

# CROSS-COUNTRY EVIDENCE ON THE CONTRIBUTIONS OF RESEARCH INSTITUTIONS TO INNOVATION

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## CROSS-COUNTRY EVIDENCE ON THE CONTRIBUTIONS OF RESEARCH INSTITUTIONS TO INNOVATION

Caroline Paunov\*, Martin Borowiecki\* and Nevine El-Mallakh\*\*

### ABSTRACT

*This paper presents preliminary evidence on the patenting activities of 21 200 research institutions - 20 091 higher education institutions (HEIs) and 1 109 public research institutes (PRIs) - for 36 OECD countries and China from 1992 to 2014. Our evidence, which builds on a database that matches research institutions to a sample of their patent applications, indicates patent applications to the European Patent Office (EPO) filed by research institutions grew faster than industry patents. Those jointly filed by industry and research institutions grew even faster. However, research institutions' share in patent applications remains low and their ratio of patents granted to applications is below that of industry. An econometric analysis at postal code level shows that geographical proximity to research institutions is associated with higher industry patenting. Results from an instrumental variable estimation indicate that research institutions positively influence local industry patenting, including in life sciences and digital technologies.*

**Keywords:** Higher education institutions (HEIs), universities, public research institutes (PRIs), patents, innovation, local knowledge spillovers, OECD countries, China

**JEL codes:** I23, O31, O34

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*Table of Contents*

<b>INTRODUCTION</b> .....	<b>5</b>
<b>1. LITERATURE REVIEW</b> .....	<b>9</b>
1.1. Research institutions' impact on productivity, growth and innovation .....	9
1.2. Research institutions' patenting and policy-driven changes .....	10
1.3. Geographic proximity and innovation .....	11
<b>2. DATA AND EMPIRICAL METHODOLOGY</b> .....	<b>12</b>
2.1. Description of the database .....	12
2.2. Additional data sources used for the analysis .....	14
2.3. Estimation strategy .....	16
<b>3. RESEARCH INSTITUTIONS' PATENTING ACTIVITY AND CO-LOCATION WITH INDUSTRY INVENTORS</b> .....	<b>17</b>
3.1. Trends of research institutions' patenting activities .....	17
3.2. Characteristics of research institutions' patents .....	19
3.3. Location of research institutions and inventors .....	22
<b>4. ASSESSING THE IMPACTS OF RESEARCH INSTITUTIONS ON INDUSTRY PATENT ACTIVITY</b> .....	<b>24</b>
4.1. Exploratory correlation analysis .....	24
4.2. Baseline results: Accounting for endogeneity of university locations .....	26
<b>5. CONCLUSION</b> .....	<b>28</b>
<b>REFERENCES</b> .....	<b>29</b>
<b>ANNEX. TECHNICAL DETAILS REGARDING THE CONSTRUCTION OF THE DATABASE</b> .....	<b>34</b>

## INTRODUCTION

Assessing the impacts of higher education institutions (HEIs) and public research institutes (PRIs) – referred to jointly as research institutions – on innovation is at the top of the policy agenda because of increasing demands on the effectiveness of public investment. Public research contributes to innovation via different channels of knowledge transfer, including patenting by university researchers and knowledge sharing with industry. Research institutions are also important players in highly innovative clusters as they boost innovation by direct interactions with local industry partners. Well-documented cases of highly successful clusters involving research institutions are Silicon Valley (Lee and Nicholas, 2012) and Route 128 (Saxenian, 1994). Several country-specific case studies have documented the contributions research institutions make to local innovation activities (Toivanen and Väänänen, 2016; Belenzon and Schankerman, 2013; Jaffe, 1989). However, little cross-country evidence exists to document the patenting activities of research institutions across the OECD and their impacts on local innovation.

In this paper, we provide new evidence on the patenting activities of research institutions and their impact on industries' patenting activity across 36 OECD countries and the People's Republic of China (hereafter "China"). The main contribution of our paper is the cross-country analysis we are in position to conduct on the basis of a comprehensive patent-research institution linked dataset we built. The cross-country database links 21 200 research institutions (7 462 public HEIs, 12 629 private HEIs and 1 109 PRIs<sup>1</sup>) with more than 2.5 million patent applications to the European Patent Office (EPO). Of those patent applications, we draw a sample of 21 664 that were filed by these research institutions while the remainder are industry filings. We geolocalise both the location of patent inventors and of research institutions across 174 376 postal code areas for the period 1992 to 2014. The latter allows identifying geographic spillover effects of research institutions on regional industry patenting. The evidence reported is preliminary as we conduct further work to improve the database for comparable cross-country coverage of research institutions and their patenting activities.

As regards research institutions' patenting activities, we find that the number of EPO patent applications of research institutions increased nearly fivefold from 1992 to 2014, much more than industry patents. However, the total share of patents issued by research institutions is low compared to industry patent with the highest estimate below 10%.<sup>2</sup>

Our data also show that EPO patent applications jointly filed by research institutions and industry grew faster than research-institution-owned patent applications. These joint applications accounted for 29% of all patent applications of research institutions. In 1992, their share was of 17% only.

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<sup>1</sup> PRIs include public research institutes, agencies, ministries and other public administrations and private non-for-profit organisations. Hospitals are excluded.

<sup>2</sup> In its latest report, the EPO provides an estimated share of research institutions in total patent applications from EPO member states of 9% (EPO, 2018). According to the methodology developed by Du Plessis et al. (2009) accessible in PATSTAT (ECONOMY-EUROSTAT-EPO PATSTAT Person Augmented Table), the share of total EPO patent applications of research institutions (excluding hospitals) is of a lower 4.3% for the 2010-15 period.

Comparing research institutions' to industry patents, the technology focus differs. Research institutions filed 44% of the EPO patent applications contained in our sample in life sciences between 1992 and 2014, compared to 15% in the case of industry. Moreover, research institutions have increased their share of patent applications in digital technologies, while the share of patents in life science related technologies decreased. This decrease points possibly to a diversification in research institutions' patenting activities.

The acceptance rate of patent applications also differs, with the ratio of patents granted over patent applications of research institutions being below that of industry over the 1992-2014 period. The acceptance rate of research institutions patents is lower in the period 2002-2004, which coincides with the period of slight slowdown and then rapid increase in the number of patents filed by research institutions.

Results from an exploratory econometric analysis of postal code-level data point to a positive correlation of research institutions' and industry patent applications in the same geographic area. We also find a positive relation between geographical proximity of inventors of industry patents to research institutions. These results hold even when differences in patenting behaviour across postal codes and across years by country are taken into account. Those results, however, do not provide evidence of a causal impact of research institution on industry inventions. This is because of potential omitted variable biases, for instance, as policy changes or industry shocks may affect the patenting behaviour of both research institutions and industry and consequently drive a spurious relationship between research institutions' and industry patents. The location of research institutions may be a result of industry dynamics but itself make little difference to local industry's inventive activity. It may also be the case that it is industries' inventive activities that drive research institutions' patent activities. We are in position to control for some caveats by introducing year and postal code fixed effects and by using lagged values of our independent variables. These controls, however, cannot fully exclude omitted variable bias and reverse causality.

We consequently analyse the causal impacts of proximity of universities on industry patenting by means of an instrumental variable specification. Our results point to a positive significant effect. These hold also specifically for life sciences and digital technologies. We do so by exploiting the location decisions of research institutions, which were influenced by proximity to historical mining sites as they contribute little to today's regional innovation activities. We also exploit information on public spending on R&D conducted in research institutions by countries over the time period we investigate as an indication of the research capacities of research institutions. Since we control for country-year and postal code fixed effects, we are confident that the estimations do not reflect other impacts than those of research institutions on industry patenting.

Our evidence focuses on the patenting activities of research institutions as patenting is an important proxy for research institutions' contributions to innovation. Patenting of research findings can be a powerful means for industry to innovate on the basis of research since, differently from scientific publications, patents are inventions with potential for commercial application. Moreover, patenting correlates strongly with research strengths of universities with many top patenting institutions being top of publications lists and recognised as leading research institutions and training centres of top talent.<sup>3</sup> Azoulay et

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<sup>3</sup> The top institutions in terms of patent applications includes top universities from the US (such as MIT and the California Institute of Technology) and Japan (e.g. University of Tokyo, Kyoto University), as well as leading research institutions, such as the French National Centre for Scientific

al. (2007), Carayol and Matt (2004) and Curi et al. (2012) show evidence of a correlation between research excellence – including via publications – and patenting activities respectively at researcher, laboratory and university level. In other words, patenting is also in many ways a proxy for excellent research and research relevant to industry in particular. Consequently, information on research institutions’ patenting can also be a good proxy on institutions that provide relevant knowledge to industry across different channels and not only patenting.

Nonetheless, the focus on patenting in our study does not allow for a comprehensive account of the contributions of research institutions to innovation. In particular, the focus on patenting – which tends to be very concentrated in leading research institutions – does not allow identifying those research institutions with good knowledge contributions that do not have direct industry orientation. The more extensive use of patents in some sectors (such as pharmaceuticals) and associated research fields also points to greater emphasis of a patent-based assessment on those than on other sectors. Other potentially often more effective ways include exchange of human capital, whether this be the recruitment of university graduates or collaborations with researchers, as well as informal exchanges at conferences and other events. We address this shortcoming by looking at the “spillover effects” of proximity to universities on university patenting, consequently capturing all kinds of possible channels many of which have a strong location bias (recruitment/informal networks, etc.). This approach, however, does not allow distinguishing differences in the knowledge contributions or training capacities of research institutions. Moreover, the focus on industry patents as an output does not fully reflect innovation performance.

The paper contributes to the existing literature on the contributions of research institutions to innovation by offering cross-country evidence. To the best of our knowledge, only Valero and Van Reenen (2019) and Breschi et al. (2019) provide cross-country assessments on research institutions’ impacts. Differently from our research, however, Valero and Van Reenan (2019) focus on universities’ contributions to economic growth in general while Breschi et al. (2019) focus on start-up activities of public research as reported in Crunchbase. Other related country-level studies have explored questions related to how universities contribute to enterprises’ innovation performance (Robin and Schubert, 2013; Maietta, 2015), entry into new technological fields (Hall, Link, and Scott, 2003), and productivity of high-tech start-ups (Motohashi, 2005).

Our paper also relates to econometric analysis of spillover effects of universities on business innovation. A major challenge these studies address is identifying the causal effect of research institutions on innovation, as very innovative industries likely co-locate with very innovative universities. Toivanen and Väänänen (2016) and Andersson, Quigley, and Wilhelmsson (2009) study impacts by exploring how the establishment of new universities in the 1960s and 1970s in Finland and in the 1970s in Sweden affected local industries’ patenting. The creation of universities, however, is rare and often influenced by regional context so that only very selected moments of “random” creation are suitable to assessing the impact of research institutions on regional industry performance. Other national case studies have addressed endogeneity concerns by exploited the forced relocation of university departments in the 1950s in China (Glaeser and Lu, 2018) and shocks to university funding in the United States (Kantor and Whalley, 2014). Glaeser and Lu (2018)

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Research, Japan’s National Institute of Advanced Industrial Science and Technology, and Korea’s Electronics and Telecommunications Institute.

identify the impacts of university education on individual earnings while Kantor and Whalley (2014) investigate impacts on regional growth and labour income. Our paper adds to this literature by embracing an alternative approach – exploiting the location of universities in proximity to historic mining sites and the share of public spending on R&D conducted in research institutions - as a way to address endogeneity.

The paper was produced for the 2017-18 “Knowledge transfer between industry and science” project of the OECD Working Party on Innovation and Technology Policy (TIP). The project’s main report “University-Industry Collaboration: New Evidence and Policy Options” provides the policy conclusions emerging from the project activities (OECD, 2019a).

The paper is structured as follows: Section 1 reviews the relevant literature while section 2 describes the data and the estimation strategy we used. Section 3 discusses the patenting activities of research institutions. Section 4 explores econometrically the impact of research institutions on industry performance. The final section concludes.

## 1. LITERATURE REVIEW

This section reviews following three fields of literature our paper relates to: the impact of research institutions on innovation, the patenting behaviour of research institutions and the role of geography for innovation spillovers. Comprehensive review of the evidence on industry-science interactions can be found in Ankrah and Omar (2015), Perkmann et al. (2013) and Grimaldi et al. (2011). OECD (2019a) offers a recent conceptualisation on industry-science linkages and the set of relevant policy options.

### 1.1. Research institutions' impact on productivity, growth and innovation

Several econometric studies have investigated impacts of universities on productivity and growth. To the best of our knowledge, Valero and Van Reenen (2019) and Breschi et al. (2019) are the only cross-country study on the topic. Using data on 15 000 universities in about 1 500 regions across 78 countries for the years 1950 to 2010, Valero and Van Reenen (2019) show that increases in the number of universities are positively associated with GDP per capita growth. Breschi et al. (2019) investigate the degree to which public research contributes to start-ups based on information from Crunchbase. They find that academic start-ups represent 15% of all start-ups in the Crunchbase sample with a much higher share in science-based technological fields. They also found academic start-ups were more likely to patent than that start-ups by researchers were more successfully in terms of receiving VC funding. In addition, Kantor and Whalley (2019) provide sector-specific case study evidence to complement those findings by showing how the creation of federal agricultural research stations in the late 19<sup>th</sup> century in the United States boosted local agricultural productivity in the decades following their creation.

A few papers have also investigated the impacts of research institutions on innovation. Andersson, Quigley, and Wilhelmsson (2009) show that the increase in universities in the 1970s had a positive impact on regional patenting. Toivanen and Väänänen (2016) show that in Finland the establishment of new technical universities in the 1960s and 1970s increased industry patents in those regions. In addition, Furman and MacGarvie (2007) find that there was a significant positive effect of university research on the creation of industrial pharmaceutical laboratories in the United States from 1927 to 1946.

The type of research influences the nature and size of the impact on productivity, growth and innovation. Kantor and Whalley (2019) document that agricultural productivity remains higher today in locations where agricultural research stations historically engaged in basic research. In other work on the US economy, Kantor and Whalley (2014) show that research universities have larger effects on regional growth and labour income than teaching-oriented colleges. They also shows that where university research and industry demand for these technologies align, the benefits for industry from university research are higher.

There are also important differences in how different sectors engage with public research (Paunov, Planes-Satorra and Moriguchi, 2017). Especially industries that are more science-related, such as pharmaceutical and biotechnology industries, may be able to capitalise on inputs from research institutions. The pharmaceutical industry, for instance, is highly reliant on public research for the development of their new products (Cohen et al., 2002; Mansfield, 1995, 1998; Jaffe, 1989; Narin et al., 1997). In the case of biotechnology, the industry's engagement in joint research and publishing with academic institutions and the

engagement of “star” scientists are effective channels for the industry to source new scientific knowledge (Zucker, Darby and Armstrong, 2002; Zucker and Darby, 2001; Zucker, Darby and Brewer, 1998; Liebeskind et al., 1996).

Finally, the policy environment arguably also influences research institutions’ impacts on industry performance. This includes, for instance, research institutions’ autonomy (Aghion et al., 2010 and 2007; Boarini et al., 2008). Intellectual property rights policies that regulate inventions generated from public research may affect degree to which research institutions engage in patenting as opposed to other forms of science-industry interaction. Policies that facilitate labour mobility between research and industry are another policy factor of importance for knowledge transfer between industry and science.

## 1.2. Research institutions’ patenting and policy-driven changes

A number of studies have analysed the patenting activities of research institutions. Seminal work by Henderson, Jaffe and Trajtenberg (1998) use information on US universities’ patents between 1965 and 1988 and show that they were of higher quality than industry patents as measured by numbers of citations. Geuna and Nesta (2006) describe trends in university patenting for selected European countries (Belgium, Finland, France, Germany and Italy) from the 1970s to 2000 by reviewing several small-scale national surveys. Moreover, in the above-mentioned study, Andersson, Quigley, and Wilhelmsson (2009) also show that new universities had a positive impact on regional industry patenting.

The unique contributions of public research to innovation arise from potentially different characteristics than industry inventions. Studies point to university inventions that are more basic and scientific excellent. Using data on 5 811 patents with US faculty as inventors, Thursby et al. (2009) show that university patents are more basic and rely to a stronger extent on excellent research than firm patents. Academic patents are arguably technologically more sophisticated as they relate to basic science and state-of-the-art research. The evidence on this is mixed with a number of papers that point to less or no differences in technological value between academic and industry patents (Rosell and Agrawal, 2009; Sapsalis et al., 2006). This, however, depends critically on the measures used to assess the quality and impact of research, requiring further investigation of the issues.

However, patents are not the main output from scientific research, particularly in disciplines that are not linked to science-based industries and in disciplines that are less applied. The most important scientific disciplines in terms of patenting include engineering, biotechnology and chemistry (Bekkers and Bodas Freitas, 2008; Geuna and Nesta, 2006; Grimpe and Frier, 2010). Other disciplines will be under-represented in patent statistics. Moreover, even among those disciplines, patent applications may only represent a small proportion of knowledge of relevance to industry. Researchers at the MIT Mechanical and Electrical Engineering Departments, for instance, estimated that patents accounted for less than 10% of research outcomes from their laboratory (Agrawal and Henderson, 2002). Fleming et al. (2019) also show that university patenting represents only a small share of patents that build on research outcomes that were funded by US government funding. Industry owned most patents.

Research institutions receive important funding from government in return for their contributions to knowledge and innovation. In this context, governments have implemented a rich policy mix aimed at incentivising research institutions to engage more with industry (see Guimon and Paunov, 2019 for an overview of policy instruments). This includes

measures aimed at incentivising research institutions' patenting, such as, the Bayh-Dole Act that was introduced in the United States in 1980 inspiring similar regulatory reforms in Europe, Latin America and beyond (see Guena and Rossi, 2011; Zuniga, 2011). Most policy analyses are qualitative in nature or provide quantitative results of specific policies in the context of small-scale samples within a single country (e.g., Mowery et al., 2001; Goldfarb and Henrekson 2003; Mustar and Wright 2010; Rasmussen 2008; Grimaldi et al., 2011; Della Malva et al., 2011). A more comprehensive overview of those studies is provided in Kochenkova et al. (2016).

### 1.3. Geographical proximity and innovation

Our analysis also relates to work that has documented that innovation is geographically more concentrated than economic activity (for a literature review, see Carlino and Kerr, 2015). Agglomeration economies, or benefits of proximity to innovative firms, arise from a shared pool of skilled graduates (Moretti, 2004), access to a dense network of suppliers and customers (Ellison, Glaeser, and Kerr, 2010), and the presence of HEIs and PRIs that boost knowledge spillovers to industry partners by direct interactions (e.g. Furman and MacGarvie, 2007; Saxenian, 1994). Such agglomeration benefits for innovation persist even as digital technologies facilitate collaboration and exchange across distances, benefiting top cities more than others (Paunov et al., 2019).

Densely populated cities provide a better mix of ideas and people and are thus more conducive to face-to-face interaction and networking between researchers. Census data for the United States shows high levels of co-location of similar businesses to exploit networking benefits from spatial proximity (e.g. Billings and Johnson, 2016; Arzaghi and Henderson, 2008). Patent and citation data show not only that U.S. patent technology clusters are concentrated in a few postal code areas, but also that inventors within these clusters cite each other's inventions much more frequently than relevant inventions produced at larger geographic distance (Kerr and Kominers, 2015).

Proximity matters for science and industry interactions. Proximity to leading research institutions have been described as critical for the success of high-tech clusters, such as Silicon Valley in California and Route 128 in Massachusetts (Saxenian, 1994). Citations from industry patents to university research publications, for instance, increase with proximity to universities (Figueiredo, Guimarães, and Woodward, 2015; Jaffe, Trajtenberg, and Henderson, 1993). Belenzon and Schankerman (2013) use U.S. patent and citation data for the years 2002 to 2007 to show that citations from corporate patents of university publications and patents are locally bound and decline sharply with distances of 100 miles of a university. Evidence for Finland shows that proximity to a newly established university increases the number of industry patents in Finland (Toivanen and Väänänen, 2016).

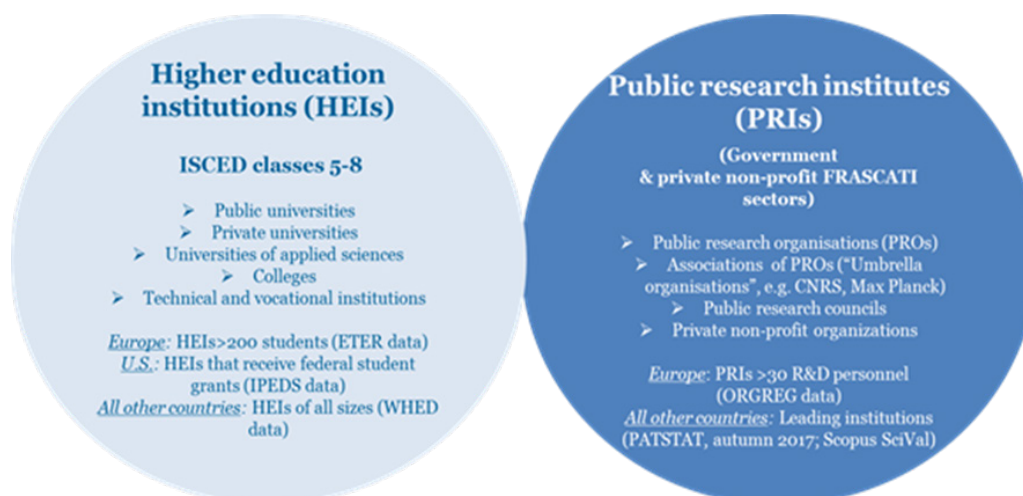
## 2. DATA AND EMPIRICAL METHODOLOGY

### 2.1. Description of the database

The cross-country analysis of impacts of research institutions on industry patenting relies on a newly compiled database we built of 20 091 HEIs and 1 109 PRIs of the 37 countries included in our study (see Table 1 for the country listed) for the 1992-2014 period. 7 462 of HEIs are public and 12 629 are private. The 1 109 PRIs include 950 PRIs as well as 79 institutions that belong to public administrations, 71 private non-profit organisations and 9 agencies. We then matched EPO patent applications to these research institutions relying on the PATSTAT database (EPO, 2018, autumn version). We also geolocalised patent inventors' information and the location of research institutions at postal code level across 174 376 postal codes. We are engaged in further work aimed at improving the database with the objective of producing a more complete coverage of research institutions and their full patenting activities that is comparable across the 37 countries we analyse.

First, regarding the coverage of research institutions across the 37 countries, our database includes public universities, private universities, universities of applied sciences, colleges, and technical and vocational institutions of ISCED classes 5-8, public research organisations (PROs), associations of public research organisations, public research councils, and private non-profit organisations performing research (see Figure 1). We relied on the following available information sources: (1) European university census information taken from the European Tertiary Education Register (ETER, 2018), (2) US university census information from the Integrated Postsecondary Education Data System (IPEDS, 2018), (3) information on European public research institutes from the Register of Public-Sector Organizations (ORGREG, 2018), (4) information on publishing PRIs outside Europe from Scopus SciVal (2018), (5) university information outside Europe and the U.S. from the World Higher Education Database (WHED) and information on patenting PRIs. In addition to information on research institutions' names and location, our database also includes information on whether research institutions are public or private entities and, for a sub-section we know the year of foundation.

**Figure 1. Coverage of research institutions**



There are important caveats as to the coverage of our research institution database, particularly for smaller research institutions. Concerning PRIs, all PRIs with 30 or more R&D personnel in Europe are included. In the absence of a comprehensive database for non-European countries, we could only include PRIs that published and were included in Scopus SciVal and those that applied for at least one patent from 1992-2014 and were included in PATSTAT. The coverage of universities across countries also differs across Europe, the United States and other countries due to different selection criteria adopted by underlying surveys.

Second, we link the database on research institutions with information on 2.55 million EPO patent applications filed by inventors resident in the 37 countries as taken from the PATSTAT (2018, autumn version) and REGPAT (2017, autumn version) databases. We matched all applications from research institutions to their respective institution using a text-matching algorithm (see description of the matching process in the Annex). We use the address of patent inventors on patent documents to capture where knowledge production took place. Information on patent owners may indicate the location of headquarters which may or may not relate to where the invention described in a patent application was made. We geolocate inventors based on the information they provide in patent application data – i.e. street, postal code, city and country.

Our data captures only a sample of research institutions' total patent applications. This is for a number of reasons. Importantly, we do not capture those patents produced in research institutions where inventors do not specify their affiliation to research institutions (see Della Malva et al., 2013; Aldridge and Audretsch, 2010 and Lissoni et al., 2009). We also do not capture fully patent applications filed by separate corporate entities that are directly affiliated to research institutions. Moreover, additional efforts on the database we engage in involve reducing systematically for all countries the underestimate of public research institutes' patents that relate to the incomplete coverage of those institutes in our research institution database.

Third, we produced a database that contains the geographic latitude and longitude coordinates of locations at postal code level of institutions and inventors (so-called geo-information). Table 1 describes the database and the distribution of research institutions and patent applications across the 37 countries for the period from 1992 to 2014. The number of research institutions varies substantially with country size playing an important role in numbers. The United States dominate with 13 726 research institutions; Mexico, Japan and China come in second, third, fourth and fifth in terms of numbers. The case of Mexico stands out and can be explained by the large number of small private research institutions. The location matching was possible for 95% of research institutions and 93% of the sample of EPO patent applications. One advantage of the postal-code-level data for our purposes is that we are in position to measure precise distances between research institutions and inventors. Details regarding the geographic matching are provided in the Annex. Insufficient geolocation information did not allow full matching and was particularly a problem for the EPO patent applications of Estonia, Greece, Latvia, Lithuania and Ireland. We consequently exclude these countries from all empirical analyses.

**Table 1. Characteristics of census of public research institutions and EPO patent applications**

Country	Number of research institutions	Share of observations with post code information (% of total research institutions)	Number of total EPO patent applications, fractional counting	Share of observations with post code information (% of total EPO patent applications)
Australia	92	95%	16 844	99%
Austria	107	65%	27 153	100%
Belgium	127	65%	27 046	99%
Canada	132	98%	35 716	65%
Chile	62	82%	373	80%
China	739	84%	39 651	16%
Czech Republic	143	94%	1 995	63%
Denmark	73	66%	22 435	100%
Estonia	47	64%	290	9%
Finland	101	90%	32 237	100%
France	371	95%	173 108	100%
Germany	553	91%	457 829	99%
Greece	101	97%	1 354	16%
Hungary	145	83%	1 757	99%
Iceland	11	91%	618	98%
Ireland	41	68%	7 534	5%
Israel	43	72%	17 991	52%
Italy	295	74%	78 817	98%
Japan	776	99%	434 690	88%
Korea	195	89%	73 295	70%
Latvia	62	73%	243	2%
Lithuania	54	89%	203	11%
Luxembourg	7	86%	5 634	99%
Mexico	1 613	88%	932	96%
Netherlands	100	90%	84 476	99%
New Zealand	26	54%	3 009	58%
Norway	111	93%	8 559	96%
Poland	341	96%	2 924	92%
Portugal	144	96%	1 407	90%
Slovak Republic	51	94%	388	73%
Slovenia	54	98%	1 539	97%
Spain	186	96%	19 619	99%
Sweden	75	55%	59 311	95%
Switzerland	59	63%	93 785	100%
Turkey	188	100%	3 649	81%
United Kingdom	249	99%	96 282	90%
United States	13 726	98%	717 601	99%
<b>Total sample</b>	<b>21 200</b>	<b>95%</b>	<b>2 550 291</b>	<b>93%</b>

Source: Authors' calculations using PATSTAT (2018) and REGPAT (2015) databases and the GEONAMES database (available at: <http://download.geonames.org/export/zip/>), European Tertiary Register (ETER, 2018), Integrated Postsecondary Education Data System (IPEDS, 2018), Register of Public-Sector Organizations (ORGREG, 2018), Scopus SciVal (2017), World Higher Education Database (WHED, 2018).

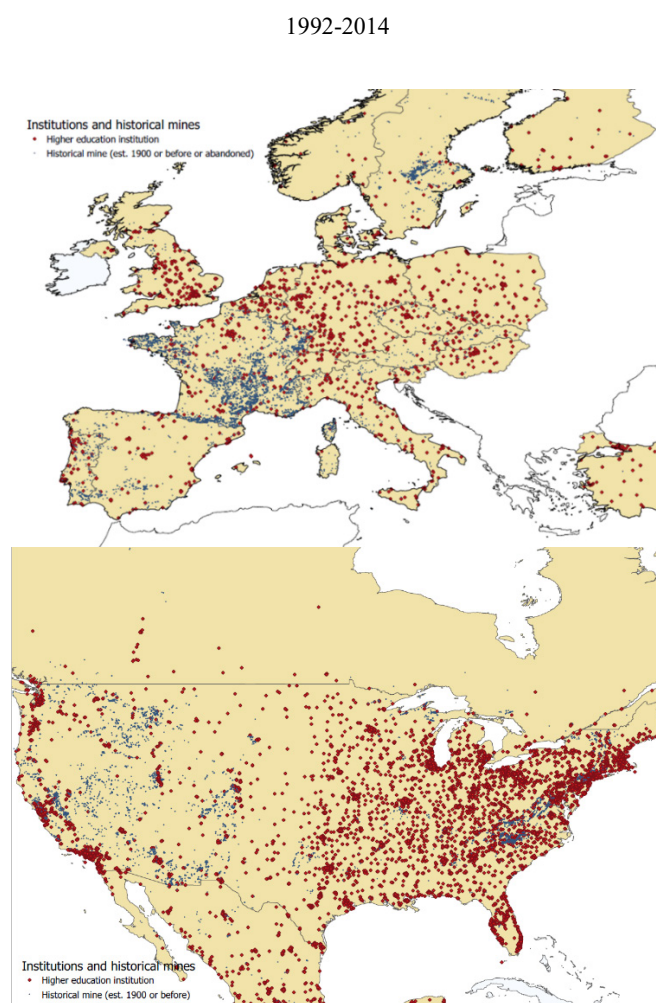
## 2.2. Additional data sources used for the analysis

We rely on data on historical mining sites to construct instruments of research institutions' location. Data on mining sites come from the 2018 US Geological Survey (USGS, 2018)

and from the European ProMine geospatial portal (<http://gtkdata.gtk.fi/Promine/default.html>). Our estimating sample contains 262 328 mines with information on the year of discovery and whether the mine is still in production or has been abandoned for a subsample. Figure 2 shows the location of historical mines for the European countries and the United States.<sup>4</sup>

We also use data on spending in R&D conducted by the higher education sector funded by the government from the OECD's Main Science and Technology Indicators Database (OECD, 2019b).

**Figure 2. Research institutions and historical mines, Europe and the USA**



Source: European ProMine Geospatial Portal database (<http://gtkdata.gtk.fi/Promine/default.html>), European Tertiary Register (ETER, 2018), Integrated Postsecondary Education Data System (IPEDS, 2018), Register of Public-Sector Organizations (ORGREG, 2018), US Geological Survey (USGS, 2018), World Higher Education database (WHED, 2018), and the US Geological Survey (USGS, 2018).

<sup>4</sup> Iceland and Lithuania are excluded from the sample due to very low mine data coverage.

### 2.3. Estimation strategy

We explore the causal effects of research institutions by exploiting the proximity of research institutions to historical mining sites. The sites' location, determined by the availability of mineral resources, influenced the creation of universities in those locations. Research institutions were created as the newly opened mines and the emerging manufacturing industries required educated engineers and skilled workers. For instance, the world's first technical university, the Berg-Schola (today's University of Miskolc, Hungary), was founded around the mining sites of Selmechánya in Austria-Hungary (today's Slovak Republic) in 1735. The first German Institute of Technology, the Braunschweig University of Technology, was established as Collegium Carolinum in proximity to mining sites in 1745.

The industrial and structural change have shifted the centres of industrial innovation away from these mining sites, disconnecting modern local business dynamics from the location of these historic universities. While mining activity could still be related to today's industrial activities (by providing the starting point for industries that are in place today), we expect proximity to historical mines to have limited impacts on industry performance trends except via their impacts on research institutions' location. That is, once postcode and country-year differences are taken into account, the distance to historical mines would be a good instrument as it only affect industry performance via the effects on the location of research institutions.

We combine this information on proximity to historic mines with the lagged value of public spending in R&D conducted by higher education institutions relative to GDP. This policy-related variable points to changes in the quality of research of research institutions' contribution to industry but does not have an impact on industry except via the effects on research institutions. Any direct impact is even weaker as we use an aggregate indicator at country-year level to investigate impacts on industry patenting at postcode level and account for country-year and postcode fixed effects in our specification.

We estimate the following instrumental variable regression model in a two-stage least square framework (2SLS) with the following first-stage regression:

$$proxRI_{pc} * PubSpend_{ct-1} = \alpha + \beta^{proxMine} proxMine_{pc} * PubSpend_{ct-1} + \mu_{pc} + \tau_{ct} + \vartheta_{pct} \quad (1)$$

where  $proxRI_{pc}$  is the proximity of the postal code to the closest research institution (we also test for proximity to any institution),  $PubSpend_{ct-1}$  is government spending in R&D conducted in higher education institutions in period  $t-1$  while  $proxMine_{pc}$  is the proximity to a historical mine.  $\mu_{pc}$  and  $\tau_{ct}$  are post code fixed effects and country-year fixed effects that capture differences across post code areas and country-specific annual time trends, respectively.  $\vartheta_{pct}$  captures the residual.

We then estimate the following second-stage regression:

$$patents_{pct}^{ind} = \alpha + \beta^{prox} proxRI_{pc} * PubSpend_{ct-1} + \mu_{pc} + \tau_{ct} + \varepsilon_{pct} \quad (2)$$

where  $patents_{pct}^{ind}$  is the number of industry patent applications of postal code  $p$  of country  $c$  in year  $t$ .  $\varepsilon_{pct}$  captures the residual.

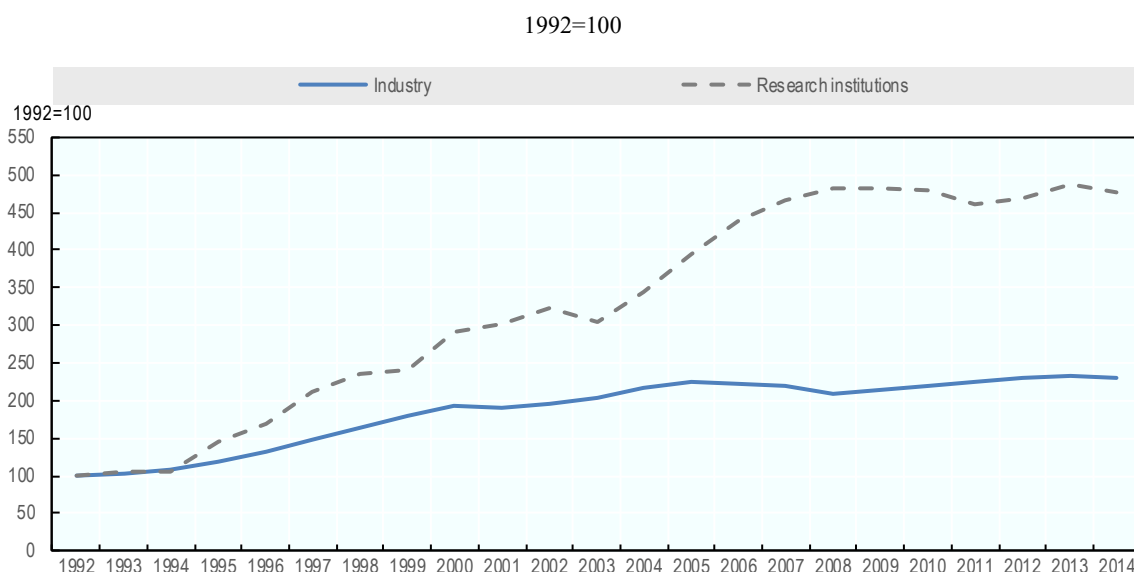
### 3. RESEARCH INSTITUTIONS' PATENTING ACTIVITY AND CO-LOCATION WITH INDUSTRY INVENTORS

#### 3.1. Trends of research institutions' patenting activities

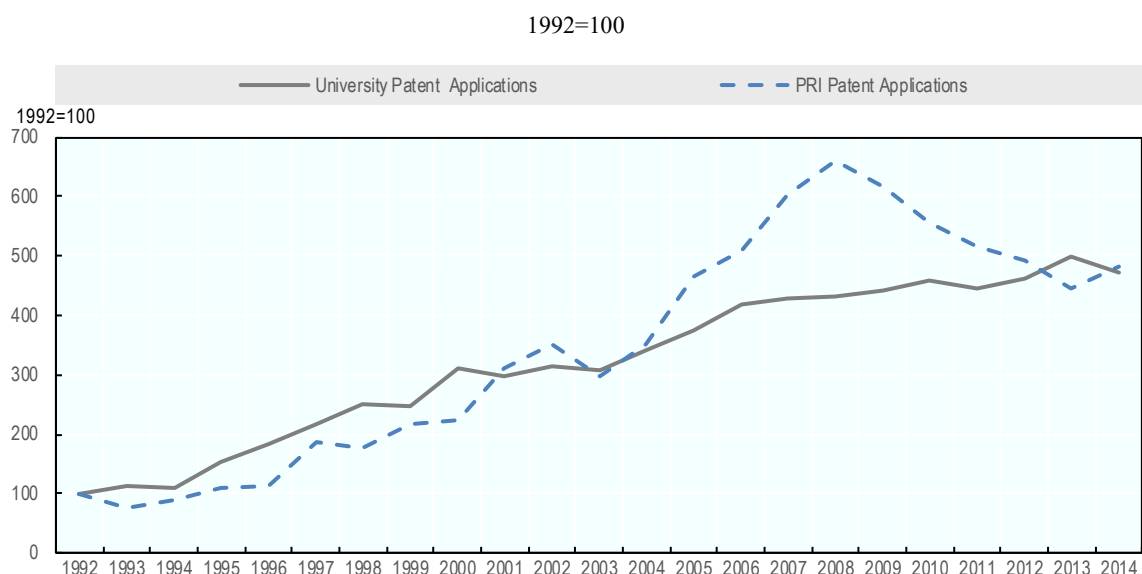
One way for research institutions to contribute to innovation is by filing patent applications, which add to the pool of state-of-the-art knowledge firms can draw on to innovate.

Looking at the trends for the 1992-2014 period, the number of EPO patent applications of research institution increased more than fivefold (Figure 3). The increase took place in two waves: the first more substantial increase started in the mid-90s and ended at the turn of the century with a 3-fold increase. The second one started in the mid-2000s and ended in 2008 with a substantive increase. Since the onset of the global financial crisis of 2008, there has been no additional increase. Industry also increased patent applications but more moderately with an increase by about 2.2 by 2005 that has remained stable since then. The rapid increase between 2004 and 2008 was driven by a sharp increase in the number of patents from PRIs, which then decreased after that period (Figure 4).

**Figure 3. Trends in numbers of EPO patent applications of research institutions and industry, 1992-2014**



*Source:* Authors' calculations based on the database described in Section 2 that uses the patent information from the PATSTAT Database (2018).

**Figure 4. Trends in number of EPO patent applications by universities and PRIs, 1992-2014**

*Note:* PRIs include also agencies, ministries and other public administrations, and private non-profit organisations. Hospitals are excluded.

*Source:* Authors' calculations based on the database described in Section 2 that uses the patent information from the PATSTAT Database (2018).

Several developments that have led research institutions to engage more with industry over the period contributed to this upward trend in research institutions' patenting. This includes policy reforms aimed at enhancing industry-science linkages. The most prominent policy reform is the Bayh-Dole Act that was introduced in the United States and led to the introduction of similar policy reforms in other countries. The reform provided research institutions with ownership rights over inventions resulting from government-funded research. Further reforms were introduced to incentivise research institutions to engage more with industry, including by engaging in patenting. See section 1 for a discussion of the available evidence on the impacts of these policy reforms.

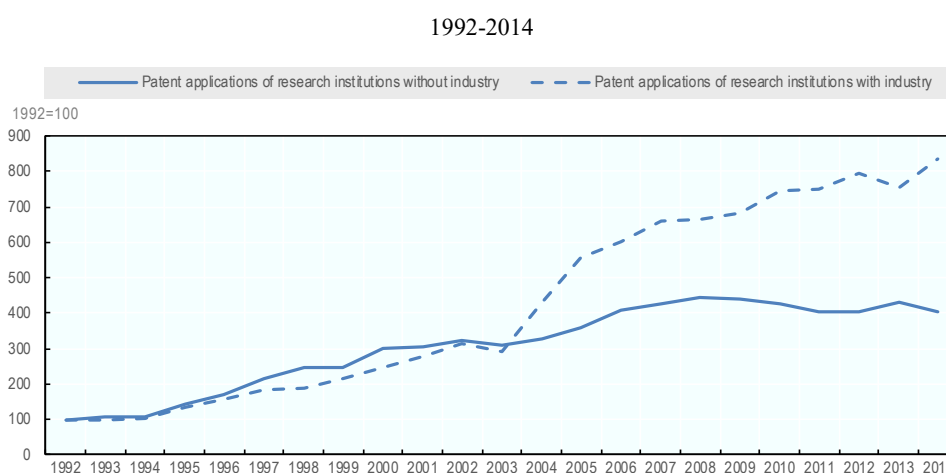
The modest increase in research institutions' patenting after 2008 until 2014 can be explained by several factors. Importantly, the slowdown in the growth rate of patent applications likely resulted from the shock of the financial crisis that dampened industry engagement in innovation activities, possibly reducing research institutions' incentives to patent. Another implication of the crisis was increased pressure on government budgets for research. While for the OECD the amount of public spending in higher education funded by government did not decrease with the financial crisis of 2008 but even increased, the investment has stayed flat since 2010. Moreover, with the initial success of policies in engaging research institutions in patenting, there was a shift in emphasis towards other forms of collaboration with industry beyond patents. This is because while patenting activities were a useful way for universities to focus on engaging in the commercialisation of their research, not all patenting resulted in subsequent innovations. Finally, the level of patenting reached while very low if compared to total patenting may reflect suitable patenting levels for research institutions if seen in the wider context of alternative ways for universities to engage with industry. This includes producing qualified researchers to work in industry, publishing research papers on new findings as well as engaging in joint projects that result in industry patents. Regarding joint project activities, the evidence on joint

patents certainly suggests a shift in the direction of such activities that patents only partly capture (as research institutions' engagement is only captured if the researchers involved are registered as co-inventors) (see OECD, 2019, for an overview).

### 3.2. Characteristics of research institutions' patents

As to the characteristics of research institutions' patents, over the entire period from 1992-2014 most research institutions' patents were not joint inventions with industry. However, the share of science-industry patents grew much faster in the 2000s than research institutions' patents produced without industry inventors (Figure 5). This points to a different mode of industry-science collaboration in the 2000s. As a result of the different trends, the number of co-applications with industry was of 29% of all EPO patents applications of research institutions, up from 17% in 1992.

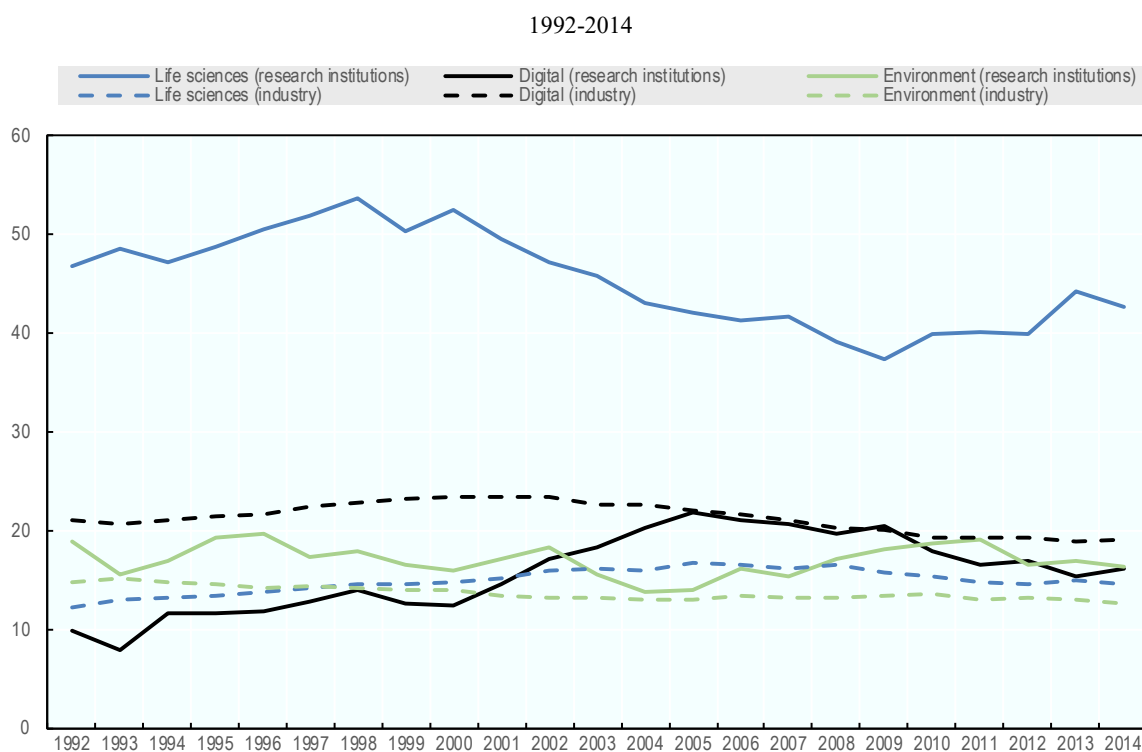
**Figure 5. Trend in the number of patent applications of research institutions with and without industry, 1992 = 100**



*Source:* Authors' calculations based on the database described in Section 2 that uses the patent information from the PATSTAT Database (2018).

With regards to the technology field of patent applications, research institutions mostly engage in life science-related technologies (i.e. biotechnology), digital technologies and environmental technologies, including CO<sub>2</sub> storage, electric vehicles, renewable energy, and water and waste treatment (Figure 6). Between 1992 and 2014, 44% of all EPO patent applications of research institutions were filed in life sciences, significantly above the 15% of total EPO patents filed by industry in this field. Regarding environmental technologies, the share of research institutions' patents was of 17%, slightly above the 14% share of industry. As to digital technologies, industry had a share of 21% compared to 17% for research institutions.

**Figure 6. Share of EPO patent applications filed by research institutions and industry, by technology fields**



*Note:* Environmental technologies include technologies for waste treatment; conservation, irrigation, distribution, and storage of water; renewable energy; enabling technologies (i.e. energy storage, batteries, thermal storage, fuel cells, and smart grids); CO<sub>2</sub> capture and storage technologies; and transportation technologies (e.g. electric vehicles, hybrid vehicles) as defined in Haščič, I. and M. Migotto (2015). Digital patents include telecommunications, computers, and office machinery and life sciences include biotechnology, pharmaceutical technologies, and medical instruments as defined in Eurostat (2017).

*Source:* Authors' calculations based on the database described in Section 2 that uses the patent information from the PATSTAT Database (2018).

Regarding trends over time, research institutions have increased their share of applications on digital technologies while the share of patents in life science related technologies and environmental technologies decreased somewhat. This decrease possibly points to a diversification in research institutions' patenting, following initial patenting in a technology field that facilitated patenting. The engagement in environmental technologies did not change much over the period.

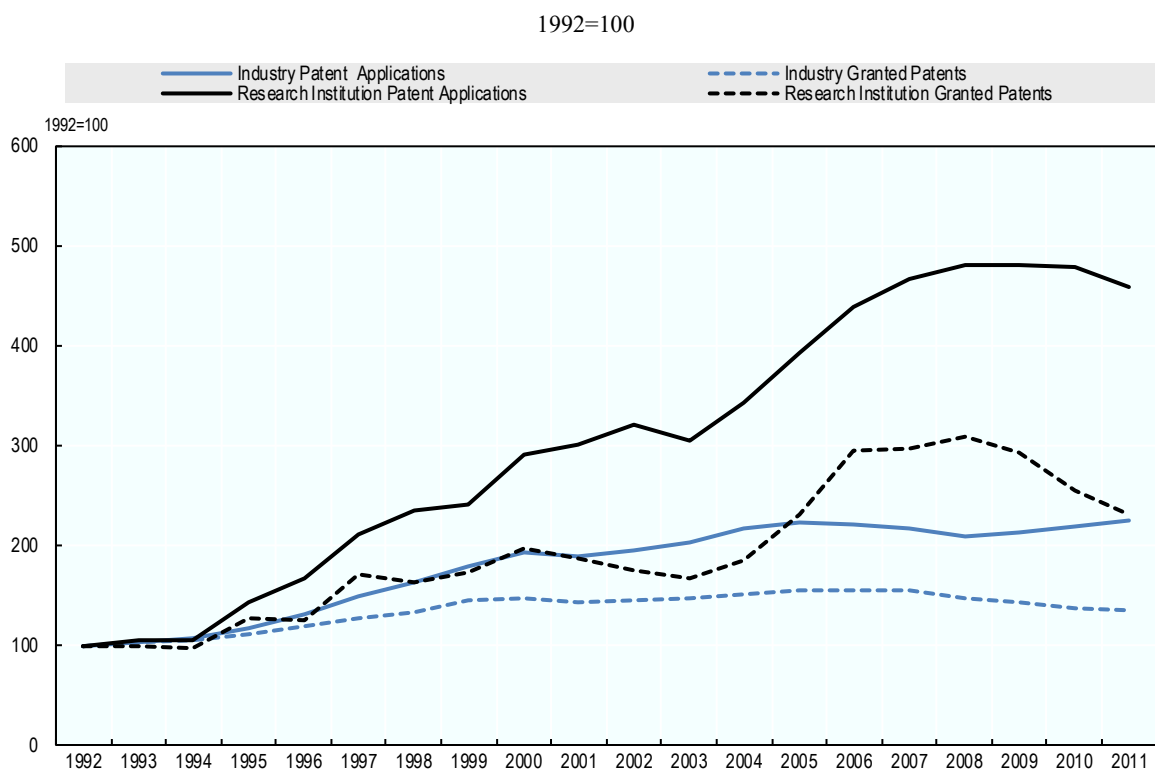
The decrease in the overall share, however, is not related to a decrease in patent applications in those technology fields. The number of patent applications of research institutions in the fields of life sciences and environmental technologies increased more than four-fold over 1992-2014. Patent applications of industry in those fields more than doubled during the period.

Different trends can also be observed regarding the number of EPO patent applications filed by research institutions and industry and the number of patents granted over time. Figure 7a shows that EPO patent applications significantly increased over time, with a high increase between 1994 and 2002, a slight decline in 2003 and a high increase again until

2010. Such raise however contrast with the more modest growth in research institution patents granted, particularly in periods after high growth in patent applications (2002-2004 and 2009-2011).

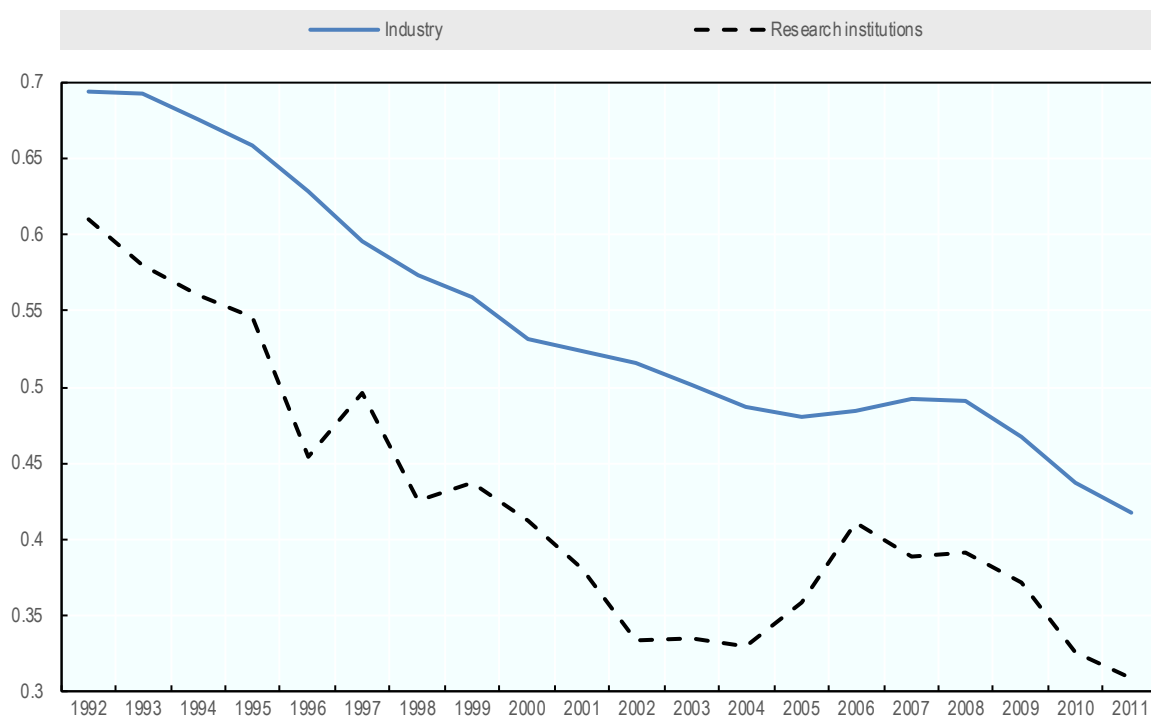
Moreover, Figure 7b shows that the acceptance rate of patents filed by research institutions is consistently below that of patents filed by industry, which raises questions on the quality of part of the patents filed by research institutions as compared to industry. The acceptance rate of research institutions patents is particularly low in the period 2002-2004, which coincides with the period of slight slowdown and then rapid increase in the number of patents filed by research institutions.

**Figure 7a. Trend in the number of EPO patent applications and patents granted, by research institutions and industry, 1992-2011**



**Figure 7b. Ratio of EPO patents granted over patent applications, by research institutions and industry**

1992-2011

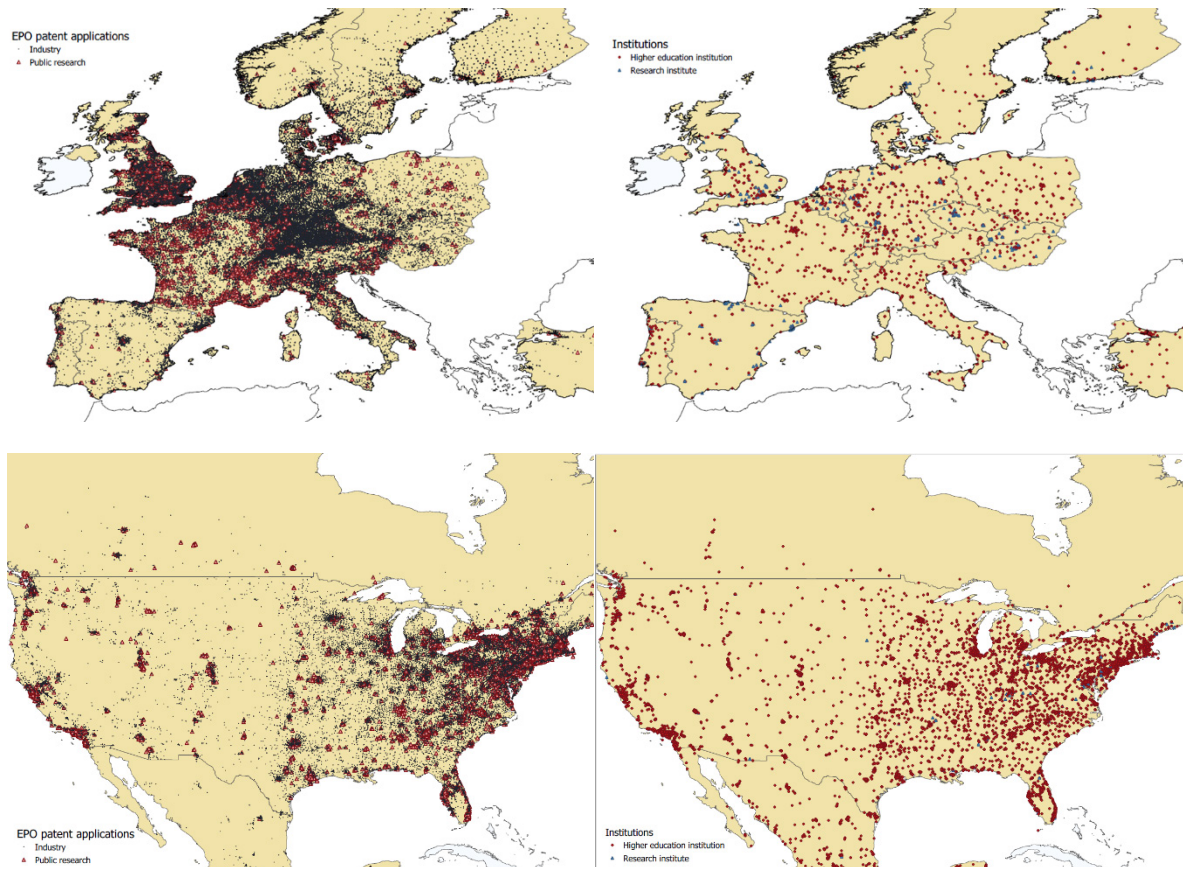


*Note:* The period represented in these graphs is shorter than that used in the remainder of the paper since as of 2011 the data on granted EPO patents is truncated with outstanding decisions on a number of applications.

*Source:* Authors' calculations based on the database described in Section 2 that uses the patent information from the PATSTAT Database (2018).

### 3.3. Location of research institutions and inventors

Industry inventions, as proxied by EPO patent applications, take place in proximity to universities and public research institutes. For 1992-2014, 69% of all inventive activity of industry in the 30 countries our estimating sample – as measured by the address of the inventors, occurred within 20 kilometres distance of a research institution. Figure 8 plots in the right-hand figure the location of universities and public research institutes and in the left-hand figure the location of inventors of EPO patent applications by industry and public research.

**Figure 8. Location of public research institutions and inventors, Europe and the USA**

Source: OECD calculations based on European Tertiary Register (ETER, 2018), GEONAMES database <http://download.geonames.org/export/zip/>, Integrated Postsecondary Education Data System (IPEDS, 2018), Register of Public-Sector Organizations (ORGREG, 2018), Scopus SciVal (2017), OECD PATSTAT database (autumn, 2018 version), and the World Higher Education database (WHED, 2018).

## 4. ASSESSING THE IMPACTS OF RESEARCH INSTITUTIONS ON INDUSTRY PATENT ACTIVITY

### 4.1. Exploratory correlation analysis

To explore how research institutions affects industry patenting, we start by conducting two simple correlation analysis. To do so we implement the following baseline econometric specification:

$$patents_{pct}^{ind} = \alpha + \beta^{pat} patents_{pct-1}^{RI} + \beta^{cop} co\_patents_{pct-1}^{RI-IND} + \mu_{pc} + \tau_{ct} + \varepsilon_{pct} \quad (3)$$

where  $patents_{pct-1}^{RI}$  and  $\Delta co\_patents_{pct-1}^{RI-IND}$  are respectively the research institutions' patents and joint industry-research institution patent applications in postal code  $p$  of country  $c$  in year  $t-1$ . The two  $\beta$  coefficients consequently indicate the correlation between industry patents and research institutions patents with and without industry participation.  $\mu_{pc}$  are postal code area fixed effects that control for unobserved differences across postal code areas, while  $\tau_{ct}$  are country-year fixed effects that control for shocks affecting countries in potentially different ways over the 1992-2014 period.  $\varepsilon_{oct}$  captures the residuals.

Results show that research institutions' patenting is associated with more industry patenting in the same postal area (column 1 of Table 2). Science-industry patent applications are also positively correlated (column 2 of Table 2) and, if jointly include with research institutions' patent applications both are significant, also if we cluster standard errors at country level (columns 3 and 4 of Table 2).

**Table 2. Linear regressions of industry patent applications on research institutions patents**

Dependent variable:	Number of industry patent applications(pct)			
	(1)	(2)	(3)	(4)
Research institutions' patent applications(pc,t-1)	0.418*** (0.019)		0.239*** (0.013)	0.239*** (0.067)
Science-industry co-patent applications(pc,t-1)		0.695*** (0.033)	0.444*** (0.030)	0.444** (0.174)
Postcode fixed effects	Yes	Yes	Yes	Yes
Country-year fixed effects	Yes	Yes	Yes	Yes
Clustering of standard errors	Postcode	Postcode	Postcode	Country
Observations	3 711 167	3 711 167	3 711 167	3 711 167
R2	0.71	0.71	0.71	0.71

*Note:* All patent application variables are included in log terms. Standard errors clustered at the level of postal code-year are provided in parentheses except for column 4 where they are clustered at country level. \*, \*\*, and \*\*\* indicate significance at 5%, 1%, and 0.1% levels respectively.

There are, however, several caveats to our evidence. First, the analysis focuses on impacts at postal-code level, treating the geographic proximity of close-by industries equivalent to those very far away. Second, universities contribute in many different ways – with patenting being just one such channel and quite a rare one in that regard – so that our analysis may misleadingly only focus on what is an activity few universities engage in. However, those who patent are even more relevant to industry – as an indicator of quality of research and orientation to research. Azoulay et al. (2007), Carayol and Matt (2004) and Curi et al. (2012) show evidence of a correlation between research excellence – including

via publications – and patenting activities respectively at researcher, laboratory and university level.

Taking into account the geographic proximity more explicitly, we investigate the correlation between proximity to research institutions and industry patenting at postal code level. As patenting research institutions may be more important to industry than other research institutions, we test not only for the proximity of industry inventors to the closest research institution but also for proximity to the closest patenting research institution. Our measure of proximity of the industry inventor is the reverse of the log distance in kilometres to the nearest (patenting) research institution at postal code level.

As described in Section 2.3, to capture the changing contributions of research institutions, we interact our measure of proximity with a measure of the logarithm of public R&D spending relative to GDP (*PubSpend*) for country *c* at time *t-1*. This combined measure provides variation over time, allowing to capture the effects of distance while keeping country-year trends that likely affect patenting activities of industry and research institutions.

Our new specification is consequently as follows equivalent to the second stage of our estimation strategy (2) but estimated directly in this case:

$$patents_{pct}^{ind} = \alpha + \beta^{prox} proxRI_{pc} * PubSpend_{ct-1} + \mu_{pc} + \tau_{ct} + \varepsilon_{pct} \quad (4a)$$

$$patents_{pct}^{ind} = \alpha + \beta^{prox.pat} proxRIpat_{pc} * PubSpend_{ct-1} + \mu_{pc} + \tau_{ct} + \varepsilon_{pct} \quad (4b)$$

where  $proxRI_p$  and  $proxRIpat_p$  denote respectively the geographical proximity to the nearest patenting research institution at postal code level. All other variables are as specified for the model specified under (3).

Using this approach, the results also show a positive correlation of our variable of interest with industry patenting. Column (1) of Table 3 shows results for proximity to any research institution while column (2) shows the result if we only consider patenting research institutions.

**Table 3. Industry patent applications and proximity to the nearest research institution**

Dependent variable:	Number of industry patent applications(pct)	
	(1)	(2)
Proximity to closest research institution(pc) * PubSpend(c,t-1)	0.099*** (0.007)	
Proximity to closest patenting research institution(pc) * PubSpend(c,t-1)		0.126*** (0.008)
Postcode fixed effects	Yes	Yes
Country-year fixed effects	Yes	Yes
Observations	3 387 591	3 387 591
R2	0.72	0.72

*Note:* Standard errors clustered at the level of postal code-year are provided in parentheses. \*, \*\*, and \*\*\* indicate significance at 5%, 1%, and 0.1% levels respectively.

The correlations we identify between research institutions and their patenting activity and industry patenting suffer from endogeneity and omitted variable biases. We address those concerns somewhat by lagging our variables of interest and controlling for a set of fixed effects. Notably postal code and year fixed effects controls allow controlling for differing trend across geographic areas that drive both industry and research institutions' patenting. However, we cannot fully exclude the possibility that industry patenting that stimulates

research institutions' performance with them having little impacts. Other trends that correlate with research institutions' patenting may also vary across time, including policy changes at country and regional level, industry shocks that affect patenting of research institutions and industry, etc. We consequently apply next an estimation strategy that relies on an instrumental variable approach as outlined in section 2.

#### 4.2. Baseline results: Accounting for endogeneity of research institutions' locations

We explore the impacts of public research on industry patent activity using information on the geographical location of research institutions established around mining sites and by means of an instrumental-variable estimation approach, applying the identification strategy as outlined in section 2.

The results show a positive significant effect of proximity to nearest research institution on industry patent applications to the European Patent Office. In Table 4, we show that proximity to the nearest historical mine site is a strong instrument for proximity to the nearest research institution (column 1) and to the nearest patenting research institution (column 2). The findings reported in columns (3) show that there is a positive impact of proximity to research institutions on industry EPO patent applications, where distance to nearest research institution is instrumented by distance to the nearest historical mine site (established in 1900 or earlier). Results of column (4) show evidence for proximity to closest patenting institutions.

**Table 4. Industry patent applications and proximity to nearest research institution: instrumental variable regression results**

Dependent variables:	Proximity to closest research institution(pc) * PubSpend(ct)	Proximity to closest patenting research institution(pc) * PubSpend(ct)	Number of industry patent applications(pct)	
	First-stage results		Second-stage results	
	(1)	(2)	(3)	(4)
Proximity to historical mine(pc) * PubSpend(c,t-1)	0.098*** (0.006)	0.126*** (0.006)		
Proximity to closest research institution(pc) * PubSpend(c,t-1)			0.289*** (0.088)	
Proximity to closest patenting research institution(pc) * PubSpend(c,t-1)				0.223*** (0.068)
Postcode fixed effects	Yes	Yes	Yes	Yes
Country-period fixed effects	Yes	Yes	Yes	Yes
Kleinbergen-Paap LM Statistic (under-identif. Test)			0.00	0.00
Observations	3 387 591	3 387 591	3 387 591	3 387 591
R-squared	0.99	0.99		

*Note:* Standard errors clustered at the level of postal code-year are provided in parentheses. \*, \*\*, and \*\*\* indicate significance at 5%, 1%, and 0.1% levels respectively.

The effects of proximity to universities may differ depending on the firms' technology. Industries that are more science-related, notably pharmaceutical and biotechnology industries, may be able to capitalise on inputs from research institutions. Industries related to ICT and environmental technologies may benefit from high-risk, transformative research undertaken at public research institutions. Table 5 shows the results of the instrumental variable estimation for the proximity-patenting relationship by different technologies, i.e. life science-related technologies, ICT, and environmental technologies. The findings show

that proximity effects hold for technologies in life sciences (columns 1 and 2 of Table 5) and for digital technologies (columns 3 and 4 of Table 5). We do not find a significant effect for environmental technologies.

**Table 5. Industry patent applications in life sciences, ICT, environmental technologies and the proximity-invention relationship: instrumental variable regression results**

Dependent variables:	Number of industry patent applications in life sciences		Number of industry patent applications in digital technologies		Number of industry patent applications in environmental technologies	
	(1)	(2)	(3)	(4)	(5)	(6)
Proximity to closest research institution(p) *	0.242***		0.135***		0.044	
PubSpend(ct-1)	(0.044)		(0.039)		(0.029)	
Proximity to closest patenting research institution(p) * PubSpend(ct-1)		0.186***		0.104***		0.034
		(0.033)		(0.030)		(0.022)
Postcode fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country-year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3 387 591	3 387 591	3 387 591	3 387 591	3 387 592	3 387 593

*Note:* Standard errors clustered at the level of postal code-year are provided in parentheses. \*, \*\*, and \*\*\* indicate significance at 5%, 1%, and 0.1% levels respectively.

## 5. CONCLUSION

The paper provides preliminary evidence on research institutions' patenting activities based on a newly compiled dataset of universities and public research institutes and their patenting activities across 36 OECD countries and China for the period 1992 to 2014. While research institutions' share in patent applications remains low compared to industry, our findings suggest that EPO patent applications of research institutions increased over the past decades. Patent applications jointly filed by public research institutions and industry made up 29% of all patents applications of universities and PRIs in 2014, up from 17% in 1992. This suggests more knowledge co-creation between research institutions and industry is taking place. Regarding impacts, the results reveal that geographical proximity of industry to universities is positively associated with industry EPO patent applications. Results hold when we exploit the location decision of research institutions, by using proximity of research institutions to historical mines as an instrument for distance to research institutions.

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## ANNEX. TECHNICAL DETAILS REGARDING THE CONSTRUCTION OF THE DATABASE

### Location-specific information of applicants and inventors

We locate inventors of EPO patent applications using postal code information that is provided in the patent application document. Fractional counting has been applied to allocate patents to inventors across regions so that where inventors of the same patent reside in different regions, the patent is counted as 1 for each region.

To assess impacts of proximity to HEIs and PRIs on the growth rate of industry EPO patent applications, we construct measures of geographical distances between inventor and HEIs and PRIs. The distances are measured in kilometres between centre points of postal code areas in which the inventor and the institution reside (i.e. headquarter of HEIs and PRIs). Centre points of postal codes are measured in geographical latitude and longitude coordinates, i.e. North-South and East-West coordinates on the globe. Data on geographical coordinates of postal code centres is taken from GEONAMES database (<http://download.geonames.org/export/zip/>, last access on 7 May 2018)

Regarding the location of HEIs and PRIs, those listed in ETER and ORGREG already includes location-specific information on the coordinates of the postal code centre in which the university is situated. IPEDS and WHED data includes the postal code information, which is linked to information on geographical coordinates using GEONAMES. Location-specific information is not available in GEONAMES for Ireland, Estonia, Greece and Latvia. For these countries, the information on latitude and longitude coordinates was retrieved using Google Maps (<https://www.google.com/maps>, last accessed 7 May 2018).

### Matching of patents to their research institutions

To retrieve patents of research institutions, EPO patents applications in the PATSTAT database were matched to names of universities and research institutes in the ETER, IPEDS and ORGERG databases as follows:

- EPO patent applications are matched to survey data using a text matching algorithm that compares how similar the text of names of patent assignees are to those of research institutions' names as found in the survey data. To do so, the names are first split into parts of 2 letters and, second, resulting text parts of two letters are compared across all pairs of patent assignee names and a university names, e.g. "University A" splits to "Un", "ni", "iv", "ve", "er", "rs", "si", "it", "ty", "y ", and "A".
- Similarity scores that measure the similarity between names of assignees and RIs are calculated based on the Jaccard index. The Jaccard index takes on values from 0 (no similarity) to 1 (identical names). Similarity scores for each assignee name-HEI/PRI name pair were calculated and only matches with similarity scores above 0.9 were kept.