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Abstract

This paper aims to study whether high-quality research in first-tier universities has greater local knowledge spillovers than that in lower-tier universities. First-tier universities are identified as those among the top-150, according to the Academic Ranking of World Universities. Several indicators of academic excellence are included among the contextual drivers of innovation in a multivariate probit regression applied to European manufacturing data. The results show that top-10 publications of second-tier universities exhibit the highest positive association with product innovation of science-based sectors but negative associations with top-10 publications of first- and second-tier universities are evidenced for process innovation in this macro-sector.

Keywords: Product and process innovation; Firm R&D collaboration; Academic excellence; Scopus publications; Academic Ranking of World Universities; Regional innovation systems

JEL: O3; I23; D22

INTRODUCTION

The literature on national innovation systems emphasises 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 differs substantially from that where the technology was initially developed (Acs, Audretsch, Lehmann, & Licht, 2017). Particularly, knowledge investments in diversified knowledge and with diversified partners explain systematically stronger national economic performance (Audretsch & Lehmann, 2017).

Since universities play a central role in national innovation systems, particularly in Europe, any reform that affects universities has important implications for the national and regional innovation systems. In recent decades, many changes have occurred in 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, 2008). In line with the EU's Lisbon Strategy, many European countries have implemented reforms whose purpose is to reinforce cooperation between universities, research institutions and industry through contracting-out or collaborative projects and to increase the commercialisation of research (European Commission, 2008). Country pathways are distinguishable in terms of how these reforms have been implemented (Moscati, Regini, & Rostan, 2010), but generally, the role that universities play in regional innovation systems is reinforced even though the way the 'third mission' is perceived may vary accordingly not only within the same university but also within the same department (Moscati et al., 2010). At the same time, academic career advancement is increasingly aligned to the international standard of American and British universities, where publications play a vital role, with a sharp improvement in the academic tradition of self-governance within national regulations.

The possibility of a trade-off between university missions, particularly between academic excellence, as measured by the number of publications in high-ranked journals vs. local knowledge spillovers useful for economic growth has been suggested in the literature (Moscati et al., 2010; Perotti, 2010). One possible explanation is the change in the incentive structure; acts conducive to knowledge spillovers may be not particularly rewarded in academia when career advancement is predominantly dictated by scholar research quality. Consequently, researchers will be more focused on high-ranked journal publications to increase their own reputation. In such circumstances, consultancies or informal collaboration may be too time-demanding, and scholars may tend to concentrate on less industry-oriented academic publications. Furthermore, the decreasing teaching orientation, the increasing internalisation of research paradigms and academic commercialisation (Arimoto, 2011) may hamper the accumulation of knowledge in the public domain and privilege only one specific firm profile (a large-sized company that invests in R&D and patents and collaborates with universities or public research labs).

Complementarity or substitutability between academic research and third mission activities, mainly measured by patent activity, are generally investigated from the university perspective, with a focus on academic research productivity and research agenda composition (Calderini, Franzoni, & Vezzulli, 2007; Calderini, Franzoni, & Vezzulli, 2009).

Scientific research and its market exploitation may be helpful to each other since academic researchers cooperating in firms' projects acquire resources that are useful for future research. This incentive may motivate particularly high performing academics working in lower ranked institutions, where fewer financial resources are available; these scholars may be more likely to be involved in collaborative research and industry networking (Perkmann et al., 2013). On the other hand, for academics involved in very basic or very high-impact research and in fields with poor feedback from industrial research (Calderini et al., 2009), scientific research may be a rival activity with respect to patenting. Particularly in academic systems where academic performances are well monitored and rewarded, academics are not incentivised to sell research in the market (Calderini et al., 2007).

From the perspective of knowledge transfer relevant to the local economy, the literature has paid considerable attention to the analysis of university-firm collaboration through the commercialisation of academic knowledge, involving patenting and licensing of inventions as well as academic entrepreneurship (De Fuentes & Dutrénit, 2016; Laursen, Reichstein, & Salter, 2011). However, informal activities, rather than patenting and academic entrepreneurship, are considered significantly more valuable by many companies and involve more academics (Perkmann et al., 2013). Academic engagement that involves collaborative research, contract research, consulting and informal relationships has a long tradition, particularly at universities with a technical orientation of education and third mission activities (Perkmann et al., 2013). Firms select potential collaborators for academic engagement taking into account individual research productivity and quality in terms of publications and success in raising government grants and funds. Informal participation in collaborative activities may be lower in higher-ranked universities since, as previously mentioned, academics working in lower-tier universities have higher incentive to build collaborations and consulting activities with firms (Perkmann et al., 2013).

The evidence on complementarity among academic excellence and knowledge spillovers from the local economy perspective is not exhaustive. Bonaccorsi, Colombo, Guerini, and Rossi-Lamastra (2014), Calcagnini, Favaretto, Giombini, Perugini and Rombaldoni (2016), Fini, Fu, Mathisen, Rasmussen and Wright (2016) and Szücs (2018) find evidence of a complementarity relationship, whereas evidence of a substitution effect is supported by Maietta (2015), Barletta, Yoguel, Pereira and Rodríguez (2017) and Maietta, Barra and Zotti (2017). 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 & Lee, 1996).

This paper focuses on the effects of reputation and academic excellence on firm innovation and specifically whether research at local first-tier universities has greater knowledge spillovers than that at local second- and third-tier universities. Therefore, a novel question of this paper is the analysis of the impact on firm innovation of different levels of reputation and academic excellence of local universities.

This issue is important since distant universities are generally not chosen as firm R&D partners in the earliest phase of the project (Broström, 2010) and ties with partners of high academic quality are not widespread among European manufacturing firms[1].

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. The source of data on company innovation is the EU-EFIGE/Bruegel-UniCredit dataset. This provides comparative transnational data on manufacturing firms in seven European countries. Information on universities is gathered from a range of sources and is collected at the NUTS3 level since this geographic unit makes it possible to capture the spillover effects of public research (Bonaccorsi, 2014).

The paper is structured as follows. The next section reviews the literature regarding the influence of university reputation on firm choices with respect to location, innovation and collaboration. The third section describes the methodology and the data sources. The fourth section presents the results of our analysis. The fifth section concludes, while supplementary material is provided in the online Appendix.

WHAT STANDARD OF EXCELLENCE MUST ACADEMIC RESEARCH MEET TO ENHANCE INDUSTRIAL INNOVATION?

The impact of academic research quality on firm geographical location or innovation turns out to be complex. Abramovsky, Harrison and Simpson (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; in other industrial sectors (i.e., motor vehicles), the location

[1] In 2012, enterprises co-operating with universities or other higher education institutions were 18,704 (5.2% over manufacturing population) in EU28. Of them, enterprises for which this kind of cooperation was the most valuable method were 31% (own calculation on Community Innovation Survey data, Eurostat).

of such activities is in places with both a high concentration of top- and lower-ranked universities. Bonaccorsi et al. (2014) investigate the impact of academic patents and publications on the birth of knowledge-intensive firms. The number of patents in universities of high-quality, according to the Scimago Institutions ranking, exerts a positive impact on the birth of these firms, whereas publications are only weakly significant. Calcagnini et al. (2016) analyse the distance of innovative new firms' location from the closest university, considering academic research quality as defined by the national performance-based research funding system. A positive effect is found only for the social science area. Fini et al. (2016) find that academic reputation, defined by national quality rankings, impacts the birth of university spin-offs but the impact on their growth potential is less statistically significant.

Mansfield and Lee (1996) ask a sample of major firms in seven high-tech industries to cite five academics whose research contributed most to firm innovation. Top-tier departments were more often 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. The relationship between the reputation of faculty and the contribution to industry is not as strong as expected in all industries, the impact of academic quality and geographical proximity not being homogeneous across disciplinary fields. Indeed, firms seem more likely to look for a high-quality faculty or department, paying less attention to where the university is located, when basic research is considered. On the other hand, when applied R&D research is considered, firms seem to prefer working with a lower ranked university located closer to firm R&D laboratories. This behaviour may be explained by the fact that more face-to-face interaction between academics and firm 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, and beyond a certain threshold of academic quality, firms may no longer consider the additional cost attached to this collaboration worthwhile, as some top-tier universities may impose more stringent conditions than those imposed by less prestigious universities. Indeed, some firms could decide to invest in supporting research at leading universities also to obtain access to promising students and graduates.

More recently, the impacts on firm innovation of indexed publications, performance-based research grade, university ranking and citations have been investigated. Maietta (2015) finds that the research quality of the closest academic institution, measured by bibliometric and research assessment indicators, has a negative impact on firm product innovation. Szücs (2018) analyses the impact of university-firm collaboration on the number of granted patents, patent citations and indicators of patent novelty, considering the Webometrics university ranking, which exerts a positive impact. Barletta et al. (2017) find a negative association between the research groups' scientific productivity, defined as the number of SCOPUS publications per researcher, and the research groups' technology transfer activities. Maietta et al. (2017) find that the number of citations presents a negative marginal effect on university-firm collaboration and does not impact innovation.

Many studies on the contribution of universities to local development focus on university-firm collaboration. Among the determinants of this collaboration, the university characteristics are: university or department size, scientific discipline composition and specialisation, geographical proximity and academic research quality (see Maietta, 2015).

Academic research quality is important when firms choose universities as R&D collaboration partners. However, a still open question in the literature is whether only top-tier universities are relevant for regional development. Academic excellence is necessary but not sufficient (Bonaccorsi, 2017); the empirical evidence is not completely exhaustive, with conflicting and ambiguous results.

By building relationships with highly ranked universities, firms gain more credibility on the market for their products' quality; therefore, improved reputation and legitimacy would mostly drive the decision to collaborate with prestigious universities. Firms make 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 & Anderson, 2006) based on the motivation that prestigious universities will make available the best technology to firms more cheaply and quickly (Mansfield, 1991). Adams (2005) underlined that firms that are more interested in funding cutting-edge research will collaborate with top-tier universities regardless of the distance between them. 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 first choose to collaborate with local top-tier universities and second, with a non-local, but highly ranked, university rather than cooperating with a local second-tier institution. On the other hand, Hong and Su (2013) show that prestigious universities are less likely to attract local industrial partners and more likely to attract non-local industrial partners. This could be explained by the fact that second-tier universities can probably better solve the problem of firms not interested in cutting-edge research. In this case, indeed, firms might not look for star universities.

In conclusion, research excellence, although very important, is not sufficient to explain university-based knowledge spillovers. It may 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 to evaluate the direct effect of academic research quality on the likelihood of firm innovation.

THE EMPIRICAL FRAMEWORK

The econometric approach

To consider the endogenous nature of R&D decisions, a simultaneous equation approach is suggested for modelling internal and external R&D expenditures (Veugelers, 1997), R&D collaborations with different partners (Belderbos, Carree, Diederen, Lokshin & Veugelers, 2004) and R&D expenditures and innovation (Becker & Dietz, 2004).

Our econometric model consists of equations related to dependent variables that are binary and 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:

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

The five latent variables are defined as follows: y_1* is *intra muros* R&D investment; y_2* are R&D collaborations with universities/research labs; y_3* are R&D collaborations with other firms/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 that describe a structural relation between y_k and y_l 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 is rejected, this implies that the equations need to be estimated as a system and cannot be estimated separately. The variables y_2* and y_3* are potentially endogenous since they may have a causal effect on product and process innovations.

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:

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

The multivariate probit model can be described as an instrumental variable framework for categorical variables and can be estimated using the simulated maximum likelihood method.

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 that is rather weak in economic applications. Given the assumption of joint normality, the multivariate probit model is identified by the 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 & Radice, 2008).

Consequently, we introduce *R&D subsidies* in the three R&D decision equations, following Kleinknecht and Reijnen (1992), plus *R&D acquired abroad*, *Intra muros R&D intensity* and *Extra muros R&D with other firms/consultants* in equation y_2 and *R&D acquired abroad, Intra muros R&D intensity* and *Extra muros R&D with universities/research labs* in equation y_3. On the other hand, equation-specific regressors of the innovation equations are *R&D intensity*[2] and the dummies for subsidies[3] and sectors.

The data and the variables

The source of company information is the EFIGE (European Firms in a Global Economy) database. The EFIGE dataset consists of a representative sample for the manufacturing industry of firms with

[2] *R&D intensity* has been split into: *Intra muros R&D intensity, Extra muros R&D with universities/research labs* and *Extra muros R&D with other firms/consultants.*
[3] Financial incentives provided by the public sector in 2009, whereas *R&D subsidies* are tax allowances and financial incentives for R&D activities in the 2007-2009 period.

more than 10 employees in 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), macro-region (NUTS1 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. 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. 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 has in the last three years applied for a patent, registered an industrial design or 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 emphasis on research-active universities, containing information for each university such as the units of academic staff, the number of national and international students, the fields of education, the year of university foundation and the NUTS3, which is the university main location. 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, as for the data described below, has been averaged out or summed up at the NUTS3 level and then matched with firm-level characteristics.

The third source of data is represented by the Global Research Benchmarking System (GRBS) dataset, which is based on Scopus publications in 251 Subject Categories covering all science and technology fields. The dataset includes universities that have published at least 50 papers in at least one Subject Category in the period 2007–2010 (Bonaccorsi, Haddaway, Cicero & Ul-Hassan, 2017). From this data set, we have sourced the total number of publications and the number of those found in titles that are within the top-10 and top-25 of that subject area based on the Source Normalised Impact per Paper (SNIP) value in 2010. We also consider the total number of citations within a 4-year time window to papers published in 2007-2010 received from citing publications in source titles that are within the top-10 and top-25 of that subject area. All fields of science as well as the science and technology subjects have been considered.

Since the GRBS source titles include conference proceedings, we also hand collected from SCOPUS by Elsevier for each university the overall number of publications in scientific journals in the field of science, technology, medicine, social sciences, art and humanities in the period 2007-2009. SCOPUS has been chosen among other sources of information because it provides good tools to visualise the research output of an institution using both the institution name and its English translation.

The Academic Ranking of World Universities (ARWU) by Shanghai Jiao Tung University, also known as the Shanghai academic ranking of the universities, has also been adopted to use an internationally accepted measure of academic institution reputation. It has been chosen among other measures because it is the first developed indicator of university world ranking. We use the ARWU referring to 2008, the intermediate year of the analysed period.

Finally, information on total patents, which are used as a proxy of technology level, by NUTS3 and by selected technology field is sourced from the OECD Patent Database.

Table A1 in the Appendix defines the variables used in our analysis and provides their descriptive statistics.

The definition of reputation and academic excellence at the university level

We use the ARWU to define academic reputation. Universities are ranked to the 500th position by several indicators of academic or research performance, including alumni winning Nobel Prizes and Fields Medals, staff winning Nobel Prizes and Fields Medals and frequently cited researchers, papers published in Nature and Science and papers indexed in Science Citation Index-Expanded and Social Science Citation Index, and the per capita academic performance of an institution. We use the overall ranking of the institutions to define all the institutions ranked between the 1st and the 150th position "first-tier universities". The choice of the 150th position is due to the evidence that the number of top institutions is generally not particularly high[4] (Arimoto, 2011). We then define those ranked between the 151th and the 500th position "second-tier universities". Finally, universities not ranked and thus above the 500th position were defined "third-tier universities". We have then imputed to each university the definitions of academic excellence listed below, summed up at the NUTS3 level and then matched with company-level characteristics.

Academic excellence is defined by the volume of scientific production and its quality. The former is proxied by the number of publications in source titles that are within the top-10 and top-25 of that subject area; the total number of publications (from the GRBS source) is also used for comparability. Quality is represented by the number of citations received from citing publications in journals that are within the top-10 and top-25, we also use the total number of citations. The choice of the first decile is suggested in the literature as a comprehensive and realistic definition of excellence (Tijssen, Visser, & Van Leeuwen, 2002). Finally, we also consider the ratios of the number of top-10 publications to the academic staff and the total number of publications (from SCOPUS) to the academic staff.

The empirical specification

The choice of the explanatory variables in the R&D collaboration equations is derived by the introduction of firm, university and territory characteristics suggested in literature as determinants of university-firm collaboration (Fritsch & Lukas, 2001; Kleinknecht & Reijnen, 1992; Maietta, 2015). To explore complementarity or substitution effects among the R&D decision variables, university

[4] The number of first-tier universities is 32, that of second-tier universities is 103 and that of third-tier universities is 226.

variables have also been introduced as covariates in the equations *R&D collaboration with other firms/consultants* and *Intra muros R&D*. For this latter equation, following Veugelers (1997), other explanatory variables are selected. For the innovation equations, covariates are related to firm, territory and sector characteristics suggested by innovation studies *plus* variables describing the characteristics and the knowledge production of local universities. These latter have been introduced in all the five equations to see how they are indirectly and directly associated with innovations of local firms.

The empirical specification of the five equations is as follows:

Intra muros R&D = f_1 (*R&D subsidies*, *Skilled employees*, *CEO age*, *CEO gender*, *Firm age*, firm size dummies, firm legal form dummies, intellectual property dummies, *Rurality of the province*, 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 ≠ *m*, *R&D acquired abroad*, *R&D subsidies*, *Skilled employees*, *CEO age*, *CEO gender*, *Firm age*, firm size dummies, firm legal form dummies, intellectual property dummies, *Rurality of the province*, 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*, *Subsidies*, *Skilled employees*, *CEO age*, *CEO gender*, *Firm age*, firm size dummies, firm legal form dummies, intellectual property dummies, *Rurality of the province*, industrial sector dummies, country dummies or university's characteristics), where *j* = product or process.

Several specifications of variables reflecting the university's characteristics, output and world excellence have been alternately tested. The baseline specification is Model 1, which includes only national dummies. Model 2 tests the role of average university scientific composition in the province (proxied by the average age of the university, the presence of medical schools and the type of faculties). Models 3 and Model 4 analyse the university outputs in terms of the number of national and international students, the academic excellence indicator plus the total number of patents and the number of patents by technology field, respectively. 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 number of national and international students, the academic excellence indicator and the total number of patents. In Model 6, the academic excellence indicator is split into those referred to as the first-, second- and third-tier universities in the province[5]; alternate indicators, whose marginal effects are reported in Tables 1-3, are tested.

Finally, since industrial sectors vary in terms of sources, paces and rates of technological change, which modulate firm requirements to be engaged in innovation networks, and the extent and character of such networking, university-based knowledge spillovers may be industry-specific (Bonaccorsi, Colombo, Guerini & Rossi-Lamastra, 2013). As a consequence, firms are grouped into Pavitt's macro-sectors (Pavitt, 1984); the results of the multivariate probit, run only for top-10 publications, are reported in Table 4.

Multicollinearity among the regressors is assessed by computing the variance inflation factor (VIF)[6]. The sample consists of 14,744 observations.

THE EMPIRICAL EVIDENCE

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[7]. The marginal effects of the multivariate probit regressions are reported for various specifications (Models 1 to 6) in Tables A4–

[5] For robustness, we have also used the academic excellence indicator of the first- and lower- (sum of second and third) tier universities in the province. The results, available upon request, evidence the absence of non-linear effects.
[6] The VIFs, reported in Table A2 in the Appendix, suggest the absence of multicollinearity among the regressors.
[7] The correlation coefficients are reported in Table A3 in the Appendix.

A8 in the Appendix. The standard errors of the coefficients have been clustered around the country in which the firm is located.

Table 1 reports the marginal effects for the numbers of top-10 and top-25 publications plus the total number of publications only in the Science and Technological (S&T) subjects, whereas Table A9 in the Appendix refers to publications in all scientific subjects. The association with S&T publications of all the dependent variables is generally higher than that of all scientific subjects, as expected. From the comparison of different title sources, the association of top-10 publications is always higher than that of top-25 publications, and both are always higher than that of the total number of publications. This means that academic excellence generates more knowledge spillovers.

Looking at the provincial totals, the association of publications with *Intra muros R&D* and with *Product innovation* are of the same magnitude, whereas that with *Process innovation* is lower and only weakly significant for top-10 publications meaning that academic excellence is less important for process innovation.

Top-10 publications of first-tier universities display the highest marginal effect on *Product innovation*, followed by third-tier universities. Top-10 publications of third-tier universities display a significant marginal effect on *Process innovation*. Higher academic reputation is not always associated with more knowledge spillovers.

The association with universities/research labs' R&D collaborations is weakly significant and negative for top-10 publications of third-tier universities, suggesting that the publications in top-10 source titles is not enough to counterbalance the image of less prestigious universities from the firm point of view in the case of R&D university partner choice.

[Tables 1 around here]

The citation pattern (Table 2) resembles that described for publications, with the difference that citations of second-tier universities are highly significant for *Process innovation*. Citations of S&T

publications exhibit a lower association with all the dependent variables than S&T publications. This means that the quantity of publications, for each journal rank position, is more important than their scientific impact from the perspective of knowledge spillovers.

[Tables 2 around here]

Table 3 reports the marginal effects of the ratio between publications and academic staff for top-10 and all publications. For *Product innovation*, the marginal effect of top-10 publications of first-tier universities is highly significant and negative, suggesting that more efficient institutions, from the research-orientation perspective, may exhibit fewer knowledge spillovers; most likely, their higher patenting activity and greater levels of secrecy may slow the unencumbered diffusion of academic knowledge. Publications of third-tier universities display the highest absolute value of the marginal effect on *Product innovation*, but the marginal effect is not significant for top-10 publications. Third-tier institutions are more resource-constrained, and a higher research-orientation, given the academic staff, seems to be possible at the expense of knowledge spillovers. However, for top-10 publications of these institutions, neither a positive relationship is evidenced nor a trade-off (probably because of resources stemming from academic engagement).

[Table 3 around here]

Table 4 reports the marginal effects only of top-10 publications by Pavitt's macro-sector. Supplier-dominated sectors do not directly benefit from knowledge spillovers for innovations most likely because firms at the forefront of technology able to immediately use new academic knowledge are relatively few (but for these latter, the impact on *intra muros* R&D investment seems to be important). On the other hand, science-based sectors exhibit a very high marginal effect for top-10 publications of second-tier universities on *Product innovation*, whereas the association between

Process innovation and top-10 publications of first- and second-tier universities is negative. One explanation may be that these universities prefer to interact with firms on product innovation activities, which may generate valuable economic benefits, such as patents, whereas this is not the case for process innovation (Duguet & Lelarge, 2012). For scale-intensive sectors, top-10 publications of second- and third-tier universities are associated with innovations; for specialised-suppliers, top-10 publications of third-tier universities are also associated with innovations.

[Table 4 around here]

For robustness, we also identify all the institutions ranked by ARWU between the 1st and the 250th position and label these universities as "first-tier universities"; those ranked between the 251th and the 500th position are labelled as "second-tier universities". Finally, universities not ranked and thus above the 500th position are still labelled "third-tier universities". The results, summarised in Table A10 in the Appendix, evidence a lower significance of second-tier universities on *Product innovation* and a higher significance of first-tier universities on *Intra muros R&D*.

CONCLUDING REMARKS

The aim of the paper is to examine whether academic excellence – measured by indicators of publications and citations, differentiated by source title, and of scientist productivity – may enhance innovation of local firms and the extent to which a university must be a top-tier institution to generate knowledge spillovers useful for firm innovation.

The empirical evidence suggests that academic excellence may generate more university-based knowledge spillovers since top-10 publications of local universities are always associated with more firm innovation than top-25 publications and both are associated with more firm innovation than total publications of local universities. However, this evidence is less strong for process innovation.

Second- and third-tier universities may generate more knowledge spillovers than first-tier universities since their publications are associated with more innovation of local firms. This behaviour is industry-specific since differences emerge at Pavitt's macro-sector level. For the sectors belonging to Pavitt's science-based macro-sector, even negative associations with top-10 publications of first- and second-tier universities are evidenced in case of process innovation. Second- and third-tier universities are important for innovation of sectors belonging to Pavitt's scale-intensive and specialised-suppliers macro-sectors. For all sectors, our results support the evidence of a negative association between scientific productivity and local knowledge spillovers. Finally, for each journal rank position, the quantity of publications generates more knowledge spillovers than their scientific impact.

From the policy viewpoint, our results suggest that it is not possible to kill two birds with one stone since international academic reputation does not automatically imply production of local knowledge spillovers. The allocation of funds to universities based on academic research output indicators is crucial, but even indicators of 'third mission', currently used in the allocation of funds to universities in some countries, seem to be tailored to needs of universities and large-sized firms. More broad indicators need to be studied, so that the distribution of resources does not exceedingly penalise both very small and small firms, which are numerous in European manufacturing, through knowledge under-production and scholars of less prestigious universities publishing in high-ranked journals, whose knowledge and technology transfer activities may be directly useful to most local firms.

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TABLES

Table n. 1. Marginal effects for all the dependent variables – Top-10, top-25 and total publications (10 th) in S&T

Variables	Model 5 dF/dx		Model 6 dF/dx		Model 5 dF/dx		Model 6 dF/dx		Model 5 dF/dx		Model 6 dF/dx	
	Top-10				Top-25				Total			
Intra muros R&D												
Publications of local universities	**0.074**	***			**0.044**	***			**0.028**	***		
Publications of first-tier universities			**0.053**	*			0.034				0.022	
Publications of second-tier universities			**0.102**	***			**0.058**	***			**0.037**	***
Publications of third-tier universities			**0.071**	***			**0.040**	***			**0.023**	**
R&D collaboration with universities/research labs												
Publications of local universities	-0.013				-0.008				-0.004			
Publications of first-tier universities			-0.010				-0.005				-0.003	
Publications of second-tier universities			-0.018				-0.010				-0.006	
Publications of third-tier universities			**-0.015**	***			**-0.008**	**			**-0.005**	**
R&D collaboration with other firms/consultants												
Publications of local universities	0.004				0.001				0.0003			
Publications of first-tier universities			0.008				0.004				0.002	
Publications of second-tier universities			0.013				0.006				0.003	
Publications of third-tier universities			-0.013				-0.009				-0.007	
Product innovation												
Publications of local universities	**0.073**	***			**0.042**	***			**0.026**	***		
Publications of first-tier universities			**0.085**	**			**0.053**	**			**0.034**	***
Publications of second-tier universities			**0.061**	***			**0.036**	**			**0.022**	**
Publications of third-tier universities			**0.072**	***			**0.039**	***			**0.022**	**
Process innovation												
Publications of local universities	**0.030**	*			**0.019**	**			**0.013**	*		
Publications of first-tier universities			0.023				0.016				0.010	
Publications of second-tier universities			0.029				0.018				0.011	
Publications of third-tier universities			**0.043**	***			**0.026**	***			**0.018**	***

*, **, *** indicate significance at 10%, 5% and 1%, respectively

Table n. 2. Marginal effects for all the dependent variables – Top-10, top-25 and total citations (10 th) in S&T

Variables	Model 5 dF/dx	Model 6 dF/dx	Model 5 dF/dx	Model 6 dF/dx	Model 5 dF/dx	Model 6 dF/dx
	Top-10		Top-25		Total	
Intra muros R&D						
Citations of local universities	**0.014** **		**0.008** **		**0.006** **	
Citations of first-tier universities		**0.009** *		0.006		0.004
Citations of second-tier universities		**0.026** ***		**0.016** ***		**0.011** ***
Citations of third-tier universities		**0.019** ***		**0.014** ***		**0.007** ***
R&D collaboration with universities/research labs						
Citations of local universities	-0.003		-0.002		-0.001	
Citations of first-tier universities		-0.003		-0.002		-0.001
Citations of second-tier universities		-0.006		-0.003		-0.002
Citations of third-tier universities		**-0.003** **		**-0.002** **		**-0.001** **
R&D collaboration with other firms/consultants						
Citations of local universities	0.000		-0.000		-0.000	
Citations of first-tier universities		0.001		0.000		0.000
Citations of second-tier universities		0.002		0.001		0.000
Citations of third-tier universities		-0.002		-0.001		-0.001
Product innovation						
Citations of local universities	**0.015** ***		**0.010** ***		**0.006** ***	
Citations of first-tier universities		**0.015** **		**0.010** **		**0.007** **
Citations of second-tier universities		**0.013** **		**0.008** **		**0.005** **
Citations of third-tier universities		**0.017** ***		**0.010** ***		**0.007** ***
Process innovation						
Citations of local universities	**0.006** **		**0.004** **		**0.003** **	
Citations of first-tier universities		0.005		0.003		0.002
Citations of second-tier universities		**0.008** ***		**0.005** ***		**0.003** **
Citations of third-tier universities		**0.010** ***		**0.006** ***		**0.004** ***

*, **, *** indicate significance at 10%, 5% and 1%, respectively

Table n. 3. Marginal effects for all the dependent variables – Top-10 publications/academic staff and publications/academic staff in S&T

Variables	Model 5 dF/dx	Model 6 dF/dx	Model 5 dF/dx	Model 6 dF/dx
	Top-10 publications/academic staff		Publications/academic staff	
Intra muros R&D				
Publications/academic staff of local universities	-0.0001		-0.0001	
Publications/academic staff of first-tier universities		-0.0001		-0.0001
Publications/academic staff of second-tier universities		**0.026*** **		**0.025*** **
Publications/academic staff of third-tier universities		0.010		0.004
R&D collaboration with universities/research labs				
Publications/academic staff of local universities	**-0.0004*** **		-0.0006	
Publications/academic staff of first-tier universities		**-0.0003** **		**-0.0003** **
Publications/academic staff of second-tier universities		-0.0003		0.0006
Publications/academic staff of third-tier universities		0.001		0.001
R&D collaboration with other firms/consultants				
Publications/academic staff of local universities	**-0.0006** **		**-0.0006** **	
Publications/academic staff of first-tier universities		**-0.0005*** **		**-0.0006*** **
Publications/academic staff of second-tier universities		0.008		0.007
Publications/academic staff of third-tier universities		0.002		0.003
Product innovation				
Publications/academic staff of local universities	-0.0002		-0.0002	
Publications/academic staff of first-tier universities		**-0.0002*** **		**-0.0002*** **
Publications/academic staff of second-tier universities		0.009		0.011
Publications/academic staff of third-tier universities		-0.013		**-0.025*** **
Process innovation				
Publications/academic staff of local universities	-0.003		**-0.003** **	
Publications/academic staff of first-tier universities		-0.007		-0.004
Publications/academic staff of second-tier universities		-0.001		-0.0009
Publications/academic staff of third-tier universities		-0.001		-0.001

*, **, *** indicate significance at 10%, 5% and 1%, respectively

Table n. 4. Marginal effects for all the dependent variables - Top-10 publications (10 th) in S&T by Pavitt's macro-sector

Variables	Supplier-dominated Model 6 dF/dx		Scale-intensive Model 6 dF/dx		Specialised-suppliers Model 6 dF/dx		Science-based Model 6 dF/dx	
Intra muros R&D								
Top-10 publications of first-tier universities	**0.051**	**	-0.007		**0.152**	*	**0.097**	**
Top-10 publications of second-tier universities	**0.097**	**	**0.098**	***	0.055		**0.279**	***
Top-10 publications of third-tier universities	**0.096**	***	0.058		**0.078**	**	0.023	
R&D collaboration with universities/research labs								
Top-10 publications of first-tier universities	-0.020		0.001		-0.002		0.057	
Top-10 publications of second-tier universities	**-0.046**	***	**0.056**	**	-0.037		**0.292**	***
Top-10 publications of third-tier universities	-0.015		-0.004		-0.030		0.016	
R&D collaboration with other firms/consultants								
Top-10 publications of first-tier universities	-0.004		0.016		0.007		-0.069	
Top-10 publications of second-tier universities	0.001		0.040		0.039		-0.142	
Top-10 publications of third-tier universities	0.016		-0.138		**-0.075**	**	**-0.118**	*
Product innovation								
Top-10 publications of first-tier universities	0.072		0.023		**0.121**	**	**0.232**	**
Top-10 publications of second-tier universities	0.031		0.005		**0.063**	**	**0.466**	***
Top-10 publications of third-tier universities	0.039		**0.112**	**	0.043		**0.168**	**
Process innovation								
Top-10 publications of first-tier universities	0.014		0.052		0.040		**-0.104**	**
Top-10 publications of second-tier universities	-0.005		**0.198**	***	0.024		**-0.223**	***
Top-10 publications of third-tier universities	0.004		0.066		**0.075**	***	0.059	

*, **, *** indicate significance at 10%, 5% and 1%, respectively