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Assessing the impacts of research institutions on innovation: Initial evidence

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This document reports initial findings of the 2017-18 TIP project on “Assessing the Impacts of the Policy Mix for Knowledge Transfer” [DSTI/STP/TIP(2017)6] and in particular to the activity that aims at investigating the effects of different impact channels of public research, the influence of characteristics of industry and research institutions on knowledge transfer as well as the contributions of research institutions on inventions of high impact.

The draft report was written by Martin Borowiecki and Caroline Paunov. Jules Hugot contributed substantially to the statistical and econometric analysis. The results are preliminary at this stage in the project.

Delegates are invited to comment and propose case studies to inform this activity.

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EXECUTIVE SUMMARY

1. Universities and PRIs are key players in innovation ecosystems and contribute in multiple ways as they engage in basic and applied research, provide education and training, and engage in innovation. It has been also suggested that the contributions of research institutions to high-impact inventions are also important drivers for innovation.
2. Channels of knowledge transfer and innovation include collaborative research and academic consultancy but also labour mobility and informal knowledge sharing. These contributions are also critical in the context of the digital transformations.
3. Different country experiences point to the importance of research institutions' characteristics (such as their size, research orientation, autonomy), of industry characteristics (such as sector of activity, size distribution of firms) and of other policy and framework conditions.
4. The TIP activity on impact assessment aims to provide cross-country evidence on the role of different channels for knowledge transfer between industry and science and the effects of industry, university, policy and wider framework conditions. To date such evidence is scarce. The activity will combine both statistical methods and case study evidence.
5. Preliminary analysis, based on data for 4 220 universities and 581 PRIs across 50 578 locations (corresponding to postal codes) in 23 countries for 2011-2013, shows that 50% of all patent inventors to the EPO in the United States and Europe reside within 13 kilometres of a research institution. For inventions in biotechnology, medical devices, and pharmaceutical fields, 50% of all inventors reside within 3 kilometres of a research institution.
6. This evidence on proximity of inventions to research institutions is also a reflection of the presence of universities in most innovative regions and does not necessarily indicate causal effects of universities on inventions. Most inventors reside in a few urban places where most inventive activity is concentrated and the top 5% of postal codes zone alone account for more than 60% of all patent applications over the 2011-13 period. Top inventors account for one in five of those applications.
7. Taking a step forward towards a causal analysis of the impacts of research institutions on industry inventions, a preliminary analysis that was conducted using the data gathered confirms to a positive effect of research institutions' inventions on industry inventions at local level. Specifically science-based industry inventions benefit from public research inventions.
8. One factor that positively correlates with a higher number of public institutional inventions is the share of private universities, independently of the spending size of institutions in the local area.
9. Immediate next steps include, for the cross-country statistical work, efforts to expand the dataset to the extent possible (contributions of national data would help) and an in-depth analysis of channels of knowledge transfer between industry and science and their importance and the value of research contributions of public research. Regarding the case study work, delegates are invited to propose case studies that respond to the questions set by this activity.

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INTRODUCTION

10. In view of increasing demands on the effectiveness of public funds in generating growth, social inclusiveness and economic development, evidence on how research institutions contribute to innovation outcomes is increasingly important. However, to date little cross-country evidence exists to document the impacts of universities and public research institutions (PRIs) on innovation, on the channels of knowledge transfer between industry and science and on how framework conditions and policy environments influence linkages and their impacts on innovation.

11. The TIP project on assessing the impacts of knowledge transfer aims to provide cross-country evidence on these questions (see [DSTI/STP/TIP\(2017\)6](#)). This analysis will combine statistical evidence and country case studies.

12. This report presents initial findings from an exploration of a newly assembled dataset on the precise geographic location (referred to as “geolocation”) of inventors of 268 160 patent applications to the EPO over 2011-13, 4 782 research institutions, including 4 201 universities and also 581 PRIs, and 1 497 of the 2 000 top R&D inventors reported in the 2011-2013 EU R&D Scoreboards located in 22 European countries and the United States.

13. The document is structured as follows: Section 1 introduces briefly the role of research institutions in innovation and the objectives of the TIP activity. Section 2 offers an initial analysis of the data and section 4 outlines next steps that will be undertaken.

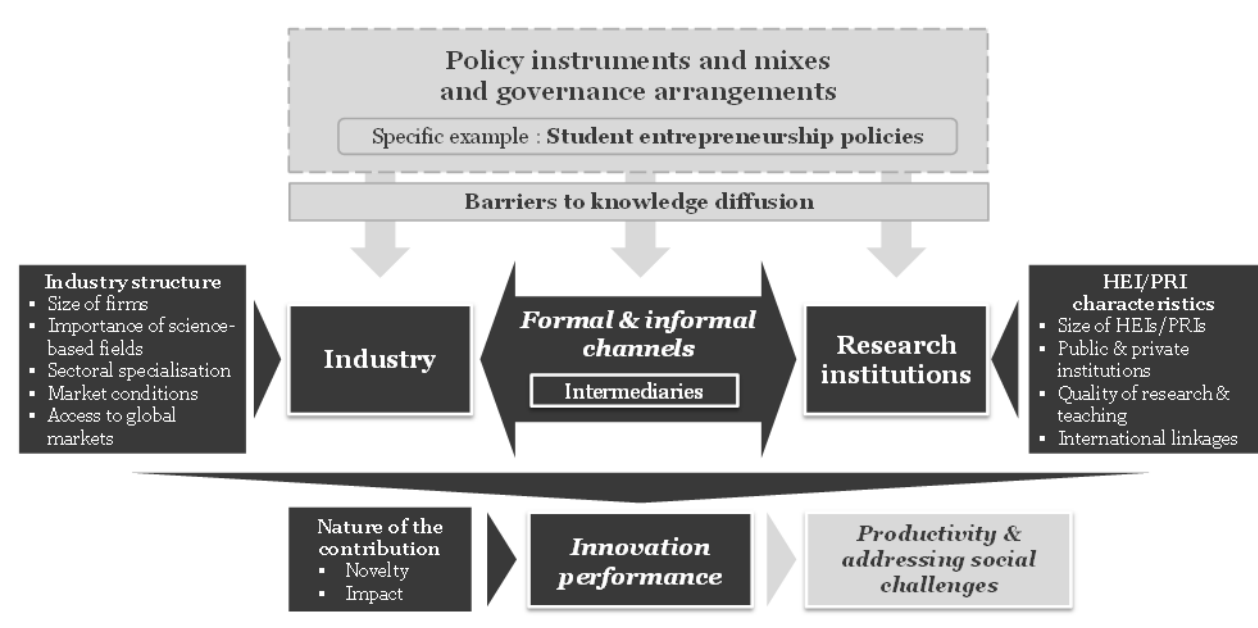
1. THE ROLE OF RESEARCH INSTITUTIONS IN THE INNOVATION ECOSYSTEM

1.1. The proposed TIP activity on impact assessment

14. The 2017-18 TIP work on impact assessment within the wider project activity on knowledge transfer between industry and science aims to understand better the impacts of research institutions (i.e. universities and PRIs) on innovation, assess the importance of different channels for such knowledge transfer, and analyse the impacts of research institution and industry characteristics as well as wider framework conditions (Figure 1). Specifically the project aims to address the following questions:

- Which impact channels are most important drivers of knowledge transfer?
- What is the impact of industry and research characteristics on those impact channels?
- What are the contributions of public research to new high-impact inventions?
- What is the role of knowledge intermediaries in fostering the relationship?

Figure 1. Scope of the TIP project on impact assessment



15. Answering these questions will involve using statistical methods (section 2 provides a discussion of initial findings) and case study evidence to illustrate the role of different impact factors and framework conditions.

16. Delegates are invited to propose case studies that would allow respond to the questions set out by this activity. Case studies could focus on the role of intermediaries in fostering the knowledge transfer

between industry and science as well as analyses of how specific channels have contributed to support innovation performance. Also relevant are case studies that illustrate the role research institutions have played in bringing forward specific high-impact inventions, such as advances in artificial intelligence or other digital technologies. An additional topic could be a study on the characteristics of investments of top R&D investor engaged with different local, national and global research. To allow for cross country comparability, a template will then be developed.

1.2. Background on the role of research institutions for knowledge transfer and innovation

17. The following provides a brief background discussion of those core questions that will be complemented by a comprehensive literature review as the project is developed further.

1.2.1. Roles of universities and PRIs and channels of industry-science knowledge transfer

18. Universities and PRIs are key players in innovation ecosystems and contribute in multiple ways as they engage in basic and applied research; provide high-quality education and training to students; contribute to life-long learning and reskill of the labour pool; and engage and promote innovation through various channels of interaction and collaboration with industry (OECD, forthcoming).

19. Evidence for the United States, in particular, has provided suggestive evidence of the roles of universities and their research on productivity (Adams, 1990; Griliches, 1998), industrial innovation (Rosenberg and Nelson, 1994; Mansfield, 1995; Shane, 2002), and entrepreneurship (Audretsch and Stephan, 1996; Zucker, Derby, and Brewer, 1998). More recent research that has looked into providing causal evidence has shown that the establishment of a new university increases the number of industry patents in Finland over the period 1988 to 1996 (Toivanen and Väänänen, 2016).

20. Different channels of science-industry interactions can be distinguished. Formal channels of science-industry interaction include:

- *Collaborative research*: This is about research projects carried out jointly by public researchers and private firms. It can be fully or partly funded by industry, and can range from small-scale projects to strategic partnerships with multiple stakeholders (i.e. public-private partnerships).
- *Contract research*: This is research commissioned to HEIs or PRIs by a private firm. It generally involves the creation of new knowledge per the specifications or goals of the client, and is frequently more applied than collaborative research.
- *Academic consultancy*: This refers to research and advisory services provided by public researchers to industry clients.
- *Intellectual property (IP) transactions*: This refers to licensing and selling of IP generated by HEIs and PRIs to industry.
- *Research mobility*: This refers to both university researchers working in industry and the reverse, including temporary assignments.
- *Public research spin-offs*: That is, the entrepreneurial route to commercialising knowledge developed by public research.
- *Labour mobility*: This refers to university graduates that join industry.

21. More informal channels of interaction that serve the transfer of knowledge from research to industry and from industry to research include the following:

- *Publication of public research results* in scientific journals and other specialised media.
- *Conferencing and networking*: the interaction between public researchers and industry actors is an important mechanism of knowledge transfer between science and industry. It can take place in the context of formal conferences or dissemination events (e.g. expositions), but also in more informal settings (e.g. meetings of former class-mates that are employed in public research and industry sectors).
- *Networking facilitated by geographic proximity*: informal interactions between public research staff and industry researchers. These might be facilitated, for example, by the location of science parks near to university campuses, or firms' laboratories within university campuses.
- *Facility sharing* between industry and public research (e.g. laboratories, equipment).
- *Courses and continuing education* provided by HEIs to enterprises, and lectures at universities held by industry employees.

1.2.2. Proximity and research impacts on innovation

22. The impact of different channels of science-industry interaction can be most comprehensively explored by focusing on the regional impacts of research institutions. Direct effects of universities, i.e. their own innovation activities such as research institution patenting reflect but a minor impact channel on innovation. The most important impacts come from universities' overall impacts on industry innovation, whether via formal or informal linkages. These additional impacts can be explored by taking into account the importance of geographic proximity to collaborations for innovation that shape regional industry innovation performance. Factors shaping the role of proximity include that science-industry interactions often benefit from face-to-face contact and personal relationships that are built on trust. Such dynamics have shaped the success of high-tech clusters, such as Silicon Valley in California and Route 128 in Massachusetts (Saxenian, 1994).

23. Exploring the regional context presented by universities and PRIs is relevant also in its own right, as identified in the dedicated module on those questions of the 2015-16 knowledge triangle project (OECD, forthcoming). In lagging regions, especially, research institutions have a role to play in fostering economic development. This includes providing technology assistance to small and medium enterprises, offering the breeding ground for high-tech start-ups and building research talent and a skilled workforce for local industry.

1.2.3. The roles of university and industry characteristics and framework conditions

24. The opportunities for science-industry knowledge transfer are affected by the characteristics of research institutions and industry. Regarding industry, firms benefit to different degrees from research institutions depending on their sector of activity and their capacity to absorb research institutions' research. Using data for the United States over the period 1981 to 1996, Kantor and Whalley (2014), for instance, shows where university research and industry technology priorities align, the benefits for industry from university research are higher. Large companies and specifically those with strong R&D capacities have also benefited more where they had larger capabilities to absorb scientific inputs than many smaller firms (that often have weak internal R&D capabilities). At the same time, leading firms may be less in need for some types of inputs from research institutions than smaller firms, specifically with regards to basic technical inputs.

25. 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 (Jaffe, 1989; Cohen et al.,

2002; Narin et al., 1997; Mansfield, 1995, 1998). 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 (Liebeskind et al., 1996; Zucker, Darby and Armstrong, 1998, 2002; Zucker and Darby, 2001) [see more detailed analysis in [DSTI/STP/TIP\(2016\)12](#)]. Evidence for the US also shows that biotechnology and pharmaceuticals industries co-locate near universities (Abramovsky, Harrison and Simpson, 2007) and that, while the presence of industrial facilities helped shape the direction of university research programs in some cases, there was a significant positive effect running from university research to the growth of pharmaceutical research laboratories (Furman, and MacGarvie, 2007).

26. Regarding research institutions, their size, research quality, research specialisation, whether they are public or private also influence knowledge transfer with industry. Universities of applied sciences, for instance, focus specifically at training and providing responses to regional industry needs, while more traditional research universities specialise in research excellence at the international level. Private research institutions may have more autonomy to engage in industry relations facilitating collaborations. The impact of policies in support of knowledge transfer will also be affected by institutional characteristics.

27. In addition, the policy environment of research institution systems also has implications on their impacts. This includes, for instance, the degree of research institutions' autonomy (Boarini et al., 2008; Aghion et al., 2007). 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.

28. More general structural features of countries and regions will affect the contributions of research institutions. For instance, industry demand for researchers and skilled graduates, or entrepreneurial attitudes of students to engage in start-up activity differ across regions. The urban context, especially, may also be of relevance for the impact of public research. Densely populated cities might provide a better mix of ideas and people and be thus more conducive to face-to-face interaction and networking between researchers. Urbanisation may affect science-industry interactions as the vicinity to public research may be stronger in denser urban areas than rural areas.

1.2.4. Quality of research inventions compared to those of industry

29. Another important element in discussions regarding the contributions of public institutions to innovation is whether inventions generated by research institutions are of higher quality than industry inventions. This may notably be the case because industry may focus more on inventions that generate revenue quickly while research institutions may conduct more basic research that could result in higher impact inventions i.e. to inventions with higher knowledge content and more long-run economic benefits to the economy. There is anecdotal evidence that points to university inventions that are more novel or technical advanced than those of industry. Thursby et al. (2009), for instance, argue that academic patents are technologically more sophisticated as they relate to basic science and state-of-the-art research.

30. However, 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 (Sapsalis et al., 2006; Rosell and Agrawal, 2009). This, however, depends critically on the measures used to assess the quality and impact of research, requiring further investigation of the issues.

2. PRELIMINARY ANALYSIS OF PUBLIC RESEARCH AND INVENTIVE ACTIVITIES

31. The section provides preliminary evidence on the data that has been gathered to investigate the questions outlined in the previous section. These statistics should not be interpreted as findings but rather as very preliminary inputs to this project for a first discussion. The dataset is to be expanded and a more in-depth analysis will be conducted (see section 3 for next steps).

2.1. Brief overview of the data

32. The dataset combine data from the 1) European Tertiary Education Register (ETER) census and the Integrated Postsecondary Education Data System (IPEDS) census that cover more than 4 782 research institutions, including 4 201 universities and 581 PRIs in Europe and the United States; the 2) OECD REGPAT and PATSTAT databases on around 268 160 patent applications at the European Patent Office (EPO) and their inventors; 3) and the IPTS-OECD database on 1 497 out of 2 000 top R&D investors in terms of R&D expenditures across 50 578 locations (corresponding to postal codes) in 23 countries for 2011-2013. 4) PRIs' registered in Elsevier's SciVal database on 8 500 research institutions was used to identify patent applications of 581 PRIs in France, Germany, Ireland, Spain, the United Kingdom, and the United States (see Annex 1).

33. To retrieve patents of research institutions, patents applications in the PATSTAT database were then matched to university names in the ETER and IPEDS databases and PRIs' names in the Elsevier's SciVal database.¹ With regard to coverage of PRIs, these represent only the name and location leading institutions in selected OECD countries for which data is available. Countries are invited to provide additional data on further PRIs as well as on characteristics of those PRIs as described in annex 3.

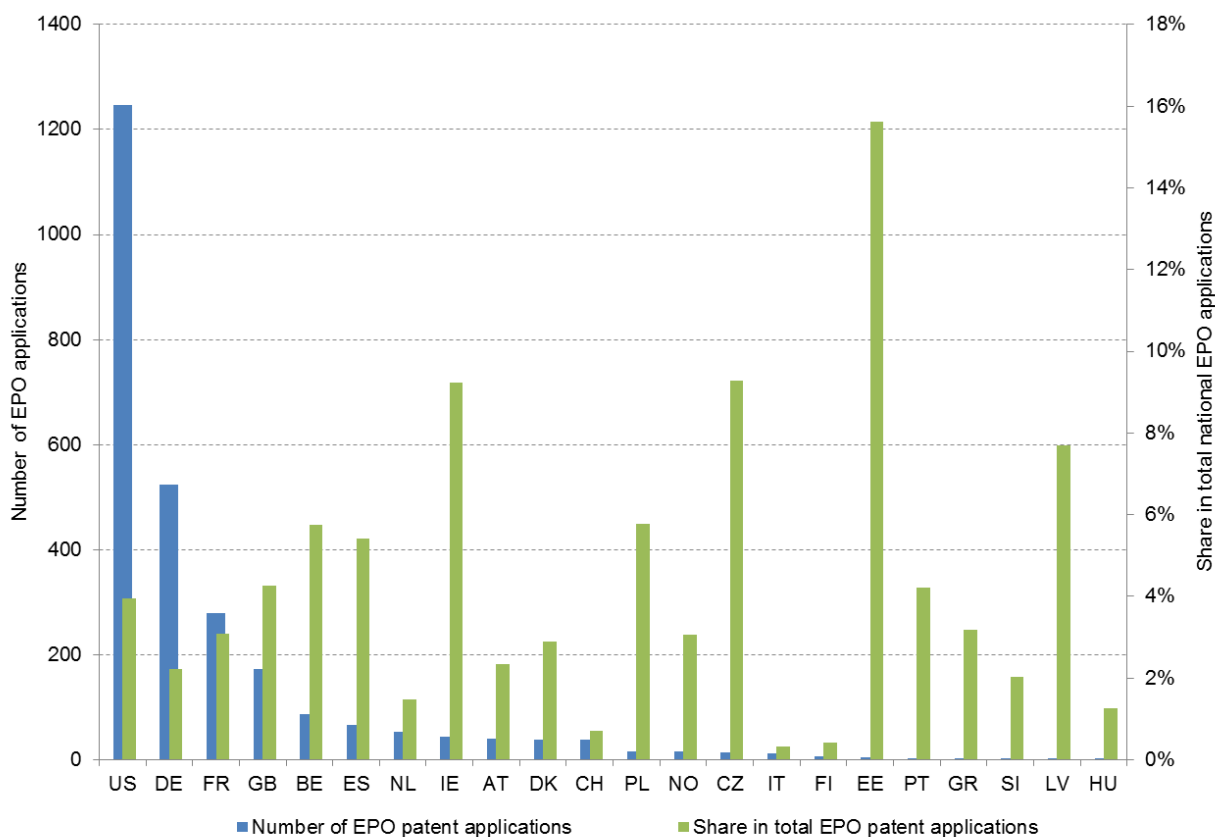
2.2. Public research and inventive activities: Descriptive evidence

2.2.1. Patenting activities of universities and PRIs

34. As outlined in 1.2., one direct channel between public research and industry lies in patenting of universities and public research institutes (PRIs). University and PRIs patent applications provide a useful source of state-of-the-art knowledge for industry. Many of patents that were generated from public research also included industry as research partner. In 2011-13 the number of EPO patent applications filed by the universities and selected PRIs captured in the dataset across the United States and 22 European countries represented 3.5% of total patent applications. This corresponds to a total of around 9 960 EPO patent applications, where 8 343 (84%) were filed by a university as an applicant and 1 617 (16%) by PRIs. There are important differences, also driven by differences in HEIs' and PRIs' rights to commercialisation IP from public research. The share of university and PRI patent applications is higher in the Slovak Republic (16%), Ireland (9%), Czech Republic (9%), and Latvia (8%) (Figure 2). It is important to note that these numbers are an underestimate with regards to PRIs as there are only 581 included in the current database.

¹ The number of patent applications for a given locations (zip code area) is calculated based on the inventor's address using fractional counting. For example, a patent application with two inventors that reside in different locations A and B is allocated as a share of 0.5 to area A and as a share of 0.5 to location B.

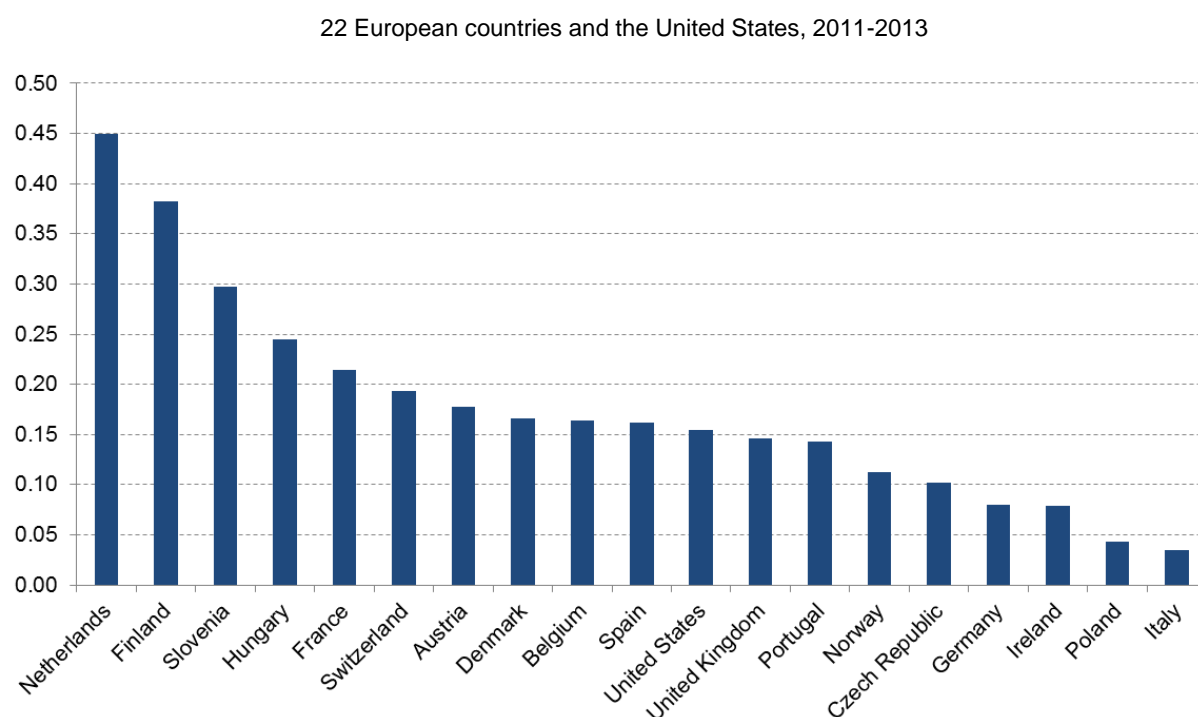
Figure 2. EPO patent applications of research institutions by country, 2011



Source: OECD calculations based on the OECD PATSTAT Database (2016).

35. University and PRI patent applications are geographically concentrated within countries but in most countries concentration is weaker than that of industry patent applications. The Gini coefficient, calculated at the level of postal codes, for the 22 European Countries and the United States, which measures how equal or unequal inventors are distributed across a country's geography, is 0.63 for universities and PRIs and 0.68 for industry patent applications. This suggests that public investment in research facilities and researchers benefit localities in mitigating the concentration of industry inventors R&D (Figure 3).

Figure 3. Difference in the Gini coefficient of the geographic concentration of research institutions' patent activity and that of all other inventors



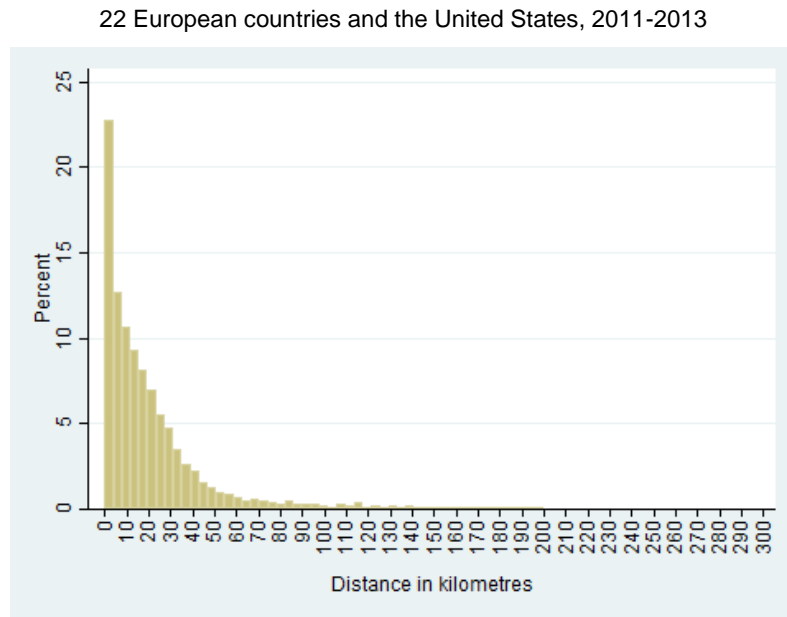
Note: Gini coefficient measures the concentration of patent applications within a country. The location of inventors as measured by the postal code is used as unit of analysis. For Ireland and Luxembourg, postal code information is not available and the inventor's address was used instead. There are no research institutions patent applications in Iceland, Luxembourg, the Slovak Republic, and Sweden.

Source: OECD calculations based on the OECD PATSTAT Database (2016) and the IPTS-OECD Database (2014).

2.2.2. Distance to research institutions

36. Inventive activity, as proxied by patent applications, takes place in proximity to universities. For 2011-13, 50% of all inventive activity in the United States and the 22 European countries in the database took place within 13 kilometres distance of the university (Figure 4). The distance of the median inventor to a university is of less than 30 kilometres (Table 2). The distance is even shorter for patent applications in biotechnology, pharmaceuticals, and ICT where 50% of their inventors are located within 6 kilometres distance of universities. The closeness is substantial in view of the larger distance of “close” locations, such as Palo Alto and San Francisco (Table 1).

Figure 4. Distance in kilometres between inventor and nearest research institution



Source: OECD calculations based on the OECD PATSTAT Database (2016), ETER (2016) and IPEDS (2014).

Table 1. Distance in kilometres between selected city centres

Origin (city centre)	Destination (city centre)	Distance in kilometres
Boston	Cambridge, Harvard Square	7
Malmö	Lund	18
San Francisco	Palo Alto	30
London	Oxford	60
Paris	Brussels	312

Table 2. Median distance between inventor and nearest research institution by country, 2011-2013

Distance to HEIs in kilometres	
Austria	23 km
Belgium	19 km
Czech Republic	17 km
Denmark	15 km
Finland	28 km
France	22 km
Germany	14 km
Hungary	2 km
Ireland	7 km
Iceland	5 km
Italy	17 km
Luxembourg	6 km
Netherlands	11 km
Norway	27 km
Poland	< 1 km
Portugal	6 km
Slovenia	61 km
Slovak Republic	14 km
Spain	177 km
Sweden	26 km
Switzerland	17 km
United Kingdom	12 km
United States	11 km
Total	13 km

Note: First row, first columns, shows that 50% of national patent applications in Austria take place within a radius of 23 kilometres of a HEI.

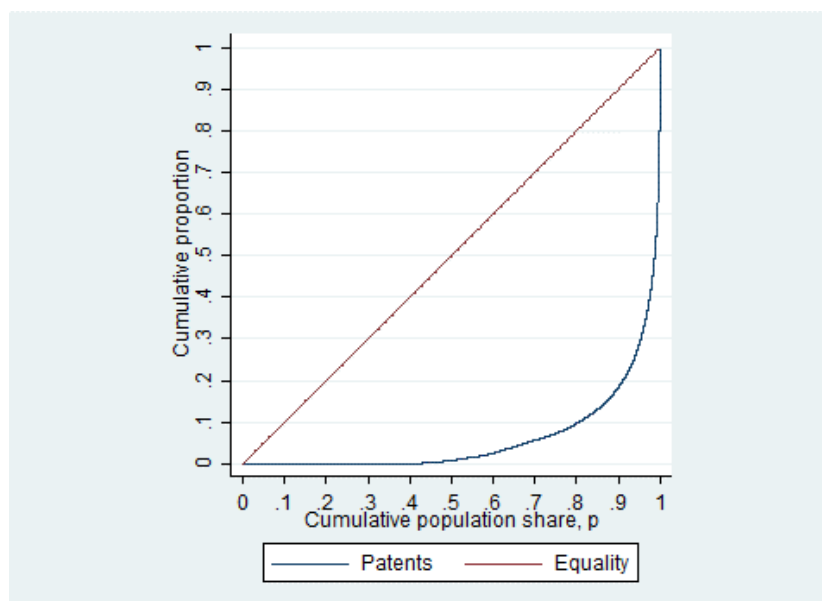
Source: OECD calculations based on the OECD PATSTAT Database (2016), ETER (2016) and IPEDS (2014).

2.2.3. Industry characteristics

37. Regarding the patenting activity of industry inventors, a few top locations account for the majority of industry inventions. The top 5% postal code areas in terms of patent applications account for 63% of total patent applications in the United States and 22 European countries. On the other hand, the bottom 50% locations account for less than 1% of all patent applications (Figure 5). The evidence corresponds to evidence on concentration of inventive activity for the United States (Belenzon and Schankerman, 2013; Fischer and Varga, 2003; Jaffe and Trajtenberg, 1996; Jaffee et al., 1993; Audretsch and Feldman, 1996; Ellison and Glaeser, 1997). High levels of concentration are also related to the dominant role of top R&D investors, 95% of them are located in the top 1% of postal code areas (Box 1).

Figure 5. Concentration of EPO patent applications across locations (postal code areas)

22 European countries and the United States, 2011-2013



Note: The Figure shows that the top 10% locations in terms of patent applications account for more than 80% of all EPO patent applications filed between 2011 and 2013 (blue line). The number of patent applications is weighted by economic activity within ten kilometre distance from postal code centre to control for concentration of patenting that arises due to industry concentration.

Source: OECD calculations based on the OECD PATSTAT Database (2016).

Box 1. Patent applications by top R&D investors

Leading business are important players in national ecosystems. Data from the EC-JRC/OECD COR&DIP (IPTS-OECD) database contains observations on the top 2 000 R&D performing firms and their patent applications worldwide for the years 2010 to 2012. The data reveals that the top 2 000 companies (hereafter referred to as *top R&D investors*) account for approximately 50% of global R&D expenditures and 90% of global business R&D expenditures. For the United States and the 22 European countries analysed, top R&D investors account for around a fifth of all patent activity between 2011 and 2013. However, there are marked differences between countries (Table 3).

Table 3. Share of EPO patent applications filed by top R&D investors, 2011-2013

	EPO patent applications of top R&D investors	Total EPO patent applications	Share of top investors' patent applications
United States	24 475	99 578	24.6%
Germany	10 733	68 714	15.6%
France	5 587	27 647	20.2%
Netherlands	2 853	11 424	25.0%
Switzerland	2 474	15 566	15.9%
Sweden	2 141	10 311	20.8%
United Kingdom	2 065	12 394	16.7%
Finland	964	5 299	18.2%
Denmark	745	4 016	18.6%
Italy	490	10 979	4.5%

Belgium	363	4 386	8.3%
Ireland	341	1 350	25.3%
Spain	302	3 803	7.9%
Austria	252	5 194	4.9%
Norway	103	1 400	7.4%
Luxembourg	39	1 051	3.7%
Czech Republic	12	462	2.6%
Iceland	9	104	8.7%
Hungary	5	281	1.8%
Slovenia	4	309	1.3%
Portugal	3	275	1.1%
Poland	1	982	0.1%
Greece	0	199	0.0%
Slovak Republic	0	102	0.0%
Estonia	0	86	0.0%
Latvia	0	108	0.0%
Total	53 961	286 020	18.9%

Source: OECD calculations based on IPTS-OECD (2014).

R&D activity of around 2 000 top investors is located in 2 200 different locations. The average top investor in the sample has 2 patenting locations. Figure 2 shows the top ten postal code areas in terms of EPO patent applications and points to urban centres as important hubs for these firms. 6 of the top 10 locations are in or around the 3 cities of München, Paris, and San Diego. Exceptions are Schenectady and Mansfield in the United States due to the reason that General Electric has its headquarters in Schenectady and Mansfield houses a strong healthcare industry.

Most R&D activity of top investors are from a small number of countries: 75% of top investors' patenting are located in France, Germany, and the United States, while 7 countries are responsible for 93% of all patent activity of top R&D investors (Table 4).

Table 4. Top ten postal code areas in terms of total EPO patent applications of top R&D investors, 2011-2013

Postal code	City name	Country	Total EPO patent applications
12345	Schenectady	United States	1690
80333	München	Germany	1677
5656	Eindhoven	Netherlands	1441
16483	Stockholm	Sweden	1287
75015	Bretten	Germany	1173
92121	San Diego	United States	1047
92100	Boulogne-Billancourt	France	849
92200	Neuilly-sur-Seine	France	816
75007	Paris	France	707
02048	Mansfield	United States	657
95014	Cergy-Pontoise	France	636

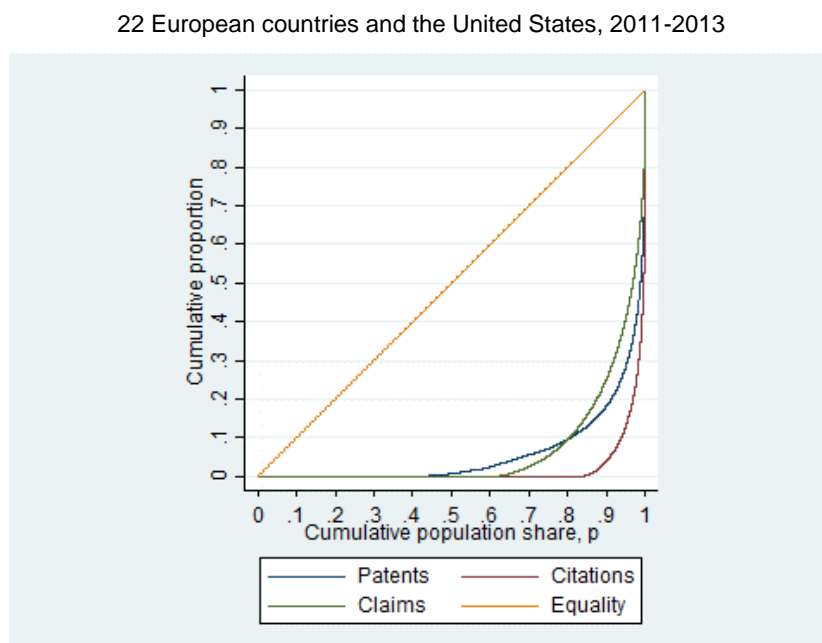
Note: Others include Austria, Belgium, Czech Republic, Denmark, Finland, Hungary, Iceland, Ireland, Italy, Lithuania, Luxembourg, Norway, Portugal, Slovenia, and Spain.

Source: OECD calculations based on IPTS-OECD (2014).

By industry, the 5 top sectors that represent around 50% of top R&D investors are automobiles and parts, electronic and electrical equipment, pharmaceuticals and biotechnology, software and computer systems, and technology hardware and equipment. In 2011, software and computer services included 77 leading businesses, e.g. Alphabet, Microsoft, and Oracle in the United States, while technology hardware and equipment accounted for 30 firms, e.g. Intel and Apple in the United States, and Huawei in China. Biotechnology and pharmaceutical industries covered 78 firms, e.g. Novartis and Roche in Switzerland, and health care equipment and services 76 firms, e.g. Medtronic in Ireland and Boston Scientific in the United States.

38. Concentration is even more important if different measures of the quality of patent applications are applied (Figure 6). 70% of all patent claims on specific economic applications can be traced to inventors that reside in the top 5% of postal code areas. Patent claims, which delimit the scope of what a patent does, can be considered as positively correlated with the economic value of patents, as a broader scope generates larger impacts (OECD 2009 - OECD Patent Manual; Bessen, 2008; Harhoff, 2016).²

Figure 6. Concentration of EPO patent applications, citations and claims of patent applications across locations (postal code areas)



Note: The Figure shows that the top 10% locations in terms of citation numbers account for more than 90% of all citations in EPO patent applications filed between 2011 and 2013 (red line). The number of patent applications, citations and claims is weighted by economic activity within ten kilometres distance from postal code centre to control for concentration of patenting that arises due to industry concentration.

Source: OECD calculations based on the OECD PATSTAT Database (2016).

2.3. An initial assessment of the impact of research institutions on inventions

39. Descriptive statistics presented above is consistent with the view that public research is a driver of inventive activities in the geographic proximity of universities and PRIs. However, the evidence does not demonstrate impact because other factors may explain why research and industry inventive activities coincide in geographic space. Particularly the most inventive research institutions may be located where most innovative business is located because it is in these locations that universities were historically created to support industry. Inventive research institutions and inventive business may also be co-located because these research institutions receive largest financial and other support from industry and consequently patent more without necessarily leading to benefits for industry. It may also be industry that benefits research rather than the reverse.

² In a patent application, the claims define which subject-matter is sought to be protected by the patent application, indicating to others what they must not do if they are to avoid infringement liability. As claims are of the utmost importance during prosecution and litigation, patents with a higher number of claims are generally considered of higher economic value to a firm.

40. To go one step further, a more systematic econometric analysis is needed. A first analysis is conducted here to test whether the association remains positive aside from ensuring specific regional and year characteristics do not drive effects (column 1 of Table 5). This study adopts an instrumental variable approach to address the issue of reverse causality. The location of universities established before the year 1900 is used to instrument for local patent applications of research institutions in 2011-13. The distance to pre-1900 universities is likely to have an impact on patent applications of research institutions in 2011-2013 because many universities trace their roots back to that period.³ It may, however, be assumed that the distance to pre-1900 universities is not strongly related to current industry inventions because changes to industry location over the 20th century have been substantial (Box 2).

Box 2. Pre-1900 location of universities and current innovation activity of industry

Reasons why the location of pre-1900 HEIs is not affected by factors that shape current location of innovation performance include the following:

1. The location decision of pre-1900 HEIs was driven by then existing urban centres and trade routes as they determined communication channels between scholars. Urban patterns and trade routes have changed considerably since then not least because of the industrialisation which markedly shaped regional and economic structures. Although several universities were established in the 19th century to support local industrialisation (e.g. U.S. *land grant universities*, *Technische Hochschulen* in Germany), the location decision of those institutions predates patterns of urbanisation and industry developments in the 20th century.
2. New industries and technologies have developed with the 20th century and hence after the establishment of pre-1900 HEIs. For instance, biotechnology and ICT did not play a role for the location of pre-1900 HEIs.

41. The evidence, reported in Column (2) of Table 5, confirms the positive effects of inventive activities of public research institutions as proxied by their patent applications on local industry patent applications. These results also point to the importance of a specific impact channel, patent documents, on the number of local inventions as measured by patent applications. These effects are not stronger with greater proximity of inventors to universities, suggesting that patent applications contain the most important information for innovators already. Consequently, proximity does not offer additional benefits. Distance of top R&D investors, however, affects impacts of research institutions' patents, possibly signalling that these firms are critical to exploit research results.

³ In a first step, the *distance to pre-1900 HEIs*_{*i*} is regressed against number of local university patent applications

- **First stage:** $pat^{uni}_i = p_0 + distance\ to\ pre-1900\ HEIs_i + u_i$

The F-test (F-value of 66) shows that the correlation between the distance variable and research institutions patent applications is statistically different from zero. In a second stage, only the variation of the relationship $x^*_i = p_0 + distance\ to\ pre-1900\ HEIs_i$ that is not correlated with the research institution patents residual u_i is used to instrument local research institution patent applications in the empirical model (1):

- **Second stage:** Replace *distance to pre-1900 HEIs*_{*i*} with x^*_i in empirical model (1).

Table 5. The impact of research inventions on industry inventions, sample of 22 European countries for 2011-2013

	TOTAL NUMBER OF LOCAL PATENT APPLICATIONS			TOTAL NUMBER OF CLAIMS OF LOCAL PATENT APPLICATIONS
	(1)	(2)	(3)	(4)
<i>Local research institution patent applications</i>	0.200*** (-0.020)	1.300*** (-0.070)	0.600*** (-0.100)	1.200*** (-0.090)
<i>Distance in km to research institution * Local research institution patent applications</i>			0.005 (-0.010)	-0.050*** (-0.010)
<i>Distance in km to top R&D investor * Local research institution patent applications</i>			-0.100*** (-0.008)	-0.080*** (-0.006)
<i>Control variables</i>				
<i>Distance in km to the closest university</i>			Yes	Yes
<i>Distance in km to top R&D investor</i>			Yes	Yes
<i>Urbanisation</i>			Yes	Yes
<i>Fixed effects</i>				
<i>Region</i>	Yes [301]	Yes [301]	Yes [301]	Yes [301]
<i>Year</i>	Yes [3]	Yes [3]	Yes [3]	Yes [3]
<i>N</i>	6 674	25 456	23 205	45 529
<i>Corrected R²</i>	0.09	0.07	0.25	0.13

42. The evidence also shows that local research institution's patent applications have a stronger positive impact on patent applications of higher impact (columns 4 of Table 5).

43. The results also show that top R&D investors' patent activity, which represents one in five of all patent applications in our database, is not associated with research institutions. Patent applications generated by research institutions and vicinity to them do not seem to be important for these firms' inventions (columns 1 and 2 of Table 6). With their leading innovation capacities, they might be in a better position take advantage of other interaction channels that require higher upfront investment such as e.g. joint R&D and global linkages with leading university laboratories. They may also be less reliant on local university research and source globally while local institutions may critically serve laggards access lead technology. Evidence from case studies might provide valuable insights into how these large entities collaborate with research institutions at local, national and international levels.

44. Patent applications of universities and PRIs benefit patent applications in the more science-based fields of biotechnology, pharmaceuticals and medical instruments (columns 3 and 4 of Table 6). This is in line with literature on the contributions of research to science-based industries. Previous research has also emphasised the specific contributions of public research to certain sectors of the economy (Schartinger, et al. 2002; Furman, and MacGarvie, 2007). Distance to research institutions negatively affects patent applications; this points to the importance of face-to-face exchange with regards to complex knowledge exchange. The distance of inventors to top R&D investing firms also has negative effects on the impacts of patents, pointing to the role of these firms in using outcomes for research institutions in these science-based sectors.

Table 6. The impact of research inventions on industry inventions by sector and inventor, sample of 22 European countries for 2011-2013

	PATENT APPLICATIONS TOP R&D INVESTORS	PATENT APPLICATIONS OF ALL OTHER FIRMS	PATENT APPLICATIONS IN SCIENCE-BASED SECTORS	PATENT APPLICATIONS IN OTHER SECTORS
	(1)	(2)	(3)	(4)
Instrumental variable estimation (1) - (4)				
<i>Local research institution patent applications</i>	0.300 (-0.300)	0.600*** (-0.100)	0.800*** (-0.100)	0.300 (-0.200)
<i>Distance in km to research institutions * Local research institution patent applications</i>	0.020 (-0.040)	-0.020 (-0.010)	-0.050** (-0.020)	0.040 (-0.020)
<i>Distance in km to top R&D investor * Local research institution patent applications</i>			-0.060*** (-0.009)	-0.080*** (-0.010)
<i>Controls</i>				
<i>Distance in km to closest research institution</i>	Yes	Yes	Yes	Yes
<i>Urbanisation</i>	Yes	Yes	Yes	Yes
<i>Distance in km to top R&D investor</i>			Yes	Yes
<i>Fixed effects</i>				
<i>Region</i>	Yes [301]	Yes [301]	Yes [301]	Yes [301]
<i>Year</i>	Yes [3]	Yes [3]	Yes [3]	Yes [3]
<i>N</i>	4 031	22 471	14 976	14 389
<i>Corrected R²</i>	0.07	0.14	0.14	0.19

45. With regards to possible drivers of research institutions' inventive activities, the evidence points to a positive relationship between private universities and patent activity of research institutions across 22 European countries. A higher share of private institutions is positively associated with patenting of

research institutions after controlling for university size (Table 7).⁴ A variety of reasons might explain contributions of private institutions, including possibly greater openness to collaborations with industry. The role of private institutions in innovation differs also as a consequence of the diverse characteristics and the history of these institutions across countries.

Table 7. The impact of university characteristics on research inventions, sample for 22 European countries for 2011-2013

	PATENT APPLICATIONS RESEARCH INSTITUTIONS
<i>Share private institutions</i>	0.700*** (0.100)
<i>Controls</i>	
<i>University expenditures</i>	0.300*** (0.030)
<i>Distance in km to top R&D investor</i>	0.080*** (0.008)
<i>Urbanisation</i>	0.300 (0.100)
<i>Fixed effects</i>	
<i>Region</i>	Yes [301]
<i>Year</i>	Yes [3]
<i>N</i>	14 976
<i>Corrected R²</i>	0.14

⁴ The share of private institutions is measured using the share of student enrolment in private institutions of the two nearest universities while university size is proxied by total expenditures of the two nearest universities (see Annex 2). Unreported results show that the findings are robust to different specifications, such as distance to the nearest and the three nearest institutions.

3. NEXT STEPS

46. The document offers a first discussion of the questions posed by TIP project activity on impact assessment and proposes a very preliminary analysis of a dataset to be used. Immediate next steps for the cross-country analysis include the following:

1. Broaden country and year coverage of the analysis: The use of other datasets, such as the World Higher Education Database (WHED) published by the International Association of Universities (IAU) in collaboration with the UNESCO, will be explored to expand the country coverage. A downside to other datasets is they cover less country information. If delegates can provide additional data sources on universities and PRIs as described in annex 3 this would be most welcome. Regarding the time dimension, patent data coverage will be expanded so as to allow for analysing trends.
2. Expand the analysis on quality and novelty of the inventions to understand which channels matter more for knowledge transfer between science and industry. This requires a more systematic analysis of channels. The preliminary analysis only focused on the role of research institutions patenting activities. While more can be done with the current data available, the Secretariat also welcomes suggestions for data that could allow analysing more impact channels.
3. Explore the effects of policy and other framework conditions: Beyond the urban and local environment, the policy environment of research institution systems also has implications on their impacts. This includes, for instance, the degree of research institutions' autonomy (Boarini et al., 2008; Aghion et al., 2007). Other factors likely also play a role and could be explored further, building on governance indicators [[DSTI/STP/TIP\(2017\)10](#)].

47. Delegates are invited to propose case studies that would allow respond to the questions set out by this activity. Case studies could focus on the role of intermediaries in fostering the knowledge transfer between industry and science as well as analyses of how specific channels have contributed to support innovation performance. Also relevant are case studies that illustrate the role research institutions have played in bringing forward specific high-impact inventions, such as advances in artificial intelligence or other digital technologies. An additional topic could be a study on the characteristics of investments of top R&D investor engaged with different local, national and global research. To allow for cross country comparability, a template will then be developed to allow for cross-country comparisons.

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ANNEX 1: OVERVIEW OF THE DATA USED FOR THE ANALYSES

48. The primary data needed for the econometric analysis includes location-specific information on higher education institutions, their characteristics including expenditures, enrolment, year of foundation, institutional type (college, university of applied science, or university), legal status, as well as information specific information on inventors and patent applicants. Two types of datasets are used for the analysis of HEIs: i) census data on higher education institutions in the European Union and the United States; and ii) data on teaching, research and education outcomes specifically pertaining to the leading European and American institutions. Location specific information on inventors and patent applicants are taken from patent data.

Data on university characteristics

The ETER census for Europe

49. The European Tertiary Education Register (ETER), a project by the European Commission in co-operation with Eurostat, provides data for 2011, 2012 and 2013 of all bachelor-degree awarding higher education institutions across 36 countries. The total coverage is of 2 784 higher education institutions located in 36 European countries that collectively educate more than 16.7 million tertiary education students enrolled in institutions that provide bachelor degrees. The original data come from national statistical institutes. More detail can be found in Lepori et al. (2015) and ETER (2015).

50. The sample used in this paper's analysis is restricted to 2 096 institutions located in 25 European countries (22 EU members plus Iceland, Norway and Switzerland). Institutions described as online or distance learning HEIs and those with fewer than 10 students are excluded. The ETER database contains information for Slovenia and the French-speaking part of Belgium but it cannot be used because only university names are available in these cases. Table 8 reports the number of universities and students covered in each country

Table 8. Number of universities and students in the sample, 2011

	Number of institutions	Number of students
Austria	68	339 551
Belgium	23	229 007
Switzerland	35	213 421
Czech Republic	69	399 925
Germany	383	2 304 657
Denmark	30	237 145
Estonia	30	67 347
Spain	76	1 354 058
Finland	42	308 840
France	242	1 631 399
Greece	54	348 637
Hungary	52	355 639
Ireland	27	183 803
Iceland	7	18 709
Italy	160	1 782 129
Luxembourg	1	4 710
Latvia	49	82 912
Netherlands	55	676 742
Norway	49	237 258
Poland	278	1 870 008
Portugal	94	388 412
Sweden	39	431 767
Slovenia	47	0
Slovak Republic	32	216 266
United Kingdom	154	2 278 600
United States	2 105	8 991 885
Total	4 201	24 952 827

Source: OECD analysis of ETER and IPEDS databases.

51. The ETER dataset provides the following information: i) university descriptors such as name, address, geographical coordinates, foundation year and legal status; ii) on the number of students and graduates, broken down by gender and degree level, field of study, the share of national/foreign students, as well as the share of students on campus versus distance learners; and iii) information on staff numbers, including head count and full-time equivalents, broken down by gender, the share of national/foreign staff, functions (administrative, academic, full professors) and research fields of academic staff. Beyond university descriptors and student numbers the information is far from complete. About two thirds of the observations also contain information on iii) expenses, broken down by allocation (personnel, non-personnel, R&D, and capital expenditure) and revenues, broken down by source (third party, private, tuition fees).

IPEDS and NSF census for the United States

52. The census dataset used in this analysis for the United States covers between 2 105 (in 2011) and 2 221 (in 2013) HEIs from the Integrated Postsecondary Education Data System (IPEDS). The full IPEDS database provides a census of 7 300 higher education institutions in the United States, covering all US institutions that apply for and/or participate in federal student financial aid program surveys (National Center for Education Statistics, 2015). For comparability with the European data, the sample used is restricted to institutions that offer degrees of four years or more, i.e. institutions that grant at least

bachelor's degrees. Other institutions that are excluded are those: i) where the majority of students were enrolled by distance; ii) where the majority of students study for 2-year associate's degrees; iii) institutions that are administrative university system offices; and iv) institutions with missing enrolment or characteristics data. Finally, a small number of institutions could not be included as the data could not be matched to information from other sources (see below for the matching procedure).

53. IPEDS variables cover institution characteristics, student and staff numbers, financial indicators, and some coverage of educational characteristics. Most HEI characteristics are standardised across all institutions, except for financial information, as two different but not directly comparable accounting practices are used by HEIs.

54. A second dataset from the National Science Foundation (NSF) includes those IPEDS institutions that spend at least USD 150 000 on R&D within the fiscal year. The NSF census of R&D-active HEIs covers on average about 770 institutions over 2007 to 2013. There is no equivalent to the NSF data for Europe. Data come from the NSF Higher Education Research and Development Survey (2010-2013), and its predecessor, the NSF Academic R&D Expenditures Survey (2007-2009). Variables include R&D expenditure by field of science and R&D by source of funds. This information is matched at the university level with the IPEDS database (see below for details).

Patent data

55. Patent application data for European regions is retrieved from the OECD PATSTAT (version autumn 2016) and REGPAT Databases (version autumn 2015). For 2011-2013, patents filed under the European Patent Office (EPO) from 2011- 2013 (priority year) are retrieved. The following International Patent Classification (IPC) codes are used Table 9 for a concordance between technologies and International Patent Classification (IPC) classes as found in patent documents.

Table 9. Correspondence table between IPC classes and technologies

Technology class	IPC class
<i>Life sciences</i>	
Biotechnology	A01H1/00, A01H4/00, A61K38/00, A61K39/00, A61K48/00, C02F3/34, C07G (11/00, 13/00, 15/00), C07K (4/00, 14/00, 16/00, 17/00, 19/00), C12M, C12N, C12P, C12Q, C12S, G01N27/327, G01N33/ (53*, 54*, 55*, 57*, 68, 74, 76, 78, 88, 92)
Medical technology	A61B, A61C, A61D, A61F, A61G, A61H, A61J, A61L, A61M, A61N, H05G
Pharmaceuticals	A61K <u>not</u> A61K-008
<i>ICT</i>	
Telecommunications	G01S, G08C, G09C, H01P, H01Q, H01S3 (025, 043, 063, 067, 085, 0933, 0941, 103, 133, 18, 19, 25), H1S5, H03B, H03C, H03D, H03H, H03M, H04B, H04J, H04K, H04L, H04M, H04Q; <i>Other ICT:</i> G01B, G01C, G01D, G01F, G01G, G01H, G01J, G01K, G01L, G01M, G01N, G01P, G01R, G01V, G01W, G02B6, G05B, G08G, G09B, H01B11, H01J (11/, 13/, 15/, 17/, 19/, 21/, 23/, 25/, 27/, 29/, 31/, 33/, 40/, 41/, 43/, 45/), H01L G11B, H03F, H03G, H03J, H04H, H04N, H04R, H04S
Consumer electronics	
Computers and office machinery	B07C, B41J, B41K, G02F, G03G, G05F, G06, G07, G09G, G10L, G11C, H03K, H03L G01B, G01C, G01D, G01F, G01G, G01H, G01J, G01K, G01L, G01M, G01N, G01P, G01R, G01V, G01W, G02B6, G05B, G08G, G09B, H01B11, H01J (11/, 13/, 15/, 17/, 19/, 21/, 23/, 25/, 27/, 29/, 31/, 33/, 40/, 41/, 43/, 45/), H01L
Other ICT	

Source: International Patent Classification, 8th edition, 2000: www.wipo.int/classifications/ipc/ipc8.

Location-specific information on inventors

56. Patent applications' inventors are located by the postal code provided in the patent application on where the inventor resides. The postal codes of the inventor's address have been used, whereas fractional counting has been applied to allocate patents to inventors [DSTI/DOC(2008)2]. This means that, where a patent with two inventors that reside in two different regions, region A and B, are counted as 0.5 patents each, i.e. 0.5 patent counts in region A and 0.5 in region B. The only country for which postal codes were not used for Ireland where addresses were geocoded, i.e. the address was converted into geographic coordinates and each coordinate was treated as a single observation since postal codes were not available. Data on geographical coordinates of postal code centres is taken from GEONAMES⁵ database to allow mapping patents by latitude and longitude coordinates, in degrees.

57. Location-specific information is not available in GEONAMES for Estonia, Greece and Latvia. Patent information contains inventor's address for these countries so expanding the dataset would require postal code information that is linked to geographical coordinates.

58. Location specific information taken from REGPAT accounts for nearly all patent applications ranging from 0.97 to 1 in coverage. The remainder cannot be allocated because the address information is incomplete. This applies to Ireland and Luxembourg. More than 95% of EPO patent applications can be matched to postal code information using GEONAMES data (see Table 10). Data coverage for the United Kingdom is lower due to a high share of postal code information in PATSTAT and GEONAMES that does not match.

Table 10. EPO patent applications with location-specific information as a share of EPO total patent applications per country of residence, 2011-2013

	PATSTAT	GEONAMES	% matched
United States	99 578	96 113	0.97
Germany	68 714	65 925	0.96
France	27 647	26 741	0.97
Switzerland	15 566	15 165	0.97
United Kingdom	12 394	6 160	0.50
Italy	10 979	9 848	0.90
Netherlands	11 424	11 041	0.97
Sweden	10 311	9 568	0.93
Austria	5 194	5 059	0.97
Finland	5 299	5 101	0.96
Belgium	4 386	4 285	0.98
Denmark	4 016	3 901	0.97
Spain	3 803	3 542	0.93
Norway	1 400	1 202	0.86
Ireland	1 350	1 085	0.80
Luxembourg	1 051	892	0.85
Poland	982	848	0.86
Czech Republic	462	385	0.83
Slovenia	309	290	0.94
Hungary	281	248	0.88

⁵ <http://download.geonames.org/export/zip/> (Accessed 11 January 2017).

Portugal	275	229	0.83
Greece	199	166	0.83
Slovak Republic	102	83	0.81
Estonia	86	77	0.90
Iceland	104	102	0.98
Latvia	108	104	0.96
Total	286 020	268 160	0.94

Source: OECD calculations using PATSTAT (2016) and REGPAT (2015) databases and GEONAMES database <http://download.geonames.org/export/zip/>.

Patents of universities and PRIs

59. Regarding patents of research institutions, the study matches patent applications from PATSTAT to the 4 782 research institutions in the sample, including 4 201 universities and also 581 PRIs. Patent applications that are filed by HEIs and PRIs are retrieved using a list of HEIs taken from ETER and IPEDS, while information on PRIs is available for leading PRIs in France, Germany, Spain, the United Kingdom, and the United States using the Elsevier SciVal database.

60. Additionally, patent applications that contain the following expressions in their name are included as HEIs patent applications: Universitet, Akademia, Augstskola, Board of Regents, College, Fachhochschule, Hochschule, Hogeschool, Institut National Polytechnique, Institute of Technology, Medical School, Montanuniversität, Politechnika, Rijksuniversiteit, School of Medicine, Technikaülikool, Universidad, Università, Universitat, Universität, Universitate, Universite, Université, Universitet, Regarding data on universities, those taken from ETER already includes location-specific information on the coordinates of the postal code centre in which the university is situated. IPEDS data includes the postal code which is matched to coordinate using GEONAMES.

Data on top R&D investors

61. The EC-JRC/OECD COR&DIP (IPTS-OECD) database contains observations on patent applications of the top 2 000 R&D performing firms worldwide for the years 2010 to 2012. They account for approximately 50% of global R&D expenditures and 90% of global business R&D expenditures. The address of patent applications filed by top 2 000 R&D performing firms worldwide is available to account for the location of their R&D activity.

Data on night-time light

62. Defense Meteorological Satellite Program's night-time lights series (**DMSP-NTL**) data is available for the years 1992 to 2010 to account for differences in regional structure. The amount of light that can be observed from outer space is used in literature to measure local economic activity. The report uses data from the National Geophysical Data Center (NGDC) of the U.S. National Oceanic and Atmospheric Administration (NOAA) of the United States since 1992 for 1992 -2013. Satellites from the U.S. Air Force DMSP have been circling the earth 14 times per day to record the intensity of Earth-based light using their Operational Linescan System (OLS) since the 1970s. Each satellite observes every location on Earth every night at some instant between 8.30 pm and 10 pm local time.

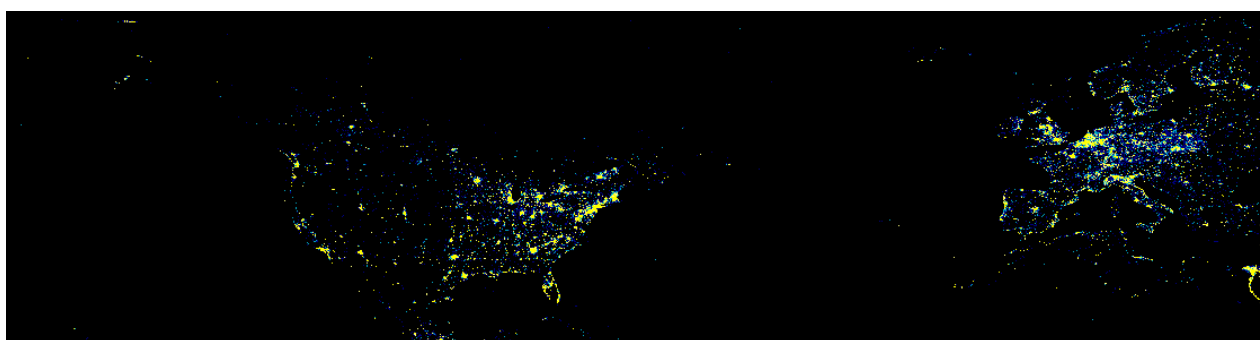
63. In order to measure light intensity from economic activity, the data is processed to remove intense sources of natural light such as e.g. the bright half of the lunar cycle, the summer months when the sun sets late, aurora activity, and forest fires. Observations where clouds cover the Earth surface are also

excluded. The data from all orbits of a given satellite in a given year is averaged over all nights to produce satellite-year datasets⁶.

64. The data is available as a raster file reporting the intensity of lights as a six-bit digital number for every 30 arc-second output pixel. This corresponds to 0.86 square kilometres at the equator and allows for very detailed observations of economic activity.

65. The intensity of lights reflects outdoor and indoor use of light and is measured by a digital number reporting the intensity of light on a scale between 0 (no light) and 63. In the United States, for instance, 70% of the country's surface is unlit while only 1% is unlit in the Netherlands. Figure 7 shows the night light intensity for Europe and North America.

Figure 7. Lights at night, 2010



Source: OECD illustration using the DMSP-NTL database (2017).

66. The mean of the digital number tells us the average light intensity within a given area. Spatial bands are defined to construct measures for mean night light intensity within 1 kilometre, 5 kilometres, 10 kilometres, 15 kilometres, and 30 kilometres of a university. The spatial bands were chosen partly based on the distributions of the distance between inventors and HEIs: 50% of all patent activity is concentrated within 15 kilometres, and 75% of all inventors within 30 kilometres of a university in the sample.

Description of variables and summary statistics

67. Table 11 summarises the variables and data from these respective sources used in the analysis.

⁶ <https://www.ngdc.noaa.gov/eog/dmsp/downloadV4composites.html> (accessed 31 March 2017).

Table 11. Description of European sample, 2012

Name	Description	Source	N	Mean	Std. Dev.
Total number of local patent applications	Total number of EPO patent applications of postal code area	PATSTAT, REGPAT	151 735	4.5	29.4
Total number of local research institution patent applications	Total number of EPO patent applications assigned to HEIs and PRIs of postal code area	PATSTAT, REGPAT	114 915	2.1	6.6
Total number of citations of local patent applications	Total number of backward citations of EPO patent applications of postal code area	PATSTAT, REGPAT	49 911	2.0	18.6
Total number of claims of local patent applications	Total number of claims of EPO patent application of postal code area	PATSTAT, REGPAT	49 911	19.5	78.0
Distance in km to nearest research institutions	Distance in km of inventor to two nearest higher education institutions	ETER, IPEDS	146 607	14.4	21.2
University expenditures	Total expenditures of two nearest higher education institutions (in thousand EUR)	ETER, IPEDS	148 986	209 000	354 000
Share of private research institutions	Share of students enrolled privately-owned institutions among two nearest higher education institutions	ETER, IPEDS	146 341	0.3	0.4
Distance in km to top R&D investor	Distance in km of inventor to nearest top R&D investor	IPTS-OECD	146 607	3.2	4.9
Urbanisation	Mean night light intensity (0=no light; 63=max. light intensity)	U.S. Defense Meteorological Satellite Programme Night-Time Light Series	150 242	50.8	15.4

ANNEX 2: EMPIRICAL MODEL AND ESTIMATION STRATEGY

68. The empirical approach aims to estimate the relationship between channels of science-industry interaction and patent activity in 22 European countries and the United States using a panel model with fixed effects. Equation (1) shows the empirical model for $i = 1, \dots, N = 50\,578$ and $t = 1, \dots, T = 3$ years,

$$y_{it} = \beta_0 + \beta_1 pat_{it}^{research} + \beta_2 pat_{it}^{research} \times d_i^{research} + \beta_3 pat_{it}^{research} \times d_i^{top} + \beta_4 d_i^{research} + \beta_5 d_i^{top} + \beta_6 urban_i + \mu_j + \tau_t + \varepsilon_{it} \quad (1)$$

69. where y_{it} corresponds to the logarithm of the total number of local patent applications (excluding those of research institutions) in zip code area i at time t , while pat_{it}^{pub} denotes the logarithm of the total number of local research institution patent applications in zip code area i at time t . The term $pat_{it}^{research} \times d_i^{research}$ measures interaction between the number of local research institution patent applications and the distance in km to nearest research institutions. By including this term, it is possible to estimate whether the effect of local research institution patent applications on the total number of local patent applications is higher in vicinity to research institutions (or lower with distance to them). Distance to research institutions is measured by the logarithm of distance in kilometres to the two nearest universities $d_i^{research}$. The term $pat_{it}^{research} \times d_i^{RD}$ measures the interaction between local research institution patent applications and distance in km to nearest top R&D investor. urb_i measures urbanisation as proxied by night light intensity.

70. The coefficients of interests are as follows: β_1 captures the effect of a one percent increase in the total number of local research institution patent applications on the total number of local patent applications. β_2 indicates whether vicinity to research institutions facilitates the impact of the total number of local research institution patent applications on the total number local patent applications. β_3 indicates whether vicinity to top R&D investors strengthens the impact of research institution patent applications on total local patent applications. β_4 captures the effect of distance in km to the nearest research institutions on the total number of local patent applications; β_5 denotes the relationship between distance in km to leading top R&D investors and local patent applications; and β_6 measures the association between urbanisation and local patent applications.

71. The empirical specification includes fixed effects where μ_j captures region-specific fixed effects for $j = 1, \dots, 301$ sub-national regions in 22 European countries and the United States to capture idiosyncratic factors of regions that might drive innovation performance; τ_t captures time-period fixed effects, and ε_{it} is the residual terms varying across i and t with zero mean and variance σ^2 .

	Name and address including zip code	Year of foundation	Student number	Number of staff (academic staff, administrative staff)	Total expenditures (personnel, infrastructure, research, etc.)	Legal status (ownership, public, private) and type (university, college, university of applied sciences, etc.)	Publications	Number of/income from licensed intellectual property (e.g. patents)	Number of/income from university-industry collaboration	Number of/income from consulting services	Number of/income from industry contracts	Number of/income received from public grants (i.e. national research grants, European grants, etc.)	Spin-off companies (university supported, independent by faculty)	Name and address including zip code	Year of foundation	Student number	Number of staff (academic staff, administrative staff)	Total expenditures (personnel, infrastructure, research, etc.)	Legal status (ownership, public, private) and type ¹	Publications	Number of/income from licensed intellectual property (e.g. patents)	Number of/income from PRIs-industry collaboration	Number of/income from consulting services	Number of/income received from public grants (i.e. national research grants, European grants, etc.)	Spin-off companies (PRIs supported, independent by faculty)
Israel																									
Italy	X	X	X	X	X	X																			
Japan																									
Korea																									
Luxembourg	X	X	X	X	X	X																			
Mexico																									
Netherlands	X	X	X	X	X	X																			
New Zealand																									
Norway	X	X	X	X	X	X																			
Poland	X	X	X	X	X	X																			
Portugal	X	X	X	X	X	X																			
Slovak Republic	X	X	X	X	X	X																			
Slovenia	X	X	X	X	X	X																			
Spain	X	X	X	X	X	X																			
Sweden	X	X	X	X	X	X																			
Switzerland	X	X	X	X	X	X																			
Turkey																									
United Kingdom	X	X	X	X	X	X																			
United States	X	X	X	X	X	X																			