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BART LETEN

Bart.Leten@vlerick.com

PAOLO LANDONI

BART VAN LOOY

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BART LETEN

Katholieke Universiteit Leuven, Belgium

Vlerick Leuven Gent Management School

PAOLO LANDONI

Politecnico di Milano, Italy

BART VAN LOOY

Katholieke Universiteit Leuven, Belgium

Steunpunt STI Indicators (ECOOM), Belgium, Research division INCENTIM, K.U. Leuven R&D, Belgium-

Institute of Governance Studies, University of Twente

Contact:

Bart Leten

Vlerick Leuven Gent Management School

Reep 1

9000 Gent

Tel.: 09/210.98.57

3 ABSTRACT

This paper examines the impact of universities on the technological performance of adjacent firms. We extend existing research by jointly analyzing, and comparing, the effects of education (graduates) and scientific research activities (publications) of universities on firms' technological performance. Adopting the Griliches-Jaffe knowledge production framework, our study is conducted at the regional level, employing panel data for 101 Italian provinces and four industries. Overall, fixed effect panel data models reveal a positive effect of both university graduates and publications on the technological performance of firms. At the same time, considerable industry differences are observed. While in electronic and electrical industries both graduates and publications affect the technological performance of firms, chemical and mechanical industries only benefit from graduates, while the opposite holds for pharmaceutical firms. Combined these findings suggest that the impact of different academic activities is contingent on the industrial texture of regions in which universities are embedded.

Keywords: Innovation, Universities, Education, Scientific Research, Graduates; Patents

INTRODUCTION

Since the seminal work of Schumpeter (1934), innovation is considered an important driver of economic growth and welfare. Countries and regions that build up strong competences in innovation are more productive, grow faster, and attain higher per capita income levels (Fagerberg et al., 1997; Maskell and Malmberg, 1999; Sterlacchini, 2008). Regional innovation dynamics benefit from interaction and spillovers between multiple actors including firms, financial institutions, governments and universities (Van Looy et al, 2003); an idea captured explicitly by notions such as national and regional innovation systems (Freeman, 1987; Lundvall, 1992; Nelson, 1993; Acs, 2000) and the triple Helix model (Leydesdorff and Etzkowitz, 1996).

Universities play an important role in innovation systems. In particular universities contribute to innovation systems in two different ways (Nelson, 1986). First, they educate and train people in fields that are critical to corporate R&D, like sciences and engineering disciplines (Salter and Martin, 2001; Rothaermel and Ku, 2008). Second, they conduct scientific research, resulting in knowledge that can be instrumental for firms' innovation activities (Bercovitz and Feldman, 2007; Mansfield, 1995). Moreover, as the mobility of university graduates is not unlimited (Faggian et al, 2007) and scientific knowledge is to some extent tacit (Polanyi, 1966), the benefits of university education and research to firms tend to be 'localized'.

A significant number of studies has examined the impact of universities on firms' innovative performance. These studies have focused either on the effects of university research (e.g. Jaffe, 1989; Anselin et al, 1997; Autant-Bernard, 2001) or, more recently, on academic education (Rothaermel and Ku, 2008; Faggian and McCann, 2009). A first set of studies examined the effects of *university research* on firms' innovative performance. Jaffe (1989) observed a positive relationship between US state-level university R&D spending and the level of corporate patenting. Similar - positive - effects of university research have been reported at the level of US metropolitan statistical areas (Anselin et al, 1997 & 2000), and for regions in various European countries (e.g. Autant-Bernard, 2001; Fischer and Varga, 2003; Piergiovanni et al, 1997; Blind and Grupp, 1999; Del Barrio-Castro and Garcia-Quevedo, 2005). A second, much smaller, set of studies examined the effect of *university education* on firms' innovative performance. Using data on medical device clusters in the US, Rothaermel and Ku (2008) reported a positive effect of the number of university graduates in electrical engineering on the number of medical device patents (within the region). Faggian and McCann (2009) similarly found a positive effect of the inflow of university graduates on the innovative performance of UK regions.

Our study extends this prior work by *jointly* analyzing, and comparing, the effects of academic education and scientific research on firms' technological performance. We study whether the relative importance of university education and research differs across industries. Adopting the Griliches-Jaffe knowledge production framework, our study is conducted at the regional level, employing panel data for 101 Italian provinces and four different industries. Analyses are conducted at the combined province and industry level. The involvement of universities in education and research is measured by using, respectively, information on the annual number of university graduates and the annual number of scientific publications.

Based on fixed-effect panel data models, we observe overall, positive effects of education as well as academic research on the technological performance of firms. At the same time, our findings reveal strong differences across industries on the relative importance of both academic activities. In electronic and electrical industries, firms' technological activities benefit both from graduates and publications of local universities. Within chemical and mechanical industries, firm's technological performance varies only with the number of graduates, while for the pharmaceutical industry, the opposite holds. While our findings suggest that variation both in terms of graduates and publications is affecting the technological performance of firms; the impact of both types of academic 'outcomes' presents itself as industry specific.

The remainder of the paper is structured as follows. The next section reviews the existing literature, and details the contributions of the paper. The third section describes the data and indicators employed. The empirical findings are reported in the fourth section. In the final section, we summarize the main findings of the paper and suggest avenues for further research.

LITERATURE REVIEW

During the last decades there has been an increasing interest - both in research and policy circles - in understanding and measuring the impact of universities with respect to regional (and national) development (Drucker and Goldstein, 2007). A prime reason for this interest resides in the observation that many developed countries face a transformation of their economies from traditional-manufacturing to knowledge-intensive production and services. Universities support the creation of a knowledge-based economy by their involvement in two different tasks (Nelson, 1986; Baptista and Mendonca, 2010). First, they educate people and by doing so supply skilled labor; second they conduct scientific research and generate knowledge that can be instrumental for extending existing economical activities and/or creating new economic activity.

A first role of universities pertains to educating and training people which makes them suitable for entering knowledge-intensive jobs in the private sector. The skills acquired during university education allow graduates, especially those in exact sciences and engineering disciplines, to perform industrial R&D jobs. Universities teach students scientific principles and research techniques that enable them become involved in complex problem solving activities (Salter and Martin, 2001). In addition, as academic education is based on the latest scientific insights, hiring new graduates even entails the promise of introducing novelty within the existing industrial texture on the level of problem definition and solving activities. Indeed, regions that can increase the average level of education of their employees are found to become more innovative (Chi and Qian, 2010; Gumbau-Albert and Maudos, 2009).

The benefits of university education, in the form of skilled labor, are not equally accessible to all firms: firms situated in the vicinity of universities seem to find themselves in an advantageous position. The reason for this resides in the observation that a significant share of graduates accepts jobs in the region where they received their education, even if this is not their region of origin (Felsenstein, 1995; Glasson, 2003). Glasson (2003), for example, calculated that 64% of the UK-domiciled graduates of Sunderland university are still in the Sunderland region 6 months after graduation. Recently, several studies have examined the effect of university graduates on the innovative performance of adjacent firms. Using data on medical device clusters in the US, Rothaermel and Ku (2008) reported a positive effect of the number of university graduates in electrical engineering on the number of medical device patents within the region. Likewise, Faggian and McCann (2009) found a positive effect of (the inflow of) university graduates on the innovative performance of UK regions.

A second role of universities, relevant to the technological and innovative activities of firms, relates to the conduct of (basic) scientific research activities leading to an expansion of the knowledge base available for firms to engage in technological and innovative activities (Klevorick et al, 1995). Basic scientific research can be defined as experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view (Nelson, 1959; OECD, 2002). At the same time, Stokes (1997) argues convincingly that both basic science and technology development benefit from joint undertakings. Not only technology has increasingly become science-based; science itself is becoming also more technology-based, signaling the intimate relationship between understanding (science) and use (technology).

Despite the important role of scientific research for firms' innovation, many firms refrain from investing heavily in scientific research due to the high levels of uncertainty present within such activities; the often extended time frames before research efforts are being translated into (sellable) products and – closely related to this phenomenon – the complexities of appropriating the benefits of knowledge creation efforts (Arrow, 1962). To avoid an under-investment in scientific research, governments in most developed countries invest considerable amounts of public money in scientific research at universities and public research institutes (Pavitt, 1991).

Firms that rely on scientific research findings are expected to develop a deeper understanding of the technological landscapes in which they search for new inventions, allowing them to better anticipate, evaluate and translate the outcomes of their technology activities (Rosenberg, 1990; Fleming and Sorenson, 2004). Surveys of firm and academic researchers (Mansfield, 1995 & 1998; Cohen et al, 2002) indeed have shown the importance of university research for industrial innovation activities. Mansfield (1995 & 1998) estimated that, during the period 1975-1985, 11% of firms' new products and 9% of new processes could not have been developed (or with substantial delay) in the absence of university scientific research. These numbers are even higher for the period 1986-1994 (15% and 11%), suggesting that university research findings have become increasingly important for industrial innovation activities. Complementary evidence for the growing reliance of industrial innovation activities on university scientific research can be found in the analysis of citations to scientific literature in patent documents by Narin et al (1997), which revealed a threefold increase in the number of citations to scientific literature in industrial patents in the US during the 1990s.

Notice that the effectiveness of firms to access findings of university research depends on the geographic distance between the university and firm. As stated by Polanyi (1966), knowledge is difficult to codify and partly 'tacit' in nature. Tacit knowledge requires direct interaction for knowledge transfer to be effective (Nonaka, 1994; Woolcock, 1998; von Hippel, 1994). Developing and maintaining interactions, instrumental for the transfer of (tacit) knowledge, is facilitated by geographical proximity, explaining the geographically bounded nature of knowledge spillovers from universities to firms (Döring and Schnellenbach, 2006).

A significant body of empirical work in the fields of economic geography and technological innovation has studied the effects of university research on the technological performance of firms. Most of these studies are based on the regional knowledge production framework in which the total technological performance of firms in a geographic area is related to the amount of research conducted by universities in the area, measured by R&D expenses or publications.[1] Jaffe (1989) was the first to estimate the effects of university research at a regional level. He observed strong relationships between state-level university R&D spending and the level of corporate patenting. Follow-up US state-level studies showed the robustness of these initial findings by using firm

[1] A notable exception is the study of Bonaccorsi and Daraio (2007). Using patent and publication data at the level of Italian provinces, the authors implement a different empirical approach to measure the impact of university knowledge on the performance of adjacent private firms, namely a non-parametric frontier efficiency analysis.

innovation counts – rather than patent counts – as the dependent variable (Acs et al., 1991 & 1994) or by adding additional control variables (Feldman and Florida, 1994). The geographic-bounded impact of university spillovers is investigated more directly in the work of Anselin and colleagues (Anselin et al., 1997 & 2000) whereby lower spatial levels are introduced for the US (125 U.S. Metropolitan Statistical Areas). They did find positive effects for MSA-level university research on the innovative performance of neighboring firms. More recently, empirical studies using knowledge production functions have been undertaken for several European countries. Using data for regions in Germany (Blind and Grupp, 1999), France (Autant-Bernard, 2001; Piergiovanni and Santarelli, 2001), Austria (Fischer and Varga, 2003), Italy (Piergiovanni et al., 1997) and Spain (Del Barrio-Castro and Garcia-Quevedo, 2005) for different levels of spatial aggregation, these studies did confirm the presence of localized spillover effects of university research to firms.

The importance of university research for industrial innovation has inspired many countries to develop policies to stimulate the transfer of university knowledge to firms. Examples include the adoption of legislation that facilitates university-firm knowledge transfers (e.g. US Bayh-Dole Act of 1980) and the financial support of joint research projects of universities and firms (Link and Siegel, 2005). These national policies have contributed to a significant increase of interactions between universities and firms over the past decade as becomes visible in growing numbers of university-industry R&D collaborations (Liebeskind et al, 1996; Link and Scott, 2005), increasing university licensing revenues (Thursby and Thursby, 2002), emerging joint industry-university R&D centers (Cohen et al, 2002) and increasing citations in corporate patents to university publications (Narin et al, 1997). Recent studies (e.g. O'Shea et al, 2005; Van Looy et al, 2011) found shown that the scientific eminence of universities affects their entrepreneurial performance. As such, it seems plausible to assume that the scientific performance of universities might impact positively on the technological performance of adjacent firms.

Also the notion that knowledge spillovers are localized has been confirmed empirically. Surveying US firms, Mansfield (1995) showed that geographic proximity determines how frequent universities are consulted by firms on R&D issues. By comparing the geographic location of citing and cited US patents, Jaffe et al (1993) reveal that patent citations are more likely to come from patents from the same region as the citing patent , compared with a "control frequency" reflecting the concentration of relevant technological activity in US regions.

Within this paper we further investigate whether and how the presence of universities serves as a catalyst for the innovative activities of adjacent firms. In line with most existing studies, our conceptual framework is based on the regional knowledge production function approach of Jaffe (1989). We extend existing empirical evidence in different ways. First, we make an explicit distinction between education (measured by graduates) and scientific research of universities (approximated by peer reviewed publications), and jointly analyze and compare the effects of both types of university activities on the technological performance of firms. Second, we study variations across industries regarding the importance of both types of university activities. The distinctiveness of different industries has been highlighted in previous studies addressing innovation systems (Malerba, 2002) and technological change (Pavitt, 1984). However, only few studies empirically examined the impact of universities on industrial innovation activities by industry. These studies (Jaffe, 1989: Anselin et al. 2000, Acs et al, 1991) focused on the differential role of university research across industries by relying on only one measure (i.e. higher education expenditures). Whereas their findings suggest that the relevance of university research is to some extent industry specific, a more comprehensive analysis including indicators for both university education (graduates) and scientific research (publications) is needed to assess more properly if – and how (via education or scientific research) – the presence of universities affects the technological performance of adjacent firms. According to our knowledge, no previous studies have examined the distinctive contributions of both scientific and educational activities on the technological performance of adjacent firms.

DATA AND METHODS

Sample

The basic model for the econometric analyses is a regional knowledge production function. This function relates the technological performance of firms in a certain region and industry to the activities of universities that are located in that region and which are relevant to the industry. The use of fixed effects panel data models allows to control for the effect of regional and industrial unobserved variables, which do not vary during the period of observation, providing a more robust verification of the relationships under study. We distinguish between two university activities: education and scientific research. Our dataset is a panel dataset (1992-1998) that contains information for 101 Italian provinces (NUTS3 level[2]) and 4 broadly defined manufacturing industries: chemicals, pharmaceuticals, electrical engineering and electronics and mechanical engineering. The sample industries contain most of the manufacturing industries, except industries with a limited propensity to patent (such as food, textiles, paper and furniture). While Italy is composed of 103 provinces, missing R&D expenditures data for two provinces (Bolzano and Trento) reduces the dataset to 101 provinces.

[2] The "Nomenclature of Units for Territorial Statistics (NUTS)" is the classification of European spatial units developed by the European Office for Statistics (Eurostat).

Our analyses are situated at the combined province and industry level. For an analysis at this level, the main independent variables (university education and scientific research) have been constructed by relying on concordance tables (see infra) that relate science fields, technology areas, university departments and industries. This approach allows for a more precise assessment of the impact of universities on firms' technological performance, compared to aggregated approaches whereby variables are summed up across industries and fields/disciplines.

Dependent Variable and Estimation Method

The technological performance of firms is measured by means of patent data. While patent data do not fully account for the innovative or technological activities of firms, the use of patent indicators has a number of advantages (Pavitt, 1985; Griliches, 1990): (i) patents contain highly detailed information on the technological content, owners and inventors of patented inventions; (ii) they cover a broad range of technologies; (iii) patent data is objective in the sense that it has been processed and validated by patent examiners; and (iv) patent data is easily available from patent offices and (v) cover long time series. Like any indicator, patents are also subject to a number of drawbacks: not all inventions are patented and those that are patented vary in terms of technical and economical value (Griliches, 1990; Hall et al, 2005; Harhoff et al, 1999). The 'value' problem can to some extent be adressed by weighting patent counts by the number of received citations, the so called 'forward' citations' (Trajtenberg, 1990; Hall et al, 2005). This approach is followed in this study. Despite some shortcomings, there is however no other indicator that provides the same level of detail of firms' technological activities as patents do. An alternative way to obtain detailed information on firms' technological activities – including technology field and location information – implies surveys. However, firms are generally unwilling to disclose this type of sensitive information in an exhaustive manner whereas, patent data are made publicly available. Further, studies indicate that there is a strong overlap between patent counts and other indicators of technological activities, such as expert rankings of companies' technological capabilities (Narin et al, 1987) and the number of new product announcements in trade and technical journals (Acs et al, 2002; Hagedoorn and Cloodt, 2003), qualifying patents as a valid indicator of technological activity.

In this study, indicators based on European (EPO) patent applications have been used. European patents are preferred to national patents since they reflect, on average, higher value inventions (Malam, 1990). Patent applications, having at least one inventor address located in Italy, have been considered as patents resulting from inventive activities in Italy. From this pool of patents, firm-owned patents have been identified by applying the sector allocation methodology[3] developed by Van Looy et al. (2006). In a subsequent step, address information of patent inventors is used to allocate patents to provinces. Inventor addresses are considered as more accurate indications of the geographic origin of firms' patents than applicant addresses since companies often indicate the corporate headquarters' address as assignee address rather than the address of the research laboratory where the invention originated (Deyle and Grupp, 2005; Landoni et al, 2008). In case a patent contains multiple inventors from different Italian provinces, it is fully counted in each province. Patents are assigned to economic industries based on the IPC technology codes listed on the patents and the concordance table developed by Schmoch *et al.* (2003) that relates IPC technology codes to industries. This table uniquely links 4-digit IPC classes to different manufacturing industries (ISIC Classification) We have aggregated several of these sectors into the four manufacturing industries used in our study.

The dependent variable in our study is the number of firm patents in an industry and province, weighted by the number of forward patent citations received over a fixed five year time window. This weighing allows to control for differences in the technical and economic value of patents. Forward citations are calculated on the patent citation database of Webb et al (2005) and are calculated for all citing EPO patents and national patents with EPO patent equivalents. The dependent variable constitutes a typical example of a count variable; it takes non-negative integer values for all observations. In this case, non-linear count data models are preferable to standard linear regression models as they explicitly take into account the non-negativity and discreteness of the dependent variable (Wooldridge, 2001). We adopt a Negative Binomial regression model which allows for over-dispersion of the conditional mean and variance.

To control for any residual unobserved effects at the combined province and industry level, we used fixed effect estimators in all regressions. We verified the appropriateness of random effects estimators by performing Hausman (1978) tests. These tests rejected the appropriateness of random effects estimations. Our analyses are restricted to observations (province and industry level) that record a minimum number of technological activity, as reflected in patent counts that equal or exceed 5 patents during the period 1992-1998. Observations with less than 5 patents are removed to study meaningful changes in firms' technological output within a province and industry over time (fixed-effect analyses).

[3] Notice that 'sector' here refers to the type of applicant: firms, knowledge generating institutes (including universities and public research organizations), governmental agencies, individuals and hospitals.

University Education: Graduates in Science & Engineering

Information on the number of university graduates is used to assess the involvement of Italian universities in the education and training of skilled labour. The Italian Statistical Office (ISTAT) provides, for all Italian universities, annual information on the number of graduates per university department, and the locations (province) of the universities. To create the university graduate variable, we start from an annual list (1991-1997) of university graduates at the level of Italian provinces and university departments active in exact science disciplines (including engineering). Half of the Italian provinces (52 out of 101) host universities that offer degrees in these disciplines.

The university graduate variable is calculated at the combined province and industry level and contains the sum of graduates in departments of universities that are located in a province and that are considered relevant for the technological activities in a particular industry. The assignment of university departments to industries reflects the approach adopted by Jaffe (1989) who used data on research spending by departments of US universities to create state level university research spending variables for the four industries used in this study[4]. The university graduate variable is divided by the number of inhabitants of the province (expressed in thousands) to make it independent from the scale of the province.

University Scientific Research: Publications

We use information on scientific articles authored by Italian universities and published in peer reviewed journals to measure the research activities of universities in scientific disciplines that are relevant for the four manufacturing industries. Publication data are extracted from yearly updates of the 'Web of Science' database of ISI/Thomson Scientific; only papers of the document type article, letter, note and review have been selected. After extensive name cleaning of Italian publishing institutes, we have created a list of all publishing Italian universities[5] together with their annual publication numbers in 240 different ISI science fields. The assignment of publications to

[4] University departments are assigned to industries as follows: Pharmaceuticals includes biology, medicine, pharmacy, biotechnology, (pharmaceutical) chemistry, and natural sciences; Chemicals include industrial chemistry, chemistry, chemical and nuclear engineering, and materials sciences/engineering; Electrical Engineering and Electronics includes electrical/electronic engineering, informatics (engineering), telecommunications engineering, and physics; Mechanical Engineering includes mechanical engineering, material sciences, material and chemical engineering, physics, marine and nautical engineering, and other engineering and industrial technologies.

[5] We have considered only universities with a significant number of scientific publications (at least 15 over a 10-year time period). The few excluded universities were recently founded and have very low publication totals.

science fields is feasible as ISI assigns each issue of Web of Science covered journals to one or more science fields based on an expert evaluation. Based on address information of universities, universities are situated in Italian provinces. Our list contains 62 different Italian research universities, which are located in 47 Italian provinces.

The scientific research variable is calculated at the combined province and sector level and contains the sum of publications of universities that are located in a province and that are classified in science fields that are considered relevant for a particular industry. The publication variable is constructed in two steps. We first calculated the number of university publications relevant to different technology classes by using publication numbers by science fields and the science-technology concordance table developed by Van Looy et al (2004). This concordance table is created based on citation frequencies between patents (technology classes) and publications (science fields) and relates ISI science fields to 4-digit IPC technology classes via a set of probabilities. Second, we calculated the number of university publications relevant to each of the four manufacturing industries by converting publication numbers by technology classes into industries using the technology-industry concordance table of Schmoch et al (2003). The publication variable is divided by the number of university graduates in exact sciences in a province to make it independent of the size of universities' education activities.[6] The variable expresses whether universities in a particular province do more or less scientific research, relevant to a certain industry, than what could be expected from the mere size of their education activities.

Control Variables

Our empirical models include other - time varying - factors that may affect the technological performance of provinces and industries. First, we control for differences in R&D expenditures across provinces and industries. Since Italian business R&D figures are only available at the level of 19 Regioni[7] (source: Eurostat Regional Databases), weights have been used to apportion aggregate annual business R&D figures to the lower province and industry level. Hereby higher weights are given to provinces and industries that have a higher number of employees and industries which have higher R&D intensities. Annual data on the number of manufacturing employees of provinces and industries are obtained from the CIS database of the Italian Statistical Office (ISTAT); annual data on industry level R&D intensities (i.e. the ratio of R&D expenditures and number of manufacturing

[6] Similar results are obtained when the number of university graduates relevant to a particular industry is used as denominator. The denominator is increased by 1 so that the ratio can be calculated for all regions.
[7] The 101 Italian provinces used in this study belong to 19 broader geographic areas, called Regioni (NUTS2 level). Business R&D data reported for these Regioni are total R&D figures across all manufacturing industries.

employees) for Italy are obtained from the Eurostat ANBERD and STAN databases. The weight for province p and industry s is hence calculated as follows: $Weight_{p,s}$ = ($Employment_{p,s}$*R&D $Intensity_{s}$)/(∑p,s Employmentp,s*R&D $Intensity_{s}$). The summation is done for all provinces and sectors in the same Regioni. The reliability of this approximation has been verified by comparing real business R&D figures of Italian Regioni with estimated figures based on the numerator of the above expression (summed over all provinces and industries belonging to the same Regioni), yielding a correlation of 0.974 (n=152: 19 Regioni * 8 years). Remark that prior studies that estimated knowledge production functions at the industry level (Jaffe, 1989; Acs et al, 1991; Anselin et al, 1997) did not break down aggregate R&D expenses at the US state or MSA level across industries.

Second, we control for the potential spatial dependence of observations by including a spatially lagged dependent variable in the analyses (Varga, 1998). The spatially lagged dependent variable equals the average value of the dependent variable (firm patents within an industry) for neighbouring regions (provinces). In line with prior work (e.g. Autant-Bernard, 2001; Del-Barrio Castro and Garcia-Quevedo, 2005) neighbouring is defined as fulfilling the contiguity criteria, i.e. sharing a common border. Third, we add the variable 'year' to control for changes over time that affect the technological performance of firms, measured by citation-weighted patent counts. In addition to these three time varying variables, all regression models include fixed effects at the combined province and industry level, which controls for any residual unobserved heterogeneity between provinces and industries.

All explanatory variables are one year lagged in time and logarithmic transformed, except for the spatially lagged dependent variable. A value of 1 is added to the variables before logarithmic transformation because all explanatory variables have a minimum value of zero. As a consequence of the logarithmic transformation, the estimated coefficients of the transformed variables can be interpreted as elasticities (Wooldridge, 2001).

Summary statistics and correlations for the variables are given in table 1. The mean citation weighted number of firm patents (dependent variable) equals to 12, with large differences across provinces and sectors, as indicated by the standard deviation of 31. Both university variables, education and research, correlate positively (0.25). None of the correlations between the explanatory variables is high, ruling out multi-collinearity concerns.

Insert table 1 About here

We first analyze the impact of university education and scientific research on firms' technological performance across all sample industries. Analyses are restricted to observations (province and industry level) with minimum 5 patents during the observation period (1992-1998). This is the case for 275 groups, resulting in 1925 observations. Results are reported in table 2. Model 1 only includes the control variables. Firm R&D has a positive and significant effect. The spatially lagged dependent variable also has a positive and significant coefficient, displaying evidence of spill-overs from neighboring regions. The positive and significant coefficient of the year variable indicates a positive time trend in industrial patenting. In model 2, the variables university education and research are added. The addition of these two variables does significantly increase the explanatory power of the model, as indicated by the log-likelihood ratio test (Chi2-value= 22.14***). Positive and significant effects of both university education and scientific research are found indicating that, across industries, firms benefit in terms of technological innovation from both the education and research activities of local universities.

Insert table 2 about here

In a second step, we explore whether there are differences across industries in the relative importance of university education (graduates) and scientific research (publications) for firms' technological performance. For all four industries, the explanatory power of the model including the variables of interest is significantly higher than the model including only control variables. As the control variables display similar relationships in both types of models, table 3 reports only the results obtained when including all variables. Positive and significant effects for firm R&D and the spatially lagged dependent variable are found for all industries. In line with prior work (Jaffe, 1989), firm R&D expenses have a smaller effect on firms' technological performance in mechanical engineering than the other three industries. The year variable has a positive sign in all industries, but is only significant for the pharmaceutical industry.

The university education variable (graduates) is positive, and significant, in three of the four industries: chemicals, electrical engineering and electronics, and mechanical engineering. No effect of education is found for the pharmaceutical industry. University research has a positive and significant effect in two industries: pharmaceuticals, and electrical engineering and electronics. No effect of university research is observed for the chemical and mechanical engineering industries.

Combined, these results suggest that industries differ in terms of how the presence of local universities affects their technological performance. For chemical and mechanical industries, only the education and training of skilled labor is important, while in electrical industries both university education and research activities have a positive effect on firms' innovative performance. In the pharmaceutical industry, firm's technological activities benefit only from the scientific research undertaken by universities.

Insert table 3 about here

CONCLUSION AND DISCUSSION

This paper examines the impact of universities on the technological performance of firms. A significant number of contributions has analyzed the impact of universities, but these studies have focused either on the effects of education (Rothaermel and Ku, 2008; Faggian et al, 2009) or university research (e.g. Jaffe, 1989; Anselin et al, 1997; Del Barrio-Castro and Garcia-Quevedo, 2005). We improve on existing research by jointly analyzing, and comparing, the effects of education and scientific research, the two main activities of universities, on firms' technological performance. In addition, we examine whether there are differences in the relative importance of both university activities across different industries.

Based on fixed-effect panel data models, we find positive effects of both the education and scientific research activities of universities on the technological performance of adjacent firms. At the same time, we observe outspoken differences across industries in terms of the importance of both university activities. For chemical and mechanical industries, only the number of graduates (in science and engineering) affects the technological performance of firms, while in electrical and electronic engineering industries both the education and research activities of local universities positively impact firms' technological performance. In the pharmaceutical industry, only the scientific performance of local universities affects firms' technological performance.

The positive relationship – between scientific activities of universities and adjacent firms - might come as no surprise for 'science intensive' industries like pharmaceuticals and electrical/electronic industries. Indeed, several scholars argued that for these industries scientific research is a relatively important source of technological innovation (Gambardella, 1992; Cockburn and Henderson, 1998; Leten et al, 2009; Lim et al, 2004). The presence of scientific eminence within a region might – at least partially – remedy the occurrence of market failures related to in-house investments in scientific research at the firm level,. At the same time, it can be noted that the *rate* of technical change is considerable in these two industries, making it more difficult for firms to determine the most promising technological trajectories to invest in (Salter and Martin, 2001). Basic scientific knowledge, generated by university research, may help firms to get a better understanding of the technological landscape in which they search for new inventions and to improve the efficiency of their technology activities (Rosenberg, 1990; Fleming and Sorenson, 2004). No effect of university research on firms' technological performance is found for the chemical and mechanical engineering industries. It may be that university research is less important for corporate innovation in these industries or that the rate of change in the relevant knowledge base is less outspoken within these industries.

University education has a positive effect on firms' technological activities in most of the sample industries, except for pharmaceuticals. A possible explanation why no effect of education is observed for pharmaceuticals can relate to the nature of human capital in this industry; the availability of PhDs, and not merely holders of academic master degrees, might be more important for the technological activities of firms within this industry.

Our research findings highlight several possible avenues for further research. First, the observed differences between industries – in terms of relevant knowledge spill-over mechanisms – deserve further investigation: to what extent do these differences reflect the relevance of science (for industrial, technological activity), signal differences in terms of knowledge dynamics within relevant scientific domains or stem from other constituents? In order to investigate possible explanations, a more detailed analysis on the level of industries and scientific domains is required, covering extended time frames and probably more regions (and countries) than considered within this study. Such efforts would benefit from the availability of fine-grained indicators, related to scientific activities, industrial practices and education (e.g. lists of PhDs in Science and Engineering fields) alike.

Second, within this study, we have focused on the effects of university education and research. Recently, many universities have become more explicitly engaged in 'third mission' activities, implying "technology transfer" activities, aimed to transfer university knowledge to the industrial texture via research collaborations, patenting and licensing-activities and spin-off creation (Etzkowitz, 1983; Branscomb, Kodama and Florida, 1999). To be effective in these technology transfer activities, universities have created supporting mechanisms –like Technology Transfer Offices (TTOs) - and adjusted incentive systems (e.g., Debackere, 2000; Bozeman, 2000). Further research could examine to what extent the effects of university research on firms' technological performance depend on the availability of TTOs and incentive systems for technology transfer.

Finally, we relied on patent indicators to measure firms' innovative activities. Innovative activities within certain industries are however not fully grasped by patent indicators; future research might examine these dynamics by considering a more diverse set of indicators signaling industrial innovation (e.g trademarks, design rights, organizational innovation including supply chain management practices). We do hope that the reported research inspires other researchers to engage in such efforts, which we consider as highly relevant for further informing practitioners and policy makers alike on the impact of university activities on the innovation activities of private firms.

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TABLES

TABLE 1: DESCRIPTIVE STATISTICS AND CORRELATIONS

		Mean	Stdev	(1)	(2)	(3)	(4)	(5)
(1)	Dependent Variable	12.09	30.67	1				
(2)	Firm R&D Expenditures	1.80	1.21	0.58	1			
(3)	Spatially Lagged Dep. Variable	12.78	18.15	0.20	0.26	1		
(4)	University Education	0.09	0.18	0.25	0.15	-0.10	1	
(5)	University Research	0.15	0.32	0.09	0.16	0.05	0.25	1

Remark: Statistics are calculated on the set of observations that are included in the analyses (n=1925).

All reported correlations are significant at the 5% level

TABLE 2: IMPACT OF UNIVERSITIES OF INDUSTRIAL INNOVATION: ALL SECTORS

	Model1	Model2
Firm R&D Expenditures	0.6388***	0.6245***
	(0.0401)	(0.0409)
Spatially Lagged Dep. Variable	0.0130***	0.0138***
	(0.0023)	(0.0022)
Year	0.0421***	0.0346***
	(0.0085)	(0.0085)
University Education		0.8454***
		(0.2455)
University Research		0.2724***
		(0.0945)
Constant	-84.8652***	-70.1316***
	(16.8859)	(17.0112)
Number of Observations	1925	1925
Number of Groups	275	275
Log-Likelihood Value	-3928.20	-3917.13
Chi2 Value	406.73***	438.74***
LR-Ratio Test		22.14***

Remark: *, **, *** denote significance levels at 10, 5 and 1 percent. Fixed-effects (province and sector level) are included in all models.

TABLE 3: IMPACT OF UNIVERSITIES ON INDUSTRIAL INNOVATION: SECTOR SPECIFIC ANALYSES

	Chemical	Pharmaceutical	Electrical	Mechanical
Firm R&D Expenditures	0.7928***	0.7141***	0.8590***	0.5357***
	(0.1567)	(0.0926)	(0.0918)	(0.0740)
Spatially Lagged Dep. Variable	0.0234*	0.0140***	0.0173***	0.0079*
	(0.0121)	(0.0033)	(0.0046)	(0.0047)
Year	0.0000	0.0293*	0.0233	0.0291
	(0.0256)	(0.0151)	(0.0169)	(0.0178)
University Education	4.4864***	0.4600	1.1027*	2.1252***
	(1.7311)	(0.3385)	(0.6005)	(0.6683)
University Research	1.1994	0.3666**	0.3572***	-0.0466
	(1.0917)	(0.1486)	(0.1287)	(0.3479)
Constant	-0.8919	-59.5635**	-48.6512	-58.6463*
	(51.1005)	(30.0953)	(33.7046)	(35.4305)
Number of Observations	378	497	532	518
Number of Groups	54	71	76	74
Log-Likelihood Value	-606.99	-1034.65	-1075.25	-1162.15
Chi2 Value	46.67***	132.52***	193.47***	126.10***

Remark: *, **, *** denote significance levels at 10, 5 and 1 percent. Fixed effects (province and sector level) are included in all models.