The Journal of Technology Transfer
https://doi.org/10.1007/s10961-023-10008-y

Is higher education more important for firms than research? Disentangling university spillovers

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Accepted: 7 April 2023

Abstract
The paper is the first attempt to integrate microdata on universities and firms across most European countries in order to disentangle the impact of knowledge spillovers from human capital (graduates) and intellectual capital (codified research output) on the performance of firms. Data cover all Higher Education Institutions (HEIs) registered in the official European Tertiary Education Register (ETER). Data on performance of firms are from ORBIS and refer to change in the 2011–2015 period in turnover, total assets, intangible assets, and employment. Firms are georeferred and the spillovers from all HEIs located at a given distance are summed and integrated. The findings suggest that, among knowledge spillovers, the creation of human capital via education of students has a larger impact than the circulation of research knowledge. Moreover, the two factors seem to be complements rather than substitutes. Spatial proximity is important for embodied knowledge spillovers (i.e. educated people), while for codified and disembodied spillovers (citations to publications) the spatial dimension is less relevant. The findings have important managerial and policy-making consequences.

Keywords Knowledge spillovers · Human capital externalities · Higher education institutions · Firm growth · Graduates · Citations

1 Introduction

The idea that universities (and, more generally, higher education institutions—HEIs) generate spillovers that contribute to the growth of the economic system has been advanced many times in recent decades by scientists and policymakers. Using data at world level, Valero and Van Reenen (2019) estimate that doubling the number of universities per capita generated an increase in income per capita of 4% in subsequent years for the regions in which universities are located. Similarly, Agasisti and Bertoletti (2020) report that both the creation of new universities and the increase in the size of existing ones had a positive impact on the growth of regional GDP in Europe.

From the policy perspective, spillovers have been used as a policy tool in different countries to increase economic opportunities (Sánchez-Barrioluengo, 2004; Bonaccorsi, 2016).

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Published online: 16 May 2023

The rationale behind such policymaking is a "theory of change" which links higher education—students (human capital) and research- with local development, large spillovers and growth, at the urban and regional level, generating expectations and policy actions. On the one hand, through the education of students, HEIs contribute to the creation of human capital and increase the availability of knowledge and skills that fuel productivity and innovation in regional economies (Bradley & Taylor, 1996). On the other hand, they produce new knowledge through research activities, which has been recognized as one of the main components of the knowledge spillover theory of entrepreneurship (Acs et al., 2009; see also Hausman, 2012; Orlando et al., 2019) and is crucial for processes of technology transfer and innovation (Anselin et al., 1997; Mansfield & Lee, 1996; Varga, 2000). The results from HEI's research activities find their way to the economic system following a variety of specific pathways, which are the object of a large and dedicated literature. Thus, an important dimension of the overall economic impact of universities is the positive impact of research on firms and their performance.

However, there is a research gap in estimating the *relative* importance of education (that is, the creation of human capital) and research. What does contribute more to economic growth and regional development? Universities produce both kinds of spillovers, but with diverse strategic orientations in terms of their mix and relative importance. This is clearly an under-researched issue.

In other words, we know from the relevant literature that *both* education and research have a large positive impact on regional development and economic growth. At the same time we do not know: (i) the magnitude of the relative contribution of education and research; (ii) the degree to which they are necessary complement or (possibly) substitute (iii) the difference in the way in which spatial effects influence the overall positive impact.

These issues have strong policy implications for the definition of priorities of public investment aimed at regional development and economic growth. To start with: should national and regional governments give priority to the formation of human capital by investing in higher education at all levels (that is, even by institutions that *do not* excel in research) or a strong performance in research is a necessary condition for the effectiveness of these policies? If research and education are indeed strong complements, then governments should ask *all* higher education institutions to engage in research, while if a larger commitment to education can *substitute* for research, then there would be a key policy role for institutions that are not active (or are not performing) in research. Another open issue regards the way in which positive spillovers reach the economic system at different spatial scales: given that, as we will see below, spillovers *decay* with distance, do spillovers in education and research follow the same pattern? This issue has clear implications for public policies at regional and local level that traditionally try to create and/or support universities that are located *as close as possible* to the territory. Are these policies justified by the evidence? Recent hot policy debates suggest that these issues are far from being settled down.[1]

This paper contributes to this debate by assessing the *relative* importance of human capital creation vs. research activities of universities, as well as the *complementarity* between

[1] For example, the Danish government is trying to promote the diffusion of higher education by reducing the concentration of university students in urban areas (Myklebust, 2021) and creating study places in decentralized, mainly rural, localities (Ministry of Higher Education and Science, 2021). On the contrary, the UK government is oriented to reduce the spatial concentration of research by supporting more R&D investment outside the London, the Southeast and East of England areas following the 'levelling up' agenda. Both policy measures, in isolation, have simplistic expectations. In the Danish case, while small universities in rural areas may provide decent educational services, it will miss the critical mass to create

these two activities as key missions of the universities (i.e. teaching and research) with respect to their impact on firms' growth. In particular, the value added of this work is twofold. First, we use the perspective of the demand side. That is, we look at what companies value *more* in universities by evaluating if they consider that important spillovers are from research or teaching activities. For example, some companies must recognize the need to locate their research department/activities close to the relatively small number of global hot spots that attract scientific stars worldwide[2]; while others locate close, and interact with, non-top universities, which tend to be more dispersed across geographical areas for technical consultancy activities.[3] Other companies might want to have access to large pools of graduates, not necessarily educated in research-intensive HEIs, but close to production facilities even in peripheral areas.

The second contribution of the paper provides insights into whether distance has a similar effect on spillovers when disentangling education and research. In other words, we argue that for different reasons, the effect of teaching and research activities of the universities are subject to spatial decay. Inspired by the large literature on spatial spillovers and localized flows of knowledge generated by teaching and research activities, different works suggest that spillovers reach external audiences with an intensity that decreases with geographic distance (Bottazzi & Peri, 2003; Karlsson and Anderson, 2006; Abramovsky et al., 2007; Brostrom, 2010; De Fuentes & Dutrenit, 2016). With respect to education, policymakers may know that a certain proportion of graduates migrate from the location of the university (in particular from backward regions) to other cities or regions, following better employment opportunities. In this case, the investment into universities in a given region may (unintentionally) produce positive externalities to distant regions. Notwithstanding the potential brain drain effect, policymakers usually assume that the vast majority of graduates look for employment close to the location of university studies and benefit the local economic environment. With respect to research, policymakers may know that the spatial effects greatly differ. The output of research codified in publications circulates internationally, so it is intrinsically mobile on a large spatial scale. The degree to which research creates spatially bounded externalities depends on a variety of factors. In spite of such complexity, policymakers assume that positive externalities from the research will benefit the local economic environment. Understanding the relative impact of education and research activities on growth, and more generally on economic performance is important at various spatial scales, i.e. at national and regional levels. While higher education is a national policy attribution in most (non-federal) countries,[4] recent years have witnessed a strong policy activism of regional governments on universities (Goldstein & Drucker,

Footnote 1 (continued)
the research infrastructure and to attract good researchers. For the UK several stakeholders warned that placing more R&D in a region would not automatically generate growth opportunities (Council of Science and Technology, 2021, Chaytor et al., 2021). In a certain sense, the Dutch government believes that it is education that brings the largest benefits, so that it is important to spread opportunities for student enrolment in peripheral areas, while the British government believes that it is important to spread research activities.

[2] Although the overall spatial concentration of research has diminished over time (Grossetti et al., 2013), the concentration of top level institutions has remained relatively stable, as witnessed by the large literature on university rankings.

[3] As in the case of some UK polytechnic universities that have a particular regional focus (Sánchez-Barrioluengo et al., 2019).

[4] More precisely, in some European countries the main funding role is assigned to regional governments, while the national level keeps its prerogatives in accreditation and provides various sources of funding of research. This happens in federal countries such as Germany, but also in Spain.

2006; Pinheiro, Benneworth and Jones, 2012; Lane & Johnstone, 2012; Goddard & Vallance, 2013; Kenney & Mowery, 2014). This policy orientation follows a rationale according to which the externalities created by universities have a strong local dimension, that is, are spatially bound (i.e. the magnitude of the spillovers decreases with the distance from the location of the university).

Based on the previous discussion, in this study we address the following largely unexplored research with spatial questions: (i) what is the *relative* importance of education and research in generating spillovers for companies? (ii) to what extent are education and research *complementary* in generating externalities? (iii) do spillovers from education and research decrease *with the same intensity* distance? To answer these questions we carry out a large-scale empirical analysis covering most European countries and all HEIs[5] in these countries and integrate them with firm level microdata to assess the impact of both types of spillovers. From an empirical perspective, the novelty of the paper relates to the combination of microdata from the census of HEIs (European Tertiary Education Register) with microdata on firms (ORBIS) based on their co-location, measured with georeferentiation techniques rather than traditional macro approaches using aggregate measures (e.g. regional GDP) and regressed against a simple count of universities-HEIs or its rate of growth (usually from UNESCO sources). Second, we allow for spatial effects by building several distance measures. This technique does not solve entirely the issue of spillover endogenous spatial heterogeneity but greatly mitigates it. Third, we capture more precisely the impact of HEIs by measuring directly and separately the creation of human capital (graduates) and the production of research (publication citations). Finally, we examine the impact on several measures of performance of firms (change in turnover, total assets, intangible assets, and employment) in the period 2011–2015.

We find strong confirmation for the positive influence of both education and research spillovers on the performance of firms, although the former are more important than the latter. We find support for the role of spatial decay, with heterogeneous effects for education and research. In the last section we develop the managerial and policy implications of the findings.

2 Literature review and development of hypotheses

2.1 Higher education and human capital externalities

A large and consistent literature finds a strong positive relation between the level of human capital and the absolute performance and rate of growth of countries, regions, and cities, supporting the pioneering observations of Nelson and Phelps (1966) (for a survey of the macroeconomic evidence on the effects of education on economic growth see Sianesi & Van Reenen, 2000; for a regional economics perspective see Faggian & McCann, 2009). Based on the endogenous growth theory (Aghion & Howitt, 1998; Lucas, 1988; Romer, 1986), the accumulation of human capital produces positive externalities and contributes to the growth of productivity, as well as to the development of new products and processes (Barro, 1998; Mankiw et al., 1992).

[5] The ETER dataset also includes non-university HEIs (e.g. Fachhochschule), which are included in our analysis only if they produce internationally published research.

Two main stylized facts exist on the links between human capital externalities generated by HEIs and economic growth: (a) (HEI-generated) human capital benefits firms via the increase in productivity of workers; and (b) such external effects have a spatial dimension Rosenthal & Strange 2008.

On the first stylized fact, many studies show that HEIs increase the educational attainment level in the region in which they are located and enlarge the available workforce (Audretsch & Lehmann, 2005; Castelló-Climent and Hidalgo-Cabrillana, 2012; Acs et al., 2015). In other words, by educating students, HEIs increase the stock of human capital and thus the availability of knowledge that fuel productivity and innovation in regional economies (Bradley & Taylor, 1996; Eriksson & Forslund, 2014; Valero & Van Reenen, 2019). For example, Fischer et al. (2009), Laskowska and Danska-Borjiak (2016), Lilles and Roigas (2017) and Diebolt and Hippe (2019) examine productivity and GDP data across European regions and find a strong effect of human capital. Acemoglu and Dell (2010) show that differences in human capital account for half of between-municipality differences in output per capita in the USA. Similarly, Gennaioli et al. (2013) find that education is the most important determinant of regional income and productivity.

On the second stylized fact, several studies confirm the importance of the spatial dimension, showing positive and significant effects of HEI's proximity on workers' productivity and local development. Among them, Andersson et al. (2004) suggest that the creation of university sites or branches at dispersed geographical locations has significant economic effects on regional development, particularly on productivity and output per worker. Similarly, Liu (2015) examines the short -and long-run- effects of US universities on the geographic clustering of economic activities and concludes that the designation of education institutions as land-grant universities greatly enhances local manufacturing productivity, as captured by local manufacturing output per worker, especially in the long run. Buendia-Azorin and del Mar Sanchez-de la Vega (2015) examine the relationship between human capital and labour productivity for European regions in the 2000–2009 period and find a strong positive effect on labour productivity: an increase of 10% in human capital in a region has an average direct impact of 3.0% in close regions.

Using the demand side approach, HEIs provide education to students who then (for the most part) graduate and find a job. Hence, the positive externality from education is captured by firms that hire graduates, enjoy better human capital, and are able to increase their productivity. Where are these firms located? The first beneficiaries are *firms located close to the HEI* from which students graduate. According to the literature on work mobility, work commuting is acceptable for distances below 100 km (Ciriaci, 2014; Faggian et al., 2017). This is why in this paper we estimate the impact of universities that are located up to 100 km from the site of the firm. This is also why we estimate the impact separately for several distances, assuming that employment opportunities are less attractive the larger the distance from home. The additional beneficiaries are *firms located far from the HEI* (beyond 100 km), which persuade graduates to migrate from the site of their studies and to change city and social life. In this case firms must offer a package that compensates graduates from the extra-cost of changing life. It is reasonable to assume that only large firms can offer such a package, which includes not only extra salary but also career perspectives that are often not available in small firms. To the extent that large firms are located close to the HEI, all externalities from education are captured locally. This is the pattern we expect in capital cities and in large metropolitan agglomerations. In all other cases, on the contrary, there will be some migration and the overall impact of education on the local economy will be mitigated.

Based on this we hypothesize:

Hypothesis 1 Human capital externalities from universities positively influence firms' performance but are subject to spatial decay.

2.2 Knowledge spillovers from research activities

Knowledge from university-based research may reach the economy following a variety of pathways, beyond human capital (Hughes & Martin, 2012; Pinto et al., 2013; Rasmussen & Wright, 2015; Siegel et al., 2007). These include, among others, formal university-industry collaboration, informal technology transfer activities, joint creation and/or licensing of patents, technical consultancy and new firm creation. While the studies that examine such pathways in detail are part of a large specialized literature, here we consider only those that take a more aggregate approach and examine the magnitude of externalities (Rodriguez-Pose and Crescenzi, 2008; Lendel, 2010; Schubert & Kroll, 2016).

Among these, Ponds et al. (2009) analyse spillovers from academic research to regional innovation, finding an important role in university-industry collaborations. Vertesy et al. (2013) find a strong correlation between university research performance and variables such as territorial competitiveness, labour market efficiency, and innovation capability of European regions. Cowan and Zinovyeva (2013) estimate that in Italy, in the period 1985–2000, the creation of new universities increased regional innovation activity within five years. The evidence suggests that the effect is mainly generated by high-quality scientific research brought to the region by the newly established university. A recent study exploits the opportunity offered by the creation of Universities of Applied Sciences in Switzerland to carry out counterfactual analysis and finds that the creation of a new HEI has a strong impact on the regional economy: 8.5 to 14% increase in regional patent activity, and 2 to 3.6% increase in citation per patent (Pfister et al., 2017).

While the knowledge codified in scientific publications is not subject to spatial decay, since it can be read and utilized all over the world, the literature on research spillovers, however, shows that firms need to interact directly with researchers in order to reduce uncertainties and acquire tacit knowledge. We may here replicate the question: Where are these firms located? First, they are again the *firms located close to the HEI*. This is because face to face interactions are less costly if researchers and firms are co-located in the same place. This effect will be subject to spatial decay, given traveling costs (Abreu et al., 2009). At the same time, it must be recognized that *firms located far from the HEI* may still have an interest in research produced at a distance. These firms must overcome the extra costs needed to meet researchers face to face in the absence of co-location. It is reasonable to assume that only large firms can establish relations with HEIs located at a distance. This is consistent with the literature that shows that small firms only interact with local universities, while large firms interact with the best universities, whatever the location (Mansfield & Lee, 1996; Laursen & Salter, 2004; D'Este & Iammarino, 2010; Laursen et al., 2011; Sánchez-Barrioluengo et al., 2019; Sánchez-Barrioluengo & Benneworth 2019). In this case the overall impact of research on the local economy will be mitigated. Indeed, Bonaccorsi et al. (2014) investigate how far in space university knowledge goes to breed the creation of knowledge-intensive firms (KIFs), depending on the nature (either codified or tacit) and quality of this knowledge. The econometric estimates indicate that the positive effects of scientific publications are confined within the boundaries of the province in which universities are located.[6]

Based on this we hypothesize:

Hypothesis 2 Research spillovers from universities positively influence firms' performance but are subject to spatial decay.

2.3 Complementarity between education and research and relative importance

While the above effects are largely established in the literature, we now turn to the more fine-grained and controversial issue of their *relative* impact, as well as the importance of the *combined* effect, or complementarity, between human capital and research spillovers.

With respect to the combined effect, there are good arguments to support the hypothesis of complementarity between human capital creation and research activities. For example, a recent four-country study finds that research excellence of universities (measured in terms of share of publications in the top 10% of citations) is positively related to labour market outcomes such as employment and salary after graduation in Italy, Hungary and Germany (only for salary after one year), while it is not significant in the UK (Biagi et al., 2019). These findings support the Alma Mater effect initially identified by Brunello and Cappellari (2008). The employability of university graduates is higher when they come from universities in which there is good research quality, reflecting the fact that the demand side of the labour market attributes value to research excellence.

A similar result has been recently proposed by Bonaccorsi et al. (2021) based on Italian data on the relation between quality of research of STEM and, respectively, third party funding, on the one hand, and the production of patents and spinoff companies on the other hand. The article suggests that high publication visibility of research works as a quality *signal* for third parties and attracts additional funding, which in turn contributes to a better division of labor in laboratories and to larger spillovers in terms of patents and new firms. To the extent that HEIs produce excellent research and increase visibility and prestige, the impact on the local economy will paradoxically diminish. On the one hand, graduates from prestigious, research-intensive universities will be attractive for large firms and will migrate. This phenomenon has been repeatedly observed in the United Kingdom, in which graduates from top level universities (say, Oxford and Cambridge) outside London migrate to the capital city in search of higher salaries, while large firms located in London are eager to offer higher salaries in exchange for brilliant graduates. On the other hand, research-intensive universities suffer from large opportunity costs if they engage too much with the regional economy. Why dealing with the local small software company if you can talk directly to Google or Microsoft? For these universities the extra cost of dealing with

[6] We have focused here on those studies demonstrating the positive effect on existing firms (via university-industry collaboration, consulting, technology transfer and other impact pathways) but it is important to note that other part of the literature highlight the effect of universities on new firms via creation of new firms, survival and growth (see for example Colombo et al., 2010; Colombo and Grilli, 2010).

firms at a distance is more than compensated by the amount of resources mobilized by large companies and by the opportunity to work on challenging projects.

Summing up, while it is likely that the two effects of education and research are subject, for different reasons, to spatial decay, as previously hypothesised, the overall effect is complicated to predict. This is mainly due to the role of large firms that may operate at a distance (either in recruitment of graduates and in research collaborations) and by the prestige and attractiveness of universities, particularly in research.

As a matter of fact, the issue of complementarity has been very recently re-examined with an innovative approach by Biasi and Ma (2022), who introduce the education-innovation gap indicator. This indicator is built by computing the semantic similarity between the content of syllabi of US universities and the content of scientific articles of different periods. Syllabi associated to the scientific content of older articles are rated high in the gap indicator. By using this approach the authors strongly support the complementarity hypothesis: "The education–innovation gap is significantly lower for courses taught by instructors who are more active in producing research (i.e. they publish more, are cited more, and receive more grants). The gap is instead higher for non-ladder faculty who specialise in teaching. The gap is also lower when the instructor's own research is closer to the topics of the course. These findings (…) suggest that investments in faculty research (both public, in the form of government grants, and made by each institution) can generate additional returns in the form of more updated instruction" (Ma and Biasi, 2022, 3–4). While these findings will require replicability in non-US contexts, they are robust enough to allow the formulation of a hypothesis that posits complementarity between education and research.

With respect to the relative importance between education and research the situation is less clear, as stated in the Introduction of this paper. Hattie and Marsh (1996) summarize the literature that has examined the issue of the nexus between research and teaching by using data at the level of individual institutions or restricted samples. It is difficult to generalize these results at the level of the economic system. At the same time other more recent contributions address the issue from new perspectives and use much larger datasets. Akcigit et al. (2020) study the extent to which the supply of research can be expanded, based on microdata from Denmark, a country in which the government asked universities to double the number of PhD in ten years. They show that the talent pool for research is limited so that the quality of PhD candidates deteriorated over time and generated a lower than expected impact on innovation capabilities. Bloom et al. (2021) examine the origin and spatial diffusion of 29 disruptive technologies such as mobile devices or cloud computing. While the origins of these technologies are located in small concentrated areas in which top research institutions are active (e.g. California), they show that after the introduction a rapid process of spatial diffusion takes place in other regions, generating large flows of job openings for educated people, not related to research activities.

In both these examples it is clear that while research is responsible for opening new directions for innovation, it involves a relatively small number of very talented people, often concentrated in hot spots. On the other hand, the exploitation of innovation, and ultimately the generation of economic growth, depends on the mobilization of a large number of educated people across many sectors and regions.

Summing up, we hypothesize:

Hypothesis 3 (a) There is a complementarity effect between human capital and research spillovers on firms' performance. (b) Education has a relatively larger positive impact than research.

3 Description of data and methodology

3.1 Independent variables and the ETER census

We examine the extent to which HEIs generate, directly or indirectly, positive spillovers on all firms located in their surroundings. We hypothesize that firms benefit from university spillovers by recruiting workers with a higher level of skills and by engaging with researchers in a variety of technical works (joint research projects, co-invention, technical advice, consultancy). We make the following assumptions:

(i) the creation of human capital is proxied by the number of graduates at HEI level. Graduates are, in some sense, the final product of educational activities of HEIs and the input for the creation of spillovers on firms and the overall economy;
(ii) the generation of spillovers from research is proxied by the number of citations received by the publications authored at university level. Although using citations to indicate the impact of scientific research has some limitations (as highlighted by Martin & Irvine, 1983, and Nicolaisen, 2007, among others), citation count measures are frequently employed to proxy for scientific impact. This is a measure of quality of research largely accepted in literature.

In order to find trustworthy measures, we rely on two different sources of data. The first one is the ETER database, collecting information on European HEIs in terms of students, academic staff and financing. The data include some information about 2,895 European Institutions (as for 2019) between 2011 and 2015. We use a broad definition of higher education, covering both universities (i.e. institutions delivering up to the doctoral degree) and non-university institutions (i.e. institutions delivering up to the master's degree, but not the PhD).[7]

Based on the discussion in Sect. 2, we proxy human capital creation with the number of graduates measured according to the international ISCED standard at level 5 (short courses), 6 (bachelor) and 7 (master) summed together.

ETER data are integrated with data on citations received in the 2011–2015 period to publications authored by the institution, published in the same period, disaggregated by university (using the ETER census for the definition of affiliation) for the period 2011–2015, extracted from Scopus.

[7] There is no harmonization of classifications at European level. In some countries non-university institutions, delivering up to the Master level (ISCED 7) are labelled *universities of applied sciences* (UAS). In other countries the label university is restricted to PhD-delivering institutions (ISCED 8), while other institutions are labeled in disparate ways (schools, colleges, academies, institutes etc.). In the paper we will use the umbrella label of *higher education istitutions* (HEIs) to cover both university and non-university institutions, following the ETER terminology. In the discussion of the literature, the distinction is not made explicit, as most of the studies examine only universities, or do not mention the distinction. See the recent report by ETER (2019a).

3.2 Dependent variables and the Orbis dataset

We evaluate the effects of HEIs on firms using ORBIS-Bureau van Dijk data on firms' performance in Europe. ORBIS-Bureau van Dijk is the single largest database with microdata on firms across European countries, collected from balance sheets of companies integrated with institutional, legal and financial information. While the database covers most European countries, the coverage by type of variable is non-homogeneous and there is a severe issue of missing values. We selected performance variables for which the coverage across countries is the largest and constructed a cross-country sample in which all performance variables are jointly covered. The coverage of ORBIS data is illustrated in Table A1 of the online Appendix.

We focus on a set of economic and structural variables[8] at firm level, which are interpreted as performance variables:

(a) Operating *turnover*: a measure of effectiveness in operating in the market;
(b) *Number of employees*: captures the degree to which the expansion in turnover is reflected in, or anticipated by, the growth in the labour factor;
(c) *Total assets*: a measure of investment, which may grow over time due to investment decision into long term assets (fixed assets) or as a result of the expansion of operational activities (working capital, such as cash, credit, and inventory)
(d) Fixed *intangible assets*: a proxy for innovative activities.[9] Fixed intangible assets include patents, trademarks, capitalization of R&D expenses and company goodwill.

For each of the selected performance variables we calculate absolute growth as the difference in the level of each variable between 2011 and 2015,[10] taken as natural logarithm. Since we examine variations over a four-year period, the effects are mainly short term. The period is one of relative macroeconomic stability after the financial crisis initiated in 2007–2008. It is also a period in which inflation in European countries has been close to zero, which dispenses us from deflation of monetary variables at company level.

3.3 Treatment of spatial effects

One of the main goals of this study is to understand how firms' closeness to universities affects their performance. This is obtained by examining the variation of the estimated coefficients that describe the relation between firms and their sources of knowledge, i.e. HEIs at various distance points.

The procedure is as follows.

(a) For each firm in the ORBIS dataset we take the georeferentiation coordinates. In practice, we assume as spatial reference point the location of the firm, as made available

[8] Other relevant variables (e.g. Current market capitalisation and Research and Development expenditures) are limited to very large companies and have poor coverage across countries.

[9] See Bonaccorsi et al. (2019) for a discussion about the appropriateness of these variables as a measure of firm performance and how they refer to different aspects of activities of firms.

[10] While ORBIS and Scopus data is available for a longer period, we are constrained to data availability in ETER at the time of the study. That is the reason we limit the studied period to four years (2011–2015).

Table 1 Regression results for models of impact of higher education on firm's growth. Total variation 2011–2015. Separate estimation of education and research impacts

	(1) Turnover	(2) Employment	(3) Total assets	(4) Intangible assets
Panel A. Number of graduates (ISCED 5–7)				
Graduates within 10 km	0.011***	− 0.008***	0.003*	0.020***
	(0.002)	(0.001)	(0.001)	(0.004)
Graduates between 10 and 20 km	0.011***	0.002*	− 0.002*	− 0.001
	(0.001)	(0.001)	(0.001)	(0.003)
Graduates between 20 and 50 km	0.012***	0.001	− 0.000	− 0.007
	(0.002)	(0.001)	(0.001)	(0.004)
Graduates between 50 and 100 km	0.006***	− 0.001	− 0.001	− 0.002
	(0.001)	(0.001)	(0.001)	(0.003)
N	1,385,535	1,385,535	1,385,535	1,385,535
R^2	0.2122	0.1696	0.1698	0.1549
Panel B. Total number of citations received				
Citations within 10 km	0.019***	− 0.009***	0.008***	0.044***
	(0.003)	(0.002)	(0.002)	(0.007)
Citations between 10 and 20 km	0.009***	0.001	− 0.001	0.004
	(0.001)	(0.001)	(0.001)	(0.004)
Citations between 20 and 50 km	0.008***	0.001	0.000	0.002
	(0.001)	(0.001)	(0.001)	(0.005)
Citations between 50 and 100 km	0.006***	− 0.000	− 0.001	0.002
	(0.001)	(0.001)	(0.001)	(0.004)
N	1,334,040	1,334,040	1,334,040	1,334,040
R^2	0.2124	0.1703	0.1701	0.1567

Standard errors in parentheses. Dependent variables are measured as the log growth of each variable between 2011 and 2015. Independent variables are standardized. Controls included (size, sector, legal form, region, initial values of dependent variables, R&D intensity, quality of institutions)

$^*P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$

by Orbis (GSM coordinates) or calculated by our own computation by applying a georeferencing software to the data containing the address of the firm. The location of the firm is defined as the address of the headquarters.

(b) For each HEIs (based on the location of the headquarters) we take georeferentiation in the ETER dataset.

(c) We calculate the distance between each firm and each of the HEIs in the given country.

(d) We then fix the distance for universities located in a radius to firms of: a) Less than 10 km; b) Between 10 and 20 km; c) Between 20 and 50 km; and d) Between 50 and 100 km.

(e) We identify all HEIs that are at a fixed distance from the firm and we sum the values for the relevant variables (e.g. number of graduates, number of citations) aggregating all institutions in the relative ring.

In essence, we define mutually exclusive areas[11] by constructing "rings" of various radiuses, which describe carefully the availability of HEIs centred around all firms.[12] We fix the distances exogenously (i.e. imposing the distance at 10, 20, 50 and 100 km, respectively). Using this spatial approach, we identify a differentiated spatial scale environment for each firm. HEIs located within 10 km from a firm are co-located in the same urban environment, allowing intense social and professional interaction and frequent face-to-face meetings. The 10–20 km ring extends this interaction to the province level, or the peripheries of large cities. On the contrary, the 20–50 ring captures labour market mobility (i.e. graduates' commuting). Finally, the 50–100 ring is likely to capture the effect of HEI on firms in the broader regional environment. This is considered acceptable in the literature and has been implemented in Bonaccorsi et al., (2013; 2014).[13] The maximum distance (100 km) is defined in accordance with the prevailing literature.

In the case of multisite companies we follow the ORBIS approach, which gives a geo-referentiation for each unit with a separate balance sheet. This is a satisfactory solution for companies with separate corporate accounting structures, while it introduces a measurement error in the case of multiplant operations under the same corporate umbrella. The issue of HEIs with multiple locations has been extensively examined by ETER (ETER 2019b).[14] Approximately one out of four HEIs have at least a secondary campus. However, they are located in the same region (NUTS 2), although not in the same province (NUTS 3). In addition, campuses are more frequent for non-university HEIs, which are much smaller and less active in research activities. In all cases the geo-referentiation has been assigned to the headquarters of the institution. Given that campuses are located in the same region, the maximum distance of 100 km in our model will capture the main effects of spillover, although the spatial directionality may be biased. Since we are mainly interested in the overall effect of spillovers and not in their specific geography, the solution is acceptable.

3.4 Identification strategy and control variables

The estimation of spillovers creates a well-known issue of endogeneity and omitted variables. In the absence of a time structure of data that permits the observation of long time series, it is not possible to establish causality. The spatial location of HEIs is not random and it is impossible to state whether HEIs contribute to economic growth, or whether the level of development of a region or city contribute to the creation, growth and activities of HEIs, or both hold at the same time. Our strategy is the exploitation of the census nature

[11] Given a firm in a geographic location, we identify the HEIs located within 10 km and then compute the values for the explanatory variables that only use the information from the HEI located within 10 km from the firm; then we do the same for all HEIs within between 10 and 20 km etc.

[12] In principle, we could leave the distance endogenous, adopting a full-scale spatial econometric approach. This is left for future research, given the heavy computational burden due to the huge size of the dataset. For the time being, we use an approximation, by estimating the impact for a discrete number of distances from the centroid of the area.

[13] A slightly different operationalization has been used by Orlando et al. (2019).

[14] "In the year 2016, one out of every four HEIs in ETER had a satellite campus in another NUTS 3 region. The share is significantly higher for Universities of Applied Sciences (29%) than for universities (22%) and lowest for other institutions (13%), owing to their small size and specialized nature. It is also higher for public (22%) than for private HEIs (16%). In terms of the number of campuses, most HEIs have just one or two satellite campuses, while only 47 HEIs have more than 5 satellite campuses" (ETER 2019b, 5).

of our data covering *all* universities in Europe[15] and a very large share of non-university institutions. Therefore, we follow a descriptive strategy, without claiming causality for our results.

In other words, we recognize that the price we pay for such a microdata and granular analysis is a loss in causal explanatory power. It is well known that the relation between HEIs activities and economic growth is affected by serious issues of endogeneity and unobserved heterogeneity (Debski et al., 2018). We work with 5-year data (2011–2015) that, given the time scale of the phenomena we observe, do not allow a credible panel data approach or the adoption of GMM techniques. In addition, we believe there are no reasonable instrumental variables that can be applied to all European countries in a relatively short time window. We therefore rely on a large-scale correlational analysis, which is complementary to studies based on panel data.

As a matter of fact, our approach is complementary to the ones in which causality can be addressed by making use of long time series of regional economic variables, as in Valero and van Reenen (2019) and Agasisti and Bertoletti (2020). At the same time, it is clear that the price they pay for achieving causal identification is the use of university microdata that are limited to the *presence* of universities in a given territory. We offer a complementary view by introducing rich data on the *activities* of universities, i.e. the volume of educational and research outputs. We also provide a finer spatial disaggregation by using georeferenced data at local level, rather than aggregated data at regional level.

We specify a model in which the independent variables are the number of graduates and the number of citations for all HEIs located at a given distance from any single firm in the sample. Then, in order to qualify the results, we make use of a large array of control variables from Eurostat, OECD and other sources to control for unobserved factors. Introducing control variables has two main effects. First, it wipes out the variability of the dependent variable originated by the variability of the control. Second, it allows identifying possible effects from the control to the dependent variables that deserve a closer scrutiny.

Some groups of control variables are defined following the literature. First, we control for firms characteristics (size, sector and legal form) and their location (region at NUTS2 level). Second, in all models an additional control is given by the dependent variable in absolute value at the initial year (2011). Finally, we introduce two control variables (R&D intensity and institutional quality) related to the external regional environment, to control for the non-unidirectional relation between HEIs and the regional economy. In Table A2 in the Appendix we describe in detail the definition and sources of control variables. Many of them are dummy variables (e.g. 20 sectoral categories, or 190 NUTS 2 regions in countries covered by the data). Given the large number of control variables we do not report the coefficients in the tables.[16] In addition Table A3 provides descriptive statistics of firm level variables.

[15] Twenty five countries are covered. Denmark and Croatia are not covered due to the lack of correct firm geographic coordinates in ORBIS; Romania is not covered due to the lack of complete data on HEIs in ETER.

[16] Tables with coefficients of control variables are available upon request from authors.

Table 2 Regression results for models of impact of education and research on firm's growth. Total variation 2011–2015. Joint estimation of education and research impacts

Variable	Turnover	Employment	Total assets	Intangible assets
Number of graduates (ISCED 5–7)				
Graduates within 10 km	0.004***	– 0.010***	– 0.002	0.042***
	(0.001)	(0.001)	(0.001)	(0.003)
Graduates between 10 and 20 km	0.009***	0.004***	0.003***	0.024***
	(0.001)	(0.001)	(0.001)	(0.002)
Graduates between 20 and 50 km	0.021***	0.003***	0.012***	0.027***
	(0.001)	(0.001)	(0.001)	(0.003)
Graduates between 50 and 100 km	0.029***	0.033***	0.021***	0.013***
	(0.001)	(0.001)	(0.001)	(0.003)
Total number of citations received				
Citations within 10 km	0.003**	– 0.006***	0.013***	– 0.036***
	(0.001)	(0.001)	(0.001)	(0.003)
Citations between 10 and 20 km	0.006***	– 0.007***	0.005***	– 0.019***
	(0.001)	(0.001)	(0.001)	(0.003)
Citations between 20 and 50 km	0.007***	– 0.008***	0.005***	– 0.013***
	(0.001)	(0.001)	(0.001)	(0.004)
Citations between 50 and 100 km	0.010***	– 0.024***	0.005***	0.004
	(0.001)	(0.001)	(0.001)	(0.003)
N	1,316,753	1,316,753	1,316,753	1,316,753
R^2	0.1811	0.1598	0.1451	0.1385

Standard errors in parentheses. Dependent variables are measured as the log growth of each variable between 2011 and 2015. Independent variables are standardized. Controls included (size, sector, legal form, region, initial values of dependent variables, R&D intensity, quality of institutions). *$P<0.05$, **$P<0.01$, ***$P<0.001$

4 Main results

This section is divided into three sub-sections. In the first, we report the estimates of the relationship between firm's performance and our independent variables (graduates and citations) separately. In the second one, we presents the result obtained when running models in which both proxies appear jointly. Finally, joint models with the interaction terms are displayed to analyse complementarities between education and research activities.

4.1 Separate estimation of independent variables at aggregate level

Our main independent variables (number of graduates and citations) are aggregated at the level of HEIs. This means that, for each firm in the dataset, we compute the sum of each variable for all HEIs that are located at the various distances from (the address of) the firm. Aggregated variables constitute indicators of the overall supply of education and research activities, with no consideration for the subject mix of disciplines.

Table 3 Regression results for models of impact of education and research, both aggregated, on growth of firms, and their interaction

Variable		(1)	(2)	(3)	(4)
		Turnover	Employment	Total assets	Intangible assets
Number of graduates- (standardized)	Within 10 km	0.012***	0.002	0.015***	0.089***
		(0.003)	(0.002)	(0.002)	(0.008)
	Between 10 and 20 km	− 0.001	0.005***	− 0.001	0.021***
		(0.002)	(0.002)	(0.002)	(0.006)
	Between 20 and 50 km	0.003	0.001	0.005**	0.037***
		(0.002)	(0.002)	(0.001)	(0.006)
	Between 50 and 100 km	0.026***	0.003	0.015***	0.067***
		(0.002)	(0.001)	(0.001)	(0.006)
Number of citations (standardized)	Between 10 km	0.002	− 0.010***	0.013***	− 0.049***
		(0.002)	(0.001)	(0.001)	(0.005)
	Between 10 and 20 km	− 0.007***	− 0.006***	0.001	− 0.040***
		(0.001)	(0.001)	(0.001)	(0.004)
	Between 20 and 50 km	− 0.011***	− 0.009***	0.005***	− 0.062***
		(0.001)	(0.001)	(0.001)	(0.005)
	Between 50 and 100 km	− 0.015***	− 0.012***	0.002*	− 0.092***
		(0.001)	(0.001)	(0.001)	(0.005)
Number of academic staff (standardized)	Between 10 km	− 0.022***	− 0.011***	− 0.010***	− 0.073***
		(0.003)	(0.002)	(0.002)	(0.008)
	Between 10 and 20 km	0.003	− 0.001	0.003	− 0.012*
		(0.002)	(0.002)	(0.002)	(0.006)
	Between 20 and 50 km	0.007**	0.007***	0.001	− 0.017*
		(0.002)	(0.002)	(0.002)	(0.007)
	Between 50 and 100 km	0.011***	0.030***	− 0.001	0.021**
		(0.002)	(0.002)	(0.002)	(0.008)

Table 3 (continued)

Variable		(1) Turnover	(2) Employment	(3) Total assets	(4) Intangible assets
Standardized graduates*total citations	Between 10 km	0.009***	0.003***	− 0.002*	0.019***
		(0.001)	(0.001)	(0.001)	(0.003)
	Between 10 and 20 km	0.014***	0.001	0.001	0.026***
		(0.001)	(0.001)	(0.001)	(0.003)
	Between 20 and 50 km	0.010***	0.001	− 0.000	0.024***
		(0.001)	(0.001)	(0.001)	(0.002)
	Between 50 and 100 km	0.003***	− 0.001**	− 0.002***	0.017***
		(0.001)	(0.001)	(0.000)	(0.002)
Constant		1.182***	0.280**	1.101***	− 0.448
		(0.119)	(0.088)	(0.078)	(0.266)
N		432,179	432,179	432,179	432,179
R^2		0.1733	0.1412	0.1652	0.1240
VIF		62.21	62.17	62.21	62.12

Standard errors in parentheses. Dependent variables are measured as the log growth of each variable between 2011 and 2015. Independent variables are standardized. Controls included (size, sector, legal form, region, initial values of dependent variables, R&D intensity, quality of institutions). *$P<0.05$, **$P<0.01$, ***$P<0.001$

Table 1 presents the main results when graduates and citations enter separately in the regression. The sample is restricted to firms for which data on all four performance variables are available for 2011 and 2015. This greatly reduces sample size but it ensures comparability across various performance variables. The dependent variables describe in log the absolute variation of the performance variable between 2011 and 2015. The independent variables are in standardized form. All control variables described in the previous section are included in the regression but are omitted in the tables for space sake.

All models in Table 1 show a R^2 in the range 15–21%; given that the performance of firms is a construct with many antecedents and explanatory variables, this result can be considered satisfactory.

In Panel A, we reproduce the results for human capital externalities. The impact of the number of graduates is positive, large and persistent across distance in the case of turnover. On the contrary, it is positive but only at a short distance (less than 10 km) for total assets (for which is negative between 10 and 20 km) and intangible assets. Finally, the impact on employment is not conclusive, with a negative coefficient at short distance and a positive one between 10 and 20 km. Taken together –with the exception of employment- these findings confirm at the micro level the positive effect of tertiary educated human capital (proxied by the number of graduates) on turnover and assets. Interestingly, the impact on total and intangible assets is significant only in the proximity of HEIs, a finding that supports the hypothesis of spatial decay for human capital spillovers from higher education (with a faster decay for assets).

In Panel B we consider research spillovers: the results are in line with those of Panel A (positive and significant coefficient on firm's turnover at all distances; significant and positive coefficients for total and intangible assets only at a short distance; negative coefficient on employment at short distance). These results are in line with our expectations of a positive impact of research at the local level, with a spatial decay that is faster than that observed for human capital.

Summing up, the partial models in Tables 1 show a positive and significant effect of both human capital creation and research on the growth of turnover (at all distances) and of intangible assets (at short distance).

With respect to spatial effects, we find support to the general proposition that the impact decays with distance. In fact, employment, total assets and intangible assets have statistically significant coefficients only at short distance (in 6 cases below 10 km, in other 2 cases between 10 and 20 km), while beyond these distances no coefficient is significant. With respect to turnover, the pattern is more articulated: considering the magnitude of coefficients, in the case of human capital (i.e. graduates) they are roughly constant between 0 and 50 km (0.011–0.012), and drop to 0.006 for longer distances. In the case of research (i.e. citations) the initial decrease is larger (from 0.019 to 0.006). Hence, the spatial decay hypothesis is confirmed for most models and the rate of decay is larger for citations than for graduates. The latter finding is an original one, suggesting a difference in the spatial structure of the two types of spillovers.

4.2 Disentangling human capital and research spillovers effect

In this section we build up integrated models in order to examine the joint effects of human capital and research proxies (Table 2), and their complementarity (Table 3).

In Table 2 the two sources of spillover (education and research) are estimated jointly in the same models. Human capital has a pervasive positive and significant impact on all dimensions of firm' performance (with the exception of employment and total assets at the shortest distance), but the spatial decay proposition is not confirmed (in fact, for turnover, employment, and total assets quite the opposite emerges). This finding suggests that, contrary to our expectations on the working of local labour markets, graduates accept offers from firms even if they are located at a certain distance, beyond 50 km (but below 100 km). As for citations, the estimates point to a positive impact on turnover and total assets and a negative one on employment and intangible assets, with no support to the spatial decay proposition.

For both graduates and citations we estimate positive coefficients in the case of turnover and total assets. This is broadly consistent with the idea that graduates and research quality have a positive effect on local development. However, when we consider employment and intangible assets, the positive effects is confirmed only for graduates (the exception being employment at the shortest distance), while for citations the great majority of the estimated impacts are negative. These results seem to indicate that, overall, the creation of human capital is more effective than research quality in generating positive effects on firms' performance in the proximity of HEIs.

We advance an explanation of the negative coefficients for citations that is consistent with our approach on the distance effects created by research. The higher the citations received by publications of a given university, the larger the reputation, also witnessed by several global university rankings. This pushes more graduates to migrate and to accept offers from large companies. This also deters universities from interacting intensely with local firms, in the presence of more rewarding opportunities, external to the local environment. This effect will not be visible in large metropolitan areas, in which universities and large firms are co-located, but will influence the spillovers in all other local environments.

Table 1 suggests that, taken separately, both education and research have a positive and significant impact. Table 2, on the contrary, shows that, taken together, the overall impact changes: for education the positive impact is largely confirmed, while for research the overall picture is not confirmed, with positive coefficients for turnover but negative for employment and intangible assets. It is clear that the internal interactions between education and research must be examined more carefully. We address this issue in two ways.

In Table 3 we add to the previous model the interaction between human capital and research, by introducing a simple multiplicative term. Second, we add the number of academic staff (standardized), to reflect the fact that the latter contributes to both human capital generation and research.[17] This makes the results not strictly comparable to Tables 1 and 2, but wipes away the variability in the size of the universities, as measured by the number of academic staff.

Results indicate that the number of graduates (per se[18]), tends to have a positive impact on firm's performance: when significant, the coefficients are positive. On the other hand, for research (per se) the impacts are generally negative, except on total assets. We may interpret these findings as follows: keeping citation fixed and increasing graduates generally improves firms' performance while keeping graduates fixed and increasing citations does not give a consistent sign, as the result will depend upon the values of both graduates

[17] We also run two additional regression models interacting academic staff with graduates and citations respectively. Results are presented in Tables A5 and A6 of the online appendix for simplicity.

[18] With this we mean: not considering the interaction term.

and citations. In this sense, human capital has a more positive effect on local development. Overall, for these two variables considered individually, the spatial decay proposition is not confirmed.

When considering the interaction term between the number of graduates and citations,[19] which captures the complementarity between the two, the results indicate that research activities and human capital creation are broadly complementary activities for turnover and intangible assets (but not for total assets, while for employment the evidence is inconclusive).

The most important results regard citations as an indicator of research output. The overall impact of citations will depend on the number of graduates as well as on the number of citations. In other words, disembodied and codified knowledge (publications) has an impact insofar as it is combined with educational activities that increase human capital up to the level of graduates absorptive capacity of the firm. This finding has important managerial policy implications, as we discuss below.

Finally, in the Appendix we present some robustness checks with respect to the interaction with the size of university. In Table A5 we interact the size of universities (as measured by the number of academic staff) with the number of graduates, while in Table A6 we do the same with the number of citations. Interestingly, the signs of the interacted terms strongly differ between the two cases: they are significant and *negative* for graduates, while they are significant and positive for citations. This difference holds true across most distances. This means that having a large university close to the location of firms generates positive spillovers in terms of research collaboration, but it makes it more difficult to hire graduates. This is a surprising finding, supporting the main thrust of our argument, i.e. that education and research spillovers behave differently. Further research is needed to interpret this negative result.

5 Discussion and conclusions

The main results from the analysis can be summarized as follows.

First, the covariation of firms' performance and education activities carried out by HEIs is confirmed beyond any reasonable doubt, supporting our hypothesis (H1). After controlling for many structural factors (industry, size of the firm, legal form) location factors (regions) and institutional factors (R&D intensity, quality of institutions) it appears that HEIs' production of human capital (graduates) in the large majority of cases positively influences firms located in the neighbourhood. This positive effect holds true in all our specifications, i.e. as a separate effect (Table 1), a joint effect with research activities (Table 2) and a complementary effect using interacted terms related to research (Table 3). This finding is very strong, as significant coefficients are almost positive, across distances and across measures of firm performance. The human capital argument is not new, as discussed in the survey of the literature. However, our results are based on microdata at firm level, not on aggregated data at regional or country level. Furthermore, they are robust with respect to alternative specifications of firm performance and various scales of spatial

[19] Since we are not interested in the magnitude of the impact but in the sign of the interaction term, we interact one standardized variable with the natural form of the other. We also calculate the Variance Inflation Factor (VIF).

distance. This effect is even more remarkable since it comes from flows (yearly production of graduates), that is, from relatively short-term phenomena, not from established, slowly created stocks.

Second, the findings are more ambiguous for the impact of research, a finding that goes against the received wisdom. Taken separately (Table 1), citations have a positive effect on turnover, total assets and intangible assets, but only at short distance (below 10 km) for all variables and not for employment (negative coefficient). The positive impact holds true for all distances in the case of turnover. This finding would partially support our hypothesis (H2). However, when the impact of citations is estimated jointly with graduates (Table 2) or in interaction with graduates (Table 3), many significant coefficients are negative. In particular in Table 2 citations enter positively with turnover and total assets but negatively with graduates and intangible assets.

Third, we find support for the notion that creation of human capital and research are complementary in producing externalities for firms, as witnessed by the positive and significant coefficients of the interaction term in most cases (Table 3). This confirms our hypothesis (H3a).

With respect to the issue of relative importance of education and research we conclude, on the basis of the results of joint estimation and of interaction with graduates, that education has a larger impact than research, supporting our Hypothesis (H3b).

Summing up we find strong support for the positive role of education (H1), for the complementarity hypothesis between education and research (H3a), and for the larger impact of education with respect to research (H3b), while we find only partial support for the role of research, when it is considered in isolation from education (H2).

We interpret these findings as follows. The starting point seems to be the strong finding on complementarity: education and research need to work together in order to maximize the impact. When taken in a complementary way, as it happens for universities, both education and research have a positive impact on firms in the surrounding area. However, spillovers from human capital are stronger and more pervasive than spillovers from research. It means that these spillovers reach firms more intensively and effectively when the knowledge generated by research is embodied in students and graduates. When universities produce high level research but have small number of students, the impact is reduced: students migrate to other areas (perhaps because their high quality training makes them attractive for large firms elsewhere) and research results do not flow effectively to the local economy. This finding is important and fills a gap in existing research. Spillovers from education are indeed more important than spillovers from research.

Finally, we also find partial confirmation of the traditional effect of spatial decay of impact of spillovers, since coefficients tend to be significant for closer distances in Table 1 but not in Tables 2 and 3.

The implications of this analysis are interesting. From a methodological point of view, the paper is the first attempt to build up a dataset at the European level in which microdata on firms are integrated with microdata on the creation of spillovers from HEIs. It is also the first one to allow the estimation of spillover effects by distinguishing between the creation of human capital and the uptake of research results. From a policy point of view, the finding of complementarities between graduates and citations confirms the appropriateness of the traditional model of HEIs that combines education and research. At the same time, results pointing at differential impacts on firm's performance of human capital and research may have interesting policy implications.

In recent years, there has been a strong policy emphasis on the role of universities as engines of economic growth, largely driven by research activities. This emphasis has also been central to cohesion policies, or policies aimed at reducing the distances between central and peripheral regions in Europe. The expectation has been that research activities might generate positive externalities to the local and regional economy. The implicit model of this policy orientation is one in which universities must be excellent in their research, while at the same time educating large number of students.

Our results suggests a different story. The first and most important contribution of HEIs is educating a large number of highly qualified graduates, for they contribute significantly to the performance of firms and the local and regional economy. This means that peripheral regions should adopt long-term policies for systematically increasing enrolment and graduation rates. Since the economy of peripheral regions is characterized, in general, by a lower R&D intensity, these graduates might find employment also in low-tech industries, or in the local tertiary sector. For the same reason, in these regions there is a strong tension between the goal of research excellence and the need to have an impact on the regional economy. Universities that achieve excellence in some fields are attractive for large firms that may be located at a large distance, which do not have structural incentives to allocate resources to the interaction with local firms. In turn, local firms look for collaboration with universities whatever their level of excellence in research, because they mainly look for promising graduates (who do not need to be rocket scientists), and might be also interested in consultancy and technology transfer.

A clear implication of our analysis is that there is no reason to establish a unique model of HEIs in which all institutions are asked to strive simultaneously and fiercely for research excellence *and* local impact. Peripheral regions might benefit more from HEIs that specialize in applied research of interest to the local economy, not necessarily of international standards, while still producing large numbers of qualified and employable graduates. In turn, universities that want to compete in research at international level should not be asked to demonstrate their impact at local and regional level in the same way, as for some of them the spatial scale of impact is clearly beyond these boundaries.

We also see interesting managerial implications. First, all companies in all regions benefit from the creation of human capital by universities located close to their facilities. This is an average effect over the entire population of firms. Universities create a pool of skilled people that benefit companies irrespective of the share of graduates over the total workforce or their level of investment into R&D.

Second, companies benefit from research in a more selective way. The average effect of research activities of universities, as measured by citations to publications, is the result of two conflicting effects. On the one hand, as witnessed by the positive coefficients of the interaction term (number of graduates times number of citations), research has a positive impact if associated to education. This effect can be considered a qualification of the large and positive human capital effect outlined above: the higher the level of research the better the quality of education, the stronger the positive impact on the local economy. On the other hand, however, the quality of research generates effects that mitigate the impact on the local economy, by pushing migration of skilled graduates towards accepting employment from (large) firms located elsewhere and by making face to face collaborations with local firms less attractive, relative to interaction with large firms.

The managerial implications are diversified. For small firms, the main implication is that they should engage more intensively with local universities and offer attractive employment conditions to graduates, including a clear career pathway. For large firms, the main implication is that they should engage with universities irrespective of the location, but then they should create joint infrastructures to train students and graduates. The impact of research, in fact, is conditional on the production of skilled human capital.

It is also important to highlight other limitations of our analysis. We deal mainly with flows (i.e. flows of graduates and citations of publications), not with stocks, with the only exception of academic staff for the complementary analysis, which is relatively stable at HEI level. Several models assume that it is the stock (and its obsolescence over time) which has an impact on firms and their performance. We cannot address this claim with our data, given the short time interval. Furthermore, we have no data on migration of highly educated people. We do not know from our data the proportion of graduates who migrate outside the city or the region where the university is located.

In addition, the period covered by our data (2011–2015) has been marked by the post-2008-financial crisis recovery, which however for a few European countries included a second recession (2011–2012) associated to the crisis of sovereign debt and the implementation of austerity plans. Overall, this period might have involved diverse government policies with respect to public expenditures and the funding of universities. While this context might be a limitation of our analysis, it should be remarked that we deal with the impact of the volume of university activities (i.e. education of graduates and publication of articles), which does not necessarily respond immediately to short term fiscal restrictions.

With these limitations, however, the paper is, to our knowledge, the first attempt to integrate large-scale microdata from different sources to study knowledge spillovers in the European context.

Summing up, these results point to the need to reconceptualise the relation between HEIs and the economic system, going beyond general-purpose notions of spillover and uniform types of prescriptions. This reconceptualization might contribute to a better design of regional, national and European policies.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10961-023-10008-y.

Funding Open access funding provided by Università di Pisa within the CRUI-CARE Agreement. A preliminary version of the study was realised in the framework of the Knowledge-Hub of Higher Education, an Administrative Agreement between DG EDUCATION and CULTURE (EAC) and DG JOINT RESEARCH CENTRE (JRC). Its content was developed under the Service Contract number 934514-2017 A08-IT with FBK-IRVAPP (Trento, Italy). No funding is declared for the construction of the current dataset and the development of the paper.

Data availability Appendix material available at Online additional material.

Code availability No code available.

Declarations

Conflict of interest The authors declare they have no conflict of interest. The views expressed are purely those of the author (Federico Biagi) and may not in any circumstances be regarded as stating an official position of the European Commission.

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