant probably because of rivalry between university-company co-patents and the patents produced by other firms in the province. The total Shanghai index is not significant underlining no effect of average academic quality on university-company collaboration. This result could be explained by the fact that we take into account the presence of highly quality research academic institutions at a very disaggregated level such as at the province; therefore, it might happen that firms, using cutting-edge technology, prefer to collaborate with more distant high quality universities and/or that local prestigious universities prefer to collaborate with distant large firms on richly supported cutting-edge research projects. Alternatively, for more applied research, the explanation could be that firms prefer to collaborate with close universities even if they are not very prestigious. Finally, we do not specifically know exactly which university the firm is collaborating with.

[Table 4 around here]

Table 5 reports the marginal effects for Equation 3 (R&D collaboration with other firms/consultants). The *intra-muros* R&D intensity has a negative effect on the probability of building a collaboration with other firms/consultants, suggesting substitution (and not complementarity) between *intra-muros* R&D and *extra-muros* R&D investments with other firms, whereas the *extra-muros* R&D intensity with universities or research labs has a positive effect. The dummy for R&D subsidies is still positive and highly statistically significant and in addition the dummy for R&D acquired abroad is positive and significant with a high marginal effect. Limited liability sole proprietorship is negative and significant; British, German and Italian firms are more likely to collaborate with other firms/consultants, relative to Austria. The age of the university is still positive and statistically significant, while the presence of medical schools and of agriculture faculties is not conducive to R&D collaboration with other firms or consultants. The Shanghai index is positive and statistically significant, suggesting that the presence of prestigious universities in the area where the firm is located increases the likelihood that the firm would start a collaboration with other firms or consultants.

[Table 5 around here]

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

The age of the university is negative and statistically significant, while the presence of a medical school favours product innovation. The number of international students is detrimental to product innovation, probably due to the fact that part of the knowledge spillovers channelled by education will benefit other countries; moreover, academics have to deal with additional teaching hours (as also international students are enrolled) and not much time is left for activities with local knowledge spillovers; finally, universities with international students may be also relatively more involved in codified knowledge teaching and research, and less focused on applied activities. The Shanghai index is always positive and highly statistically significant; this means that academic excellence has an important direct effect on the firm's propensity to innovate and develop new products, apart from the indirect effect going through the partner choice in university-firm collaboration.

[Table 6 around here]

Finally, Table 7 reports the marginal effects for Equation 5 (process innovation). Process innovation is strongly determined by R&D collaboration both with universities/research labs and with other firms. R&D intensity and skilled employees are positive and highly significant. Process innovation is also favoured by public incentives. Very small and small firms are less likely to innovate their processes as well as proprietorship. France, Germany, Hungary, Italy, Spain and UK all exhibit lower propensities for process innovation than Austria (the base or benchmark case). Regarding the university's characteristics, the age of the university is positive and statistically significant, whereas the presence of the faculty of humanities is detrimental to process innovation. The Shangai index is not statistically significant.

[Table 7 around here]

So far, the empirical evidence suggests that academic research quality has an important direct effect on the firm's propensity to develop innovative products. In order to explore whether this result is mainly driven by top tier universities or whether also less prestigious universities play a role, we disaggregate the total Shanghai index. First of all, we isolate the most prestigious university in the province where the firm is located. We start from the Shanghai ranking and first separate the most prestigious university (*First tier university*) which corresponds to the university in the province that has the highest Shanghai index. Then, we grouped all the other universities apart from the most prestigious one naming them *Lower tier universities (1)*. The main results are generally confirmed, therefore we report only the models with countries dummies and all the university characteristics (Tables 3 to 7, Model 6). Focusing on the prestige of the university, the empirical evidence shows that when a first tier university is present in the same province where the firm is located, then the firm is more likely to invest in *intra-muros* R&D (Table 3, Model 6) and to collaborate with universities or research labs (Table 4, Model 6). Research at first and lower tier universities has an important direct effect on firm propensity to innovate and develop new products (Table 6, Model 6). Interestingly, the marginal effect associated with the research of lower tier universities has a higher value than that associated with the star university.

Finally, we also take into account that in a specific province there might be more than one star university. Therefore, in order to explore whether the results are affected by this possibility, we further disentangle the effect associated with the first, second and futher tier universities. Again, starting from the Shanghai ranking, we isolate the first two star universities at the province level, *First/Second tier universities,* from all the other academic institutions *Lower tier universities (2)*. Results (again only for the main specifications), confirming the main findings of the analysis, are summarized in Tables 3 to 7, Model 7. The Shangai index of the first two tier universities increases the likelihood that the firm invests in *intra-muros* R&D (Table 3, Model 7) and the propensity of the firm to collaborate with universities or research labs (Table 4, Model 7) and with other firms or consultants (Table 5, Model 7). Moreover, both the first two tier and the further tier universities have a positive marginal effect on firm propensity to develop new products but the marginal effect of the third and further tier institutions is again higher, even if weakly significant, than that of the two most prestigious universities (Table 6, Model 7).

6. **Robustness check**

A final point needs to be discussed. As previously specified (see Section 4.2 above), in order to measure the reputation of the academic institutions we have used the Academic Ranking of World Universities (ARWU), also known as Shanghai academic ranking and more specifically we focused on the ranking based on the research output criteria according to which the highest scoring institution is assigned a score of 100, and other institutions are calculated as a percentage of the top score. The main problem associated with this ranking is that the Shanghai index ranks the universities up to the 500th position; in order to solve this issue and not to lose information on the universities which are ranked further than the 500th position but that are located in a province included in our dataset, a fixed number of 3 has been assigned to each university which is ranked further than the 500th position. As the university in our dataset with the lowest ranking within the 500th position has an index of 17 meaning that it produces 17% of the research output compared to the first ranked university, we are assuming that each university which is ranked further than the 500th position produces 3% of research output compared to the first ranked university. It could be argued that this assumption might over-estimate the contribution of less prestigious universities. Therefore, for robustness, we have also assigned values of 0.5, 1 and 2 in order to test whether the value imputed to the research output of universities classified over the 500th position might influence our results; in other words, we assume that each university ranked worst than the 500th position produces 0.5%, 1% and then 2% of the first ranked university reseach output. Results (as the main findings are confirmed, we report only the main specification and the main variables proxing the research excellence of the universities) are summarized, for all the dependent variables of the multiprobit regression in Table 8. The empirical evidence shows that the values imputed to each university positioned worse than the 500th position do not affect our results; indeed, for all the robustness values, the presence of a first tier university in the same province where firms are located, increase the likelihood that firms invest in intra-muros R&D and collaborate with universities or research labs. Only for the imputed value equal to 0.5, the research at the first tier university has a higher marginal effect on product innovation than that of lower tier universities. Importantly, it is also confirmed that the coefficient associated with the Shangai index of the third and further tier universities in the equation for product innovation is higher than that associated with the first and second tier universities, even if the former is only weakly significant.

Finally, we also assume that all the universities in the province, ranked worst than the 500th position, produce not individually but together 0.5%, 1% and 2% of the first ranked university research output. The main results are confirmed.

[Table 8 around here]

7. Concluding remarks

Academic research has a direct impact on the firm's propensity to develop innovative products. This is consistent with the idea that the reputation of a research organization is not only limited to the likelihood of attracting business partners and that further effects could be displayed by research institutions on the capacity of firms to innovate through education, informal relationships as well as consultancy activities. More specifically, both the research output of second and third tier universities has an important direct effect on the propensity of firms to innovate; however, the research output of third tier universities may be even more important than that of the most prestigious universities. This could be explained by the fact that lower tier institutions might better meet firm's needs, and especially when cutting-edge research is not involved, they are more likely to solve the firm's problems guaranteeing a more productive interaction between academics and the firm's research teams, wether or not this interaction is a formal R&D collaboration.

From the policy viewpoint, this study does not support the suggestion that the attraction of star scientists, by means of appropriate financial incentives or targeted scholarships, working in disciplines relevant to local high-tech sectors, could provide some support to regional innovation. In order to better integrate the academic departments in the local economy, we find a strong case in favour of public funding not only to top tier universities but also to less prestigious academic institutions. Indeed, if the main objective of the policy maker is maximising local knowledge spillovers, then more resources should be distributed to lower tier universities, which, according to our results, are more productive of knowledge spillovers at the local level. The allocation of funds to universities on the basis of academic research output indicators is crucial but could be linked to achievable targets, so that the distribution of resources would not exceedingly penalise less prestigious universities whose knowledge and technology transfer activities are directly useful to most local firms. Indeed, by betting only on academic excellence, then very small firms, which are numerous in European manufacturing, could be strongly penalized through knowledge under-production.

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TABLES

Table n. 1 - Variables and descriptive statistics

Variables	*Description of the variables*	*Mean*	*Std. Dev.*	*Min*	*Max*
Firm characteristics					
Intra muros R&D	*Dummy variable taking the value of one in case the firm undertaken any intra-muros R&D activities*	*0.482*	*0.499*	*0*	*1*
R&D collaboration with other firms/cons	*Dummy variable taking the value of one in case the firm undertaken any R&D activities with other firms*	*0.089*	*0.285*	*0*	*1*
R&D collaboration with univ/res labs	*Dummy variable taking the value of one in case the firm undertaken any R&D activities with universities/research labs*	*0.048*	*0.215*	*0*	*1*
Product innovation	*Dummy variable taking the value of one in case the firm carried out any product innovation*	*0.490*	*0.499*	*0*	*1*
Process innovation	*Dummy variable taking the value of one in case the firm carried out any process innovation*	*0.439*	*0.496*	*0*	*1*
Dummy for R&D acquired abroad	*Dummy variable taking the value of one in case the firm undertaken any R&D activities abroad*	*0.018*	*0.0135*	*0*	*1*
R&D intensity (%)	*Percentage of the total turnover that the firm has invested in R&D*	*3.586*	*7.714*	*0*	*100*
Intra muros R&D intensity (%)	*Intra muros R&D intensity*	*3.207*	*7.278*	*0*	*100*
Extra muros R&D with impr (%)	*Extra muros R&D intensity with firms/consultants*	*0.125*	*0.966*	*0*	*50*
Extra muros R&D with univ (%)	*Extra muros R&D intensity with universities/research labs*	*0.251*	*1.661*	*0*	*70*
R&D subsidy dummy	*Dummy variable taking the value of one in case the firm received financial incentives for R&D activities*	*0.161*	*0.368*	*0*	*1*
Subsidiy dummy	*Dummy variable taking the value of one in case the firm received financial incentives provided by the public sector*	*0.182*	*0.386*	*0*	*1*
Skilled employees (%)	*Percentage of graduates in firm workforce*	*9.453*	*13.498*	*0*	*100*
CEO age	*Age of the firm CEO*	*51.982*	*10.218*	*24*	*76*
CEO gender	*Dummy variable taking the value of one in case the firm CEO is male*	*0.923*	*0.265*	*0*	*1*
Firm age	*Firm age in the year in which the firm has been surveyed*	*34.529*	*30.625*	*0*	*368*
Very small firm size	*Dummy variable taking the value of one in case the firm has betweeen 10 and 19 employees*	*0.318*	*0.465*	*0*	*1*
Small firm size	*Dummy variable taking the value of one in case the firm has betweeen 20 and 49 employees*	*0.412*	*0.492*	*0*	*1*
Medium firm size	*Dummy variable taking the value of one in case the firm has betweeen 50 and 99 employees*	*0.120*	*0.325*	*0*	*1*
Large firm size	*Dummy variable taking the value of one in case the firm has betweeen 100 and 249 employees*	*0.081*	*0.272*	*0*	*1*
Very large firm size (Reference group)	*Dummy variable taking the value of one in case the firm has more than 249 employees*	*0.068*	*0.252*	*0*	*1*
Proprietorship/Ownership dummy	*Dummy variable taking the value of 1 in case the firms is a proprietorship (entreprise individuelle / en nom personnel)*	*0.016*	*0.128*	*0*	*1*
Sa dummy	*Dummy variable taking the value of 1 in case the firm is a public company (société anonyme)*	*0.123*	*0.329*	*0*	*1*
Sarl dummy	*Dummy variable taking the value of 1 in case the firm is a limited liability partnership (société a responsabilité limitée)*	*0.731*	*0.443*	*0*	*1*
Eurl dummy	*Dummy variable taking the value of 1 in case the firm is a limited liability sole proprietorship (entreprise unipersonnelle à responsabilité limitée)*	*0.002*	*0.052*	*0*	*1*
Coop dummy	*Dummy variable taking the value of 1 in case the firm is a cooperative*	*0.019*	*0.137*	*0*	*1*

Sas dummy (Reference group)	*Dummy variable taking the value of 1 in case the legal form of the firm is a public limited company (société par actions simplifiée)*	*0.106*	*0.308*	*0*	*1*
Patent	*Dummy variable taking the value of 1 in the case the firm has applied for a patent*	*0.131*	*0.338*	*0*	*1*
Design	*Dummy variable taking the value of 1 in the case the firm has registered an industrial design*	*0.079*	*0.270*	*0*	*1*
Trademark	*Dummy variable taking the value of 1 in the case the firm has registered a trademark*	*0.127*	*0.333*	*0*	*1*
Copyright	*Dummy variable taking the value of 1 in the case the firm has claimed copyright*	*0.043*	*0.203*	*0*	*1*
Territorial and university characteristics					
Rurality of the province	*Variable taking the value of 0 if the region/province where the firm is located is predominantly urban, the value of 1 if intermediate urban and the value of 2 if predominantly rural (sourced from OECD)*	*1.843*	*0.762*	*1*	*3*
Age of university	*Average by NUTS 3 of university age*	*64.870*	*132.730*	*0*	*876*
Medical School	*Sum by NUTS 3 of the university dummy taking the value of 1 if the university has a hospital*	*0.628*	*1.217*	*0*	*8*
Agriculture	*Sum by NUTS 3 of the university dummy taking the value of 1 if Agriculture is a field of education*	*0.427*	*0.871*	*0*	*7*
Humanities and Arts	*Sum by NUTS 3 of the university dummy taking the value of 1 if Humanities and Arts is a field of education*	*1.474*	*2.990*	*0*	*20*
Business and Law	*Sum by NUTS 3 of the university dummy taking the value of 1 if Social Sciences, Business and Law is a field of education*	*1.398*	*2.988*	*0*	*21*
Engineering	*Sum by NUTS 3 of the university dummy taking the value of 1 if Engineering, Manufacturing and Construction is a field of education*	*1.404*	*2.412*	*0*	*13*
Ph.D.	*Sum by NUTS 3of the university dummy taking the value of 1 if Ph.D. programmes are offered*	*1.597*	*3.092*	*0*	*25*
National students	*Sum by NUTS 3 of the university number of national students*	*26,861*	*55,309*	*0*	*264,679*
International students	*Sum by NUTS 3 of the university number of international students*	*1,595*	*5,011*	*0*	*54,315*
Shangai index	*Value of the Shanghai ranking associated with local universities (sum of university values by the NUTS 3 where the firm is located)*	*23.217*	*46.435*	*0*	*353.7*
First tier university	*Value of the Shanghai ranking associated only with the first university located in the NUTS 3 where the firm is located*	*10.631*	*17.660*	*0*	*66*
Lower tier universities (1)	*Value of the Shanghai ranking associated with all universities other than the first one located in the NUTS 3 where the firm is located*	*12.585*	*32.826*	*0*	*295.5*
First/Second tier universities	*Value of the Shanghai ranking associated only with the first and second universies located in the NUTS 3 where the firm is located*	*15.432*	*27.290*	*0*	*127.6*
Lower tier universities (2)	*Value of the Shanghai ranking associated with all universities other than the first and second ones located in the NUTS 3 where the firm is located*	*7.778*	*25.371*	*0*	*248.5*
Total patents	*Number of total patents in the NUTS 3 where the firm is located*	*90.371*	*292.480*	*0*	*3955.744*
Biotech patents	*Number of Biotech patents in the NUTS 3 where the firm is located*	*4.850*	*15.499*	*0*	*220.90*
Inform and Comm tech patents	*Number of Inform and Comm patents in the NUTS 3 where the firm is located*	*21.242*	*102.211*	*0*	*1237*
Nanotech patents	*Number of Nanotech patents in the NUTS 3 where the firm is located*	*0.647*	*3.219*	*0*	*52.50*
Medical patents	*Number of Medical patents in the NUTS 3 where the firm is located*	*4.974*	*11.703*	*0*	*173.30*
Pharmaceutical patents	*Number of Pharmaceutical patents in the NUTS 3 where the firm is located*	*7.390*	*26.475*	*0*	*314.50*

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

Coefficients	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Rho21	0.053	0.054	0.053	0.054	0.053	0.053	0.053
Rho31	**0.084***	**0.085***	**0.084***	**0.085***	**0.084***	**0.084***	**0.085***
Rho41	**0.241*****	**0.241*****	**0.240*****	**0.240*****	**0.240*****	**0.240*****	**0.240*****
Rho51	**0.155*****	**0.155*****	**0.155*****	**0.155*****	**0.155*****	**0.155*****	**0.155*****
Rho32	**0.128*****	**0.128*****	**0.128*****	**0.128*****	**0.128*****	**0.128*****	**0.128*****
Rho42	0.007	0.007	0.006	0.007	0.007	0.007	0.006
Rho52	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Rho43	-0.003	-0.002	-0.003	-0.003	-0.002	-0.002	-0.002
Rho53	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Rho54	**0.198*****	**0.198*****	**0.198*****	**0.198*****	**0.198*****	**0.198*****	**0.198*****

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

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Variables	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
R&D subsidy dummy	**0.471*****	**0.472*****	**0.472*****	**0.472*****	**0.472*****	**0.472*****	**0.472*****
Skilled employees	**0.003*****	**0.003*****	**0.003*****	**0.003*****	**0.003*****	**0.003*****	**0.003*****
Ceo age	-0.0009	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
Ceo gender	**-2.43e-11*****	**-2.55e-11*****	**-2.52e-11*****	**-2.66e-11*****	**-2.65e-11*****	**-2.58e-11*****	**-2.52e-11*****
Firm Age	0.0002	**0.0002***	0.0002	0.0002	0.0002	0.0002	0.0002
Very small firm size	**-0.150*****	**-0.150*****	**-0.151*****	**-0.151*****	**-0.150*****	**-0.151*****	**-0.151*****
Small firm size	**-0.089*****	**-0.089*****	**-0.089*****	**-0.090*****	**-0.089*****	**-0.089*****	**-0.090*****
Medium firm size	-0.027	-0.027	-0.026	-0.027	-0.026	-0.026	-0.027
Large firm size	0.002	0.003	0.002	0.001	0.002	0.002	0.002
Proprietorship/Own dummy	**-0.085*****	**-0.083*****	**-0.084*****	**-0.082*****	**-0.083*****	**-0.083*****	**-0.083****
Sa dummy	0.007	0.006	0.006	0.005	0.006	0.006	0.006
Sarl dummy	0.011	0.011	0.012	0.013	0.012	0.012	0.012
Eurl dummy	**-0.032*****	**-0.033*****	**-0.027*****	**-0.027*****	**-0.029*****	**-0.029*****	**-0.029*****
Coop dummy	**-0.041*****	**-0.040*****	**-0.037*****	**-0.035*****	**-0.036*****	**-0.037*****	**-0.036*****
Patent	**0.230*****	**0.230*****	**0.229*****	**0.229*****	**0.229*****	**0.229*****	**0.228*****
Design	**0.116*****	**0.117*****	**0.116*****	**0.115*****	**0.116*****	**0.116*****	**0.116*****
Trademark	**0.080*****	**0.080*****	**0.081*****	**0.081*****	**0.081*****	**0.082*****	**0.082*****
Copyright	0.022	0.021	0.022	0.022	0.021	0.021	0.021
Rurality of the province	0.008	0.009	0.009	0.008	0.013	0.013	0.013
France dummy	0.012	0.023	0.005	0.003	0.020	0.020	0.029
Germany dummy	0.017	0.022	0.003	0.003	0.006	0.008	0.012
Hungary dummy	**-0.235*****	**-0.224*****	**-0.246*****	**-0.242*****	**-0.245*****	**-0.242*****	**-0.240*****
Italy dummy	**0.026*****	**0.032****	0.007	0.009	0.015	0.016	0.018
Spain dummy	**-0.073*****	**-0.072*****	**-0.087*****	**-0.094*****	**-0.075*****	**-0.074*****	**-0.073*****
Uk dummy	**0.024*****	**0.035*****	**0.021*****	**0.020****	**0.034*****	**0.032*****	**0.034*****
Age of university		0.00002			0.00001	2.93e-06	8.40e-06
Medical School		0.008			0.001	0.0007	-0.004
Agriculture		-0.006			-0.004	-0.005	-0.006
Humanities		-0.005			-0.008	-0.008	-0.007
Business and Law		0.007			**0.011****	**0.012****	**0.013****
Engineering		-0.001			**-0.009***	**-0.011****	**-0.012****
Ph.D.		-0.0004	-0.010	-0.009	-0.004	-0.0002	0.002
National students			**2.00e-07***	6.80e-08	1.60e-07	7.53e-08	-2.77e-09
International students			**-3.18e-06****	**-2.63e-06***	**-4.78e-06*****	**-4.51e-06*****	**-4.81e-06*****
Shangai index			**0.0008****	**0.0007***	**0.0009****		
First tier university						**0.001****	
Lower tier universities (1)						0.0005	
First/Second tier university							**0.001****
Lower tier universities (2)							0.0001
Total Patents			**0.00001***		**0.00001***	**0.00001***	**0.00001***
Biotech patents				-0.0002			
Inform and Comm tech patents				0.00002			
Nanotech patents				-0.004			
Medical patents				**0.0007****			
Pharmaceutical patents				**0.0007*****			

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

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Variables	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
Intramuros R&D	**-0.0007****	**-0.0007****	**-0.0007****	**-0.0007****	**-0.0007****	**-0.0007****	**-0.0007****
Extramuros R&D with firms	**0.003***	**0.003***	**0.003***	**0.003***	**0.003***	**0.003***	**0.003***
Dummy for R&D acquired abroad	**0.098*****	**0.098*****	**0.099*****	**0.099*****	**0.099*****	**0.099*****	**0.099*****
R&D subsidy dummy	**0.064*****	**0.063*****	**0.064*****	**0.064*****	**0.064*****	**0.064*****	**0.064*****
Skilled employees	**0.0003*****	**0.0004*****	**0.0004*****	**0.0004*****	**0.0004*****	**0.0004*****	**0.0004*****
Ceo age	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
Ceo gender	**-4.08e-11*****	**-3.98e-11*****	**4.01e-11*****	**-3.92e-11*****	**-4.01e-11*****	**-3.98e-11*****	**-3.98e-11*****
Firm Age	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00005
Very small firm size	**-0.014*****	**-0.014*****	**-0.014*****	**-0.014*****	**-0.015*****	**-0.014*****	**-0.015*****
Small firm size	-0.001	-0.001	-0.002	-0.002	-0.001	-0.001	-0.001
Medium firm size	**0.005***	**0.005***	0.005	**0.005***	0.005	**0.005***	**0.005***
Large firm size	**0.009***	0.009	0.009	0.009	0.009	0.009	0.009
Proprietorship/Own dummy	**-0.084*****	**-0.083*****	**-0.083*****	**-0.084*****	**-0.083*****	**-0.083*****	**-0.083*****
Sa dummy	**-0.026*****	**-0.026*****	**-0.026*****	**-0.025*****	**-0.025*****	**-0.025*****	**-0.025*****
Sarl dummy	**-0.014*****	**-0.014*****	**-0.014*****	**-0.015*****	**-0.015*****	**-0.015*****	**-0.015*****
Eurl dummy	**-0.329*****	**-0.365*****	**-0.329*****	**-0.333*****	**-0.364*****	**-0.437*****	**-0.330*****
Coop dummy	-0.004	-0.005	-0.004	-0.004	-0.004	-0.005	-0.004
Patent	**0.029*****	**0.029*****	**0.029*****	**0.029*****	**0.029*****	**0.029*****	**0.028*****
Design	0.002	0.002	0.003	0.002	0.002	0.002	0.002
Trademark	**0.013*****	**0.013*****	**0.014*****	**0.013*****	**0.014*****	**0.014*****	**0.014*****
Copyright	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Rurality of the province	0.003	0.003	0.002	0.002	0.003	0.003	0.003
France dummy	**-0.042*****	**-0.041*****	**-0.046*****	**-0.045*****	**-0.043*****	**-0.043*****	**-0.042*****
Germany dummy	**-0.010****	**-0.012***	**-0.014****	**-0.013****	-0.012	-0.013	-0.012
Hungary dummy	**-0.011****	-0.013	**-0.013*****	**-0.013****	**-0.016***	**-0.016***	**-0.016***
Italy dummy	**-0.030*****	**-0.030*****	**-0.033*****	**-0.034*****	**-0.034*****	**-0.034*****	**-0.034*****
Spain dummy	**-0.019*****	**-0.015****	**-0.022*****	**-0.020*****	**-0.016****	**-0.017*****	**-0.016****
Uk dummy	**-0.020*****	**-0.020*****	**-0.022*****	**-0.021*****	**-0.021*****	**-0.021*****	**-0.021*****
Age of university		**0.00001****			**0.00001*****	**0.00001*****	**0.00001*****
Medical School		-0.004			**-0.007****	**-0.007****	**-0.007****
Agriculture		0.0009			0.0001	0.0004	0.0005
Humanities		-0.00001			-0.001	-0.001	-0.001
Business and Law		0.0001			0.0004	0.0003	0.0005
Engineering		-0.0001			-0.001	-0.0007	-0.001
Ph.D.		-0.0001	-0.002	-0.001	-0.0006	-0.001	-0.003
National students			-1.31e-08	2.83e-08	9.98e-08	1.12e-07	9.10e-08
International students			**-6.24e-07****	**-7.98e-07****	**-1.13e-06****	**-1-14e-06****	**-1.14e-06****
Shangai index			0.0001	0.0001	0.0002		
First tier university						**0.0001***	
Lower tier universities (1)						0.0002	
First/Second tier university							**0.0002***
Lower tier universities (2)							0.0001
Total Patents			**-0.00001****		**-0.00001****	**-0.00001****	**-0.00001****
Biotech patents				0.00002			
Inform and Comm tech patents				**-0.00007*****			
Nanotech patents				**0.002****			
Medical patents				0.0001			
Pharmaceutical patents				**-0.0003*****			

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

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Variables	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
Intramuros R&D	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***	-0.001***
Extramuros R&D with univ	0.029**	0.029**	0.029**	0.029**	0.029**	0.029**	0.029**
Dummy for R&D acquired abroad	0.261***	0.261***	0.261***	0.260***	0.261***	0.261***	0.261***
R&D subsidy dummy	0.066***	0.066***	0.066***	0.066***	0.066***	0.066***	0.066***
Skilled employees	0.00004***	0.0004***	0.0004***	0.0005***	0.0004***	0.0004***	0.0004***
Ceo age	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002
Ceo gender	-6.23e-11***	-4.59e-11***	-6.25e-11***	-6.21e-11***	-5.32e-11***	-4.27e-11***	-6.19e-11***
Firm Age	-0.00003	-0.00003	-0.00003	-0.00002	-0.00003	-0.00003	-0.00003
Very small firm size	0.003	0.002	0.003	0.003	0.003	0.003	0.003
Small firm size	0.009	0.009	0.010	0.010	0.009	0.009	0.009
Medium firm size	0.011	0.011	0.012	0.012	0.012	0.012	0.012
Large firm size	0.017*	0.017*	0.017**	0.018**	0.017*	0.017*	0.017**
Proprietorship/Own dummy	-0.032	-0.033*	-0.034*	-0.035*	-0.034*	-0.034*	-0.034*
Sa dummy	-0.007	-0.006	-0.006	-0.006	-0.007	-0.007	-0.007
Sarl dummy	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015
Eurl dummy	-0.034***	-0.032***	-0.030***	-0.031***	-0.031***	-0.031***	-0.031***
Coop dummy	0.005	0.005	0.005	0.004	0.005	0.005	0.005
Patent	0.009	0.009	0.009	0.009	0.009	0.009	0.009
Design	0.048***	0.048***	0.048***	0.048***	0.048***	0.048***	0.048***
Trademark	0.026***	0.026***	0.026***	0.026***	0.026***	0.026***	0.026***
Copyright	0.018**	0.018**	0.018**	0.018**	0.018**	0.018**	0.018**
Rurality of the province	0.001	0.001	0.002	0.002	0.002	0.002	0.002
France dummy	-0.009	-0.008	-0.013	-0.013	-0.009	-0.009	-0.009
Germany dummy	0.016***	0.023***	0.014***	0.013***	0.017***	0.018	0.017***
Hungary dummy	-0.045***	-0.039***	-0.043***	-0.044***	-0.038***	-0.038***	-0.038***
Italy dummy	0.039***	0.046***	0.041***	0.041***	0.045***	0.045***	0.045***
Spain dummy	0.004	0.014**	0.009**	0.009***	0.014***	0.012**	0.014***
Uk dummy	0.044***	0.051***	0.043***	0.042***	0.049***	0.048***	0.049***
Age of university		0.00001***			0.00001**	9.75e-06	0.00001*
Medical School		-0.003**			-0.0007	-0.008	-0.0007
Agriculture		-0.009***			-0.007**	-0.008***	-0.007***
Humanities		-0.001			-0.001	-0.001	-0.001
Business and Law		0.0009			0.002**	0.002	0.002
Engineering		-0.0007			-0.001	-0.002	-0.001
Ph.D.		0.003**	-0.001	-0.001	0.00008	0.001	0.00008
National students			-2.01e-07***	-1.63e-07***	-1.21e-07**	-1.40e-07**	-1.21e-07**
International students			2.16e-07	2.82e-07	1.34e-07	-1.72e-07	-1.35e-07
Shangai index			0.0002*	0.0002	0.0002***		
First tier university						0.0003	
Lower tier universities (1)						0.0001	
First/Second tier university							0.0002**
Lower tier universities (2)							0.0002
Total Patents			6.19e-06**		6.11e-06**	6.55e-06**	6.11e-06**
Biotech patents				-0.0001			
Inform and Comm tech patents				2.53e-06			
Nanotech patents				0.001			
Medical patents				0.00003			
Pharmaceutical patents				-0.00009			

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

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Variables	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
R&D collab. with univ/res labs	**0.104*** **	**0.104*** **	**0.103*** **	**0.103*** **	**0.103*** **	**0.103*** **	**0.104*** **
R&D collab. with other firms/cons	**0.101*** **	**0.100*** **	**0.101*** **	**0.101*** **	**0.100*** **	**0.101*** **	**0.100*** **
R&D intensity	**0.009*** **	**0.009*** **	**0.009*** **	**0.009*** **	**0.009*** **	**0.009*** **	**0.009*** **
Subsidy dummy	**0.057*** **	**0.057*** **	**0.057*** **	**0.058*** **	**0.058*** **	**0.058*** **	**0.058*** **
Skilled employees	**0.002*** **	**0.002*** **	**0.002*** **	**0.002*** **	**0.002*** **	**0.002*** **	**0.002*** **
Ceo age	**-0.0008***	**-0.0008***	**-0.0008***	**-0.0008***	**-0.0008***	**-0.0008***	**-0.0008***
Ceo gender	**0.026*** **	**0.026*** **	**0.027*** **	**0.027*** **	**0.027*** **	**0.027*** **	**0.027*** **
Firm Age	**0.0003****	**0.0003****	**0.0003****	**0.0003****	**0.0003****	**0.0003****	**0.0003****
Very small firm size	**-0.070****	**-0.070****	**-0.071****	**-0.072****	**-0.071****	**-0.071****	**-0.071****
Small firm size	-0.030	-0.030	-0.031	-0.031	-0.030	-0.030	-0.030
Medium firm size	-0.010	-0.010	-0.011	-0.011	-0.010	-0.010	-0.010
Large firm size	0.019	0.019	0.017	0.017	0.017	0.017	0.017
Proprietorship/Own dummy	0.017	0.017	0.019	0.018	0.018	0.018	0.018
Sa dummy	0.016	0.015	0.017	0.016	0.015	0.015	0.015
Sarl dummy	-0.003	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
Eurl dummy	**0.022*** **	**0.022*** **	**0.024*** **	**0.023*** **	**0.024*** **	**0.024*** **	**0.024*** **
Coop dummy	**-0.081***	**-0.080***	**-0.080***	**-0.081***	**-0.080***	**-0.080***	**-0.080***
Patent	**0.238*** **	**0.238*** **	**0.238*** **	**0.237*** **	**0.238*** **	**0.238*** **	**0.238*** **
Design	**0.175*** **	**0.175*** **	**0.175*** **	**0.175*** **	**0.175*** **	**0.175*** **	**0.175*** **
Trademark	**0.164*** **	**0.164*** **	**0.165*** **	**0.165*** **	**0.165*** **	**0.165*** **	**0.165*** **
Copyright	**0.105*** **	**0.106*** **	**0.106*** **	**0.106*** **	**0.107*** **	**0.107*** **	**0.107*** **
Rurality of the province	0.014	0.012	0.013	0.013	0.012	0.012	0.012
France dummy	**-0.093*** **	**-0.096*** **	**-0.106*** **	**-0.107*** **	**-0.103*** **	**-0.103*** **	**-0.104*** **
Germany dummy	**-0.128*** **	**-0.127*** **	**-0.137*** **	**-0.137*** **	**-0.136*** **	**-0.136*** **	**-0.136*** **
Hungary dummy	**-0.093*** **	**-0.076*** **	**-0.100*** **	**-0.099*** **	**-0.084*** **	**-0.084*** **	**-0.085*** **
Italy dummy	**-0.065*** **	**-0.058*** **	**-0.077*** **	**-0.077*** **	**-0.069*** **	**-0.070*** **	**-0.070*** **
Spain dummy	**-0.109*** **	**-0.118*** **	**-0.119*** **	**-0.117*** **	**-0.123*** **	**-0.123*** **	**-0.123*** **
Uk dummy	0.001	0.007	-0.001	0.0007	0.003	0.003	0.003
Age of university		**-0.00005****			**-0.00005*** **	**-0.00005*** **	**-0.00005*** **
Medical School		**0.014****			**0.012*** **	**0.012*** **	**0.013*** **
Agriculture		-0.010			-0.009	-0.008	-0.008
Humanities		-0.004			-0.007	-0.007	-0.007
Business and Law		0.003			0.005	0.005	0.005
Engineering		-0.002			**-0.007****	**-0.007***	**-0.006****
Ph.D.		0.001	**-0.007****	**-0.006***	-0.004	-0.005	-0.006
National students			-1.63e-08	-8.33e-08	-3.64e-08	-2.29e-08	-4.62e-09
International students			**-2.78e-06*** **	**-3.46e-06*** **	**-2.48e-06***	**-2.53e-06***	**-2.48e-06***
Shangai index			**0.0007*** **	**0.0008*** **	**0.0009*** **		
First tier university						**0.0008*** **	
Lower tier universities (1)						**0.001****	
First/Second tier university							**0.0008*** **
Lower tier universities (2)							**0.001***
Total Patents			-0.00001		-0.00001	-0.00001	-0.00001
Biotech patents				0.0004			
Inform and Comm tech patents				-0.00001			
Nanotech patents				**-0.003*** **			
Medical patents				0.0001			
Pharmaceutical patents				-0.0001			

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

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Variables	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
R&D collab. with univ/res labs	**0.085*** **	**0.085*** **	**0.086*** **	**0.085*** **	**0.085*** **	**0.085*** **	**0.085*** **
R&D collab. with other firms/cons	**0.111*** **	**0.111*** **	**0.111*** **	**0.111*** **	**0.111*** **	**0.111*** **	**0.111*** **
R&D intensity	**0.004*** **	**0.004*** **	**0.004*** **	**0.004*** **	**0.004*** **	**0.004*** **	**0.004*** **
Subsidy dummy	**0.097*** **	**0.096*** **	**0.097*** **	**0.097*** **	**0.096*** **	**0.096*** **	**0.096*** **
Skilled employees	**0.001***	**0.001***	**0.001***	**0.001***	**0.001***	**0.001** **	**0.001***
Ceo age	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Ceo gender	**2.99e-11*** **	**2.88e-11*** **	**2.98e-11*** **	**2.98e-11*** **	**2.88e-11*** **	**2.86e-11*** **	**2.87e-11*** **
Firm Age	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006	0.00006
Very small firm size	**-0.162*** **	**-0.162*** **	**-0.162*** **	**-0.162*** **	**-0.161*** **	**-0.161*** **	**-0.161*** **
Small firm size	**-0.098** **	**-0.098** **	**-0.098** **	**-0.098** **	**-0.097** **	**-0.097** **	**-0.097** **
Medium firm size	-0.048	-0.048	-0.048	-0.048	-0.048	-0.048	-0.048
Large firm size	-0.006	-0.005	-0.005	-0.005	-0.005	-0.005	-0.005
Proprietorship/Own dummy	**-0.095*** **	**-0.094*** **	**-0.096*** **	**-0.095*** **	**-0.094*** **	**-0.094*** **	**-0.094*** **
Sa dummy	-0.020	-0.020	-0.020	-0.021	-0.020	-0.020	-0.020
Sarl dummy	-0.017	-0.017	-0.017	-0.016	-0.017	-0.017	-0.017
Eurl dummy	**0.111*** **	**0.108*** **	**0.110*** **	**0.110*** **	**0.108*** **	**0.108*** **	**0.108*** **
Coop dummy	**-0.050*** **	**-0.050*** **	**-0.051*** **	**-0.051*** **	**-0.050*** **	**-0.050*** **	**-0.050*** **
Patent	**0.066*** **	**0.066*** **	**0.066*** **	**0.066*** **	**0.066*** **	**0.066*** **	**0.066*** **
Design	0.021	0.021	0.021	0.021	0.021	0.021	0.021
Trademark	**0.047*** **	**0.047*** **	**0.047*** **	**0.047*** **	**0.047*** **	**0.047*** **	**0.047*** **
Copyright	**0.070** **	**0.069** **	**0.070** **	**0.070** **	**0.069** **	**0.069** **	**0.069** **
Rurality of the province	0.003	0.006	0.004	0.003	0.007	0.007	0.007
France dummy	**-0.180*** **	**-0.159*** **	**-0.172*** **	**-0.174*** **	**-0.156*** **	**-0.156*** **	**-0.156*** **
Germany dummy	**-0.173*** **	**-0.169*** **	**-0.172*** **	**-0.171*** **	**-0.167*** **	**-0.168*** **	**-0.167*** **
Hungary dummy	**-0.213*** **	**-0.205*** **	**-0.210*** **	**-0.207*** **	**-0.206*** **	**-0.207*** **	**-0.206*** **
Italy dummy	**-0.086*** **	**-0.077*** **	**-0.084*** **	**-0.081*** **	**-0.074*** **	**-0.074*** **	**-0.074*** **
Spain dummy	**-0.028*** **	**-0.015** **	**-0.026*** **	**-0.024*** **	**-0.014** **	**-0.015** **	**-0.014** **
Uk dummy	**-0.088*** **	**-0.078*** **	**-0.088*** **	**-0.085*** **	**-0.076*** **	**-0.075*** **	**-0.076*** **
Age of university		**0.00003*** **			**0.00003** **	**0.00004*** **	**0.00003** **
Medical School		-0.0004			0.0003	0.0006	0.0008
Agriculture		0.001			0.002	0.003	0.003
Humanities		**-0.009*** **			**-0.008*** **	**-0.007*** **	**-0.008*** **
Business and Law		**0.010*** **			**0.010*** **	**0.010*** **	**0.010*** **
Engineering		**-0.006** **			**-0.005***	-0.005	**-0.005***
Ph.D.		0.002	0.0008	0.002	0.005	0.003	0.004
National students			**1.42e-07***	3.05e-08	-1.41e-08	2.33e-08	-2.33e-09
International students			1.68e-06	9.05e-07	1.16e-07	-1.83e-07	1.11e-07
Shangai index			-0.0004	-0.0003	-0.0003		
First tier university						-0.0005	
Lower tier universities (1)						-0.0001	
First/Second tier university							-0.0003
Lower tier universities (2)							-0.0002
Total Patents			9.21e-06		**9.24e-06** **	**8.42e-06***	**9.15e-06** **
Biotech patents				**0.001***			
Inform and Comm tech patents				**0.0001*** **			
Nanotech patents				**-0.008** **			
Medical patents				-0.0001			
Pharmaceutical patents				-0.0001			

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

	Dependent Variables				
	Intra muros R&D investment	R&D collaboration with universities/research labs	R&D collaboration with other firms/consultants	Product innovation	Process innovaton
Variables	dF/dx	dF/dx	dF/dx	dF/dx	dF/dx
	Shangai index imputed to each university above the 500th position in the province = 0.5				
First tier university	**0.001****	**0.0001***	0.0003	**0.0009*****	-0.0004
Lower tier universities (1)	0.0005	0.0003	0.0002	**0.0008*****	-0.0002
First/Second tier university	**0.001*****	**0.0002***	**0.0002***	**0.0008*****	-0.0002
Lower tier universities (2)	-0.00009	0.0002	**0.0005****	**0.001***	-0.0004
	Shangai index imputed to each university above the 500th position in the province = 1				
First tier university	**0.001****	**0.0001***	0.0003	**0.0008*****	-0.0004
Lower tier universities (1)	0.0005	0.0003	0.0002	**0.0009*****	-0.0001
First/Second tier university	**0.001****	**0.0002***	**0.0002***	**0.0008*****	-0.0002
Lower tier universities (2)	-0.00003	0.0002	**0.0004****	**0.001***	-0.0004
	Shangai index imputed to each university above the 500th position in the province = 2				
First tier university	**0.001****	**0.0001***	0.0003	**0.0008*****	-0.0005
Lower tier universities (1)	0.0005	0.0003	0.0002	**0.001*****	-0.0002
First/Second tier university	**0.001****	**0.0002***	**0.0002****	**0.0008*****	-0.0003
Lower tier universities (2)	0.00008	0.0002	0.0003	**0.001***	-0.0003
	Shangai index imputed to all the universities above the 500th position in the province = 0.5				
First tier university	**0.001*****	0.0001	0.0002	**0.0009*****	-0.0003
Lower tier universities (1)	0.0005	0.0003	0.0003	**0.0009*****	-0.0002
First/Second tier university	**0.001*****	0.0002*	0.0002	**0.0008******	-0.0002
Lower tier universities (2)	-0.00007	0.0002	**0.0006*****	**0.001****	-0.0005
	Shangai index imputed to all the universities above the 500th position in the province = 1				
First tier university	**0.001*****	0.0001	0.0002	**0.0009*****	-0.0003
Lower tier universities (1)	0.0005	0.0003	**0.0003***	**0.0009*****	-0.0002
First/Second tier university	**0.001*****	0.0002*	**0.0002***	**0.0008******	-0.0002
Lower tier universities (2)	-0.00008	0.0002	**0.0006*****	**0.001****	-0.0005
	Shangai index imputed to all the universities above the 500th position in the province = 2				
First tier university	**0.001*****	0.0001	0.0003	**0.0009*****	-0.0003
Lower tier universities (1)	0.0005	0.0003	**0.0003***	**0.0009*****	-0.0002
First/Second tier university	**0.001*****	0.0002*	0.0002	**0.0008******	-0.0002
Lower tier universities (2)	-0.00009	0.0002	**0.0006*****	**0.001****	-0.0005