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UK universities interacting with industry: patterns of research collaboration and inter-sectoral mobility of academic researchers

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Abstract

UK research-intensive universities have become increasingly ‘enterprising’ in terms of research commercialisation, technology licensing and transfer, and other ways of engaging with the business enterprises and industry. University-industry interactions (UII) have become an important feature of the UK higher education system. We examined recent UII patterns within UK research universities from two analytical perspectives: (a) university-industry research collaboration of academic researchers; (b) their cross-sectoral mobility. The empirical information is extracted from hundreds of thousands of research articles published in international scholarly and technical journals during the years 2009-2015.

Our information items, to capture UII patterns and compare universities, are:

- *University-industry co-authored publications* (UICPs), reflecting productive and successful partnerships with research-active companies, where the organisational affiliations of participating researchers were extracted from the author address(es);
- *University-industry crossover researchers* (UICRs), individuals who have (or had) one or more UK university affiliation as well as one or more affiliation in the business sector in recent years.

In this paper we focus on identifying and describing macro-level patterns within the UICP and UICR data. We present comparative UICP and UICR statistics on those 47 UK research-active universities that are indexed in the *Leiden Ranking* (www.leidenranking.com). The UICP profiles of each university include the distribution of industry partners across three geographical zones: local UICPs (within the same UK region); domestic UICPs (located elsewhere in the UK); foreign UICPs (outside the UK). The latter category was split into UICPs where the partner companies are located in (a) the European Union; (b) other countries worldwide.

The findings indicate that research collaboration linkages and staff mobility relationships comprise large numbers of partner companies that are located abroad. We produce comparative numbers, the first ever, with compelling evidence of how significant those relationships with EU industry actually are within UK university research. Research-active companies located in a European Union member state represent 24 per cent of those academic-industry connections. Some universities have relatively large UICP and/or UICR intensities, but the largest numbers are found in the UK's 'big eight' research universities: Imperial College London, King's College London, University of Cambridge, University College London, University of Edinburgh, University of Glasgow, University of Oxford, University of Manchester.

1 Introduction

1.1 Knowledge utilisation spaces

Higher education plays a key role in science-innovation ecosystems, which are founded on the creation, transfer and utilisation of advanced knowledge and skills. The research-intensive universities bring together creativity, talent, and other vital resources to engage in scientific research. They also provide teaching and training inspired by research and science. These higher education institutions (HEIs) engage with businesses and industry, with local communities, cities and regions, and other partners in the outside world at large. Research universities in particular may supply business companies with advanced knowledge, specialised skills and university graduates (Cohen et al., 2002; Siegel et al., 2003; Perkmann et al., 2011), but may also participate in entrepreneurial and innovation processes (Link and Scott, 2003; Link and Scott, 2005; Audretsch, 2014). Universities are increasingly expected to produce the right kind of human capital for fostering entrepreneurship and for innovation (e.g., OECD, 2010; Cunningham and Link, 2015).

World class university systems, especially those within competitive countries like the UK, are characterised by productive ‘impact pathways’ that translate science-based knowledge and know-how to commercial exploitation of research results or other societal applications. Both university teaching and academic science are increasingly designed to create socioeconomic impacts and benefits. Recent UK surveys¹ by Hughes and colleagues (Hughes et al., 2010; Hughes, 2011) indicate that the contributions from UK university researchers to problem solving and socioeconomic impact are indeed significant.² The intent and ability to create such impacts is increasingly seen as a key performance measure of individuals, teams or organisations – witness the importance within the UK’s REF and university funding system, where the assessment scores on impact case studies contribute 20 per cent of the government research funding allocation formula (HEFCE, 2015).

Person-based skills and knowledge are among the most important determinants of higher R&D productivity and innovation performance within advanced economies (Furman et al., 2002). Talented employees, scientific researchers and corporate R&D staff are generally seen as key assets of today’s knowledge-intensive economies. Mutually rewarding ties and productive interactions between research

¹ A web-based survey of UK academics carried out between autumn 2008 and summer 2009 (22,000 individual academic responses drawn from all UK universities and in all disciplines; some 18 per cent of a total population of over 125,000 academics surveyed).

² Recent studies of university-industry relationships within the UK indicate that university income from firms has grown in 2016 (up to £4.2 billion), while university spin-offs and start-ups also show strong growth (Matthews, 2016a). However, information derived from a UK-wide survey² suggests that the share of academic researchers engaged in commercial consultancy has significantly declined from 15 per cent to 7 per cent (Matthews, 2016b).

universities and R&D-dependent firms are crucial features in ‘knowledge utilisation spaces’ underlying such economies. However, knowledge supply and demand are usually not clearly articulated or well-aligned in these utilisation spaces, partially because 21st century science is becoming increasingly ‘borderless’ and integrated into large interactive systems. In the wake of the digital revolution, as well as the more recent ‘open science’ and ‘open innovation’ initiatives, scientific knowledge seems to move across geographical, disciplinary and sectoral boundaries more easily than ever before. However, according to government white papers and other policy documents, neither science-based university education nor research-based knowledge flows sufficiently rapidly or effectively between research-intensive universities to R&D-active companies.

1.2 University-industry interactions

A fair share of those *university-industry interactions* (UII) start with, or are underpinned by, joint research with business enterprises (‘industry’). Close collaborative links and personal relationships between academic researchers and corporate R&D staff at these research-active companies may also arise from the labour mobility of students or faculty crossing both organisational and sectoral boundaries (‘diachronic’ mobility), or from individuals with affiliations in academia as well as in the business sector simultaneously (‘synchronous mobility’). Where collaborative links between individual researchers reflect strength of relationships between organisations or countries, the staff mobility of ‘crossover researchers’³ serves as a marker of movements of individuals, interconnected labour markets and overlapping organisational spaces of R&D staff.

In this UK-wide study we take a first exploratory look at UII patterns from this human resource perspective. Our descriptive study focuses on identifying general patterns at the level of UK research-intensive universities. We address the following research questions: what kind of general organisational patterns do we see within individual UK universities with regards to inter-sectoral connections and staff mobility patterns within this UII space? Are there distinctive differences between universities in terms of the geographical distribution of industrial research partners?

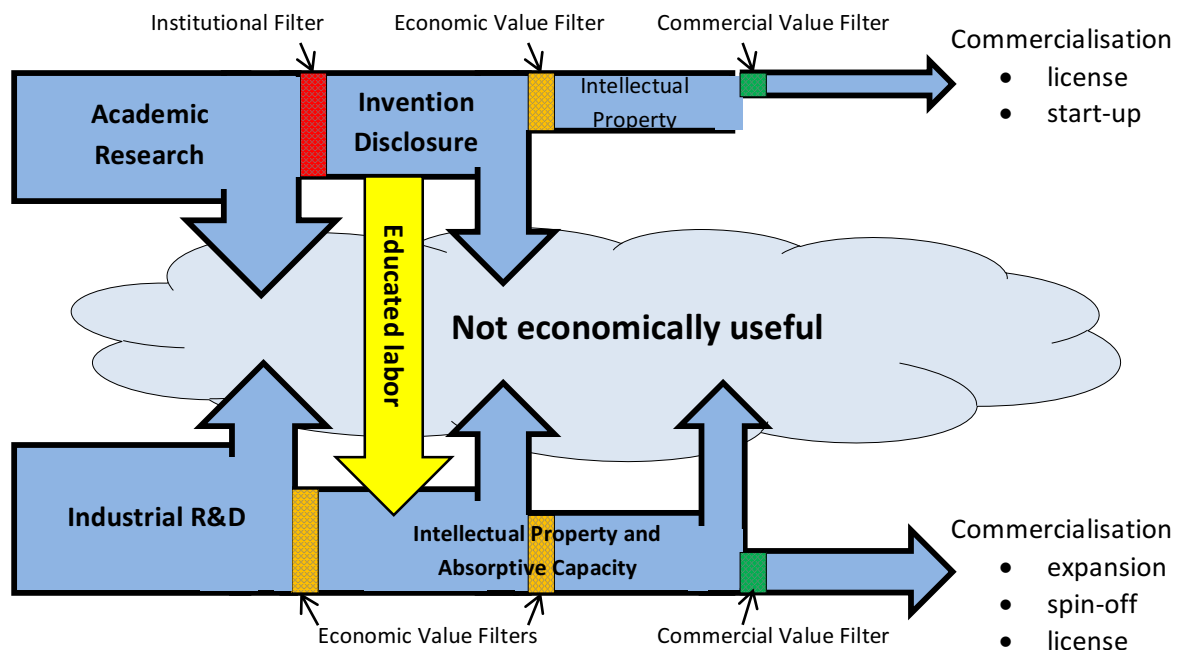
³ The concept ‘crossover researcher’ was introduced in Tijssen & Yegros (2016).

2 Analytical model

2.1 Boundary-spanning researchers

Theoretical models of university-industry interactions provide ways to understanding the economic rationales to engage in joint R&D (Piccaluga & Bonacorsi, 1994; Antonelli et al., 2010). Here we use the ‘knowledge filter’ model (see **Figure 1**) by way of an introductory framework.

Figure 1. Knowledge filter model of university-industry commercialisation processes



Source: Carlsson et al. (2007), The Knowledge Filter, Entrepreneurship, and Economic Growth, Jena Economic Research Papers 2007-057, Friedrich-Schiller-University Jena, Max-Planck-Institute of Economics.

The model presents a simplified picture of university-industry interconnections – in terms of how knowledge utilisation spaces and impact pathways may interact – from a research commercialisation perspective. A series of decision-making processes filter out promising ideas and results, determine what gets through university/industry boundaries, and ultimately what may become economically useful innovation (Carlsson et al., 2007). This model comprises a wide range of ‘boundary spanning activities’ where academic researchers and industrial R&D staff may interact and collaborate – either on joint research activities or working towards achieving research commercialisation objectives.⁴

⁴ Adopting ‘utilisation spaces’ and ‘cross-sectoral R&D links’ as an analytical perspective stresses the role of research universities as collaborative agents and knowledge producers within larger interactive systems such as ‘triple-helix interactions’ (Etzkowitz and Leydesdorff, 2001; Temple, 2012) or ‘networked innovation ecosystems’ (Carayannis and Campbell, 2012).

In this study we focus our attention on the left-hand ‘pre-filter’ stages of academic research and industrial R&D and university-industry interactions (UII). The human factor is of pivotal importance in terms of creativity, ideation and scientific research. While early empirical studies focused their attention on research collaboration and commercialisation activities (e.g. Rothaermel et al. 2007), subsequent studies tend to emphasise micro-level ‘individual’ aspects, rather than meso-level ‘institutional’ characteristics, while covering a wider range of interaction activities (D’Este & Fontana, 2007; Gulbrandsen et al., 2011; Perkmann et al., 2013). Earlier research also indicates that prior employment of work experience in industry positively affects the propensity of academics to engage in university–industry collaboration as well as their research commercialisation activities (Dietz and Bozeman, 2005; Clarysse et al., 2011; Abreu and Grinevich 2013; Bozeman et al., 2013). UII activities are likely to be more common among academics who define their research profile as ‘applied’ (Gulbrandsen and Smeby, 2005).

These ‘boundary-spanning’ individuals, straddling the public and private domain, are likely to act as both linking pins and pre-filtering agents. As such, they can make the difference between success and failure in university-industry engagement and may help shape R&D commercialisation processes later on. In this ‘pre-competitive’ stage, results are still published in open scientific and technical literature. Researchers, engineers and scientists also publish about research findings that are (possibly) industrially relevant and may ultimately become economically useful.

How many of these boundary-spanning university researchers may we expect to find within a single research-intensive UK university or across the entire national higher education system? Some studies have tried to assess ‘non-academic work experience’ among academic employees. A US study, by Lin and Bozeman (2006), found 40 per cent of their sample of researchers from industry-oriented research centres had industry work experience, but the authors note that this is most likely much lower than elsewhere in universities. A recent large UK survey with more than 20,000 respondents looked at participation in different types of academic entrepreneurship (Abreu and Grinevich, 2013). Their set of exploratory variables in the analysis included previous work experience and prior employment in small firms or large firms. The result showed that prior industrial work experience, particularly from small/newly established firms, is positively related to engagement in commercialisation activities. In a more recent study done in Norway by Gulbrandsen & Thune (2017), with 4400 survey responses from academic employees in universities and colleges, the authors find that 16 per cent of the respondents mention prior employment in the business sector (i.e. after finishing their master’s degree and lasting one year or more). Their findings also indicate that academics with a background in industry are more active than their peers in research commercialisation activities.

In this paper we build on the findings of the abovementioned studies in order to generate a better evidence-based understanding of boundary spanning research activities in the UK university system. Our empirical study focuses on research collaboration links and mobility patterns of individual researchers. These Ulls are shaped and driven by a wide range of factors. One of these factors is geography. In the era of globalisation, the numbers of UK researchers engaging with colleagues abroad is growing, especially among academics. UK research-led universities are among the most globalised institutions in British society.

In this first study we focus on just one geographical feature: the location of the related company. Is it a local company, based in the vicinity, a domestic one (somewhere in the UK) or a foreign-based firm? The spatial proximity between a university and its partner companies is a relevant distinctive characteristic of university Ull profiles under the current Brexit threat circumstances.

2.2 Cross-sectoral mobility of academic researchers

It is not surprising that academics are working outside of their 'home countries' (i.e. where they were born and/or where received their first post-secondary degree). Cross-sectoral career moves of university research staff are driven by various determinants, including job loss, temporary appointments, rent-seeking (salary increases), attractive facilities or longer-term prospects, or other socioeconomic factors that affect the employer-employee relationship. Research has shown that the propensity of knowledge workers (researchers, inventors) to move or hold multiple simultaneous affiliations correlates positively with higher productivity levels (e.g. Zucker et al., 2002; Hoisl, 2007; Crespi et al., 2007; Lenzi, 2009), where prolific scientists and inventors tend to be more mobile than less productive colleagues and peers.

As for cross-sectoral international appointments, the factors influencing decisions to move abroad are likely very different from domestic career moves. Academic researchers moving (part-time or full-time) to foreign institutions or companies are more likely to be early career researchers seeking postdoc positions or permanent (tenured) employment. They are likely to encounter bureaucratic and other procedural and legal barriers, at the national or institutional level, where rules and regulations may present serious obstacles to grant dual appointments to academics (in academia and the business sector) and may restrict the number and also the kinds of such appointments.

Even though the global percentage of international academics is usually small in the academic labour force, this group is important: they are often the gate keepers and linking pins in international research networks or consortia. As such they may act as drivers of 'international consciousness' at universities (Altbach and Yudkevich,

2017). Some of these international faculty are ‘global superstars’, others are early career academics who have obtained their doctorates abroad, or have perhaps done a postdoc overseas.

Focusing on the boundary-spanning academic researchers – whose activities facilitate, drive or boost the exchange of knowledge between academic research and business sector R&D – we introduce *university-industry crossover researchers* (UICRs for short). These individual academics can be tracked down by virtue of having their name on university-industry co-authored research publications. In doing so these individuals acknowledge some degree of organisational cross-over between the university and industry. Who are those UICRs? And what are the general characteristics of their performance profiles? Are they indeed the carriers of relevant cross-border knowledge flows and boundary spanning collaborative arrangements? And if so, what drives them and how do they perceive their work and its impacts on their academic performance and linkages to industrial R&D?

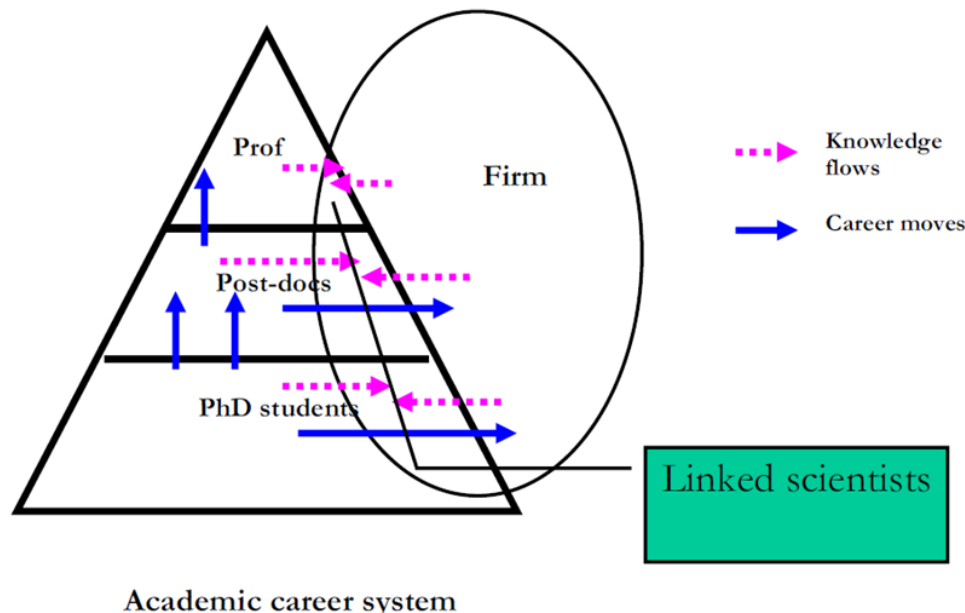
Some of these UICRs may actually represent cross-sector mobility, where academics had prior employment in the business sector or are still part-time employed by business companies, for example as a board member or adviser of university spin-offs. Research on cross-sectoral mobility of academic researchers builds on earlier academic studies that focus on ‘science and technology human capital’ development (Bozeman et al. 2001), some of which deals with university–industry relations (Bozeman et al. 2013). Recent work focuses on the role of mobility in research performance where prior jobs in industry are one of many employment options outside academia (Fernandez-Zubieta et al., 2015; Gulbrandsen and Thune, 2017).

Previous studies carried out in the UK have emphasised the crucial role that these ‘linked scientists’ (Zucker, 2002) play in connecting academic knowledge and know-how to a firm’s internal R&D. Results of those studies suggest that their engagement in collaborative projects with industry, while remaining integrated in the academic scientific communities, could constitute effective ways of knowledge transfer while creating network career structures at public/private R&D interfaces (Lam, 2007; Hughes et al., 2010; Hughes, 2011; Lam, 2011). These individuals, straddling two institutional sectors, are, most likely, familiar with the research practices in academic science, industrial R&D and business interests.

Our research design and analytical framework is guided by Lam’s interactive model which emphasises the role of university human resources, academic career perspectives, and university-industry knowledge flows within the context of labour market dynamics affecting large firms in high-technology sectors (Lam, 2007). The inflow from industry into the university may vary from non-academic staff bringing ‘practitioner’ corporate-developed skills and experience into the university (for research and/or education) to prior academics (PhD student and postdocs) who spent time in corporate R&D units doing research. Some UI job hoppers may switch between two sectors (once or more regularly); others may have several part-time

positions simultaneously – either temporary or permanent. At the level of professor one would expect to find a concentration of multiple affiliations – where academics are part-time advisers or business consultants, or senior corporate R&D staff hold part-time professorships.

Figure 2. University-industry interactions: collaboration, knowledge flows, human resource mobility and academic careers



Source: Adapted from Lam (2007).

Staff mobility within this university-industry interface contributes to creating an ‘overlapping internal labour market’ (Lam, 2007) and a supporting ‘hybrid organisational space’ (Lam, 2011) that are likely to have positive impact on research commercialisation and academic entrepreneurship. We assume that inter-sectoral mobility and/or holding multiple affiliations simultaneously will forge closer links between universities and industry, which in turn create knowledge and skills of industrial relevance and support knowledge flows to the business sector.

Geographical proximity is often an important determinant of UII characteristics. Cross-sectoral mobility patterns of academics across national borders is lesser explored territory in terms of large systematic studies. International mobility of research scientists in general tends to be affected by a wide range of factors, including research collaboration links (Appelt et al., 2015). Where academic research is often meant to have a global reach, firms usually require domestically or locally relevant knowledge. Studies have shown that knowledge transfer from local universities tends to have positive effects on a firm’s innovation performance (e.g. Audretsch and Feldman, 1996; Leten et al., 2014). The likelihood that a firm collaborates with the university decreases by spatial distance (e.g. Laursen et al. 2011; Hong and Su, 2012). Relatively little is known about how and where UK university researchers interact with their R&D counterparts in the business sector abroad.

3 Research methodology

3.1 University-industry research collaboration

Our micro-level information on university-industry research collaboration patterns and inter-sectoral mobility of academic researchers is extracted from author addresses listed in the byline of research articles. University researchers need to publish for career purposes and to share major achievements with colleagues and peers worldwide. So many of their successful joint research projects, also those involving active cooperation with corporate R&D staff, eventually lead to publications in journals, conference proceedings or other (printed or online) outlets. But only if the topic, the research activities and major findings are still in a ‘pre-competitive’ stage – that is, far removed from possible commercial applications. Clearly, our information source presents a partial view of reality: research publications signify successful work (otherwise the work would not be published) and output quantities do not necessarily reflect the volume of inputs (such as the amount of industry funding of research). The major advantage of publication-based information is the ability to produce tangible and objective data that allows for large-scale, multi-level analysis and comparisons at the level of the UK university sector or individual UK universities, but also the micro-level tracking and tracing of individual UK-based researchers.

There is no shortage of such co-authored publications in the open research literature: we find some 50,000 annually in international peer-reviewed scientific journals (Tijssen, 2012). The names of their corporate researcher partners are mentioned in the author list of these joint publications, alongside their institutional affiliations. These jointly authored *university-industry co-publications* (UICPs) present a wealth of empirical information on collaboration patterns and trends between universities and businesses worldwide. As a source of statistical data, UICPs offer a range of possibilities for studies of UII patterns and trends from a university perspective, including world university rankings (Lundberg et al., 2006; Tijssen et al., 2009; Tijssen, 2012; Tijssen et al., 2016); connectedness and services; knowledge flows and exchanges; individual mobility; industrial orientation and innovation support capability.

Some UICPs are co-authored with one or more colleagues in the business sector; some of those UICPs may carry multiple affiliate addresses of the same author referring to a UK university and a business enterprise. A single UICP may include more than one university and more than one industrial partner, in these cases we have assigned a complete publication to each of the involved organisations. Of course, UICPs differ in relevance: some are ‘one-off’ collaborations that happen to include a company somewhere on the continent; others relate to research in large and longstanding international R&D consortia. Special attention is given to UICPs where an academic author lists two or more affiliations, at least one at a UK university and another in the business sector: dual affiliate UICPs (DA-UICPs). This

particular subset of UICPs tends to signify strong, institutionalised ties at the individual level between academia and the business sector (Yegros and Tijssen, 2014).

UICP counts provide statistical data for comparisons between universities. However, UICP frequency data are often size-dependent: large research universities tend to have many UICPs. When correcting for the size of the university, i.e. the total research publication output, the share of UICPs within that total output presents us with high-quality data that enable more meaningful comparisons across universities with regards to their UICP intensity.

Our UICP profiles of UK universities include a breakdown by geographical distribution of industry partners. By geocoding and classifying companies according to their physical location, as indicated in the author addresses on the research publications, we distinguish three geographical zones: local (within the same UK region); domestic (within the UK); foreign (outside the UK). This information enables us to interpret UICP profiles in terms of proximity relationships and effects of national borders.

3.2 University-industry mobility of researchers

Academic researchers moving across academia and industry represent a continuous flow of knowledge, skills and know-how between these two institutional sectors. Industry benefits from the inflow of talent and knowledge attached to recent PhDs or other academic researchers in a more advanced stage in their scientific career. The industrial mindset of those university researchers who had previous work experience or employment in industry may contribute to their developing more application-oriented research at universities, thus facilitating future interactions with industry. As well as their contribution to scientific research and collaborations with industrial R&D partners, it has also been suggested that the level of commitment to teaching of crossover academics with past industrial experience can enhance the value of this key role of universities in educating future professionals (Fairweather and Paulson, 1996).

In this study we consider cross-organisational, cross-sectoral mobility of UICRs in a broad sense. We look at mobility from a broad perspective, not only at instances in which a researcher changes a full-time employment at a university to take a full-time job in a business company or the other way around, but consider also those researchers who simultaneously combine a part-time job both in academia and in a company.

Some academics might publish with industry R&D staff, and co-author UICPs, but have no affiliation-based ties with the business sector – either through employment contracts or formalised advisory arrangements. This is likely to be a heterogeneous collection of researchers, if only because staff may have moved into new jobs and

sectors of employment. For example, PhD graduates who moved to jobs in industry may still publish (temporarily) with both their old and new affiliate address (Roach & Sauermann, 2010). Others might have (had) part-time employment in the business sector throughout the entire seven-year time-span; others might have discontinued those full-time connections (either temporarily or permanently) and moved into university positions, or vice versa (re)established their affiliate links with industry.

It is relatively easy to identify those UICRs who are mentioned as an author on research publications in large, international databases (section 4 describes our database). We base our identification of mobile UICRs on the author address affiliations in UICPs. Here, it is not enough to analyse the publication data at the level of affiliations, it is also necessary to know – for each author participating in the publication – the organisation(s) to which (s)he is affiliated.

Using the address information in research publications enables quantification and classification, which opens up possibilities for designing metrics and ('bibliometric') indicators that enable systematic analysis of patterns and trends. Such indicators have been introduced in recent large-scale comparative studies of international mobility and migration flows (Dubois et al., 2014; Moed et al., 2013; Moed & Halevi, 2014).

3.3 Information source, methodology and units of analysis

These UICPs and UICRs are extracted from our in-house version of Thomson Reuters' *Web of Science Core Collection* database (specifically, the SCI, SSCI and ACHI indexes within this collection). Henceforth, our database will simply be denoted as the acronym 'WoS'. The in-house version of the WoS contains a number of enhancements compared to the original database, a product of the know-how developed over the years. Among the most important improvements are the following: 1) consistent and accurate assignment of publications to universities, considering all the different name variants in the database corresponding to the same university; 2) in-house algorithm for the identification of citations that publications receive from subsequent publications; 3) in-house publication-level classification which, based on citation relations, clusters together publications dealing with similar topics.

Starting from 2008/2009, the WoS includes the direct link between the author and his/her corresponding affiliation(s). Based on this information, and our own classification of affiliations in universities or industry, we are able to identify mobility of academic researchers across these two institutional sectors. We use an in-house author-identification algorithm (Caron and Van Eck, 2014) that identifies the set of publications produced by the same individual researcher, regardless of the different name variants used in the author's publications.

Our information items, to capture UII patterns and compare universities, are:

- *University-industry co-authored publications* (UICPs), reflecting productive and successful research partnerships, where the organisational affiliations of participating researchers were extracted from the author address(es);
- *University-industry crossover researchers* (UICPRs), individuals who have (or had) one or more UK university affiliation as well as and one or more affiliations in the business sector in recent years.

The UICP and UICR analyses pertain to UK-produced publications during the years 2009-2015 – the oldest year available for UICR data. These extensive time-periods provide robust aggregate-level data on relational patterns in the recent past, which are probably also representative of current patterns in 2016/2017.

Our WoS-based analysis of the UK higher education system is restricted to a set of large research-intensive universities that collectively account for the large majority of UICPs in the UK science base. These 47 universities are selected from the 2016 edition of the *Leiden Ranking* (www.leidenranking.com), an open access data source produced by CWTS.

Each UK university is characterised by its unique profile of its organisational goals, available resources, research areas, motives and opportunities for collaboration, history of the partner relationships with industry. Moreover, a mix of external determinants and contributing factors – such as geographical, cultural, political, economic and infrastructural – may significantly affect their UICP and UICR patterns (Barnes et al. 2002; Mora-Valentin et al. 2004).

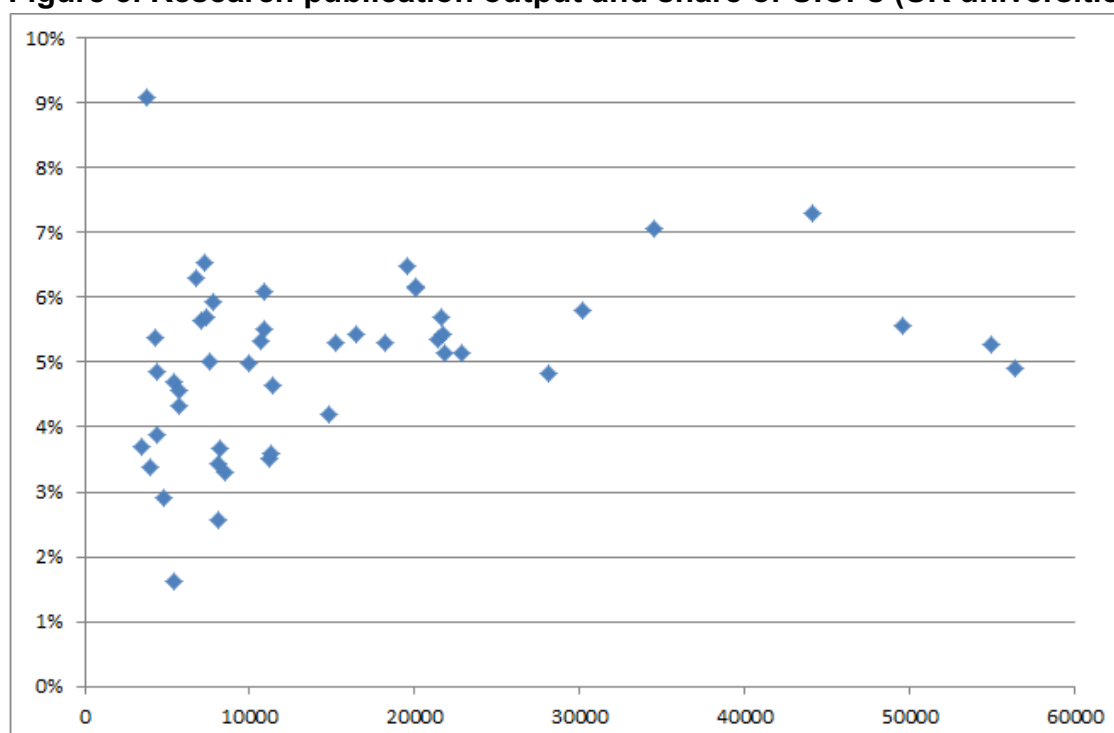
The university-level UII profiles, presented in the next section, focus on the geographical distribution of industry partners. We classified companies according to their physical location as indicated in the author addresses on the research publications. We distinguish three geographical zones: local (companies within the same UK region, at the NUTS1 level); domestic (firms located elsewhere within the UK); foreign (those that are based outside the UK). Note that many R&D-active multinational companies are located in the UK and are therefore regarded as either local or domestic.

4 Key findings

4.1 University-industry co-authored research publications

UICPs may arise from a variety of university-industry R&D relationships and partners: some are large international consortia, others are one-on-one partnerships; some emerge out of short, one-off joint projects with a US-based company, others are the fruit of a long-term EU-funded R&D programme with a steady flow of UICPs. A breakdown by organisational type of UICP could shed more light on how vulnerable some of these research-intensive universities might be for possible negative Brexit implications.

Figure 3. Research publication output and share of UICPs (UK universities)



Source: CWTS *Web of Science* database (Core Collection; SCI, SSCI and AHCI); 47 UK universities in the 2016 Leiden Ranking; vertical axis: % UICPs; horizontal axis: research publication output frequency.

Of the annual research publication output produced by UK research universities – more than one hundred thousand – 5.4 per cent list an author affiliate address referring to a business company ('industry'). Some universities are 'UICP-intensive' with shares above 6 per cent, others are 'UICP-extensive' with fractions below 4 per cent. As **Figure 3** shows, the largest and more comprehensive universities are less variable in UICP intensity than the smaller ones. Among the smaller, specialised universities, we find Cranfield University at the top with a 9.1 per cent share of UICPs, whereas London School of Economics and Political Science (LSE) sits at only 1.6 per cent. Cranfield University specialises in science, engineering, technology and management, while LSE research operates mainly within the social

and behavioral sciences. Clearly the disciplinary research profile matters. Those universities that are active in 'industry relevant fields' (like engineering and computer sciences, or medical and life sciences) tend to be much more UICP-intensive.

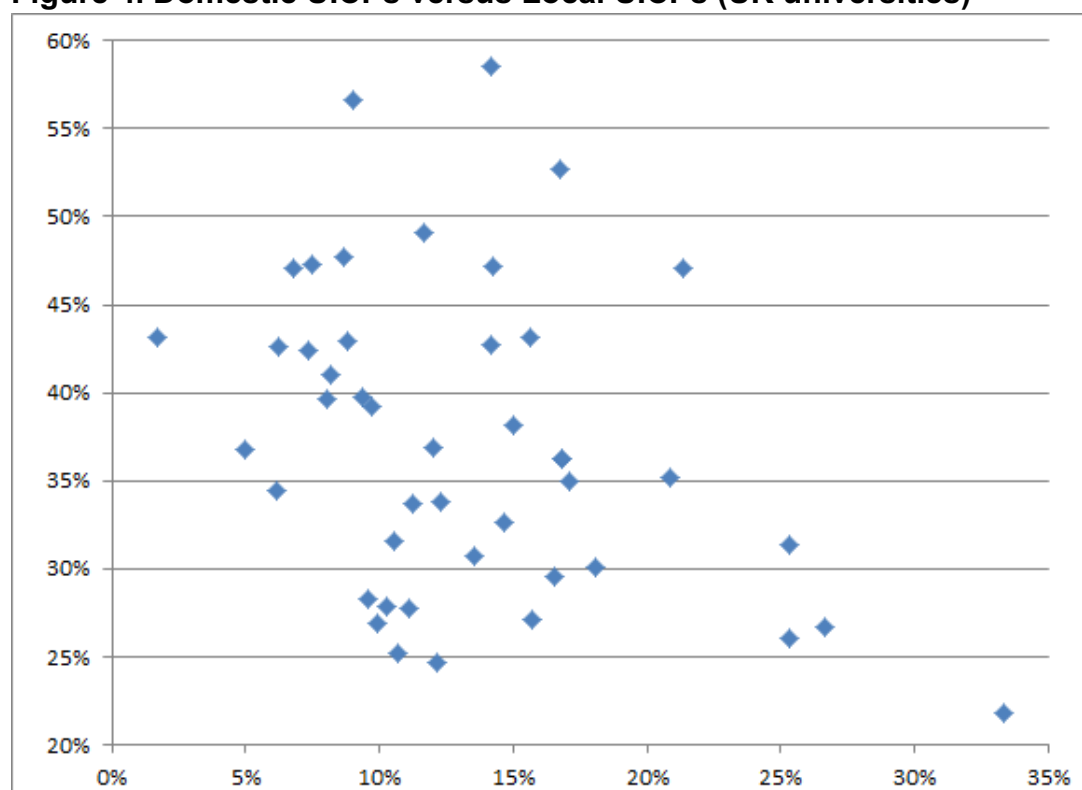
UK research universities have a wide spread of firms as research partners. Ignoring the distributions across industrial sectors and business sectors (for now), we focus our attention on the dispersion across geographical zones. Three zones are defined: 'local' (within the same UK NUTS1-level 'statistical region'⁵), 'domestic' (UK), or 'foreign' (non UK). The local and domestic zones are mutually exclusive. Depending on the number of companies mentioned in the author address list, and their geographical location, single research publications may include more than one geographical zone. Focusing on a company's geographical location presents a new perspective on UICP patterns; no prior UK research can guide us in terms of expected outcomes or specific assumptions. Hence, these observed empirical data are merely meant to be a first impression of underlying patterns, which may help gain a general idea of how UK universities engage with industry as a function of geographical distance and national borders.

Figure 4 presents the within-UK distribution, distinguishing the numbers of local UICPs from domestic ones. We find major differences among universities: a factor three in the case of domestic UICPs (vertical axis); a factor seven where local UICPs are concerned (horizontal axis). Where Cranfield University, Loughborough University and the University of Bath score highly in terms of the share of domestic UICPs, we find relatively low shares at LSEPS and London School of Hygiene & Tropical Medicine (LSHTM). Local UICPs and close proximity to research partner companies occurs relatively often at the LSEPS, University of Cambridge, Heriot-Watt, the University of Edinburgh and the University of Aberdeen, in each case suggesting a concentration of collaborative activities with firms based at local R&D hubs or science parks.

Some universities, the band in the lower left hand corner of the graph, are clearly less focused on the UK or its domestic regions. Being internationally oriented in their partnering with industry, these are the higher education institutions that are likely to be more vulnerable to Brexit-related developments. For that reason alone they merit special attention in our analysis. The split between EU-based companies and non-EU based ones enables an assessment of the UII patterns within the Brexit context.

⁵ The NUTS1 regions are: Wales, Scotland, Northern Ireland, and nine regions in England (North East; North West; Yorkshire and the Humber; East Midlands; West Midlands; East of England; Greater London; South East; South West).

Figure 4. Domestic UICPs versus Local UICPs (UK universities)



Source: CWTS *Web of Science* database (Core Collection; SCI, SSCI and AHCI); 47 UK universities in the 2016 Leiden Ranking; vertical axis: %domestic UICPs; horizontal axis: % local UICPs.

Table 1 presents the top 10 list ranked by the share of foreign UICPs in their publication output. The volume (total number of foreign UICPs) and degree of EU-orientation (per cent of EU foreign UICPs) are added. Given the nature of its research portfolio it is not very surprising to see LSHTM in the top position with 88 per cent of its UICPs including at least one company outside the UK: the university has a strong focus on public health and infectious tropical diseases, and concomitant links to firms abroad that are active in medical diagnostics and the biopharmaceutical sector. The volume of UICPs is relatively low; the EU share is slightly less than average. We find significant differences among these top 10 universities with regards to their involvement with EU industry; from 38 per cent of the foreign UICPs in the case of the University of Edinburgh to 52 per cent at LSE.⁶ Where LSHTM and LSE exhibit high shares of local UICPs (but relatively low numbers of UICPs), the large London-based universities have relatively low shares (and high numbers). We assume that these two small and specialised universities are more actively engaged with services sector companies in the greater London region. UICPs in general tend to arise from cooperation with large, R&D-intensive firms in industrial or manufacturing sectors which are less concentrated in the London agglomeration.

⁶ The highest scoring universities, both not included this top 10, are University of Ulster and Plymouth University with 55 per cent shares of EU foreign-UICPs. Heriot-Watt University of Edinburgh is at the bottom of the ranking (26 per cent).

Table 1. Top 10 UK universities by share of foreign UICPs

University	Foreign UICPs (% of all UICPs)	Foreign UICPs (frequency range)	EU foreign-UICPs (% of all foreign UICPs)
London School of Hygiene & Tropical Medicine	88	251-500	40
University of Dundee	86	251-500	49
King's College London	81	1001-2500	44
University of Glasgow	80	501-1000	45
Queen Mary University of London	79	501-1000	42
University of Edinburgh	77	1001-2500	38
University College London	77	501-1000	39
University of Leicester	75	251-500	46
London School of Economics and Political Science	75	100-250	52
Imperial College London	72	1001-2500	42

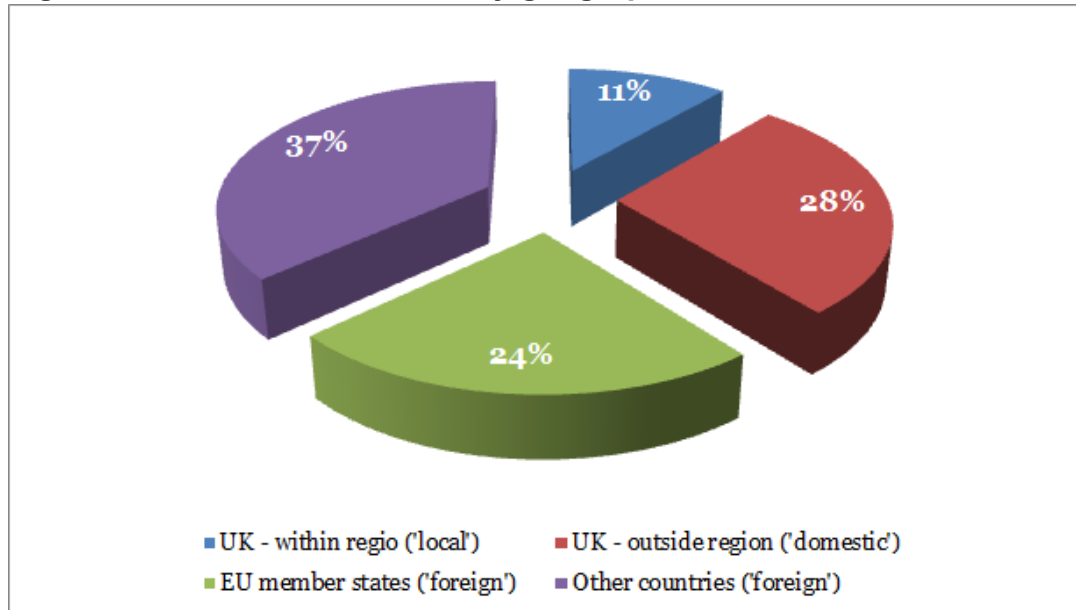
Source: CWTS *Web of Science* database (Core Collection; SCI, SSCI and AHCI); 47 UK universities in the 2016 Leiden Ranking.

These significant fractions highlight the large level of interdependent research-based relationships between UK actors and foreign partners in the European Union. Some 40 per cent of the UICPs with foreign companies include at least one firm located in a EU member state. Shares vary from 26 to 55 per cent among the 47 UK universities. In terms of quantities of 'EU foreign UICPs', we find the largest shares at the University of Ulster and Plymouth University. Overall, across all 47 universities collectively, 1.5 per cent of the research publications were co-produced in collaboration or association with an EU-based company. With this level of dependency on European industry for industrial relevant research, Brexit may have significant implications (e.g. Else, 2017).

Concluding our UICP data analysis across all 47 selected universities, we find that 68 per cent of our UICPs, which include an author address of at least one of those UK universities, also mention a company abroad in the affiliate addresses list. Almost half of those foreign UICPs (43 per cent) include at least one company based in a EU member state, which makes EU-based industry a major research partner of UK universities in the global corporate world. **Figure 5** presents a further breakdown, highlighting the relatively large share of EU-based industry (24 per cent) which is comparable in size to UK industry located outside a university's own region (28 per cent)⁷. The largest share are companies elsewhere on the globe (USA in particular).

⁷ These shares, totalling up to 100 per cent, correct for doubling counting of UICPs because of multiple occurrences of geographic zones in a single publication.

Figure 5. Breakdown of UICPs by geographical zone



Source: CWTS *Web of Science* database (Core Collection; SCI, SSCI and AHCI); 47 UK universities in the 2016 Leiden Ranking.

Our statistical analysis of the current UICP-output data also shows that the share of EU foreign UICPs is not related to either the size of universities (i.e. publication output volume), the UICP-intensity (share of UICPs in the total publication output), nor the share of local UICPs or domestic UICPs. However, the university's number of EU foreign UICPs is significantly correlated with all the other UICP-based variables in this analysis. The dispersion of corporate UICP partners seems largely size-independent. In other words, joint research relationships with foreign-based companies seem to be an integral part of a UK university's research portfolio irrespective of the company's geographical location. Nonetheless, given their foreign UICP volumes, more than 1,000 in 2009-2015, the three large, London-based universities seem especially vulnerable to sudden changes in UK international relationships that could significantly affect their UICP profile. Further assessment of these dependencies requires a closer look at the nature of the UICPs and the kind of R&D partnerships involved.

Is each UICP-intensive university an 'entrepreneurial university'? This concept was anchored by Burton (Clark, 1998), representing both, an 'institutional adaptiveness to a changing environment and [...] the capacity of universities to produce innovation through research and new ideas' (Shattock, 2009). These organisations 'embrace the spirit of enterprise and innovation, promote an entrepreneurial culture, reach across the traditional academic-industry boundaries to form mutually beneficial relationships, and create a variety of functions to accommodate the transfer of knowledge and technologies across these boundaries, while integrating new managerial and market-related practices' (Tijssen, 2006). By crossing academic-industry boundaries, by way of 'actions that lead to change in organizational posture' (Clark, 1998; p. 4), these research universities are actively engaged in shaping the

nature and structure of science/innovation ecosystems. UK-based entrepreneurial universities appear to generate significant economic impacts – either through knowledge transfer activities or university spin-off companies (Guerrero et al., 2015).

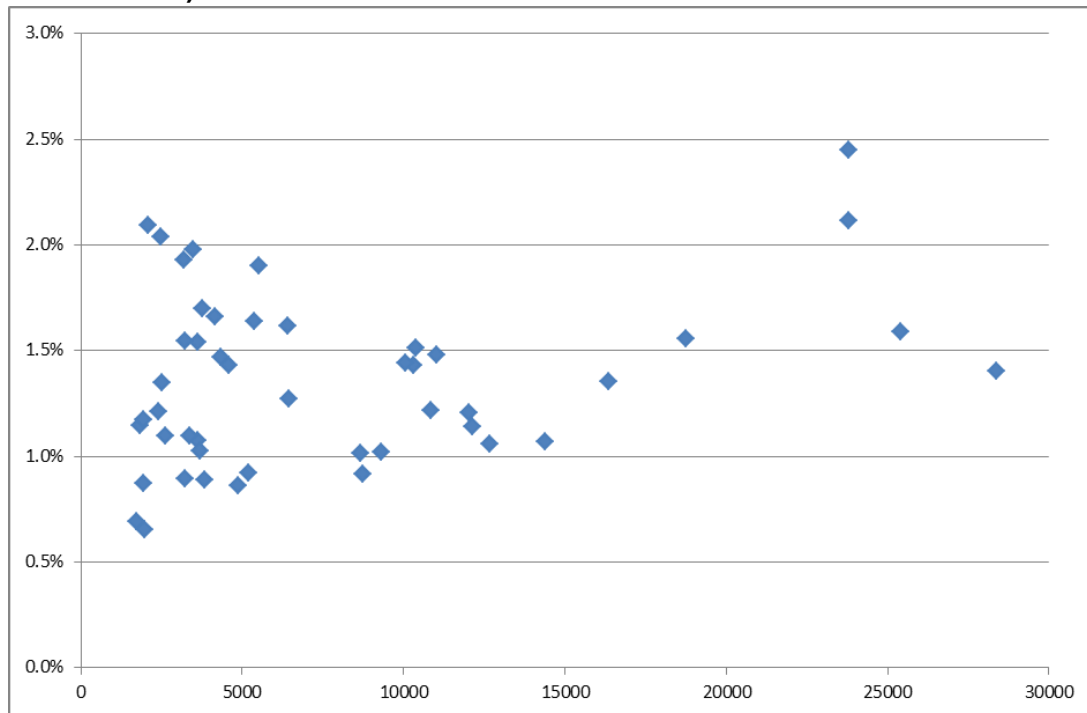
To further unfold UII patterns within universities we now direct our attention to the role of academic researchers as boundary-crossing agents of change, individuals whom we will refer to as ‘university-industry researchers’.

4.2 University-industry researcher mobility

How many of these university-industry researchers (UICRs) are there in the UK university system? Of course, exact numbers are impossible to give, but we can produce a fair (lower) estimate. Our answer is based on those academics moving to or from industry according to their author affiliate addresses on published scientific papers. This group of university-industry boundary-spanners’ includes those who (most likely) had – or still hold – dual appointments, as indicated by a university affiliation and one at a business enterprise on the same publication.

The numbers of UICRs are small, but not insignificant. About 1.4 per cent of all UK university researchers were linked to the private sector during the years 2009-2015. **Figure 6** shows the total amount of academic researchers of each of the 47 UK universities and the share of UICRs. Some of the UK’s largest universities (in terms of publishing academic staff) are also those with the highest UICR shares, like the University of Cambridge (2.4 per cent) or Imperial College London (2.1 per cent). But size is not the only factor. Much smaller universities, such as Heriot-Watt, the University of Edinburgh or the University of Surrey, also have high shares (2.1 per cent and 2.0 per cent, respectively). Many universities with UICR levels less than 1 per cent tend to have fewer researchers, like the University of Exeter, the Open University or Bangor University.

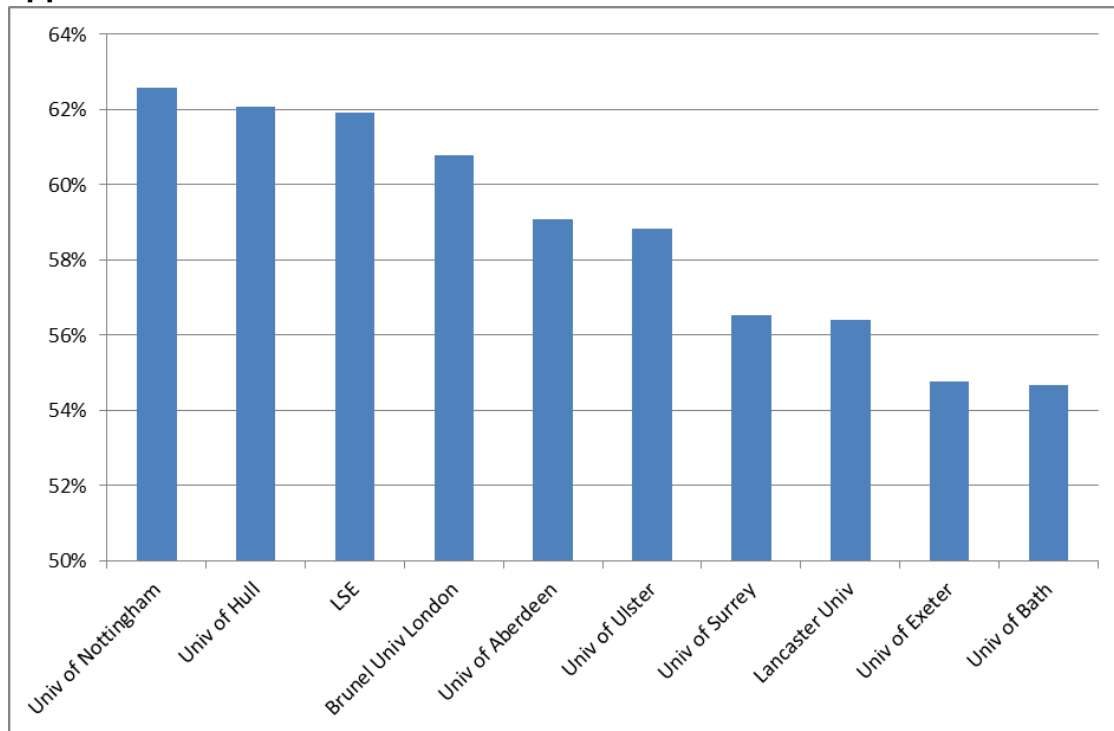
Figure 6. Total number of identified researchers and share of UICRs (UK universities)



Source: CWTS *Web of Science* database (Core Collection; SCI, SSCI and AHCI); 47 UK universities in the 2016 Leiden Ranking; vertical axis: %UICPs; horizontal axis: total number of researchers.

Figure 7 shows the top ranking universities according to the share of UICRs indicating a university-industry dual affiliation. Academics holding this type of dual appointment are expected to indicate both affiliations in their scientific publications: the university and the company. We are able to identify academics who indicate this university-industry dual affiliation and, in doing so, we detect the individuals who are likely to be active in the research space existing between universities and business companies. Our data reveal high percentages that need to be interpreted with great caution: these numbers include individuals, PhD graduates or postdocs in particular, who have moved from one sector to the other but kept listing both affiliations in their research publications during the transition stage and a while after they changed positions. The first and tentative results represented in this graph should be seen as a first step towards a more precise identification of academics who hold dual appointments.

Figure 7. Top 10 universities by share of UICRs indicating dual UI appointments

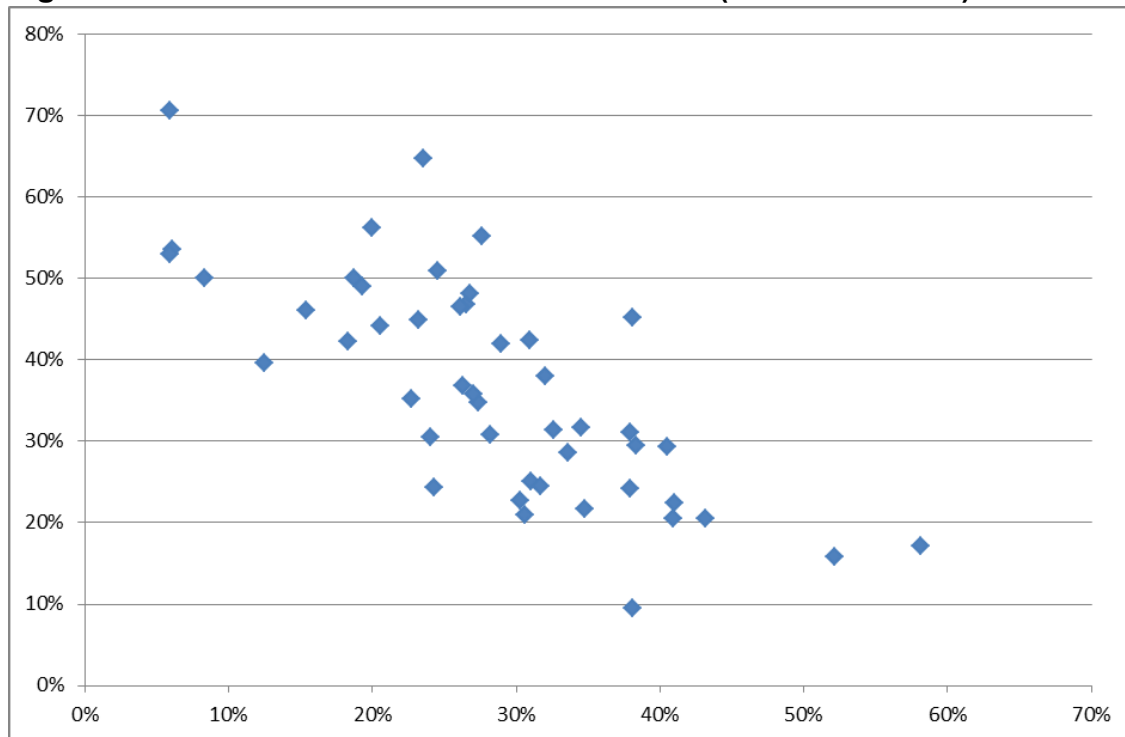


Source: CWTS *Web of Science* database (Core Collection; SCI, SSCI and AHCI); 47 UK universities in the 2016 Leiden Ranking.

Similar to our analysis of UICP patterns (see section 4.1), we also analyse the geographic dimension of cross-sectoral mobility and dual affiliations. The same zones are applied to indicate the location of the associated companies. The first of these geographic zones considered is 'local', which is defined by UK countries and English NUTS1 regions, the other two zones are domestic (UK) and foreign (non UK). Depending on the number of universities and companies where a given researcher has stayed or had/has employment, academics can be classified in more than one geographical zone.

Figure 8 shows the distinction between local and domestic mobility activities. We observe a very significant negative relationship between these two geographic zones, suggesting distinct patterns between UK universities. Comparing the extreme cases, at University of York (58 per cent) and University of Cambridge (52 per cent) UICRs move to or from industry and business companies located nearby. In contrast, Brunel University London (71 per cent) and Cranfield University (65 per cent) employ relatively many academic researchers with UI mobility patterns that involve companies outside the university's region. The large group of universities in the middle, those with a local/domestic balance in the cross-sectoral mobility of their researchers, include universities such as the University of Reading (32 per cent local and 38 per cent domestic), the University of Southampton (35 per cent local and 32 per cent domestic) and Imperial College London (33 per cent local and 31 per cent domestic).

Figure 8. Domestic UICRs versus Local UICRs (UK universities)



Source: CWTS *Web of Science* database (Core Collection; SCI, SSCI and AHCI); 47 UK universities in the 2016 Leiden Ranking; vertical axis: %domestic UICRs; horizontal axis: % local UICRs.

All in all, for most of the universities, it is the combination of local and domestic zones that determines the mobility patterns between UK universities and industry: mobility takes place within the UK. Only a few universities have 50 per cent or more of their UICRs linked to companies located abroad.

Table 2 includes the top 10 UK universities involving researcher mobility to or from foreign-based companies, as well as the extent to which these companies are located in EU countries. At the top of this list is the London School of Hygiene & Tropical Medicine (60 per cent), easily explained by the international scope of the research conducted at this university and global distribution of large and small companies active in related business sectors (e.g. medical diagnostics, clinical trials, biopharmaceuticals). More remarkable perhaps is the very high percentage of their mobile academics at the University of Dundee, which is probably explained by the off-shore oil and gas industry. Among these 10 universities, Dundee also presents the lowest share of UICRs related to companies located in the EU (15 per cent). The largest shares of UICRS related to EU-based companies are found at the University of Glasgow (56 per cent) and University of St Andrews (50 per cent).

Table 2. Top 10 UK universities by share of foreign UICRs

	Foreign UICRs (% of all UICRs)	EU foreign UICRs (% of foreign UICRs)
London School of Hygiene & Tropical Medicine	60	30
University of Dundee	59	15
London School of Economics and Political Science	57	42
University of St Andrews	54	50
University of Kent	52	25
University of Edinburgh	51	41
Lancaster University	49	21
University of Leicester	48	39
University of Glasgow	48	56
University of Oxford	48	39

Source: CWTS *Web of Science* database (Core Collection; SCI, SSCI and AHCI); 47 UK universities in the 2016 Leiden Ranking.

Juxtaposing these findings with those related to foreign UICPs (see Table 1), we find five of these ten universities appearing in both lists, suggesting the relatively strong connections with foreign companies at: London School of Hygiene & Tropical Medicine, London School of Economics and Political Science, University of Dundee, University of Edinburgh, and University of Leicester.

What kind of researchers are these UICRs at UK universities? Given their affiliations with industry (either prior or current) it is very tempting to classify them as ‘oriented towards applications’ rather than being focused on discovery-oriented ‘basic’ research. Or, adopting a categorisation introduced by Stokes’s *Pasteur’s Quadrant model*, as those who are engaged in ‘user inspired basic research’ or ‘pure applied research’ (Stokes, 1997). The UK science system seems to be dominated by such ‘application oriented’ researchers. A UK wide survey by Hughes finds a self-reported 35 per cent of the respondents describing their work as ‘user inspired basic research’ and 44 per cent as ‘pure applied research’ (Hughes, 2010; 2011).

Are the identified UICRs merely a cross section of all UK researchers, or are they something special and indeed the more application-oriented subgroup within academia? At this stage in our studies it is technically impossible to classify UICRs by type of research; our subsequent survey among these UICRs will collect further information on this issue.

5 Concluding remarks: looking backwards and forwards

This study presents a new way of looking at productive university-industry interactions in the UK university system. The first results presented in this working paper are a preliminary overview at a high-aggregate level. Entire universities are our frame of reference based on individual researchers and their publications the units of analysis. We focus on university-oriented research-based knowledge creation. Our current analytical framework is based on a 'successful science' logic and an associated 'research output' perspective. The performance indicators, unearthing collaboration and mobility patterns within UK academia, derive their information from research publications in scientific, scholarly and technical journals.

Clearly it presents a one-sided picture and may perhaps also introduce biases that lead to misinterpretations of university-industry R&D relationships. Nonetheless, our UICP and UICR data provides interesting university-level information, supplementary to metrics generated by other sources such as the UK Higher Education-Business and Community Interaction (HE-BCI) survey. Rossi and Rosli (2015) note that the HE-BCI indicators on UII are not focused on knowledge transfer processes and mobility. Our UICP and UICR data could contribute to broaden the set of HE-BCI indicators, thereby widening the usage of such metrics for comparisons within the UK science and innovation system.

Many interesting features and relevant details are still missing in this first report, subject to further data processing, analysis and interpretation in the second stage of this study. One of which is a breakdown of UICPs and UICRs by field of science; another is the taxonomy of individual academic researchers according to their UICP/UICR profiles. We will also assess the extent to which UICR mobility is related to foreign companies, and if their foreign relationships represent mainly an outflow of UK university academics or an inflow of researchers who moved from foreign companies to universities within the UK.

We have, however, taken a closer look at links with companies located outside the UK. We find a very significant share of connections between UK academic researchers and companies that based in EU member states. Tracking the most recent annual trends in the number of UICPs and UICRs with links to those companies might prove interesting information to gauge possible effects of Brexit when university-industry R&D ties are at risk or severed.

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