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Regional variation in characteristics and output of university spin-offs (USOs) in the United Kingdom

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Abstract:	Research which has analysed the formal role of universities in stimulating regional economic development, is relatively recent (see for example Lester 2005, Youtie and Shapira 2008, Huggins et al. 2008). However, their role in contributing to regional technological variety is under-researched. In this study, we use a dataset that has wide geographic coverage and provides a comprehensive understanding of the UK-wide contribution of university spin-offs (USOs) to the innovation and market capacity of their host regional economies. We propose that the survival and growth of USOs implies embeddedness in their respective innovation and business ecosystems (de Vasconcelos Gomes et al. 2018). Data on UK USOs are collected from a search of public company databases. The findings show that the majority of firms in the sample are relatively young, small in size, and are still at the early stages of their life cycle. Hence, the products and services that are offered are fairly small in number. Nevertheless, their products/services based on university research have the potential for value capture by other firms thus contributing to a range of industry sectors within a region.

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Abstract

Research on the formal role of universities in stimulating regional economic development is relatively recent (see for example Lester 2005, Youtie and Shapira 2008, Huggins et al. 2008). However, the role of universities in contributing to regional technological and service variety is under-researched. In this study, we use a dataset that has wide geographic coverage. The analysis provides a comprehensive understanding of the UK-wide contribution of university spin-offs (USOs) to the innovation capacity of their host regional economies. We argue that the survival and growth of USOs implies embeddedness in innovation ecosystems in a region (Granstrand and Holgersson 2019). The findings show that the majority of firms in the sample are relatively young, small in size, and are still at the early stages of their life cycle. Hence, the products and services that are offered are fairly small in number. Nevertheless, their products/services based on university research have the potential for value capture by other firms thus implying contributions to a range of related and unrelated industry sectors within a region or beyond the local.

1. Introduction

In recent years, the role of universities in both firm formation and innovation, nationally and regionally, has attracted a lot of attention from scientists and policymakers (see for example Lester 2005, Youtie and Shapira 2008, Huggins et al. 2008, Bagchi-Sen and Lawton Smith 2012). This role has tended to focus on firm formation and job creation, rather than on the various kinds of impact of university spin-offs (USOs) (Bolzani et al. 2014, Fini et al. 2018). Indeed, the majority of studies on academic entrepreneurship tend to emphasize macro-economic, structural, organizational, and institutional perspectives that facilitate the creation and growth of USOs[1] instead of their outputs (e.g., innovative products and solutions) (see for example Fini et al. 2017, Rasmussen et al. 2011, Wennberg et al. 2011). For USOs as a sub-set of new technology-based firms in a region, an expectation is that they will deliver a range of products and services (e.g., drug discovery, engineering solutions, and advanced software development) (Garnsey and Druhile 2004, Shane 2005,). However, a regional

[1] University spin-offs, here defined, include those firms that are founded by university academics whether or not the universities own the IP of the technology on which the firm is based.

analysis of the bundle of goods and services offered once USOs have been established is under-studied.

This omission requires attention since the study of firm's products/services usually shows the application of knowledge gained from the university with implications for local development (Ahlstrom 2010). Moreover, the products and services developed by USOs evolve over time and vary with the size of USOs thereby widening their contribution. This study addresses two research questions: (i) How are USOs distributed and characterised across different regions? and (ii) How do products and services from USOs contribute to the variety and scope of innovation opportunities in a region?

In answering these questions, the pattern of USOs within UK regions is examined to show the relationship between the total number, type, and ranking of universities and the volume of USOs. The relationships between particular profiles of USOs in the UK (e.g., years in operation, size, industry sector), with a specific focus on the type of university, and the regional location are examined. A related goal is to show the pattern of retention per region and also the size distribution of USOs. The second question is addressed by providing evidence on the products/services offered by years of operation, size, and regions.

The overall purpose is to demonstrate that USOs have contributed new products/services to increase the scope of technological variety in a region. As such, they can be seen to be contributing to innovation ecosystems because of the commercial potential created through value creation from university research. Moreover, survival and growth of USOs implies their local embeddedness in innovation ecosystems through interdependent and interconnected networked actors (de Vasconcelos Gomes et al. 2018, Granstrand and Holgersson 2019). The results are indicative of different modes of knowledge production, dissemination (direct and through spillovers of various kinds), and use (see Rutten and Boekma 2009, Carayannis and Campbell 2009).

The remainder of the paper is as follows. We first review the literature to provide the context for the two research questions by discussing evidence on the types of quantitative and qualitative impacts that USOs can have on their regions. Second, we present the

methodology. Third, the results are discussed. The final section reflects on the study and the relationship between USOs and regional development.

2. Research Background: Innovation ecosystems, USOs, and their outputs

An understanding of the possibility of regional impact of USOs is not a simple task given the difficulty in obtaining data on patterns and networks of these firms. The literature argues that the starting point of understanding where value is created and exploited (Autio and Thomas 2014, Adner and Kapoor 2010), in this case by USOs, is the geographic location of the university. The "*innovation ecosystem*" concept is one which has innovation performance of an evolving set of actors, activities, and artifacts, as well as their interrelationship as a central theme (Granstrand and Holgersson 2019, 1). Although innovation ecoystems is a non-spatial concept, in practice it also has a geographical implication. Location offers various possibilities for the ways that a set of actors, their activities, and their networks can lead to the commercialisation of their products and services (Huggins et al. 2008, Miguelez and Moreno 2015, Rodriquez-Gulias et al. 2018). While not referring explicitly to geographical context, Fini et al (2018) observe that similar questions may find different answers depending on the context under consideration.

A significant stream of literature has been devoted to debating how USOs fit into or have an impact on innovation ecosystems. Rutten and Boekma (2009) and others (Lawton Smith and Ho 2006, Shane 2005, Zhang 2009, Asterbo and Bazzazian 2011, Heblich and Slavtchev 2014, Baines, 2015, Fernández-Alles et al. 2015, Conceição et al. 2017, Association of University Technology Managers (AUTM) 2016) examine the co-evolution, co-specialisation, and co-opetition of various actors involved in innovation to conceptualize the positioning (e.g., knowledge or technology transfer to other entities) of the USOs within the (eco)system. Local absorptive capacity, the presence of local firms that are able to engage with outputs of university research in the form of products and services from USOs, is critical (Chapple et al. 2005, Lester 2005). Whether the firms (or collectively regions) (Miguelez and Moreno 2015) are able to absorb the technological opportunities created by the flow of new products and services created by USOs eventually determines whether they stay, move or face acquisition, or close. Moreover, the sectoral structure differs widely between regions (Abreu et al. 2008) and there is an issue of a potential (mis)match of university research and non-USO firms in a region.

A number of characteristics has been examined with respect to the drivers of change, evidence of change, and evidence of impact at the local/regional level (see for example Pattnaik and Pandey 2014, Corsi and Prencipe 2016). Assessment of impact includes objective measures of value creation such as the number of USOs, employment, and patents produced[2]. In this paper, we add the number and type of products and services provided by USOs as evidence of innovation. In assessing the impact quantitatively, the attention falls on the total number of spin-offs, which is expected to be a function of the total number of universities in a region and the type of university (e.g., research versus teaching-intensive). The sectors in which USOs are formed can be used as proxies to speculate about the extent of local impact.

For our purposes, it is necessary to look at the type of USO and the stage of development of their products and services. Data show that USOs, especially during the inception stage, suffer from a "liability of newness" (Stinchcombe 1965) and smallness including a lack of resources, capabilities, and experience (Rasmussen et al. 2011. During their early stages, some USOs undertake R&D or innovation activities in order to aim to develop commercially viable products or services (Rasmussen et al. 2011)—this is different from other non-technological or non-science USOs. When firms become older, they tend to gain experience, have more resources to undertake further R&D or innovation activities (Cohen and Klepper 1992, De Jong and Vermeulen, 2004), and as a result, the growth in operations often increases (Lundvall and Battese 2000).

The combination of a lack of resources and uncertain outcomes of R&D means that the volume of product/service innovations tend to be relatively low for USOs in their early stages (Lerner, 2005). However, survival is related to the value-added derived from the research base or the larger technological base used to start the USO. This base tends to offer greater longer term sustainability. Evidence from Spain (Ortin-Angel and Vendrell-Herrero 2014) shows that although university spin-offs have low commercialisation capabilities early on, over time they gain capabilities for wealth-creating opportunities and are more productive compared to other new technology-based firms. They suggest that this is because university spin-offs have greater dynamic capabilities than independent new technology-based firms.

[2] https://www.reuters.com/article/us-amers-reuters-ranking-innovative-univ/reuters-top-100-the-worlds-most-innovative-universities-2018-idUSKCN1ML0AZ (accessed June 23 2019)

In addition to employment, the outputs of USOs in the form of products and services have direct and indirect effects and may constitute important measures of impact (Sternberg 2014). While most studies note that the majority of spin-offs are in biotech and ICT (see for example Lawton Smith et al. 2014, Salvador and Benghozi 2015), Libaers et al. (2006) find that university spin-offs are important contributors to technological change in specific subfields of nanotechnology. In these sectors, large firms and (non-university affiliated) new technology-based firms are also agents of technological change and USOs are seen to fill a niche and even contribute toward technological diversification.

Druihle and Garnsey (2004) point to the importance of understanding the activity (e.g., how it is acquires inputs, the way it creates value, and how returns are realized) of a company to develop a typology. For example, their initial typology of USOs in Cambridge includes consulting/service companies (e.g., technical consulting companies building on scientists' research activities); development companies that are set up to commercialise an emerging technology, especially biotechnology; product-based companies (e.g., target niche markets); software companies; and lastly firms focused on infrastructure development. They later modified this to include different types of sub-categories (such as, licensing, product, consulting and software firm categories), illustrating the diversity that USOs add to an innovation ecosystem. Other studies note that "*servitization*" (Vandermerwe and Rada 1988; Martinez et al. 2010) is widely practised among firms that offer products to the market. More recently, Baines and Lawton Smith (2019) find that factors contributing to USOs' success are application of technology and the development of services to meet the needs of clients/markets.

3. Data

This study uses a dataset of UK USOs that combines information from university websites and public company databases. The definition given by the UK Higher Education Funding Council (HEFCE) is used to define USOs: new legal entities and enterprises created by a Higher Education Institute or its staff to allow the commercialization of knowledge from academic research. Previous studies (ASTP-PROTON 2015, Harrison and Leitch 2010, HEFCE 2017, Hewitt-Dundas 2015, Ortin-Angel and Vendrell-Herrero 2014) note that the employment impact of the USOs is limited by their small size. On average, they have 4

employees and about 69.5 percent of USOs have not generated any income (Harrison and Leitch 2010).

Similar to other UK USOs database (e.g. Fini et al. 2017), data on firms are developed by retrieving information from the Spinouts UK Survey (2014), which includes all USOs from UK universities. Additional firm-level data are retrieved through both the universities' TTO, innovation centres, the national Companies Houses, and the ICC Directory of UK Companies provided by Lexis Nexis*. This database has been complemented and corroborated by company websites for firm characteristics, such as registered address, date of incorporation, board of directors, their subsidiaries, number of employees, and financial information. Since this study aims to ascertain the USOs' contribution to the variety and scope of innovation and market opportunities in a region, firm's histories, key information including their commercial technology and product/service offerings are collected from company websites. In addition, the information on IP and the number of single patents registered by the firms are also collected via the ESP@CENET, which is the public database located on the European Patent Office website. Such information is used as a proxy of value created by innovation for firms that specifically market and license their technologies. The cross-sectional data are collected and observed at the same point of time since 2015. See the Appendix for a list of observed variables.

There are several cases that some USOs are created by and affiliated with more than one university with equal equity. These USOs are attributed to multiple parent institutions. The dataset includes the following categories of variables: products and/or services offered by years of operation, size, and sector. A total of 1,356 spin-off firms are recorded in the study database, only 844 companies are listed as active, 375 are dissolved, in liquidation, or non-trading, 87 firms are merged or acquired, and 50 companies could not be found in the UK Company House's database. With regard to these 50 companies, it can be assumed that their names may have changed or they may have been registered in other countries (as is known to be the case of one company that spun off from the University of Oxford). The subsequent

* The ICC Directory of UK Companies (ICCDIR) file provides a comprehensive reference tool covering all UK-registered companies -live and dissolved. The data contains registration details and statutory filings as well as links to other ICC products.

analysis and data presentation are based on the 844 active firms since the detailed information of those inactive firms are not available.

Several difficulties were encountered during the data collection process. Employee numbers and the latest financial data for most of university spin-off firms on public web portals are incomplete. Additionally, approximately 14% of active companies did not have a public-facing website. Nevertheless, the dataset of 844 firms has a unique set of USOs across the UK. In the past, such data have been constructed only for a particular region or university.

In the next section, data analysis is presented to offer broad generalizations about UK USOs. First, USOs' characteristics are examined: years in operation, size, regions and the nature of the universities in which the firms originated. Next, selected relationships between USO/firm-level characteristics are demonstrated. The above analysis is used to understand the current role of USOs in their respective region (note: exact measurements of economic impact are beyond the scope of this paper).

4. Results

This section provides evidence on the distribution of USOs across different regions and how products and services from USOs contribute to the variety and scope of innovation opportunities in a region.

4.1 Relationship between regions, universities, and USOs

Table 1 shows the regional distribution of universities and USOs. The key USO creating universities are presented with their ranking, typology, and size. Since USOs are normally established by academics, the number of academic staff with full-time contracts (typically 30-40 working hours/ week), a proxy of human capital, is also noted. The table shows a clear association between the type of university, ranking of the university, and the number of USOs. It has been long known that research excellence is associated with a high level of academic enterprise (Di Gregorio and Shane, 2003). In this study, the data show that 561 USOs have been created by the top 20 universities of which 14 are in the Russell Group, an exclusive group of 24 research universities in the UK. In addition, two Plate Glass universities (newer research-intensive universities, which were given royal charter between 1963 and 1992) created 90 USOs, Dundee University, a Red Brick university (civic

universities that were given charters in the late 19th Century in the UK industrial cities), is the source of 25 USOs, and Aberdeen University, established in AD 1495, is the source of 36 USOs.

The 'golden triangle' of Oxford, Cambridge and London universities dominates the geography of USOs in the UK. The Scottish universities (University of Aberdeen, University of Strathclyde and Heriot-Watt University), are the most research-intensive universities in Scotland, which also contribute a high number of university spin-off firms. They receive support in the form of funding from the Scottish Enterprise, which also provide softer forms of support such as bespoke pre-incubation and company building programmes (Scottish Enterprise, 2012).

Some explanations for the above pattern are the quality of research and the universities' reputation/trustworthiness (Matthew effect) (see Van Looy et al. 2004). Also, these universities devote a number of academic staff to facilitate spin-off activities. A relatively strong and positive correlation is observed between the number of full-time academic staff and the number of spin-off firm creation (with R^2=0.62 and significant level of 0.03) in the UK (Table 1). This point resonates with the study by Lockett and Wright (2005), which highlights the significance of resource stocks in USO creation.

Table 1: University characteristics and the number of USOs by region

Region	University	No. of USOs	Ranking by Times Higher Education (THE) World University Ranking 2012	Types of universities	No. of full-time academic staff (HESA 2011/12)
East of England	University of Cambridge	97	2	Russell	8645

South East	University of Oxford	85	1	Russell	10569
London	Imperial College London	80	8	Russell	6616
London	UCL	75	16	Russell	7973
Scotland	University of Edinburgh	64	27	Russell	7731
Scotland	University of Strathclyde	58	401	Plate Glass	2929
North East	Newcastle University	56	175	Russell	4793
West Midlands	University of Warwick	38	91	Russell	4648
North West	University of Manchester	36	54	Russell	8875
Scotland	University of Aberdeen	36	185	Ancient University	2955
Northern Ireland	Queen's University Belfast	36	201	Russell	3275
South West	University of Bristol	35	76	Russell	4830
Scotland	Heriot Watt University	34	351	Plate Glass	1654
South East	University of Southampton	34	126	Russell	5354
East Midlands	University of Nottingham	29	147	Russell	6558
Yorkshire	University of Sheffield	28	104	Russell	5432
Yorkshire	University of Leeds	25	139	Russell	6573
Scotland	University of Dundee	25	187	Red brick	2905
Yorkshire	University of York	23	137	Russell	3043
	Durham University	22	97		

North East				Russell	3553

Table 2 shows the regional pattern of active firms and retention. It shows the prevalence of universities and number of spin-offs in each region. The relationship between the number of universities, the number of academic staff members, and USOs created is examined. An estimation of ordinary least squares regression shows a strong positive relationship between the number of institutions and the number of USOs created (R^2=0.8). The correlation matrix also shows that there is a relatively strong relationship between the number of staff and the number of USOs created (Pearson's r=0.59). This also suggests that the regional stock of universities is a significant predictor of USOs (see the Appendix). The ANOVA[3] confirmed the variation of the average spin-offs created across regions (i.e., *F-value*=25.46 greater than *F crit.*= 4.844336). Scotland contains 174 active spin-off firms with 171 firms still remaining in Scotland--this finding has been confirmed by a separate study, which shows that in the past 10 years, Scotland has been the most active region in the UK for the creation and establishment of university spin-offs (PraxisUnico, 2012). The region with the second highest number of active spin-offs is London (127 firms). However, only 79 firms (62%) have been retained. USOs are identified to remain in the regions of their inception, if the firms' present postcodes stay within NUTS1 and NUTS2 regions of the parent universities. In the case of multiple affiliations, if the present postcodes of USOs are located within NUTS1 and NUTS 2 regions of any of the parent universities, they are considered as "retained" within the region.

On average 83% of USOs remain in the regions where they were established, with the exception of London (62%) and the South West (67%). A shortage of dedicated property, especially in London, for business or technology incubators is an issue--in 2011, it was estimated that there were some 300 business incubators in the UK (Dee et al. 2011), with only some 7 business and technology incubators in London (Sikimic, 2012). Most of these were established after the year 2000. Only the East London Small Business Centre was established earlier, in 1978, but its purpose is to serve small and local businesses around the East London area. The South West region has 15 established incubators—however, most of them are located around the city of Bristol, where the property price has risen at a greater rate

[3] The two factor ANOVA is run to test the null hypothesis of the equal mean of spin-offs created by universities in each region. The F value = 25.460411, the F crit. = 4.844336, and the *p-value* is 0.000375. Hence, the null hypothesis is rejected to conclude that variation exists across region.

than London (Wilson 2019). Furthermore, most of these incubators (12 out of 15) tend to focus on robotics and software sectors (Whale, 2017). These above two factors may explain USO migration seeking appropriate resources out of London and the South West.

Table 2: Pattern and retention of USOs by regional location

Region	No. of institutions located in the region	USOs founded in the region with number of active shown in parentheses	% of active USOs	No. of active USOs retained in the region	% active USOs retained in the region
Scotland	14	300 (174)	58%	171	98%
London	12	219 (127)	58%	79	62%
South East	9	123 (80)	65%	64	80%
East of England	5	121(73)	60%	64	88%
South West	8	108(61)	56%	41	67%
Yorkshire & Humber	6	88(54)	61%	48	89%
North East	5	83(46)	55%	38	83%
East Midlands	6	79(64)	81%	52	81%
North West	8	76(56)	74%	47	84%
West Midlands	6	71(49)	69%	36	73%
Northern Ireland	2	51(33)	65%	33	100%
Wales	4	32(27)	84%	25	93%

The average age and employment data show that most of the USOs are young and in the small and medium enterprise category (Table 3). The size of the firms is defined by the number of employees excluding overseas operations; USOs in most regions are micro to medium sized firms, except for the South East and Northern Ireland regions that contain USOs that are 'large' (250+ employees). West Midlands and North East regions have USOs in only micro to small sized categories (no more than 50 employees). These data correspond with previous studies on the small size of university spin-off (Lawton Smith and Ho 2006, Harrison and Leitch 2010). When examining different categories of years in operation, most active USOs in their current location have operated for 1-15 years, while just 89 firms have been in business for longer than 16 years (Table 4). In the West Midlands region, no USO is

older than 15 years. Scotland, Yorkshire and Southeast regions have USOs that have been in business longer than 30 years. The oldest spin-off companies in this sample were set up by the University of York in 1959 and by the University of Oxford in 1963. The results have confirmed the study by Lawton Smith and Ho (2006) that the survival rate of university spin-offs is likely to be high. It has typically taken 10 years at the minimum before significant growth can be observed. Despite the difficult economic environment in the UK, the number of new university spin-offs created each year has remained steady over the most recent five years for which we have the data (2006-07 to 2010-2011) (HEFCE, 2017). However, the volume of products and services is limited by their size (Granstand and Holgersson, 2019, Lerner, 2005). The next section examines the extent to which USOs contribute products and services to their region.

Table 3: Average age and size of active USOs by region

Region	USOs age and size			
	age <mean>	size <number of employees>	firm categories*	average employment
East Midlands	9.7	2-128	Micro - Medium	27.11 <*SD = 40.01*>
West Midlands	8	3-14	Micro - Small	6.29 <*SD=3.95*>
East of England	9.5	1-175	Micro - Medium	43.36 <*SD=41.56*>
London	10.3	1-66	Micro - Medium	21.22 <*SD=19.36*>
North East	8.4	7-116	Micro - Medium	61.50 <*SD=77.07*>
North West	8.4	2-78	Micro - Medium	27.78 <*SD=27.20*>
Northern Ireland	11	2-286	Micro - Large	119 <*SD=133.30*>
Scotland	9.7	1-540	Micro – Large	79.7 <*SD=144.95*>
South East	10.7	2-1834	Micro - Large	76.95 <*SD=252.30*>
South West	10.1	18-248	Small - Medium	106.40 <*SD=112.39*>
Wales	7.8	1-75	Micro - Medium	26.86 <*SD=26.62*>
Yorkshire and Humber	9.7	3-70	Micro - Medium	26.08 <*SD=24.47*>

* micro = 1-10 employees; small = 11-50 employees; medium = 50-250 employees; large = 250+ employees

Table 4: Number of active USOs in each region* by years of operations

Region	1-5 years	6-10 years	11-15 years	16-20 years	21-25 years	26-30 years	30+ years
East Midlands	12	16	19	6	0	0	0
West Midlands	11	20	13	0	0	0	0
East of England	19	31	22	7	2	0	0
London	23	37	29	9	6	1	0

North East	12	14	13	1	1	1	0
North West	17	21	20	2	0	0	0
Northern Ireland	7	9	14	1	3	2	0
Scotland	55	43	49	13	2	4	3
South East	26	42	38	9	2	2	4
South West	7	16	17	3	1	0	0
Wales	8	18	5	1	0	0	0
Yorkshire and Humber	8	29	15	2	0	0	1

*The data show the regions where USOs are presently located.

4.2 Output of USOs: the scope of impacting innovation and market opportunities in a region

The products and services of USOs can be used as proxies to understand their potential contribution to the region's economy. Sectors of USOs are categorised based on the Standard Industrial Classification (SIC) code noted in the public database—this classification is cross-checked using company websites to reflect the actual nature of their business, since in some cases the SIC code did not properly reflect the detailed nature of the operation. The largest USO sectors with greatest potential for commercialisation are engineering/technology (34% of the firms), biotech/life science (29%), biopharmaceuticals (12%), and software (10%). Others are environment and energy (4%), business and management (3%), manufacturing (2%), telecommunications (1%), leisure (1%), and others (4%). Categorising USOs using typologies offered by Druihle and Garnsey (2004) (consulting companies, development companies, product companies, and software firms) shows that 34% of the sample are categorised as development firms, followed by product companies (31%), consulting (23%), and software (12%), respectively. Some firms could not be placed simply into one category as they are likely to extend or modify their business model based on current resources and product/service offerings. For example, almost 50% of development companies engage in developing products or software or consultancy service based on their existing patents. Approximately 90% of software companies offer additional consultancy services. Nearly 10% of product firms develop application software bundled with their products.

Table 5 shows the average number of products, average number of services, and the number of total patents by region. East of England leads in average products and South East leads in terms of patents. The data do not capture outliers - for example, Expedeon Ltd located in the East of England region produces more than 51 products for protein discovery and Oxford

Instrument based in the South East holds more than 300 patents. In general, the average number of products created by USOs in most regions is between 2-9 products, with the average number of services falling between 1 and 5. The high numbers are in the East of England region (an average of 9), followed by Scotland (an average of 6). The *servitization* concept explains that services offered are additional components to products (Vandermerwe and Rada 1988; Martinez et al. 2010). USOs in the East Midlands region have developed on average 5 types of services, followed by the North East (on average 3 types of services) and the South West regions (on average 3 types of services), respectively. However, this does not affect the stage of commercialisation of these products/services.

The link between years in operation and products/services is identified in this study. On average, USOs across regions are relatively young (founded for less than 15 years), hence, they are likely to invent fewer products (the average number of products in most regions is between 2 and 3). Firms at an early stage of their life cycle own limited resources and capabilities. Accordingly, they focus on survival and growth based on their original technologies and products as opposed to inventing additional new products and services. This interpretation is consistent with Hite and Hesterly (2001) and Ortin-Angel and Vendrell-Herrero (2014). In addition, the number of patents created by university spin-offs is also used as a proxy for innovation contributing to the innovation ecosystem. The data show that university spin-offs contribute relatively high number of patents in the East of England, South East, Scotland, and London regions. The East of England and South East regions house not only world-class universities, such as Oxford and Cambridge, but also well-established and state-of-the-art technology transfer mechanisms, such as Cambridge Enterprise and Oxford University Innovation (which can facilitate the patenting process).

Table 5: Product, services, and number of patents

Region	Avg. Products	Avg. Services	Total patents by USOs
East Midlands	2	5	118
West Midlands	3	2	39
East of England	9	2	1089
London	4	2	342
North East	2	3	46
North West	2	2	232
Northern Ireland	3	1	32

Scotland	6	1	435
South East	4	2	1474
South West	2	3	112
Wales	3	1	59
Yorkshire and Humber	2	2	115

Within sub-sectors of USOs based on Druihle and Garnsey (consulting, licensing, product, and software), distinct regional patterns are not observed implying some amount of diversification within regions in terms of types of USOs. USOs' overall product and service portfolios usually reflect the founders' knowledge and a response to market demand—therefore, USOs have the potential to provide diversification within innovation ecosystems through the co-existence and co-evolution of different knowledge pathways or add value to existing sectors (Adner and Kapoor 2010, Carayannis and Campbell 2009, de Vasconcelos Gomes et al. 2018). However, it is noteworthy that although the product group leads in terms of average number of products (9.5), all three sectors have some products: consulting (2.48), software (1.79), and development (1.06). For example, Planetary Vision, located in the South East region, offers consultancy on environmental science and geology as well as 3D graphics products. Rapita System, located in the Yorkshire region, provides consultancy service to aerospace and automotive electronics industries including data logging box. Sensixa and PSE Limited, located in London, offer both products and consultancy services. Similarly, the consulting group leads in providing services (average number of services being 4.16) followed by product (0.87), software (0.77), and development (0.75). Services provided by other firm categories are usually complementary to their outputs rather than a stand-alone specialized service.

Table 6 shows the diversity of product and service offerings by USOs. Products include devices, softwares, materials, and biotech products. Within each product category, the products also serve various sectors, for example, devices range from vacuum and condenser equipment for engineering operations to tourniquets for medical purposes. Likewise, the services (e.g., licensing, consultancy, development, analysis and testing, as well as research) reflect the innovative and specialized knowledge as well as technologies that contribute toward numerous sectors within the innovation ecosystem(s) at the local level. They can be categorised under "venture friendly markets for products" (Isenberg 2011, Stam 2015, Spigel 2017).

The range of product/services per region reflects the variability of innovations developed from scientific and technological research in universities. However, the USOs do not cover the full range of products/service contained in a region. One possible explanation is that when products or services are developed, founders of USOs may take into consideration the broader market gap (to take advantage as the first mover and to try to show investors the potential for scalability of the market for their products/services) rather than the need to fit into local/regional clusters. The findings reinforce conclusions in other studies that innovation in the form of product/service offerings of USOs create local value within innovation ecosystems (Granstand and Holgersoon 2019).

Table 6: Products and services[4] of USOs across UK regions

Region	Universities that produce USOs	Cluster specifications[5]	No. of USOs' sector aligned with cluster specification	No. of USOs in the region	% of USO[6] contribution to the regional cluster	Products	Services
East Midlands	- De Montfort University - Loughborough University - Nottingham Trent University - University of Leicester - University of Nottingham	Motorsport, Automotive, Industrial Manufacturing, Furniture/Wood	9	64	14%	-Software (e.g. Family history risk -Assessment software, staff rota, and resource planning) -Antennas -Diagnostic/ medical device (e.g. device to monitor maternal activity) -Gamma Ray/Imaging sensor cameras -Drugs/ vaccine	-Consultancy - Training - Project management - Assay services - Licensing

[4] Universities recorded in the table are those with USOs, which have offered products and services.

[5] Cluster specification refers to co-location of specific industries - see https://www.centreforcities.org/wp-content/uploads/2014/07/FINAL_Centre-for-cities-report2014.pdf.

[6] This variable is constructed by calculating the percentage of number of USOs whose sectors are aligned with regional cluster specifications

						-Nano materials -Fluorescent reagents -Laser optical device -Molecular diagnostics -Voice biometric technology -Ionic liquids -High-integrity processors	
West Midlands	- Aston University - Birmingham City University - Coventry University -University of Birmingham - University of Warwick	Motorsport, Automotive, Industrial Manufacturing, Furniture/Wood	12	49	24%	Software Vehicle (e.g. low carbon hydrogen car, electric car Devices (e.g. orthopaedic trauma devices, high Temperature Superconductors, laser plastic welding) Materials (e.g. ultra-fine metal) Chemical products (e.g. dry liquid blends) Visualisation products e.g. 3D system Smoke alarms Ceramics Robust soil moisture sensors biosensors for the measurement of neuroactive chemicals	- Assay and testing service - Training - Contract research - Consultancy - Licensing

						fingerprint scanning product	
East of England	- University of Cambridge - University of East Anglia	High-tech and ICT, Instrumentation (medical and electronic), pharmaceuticals and biotechnology	58	73	79%	-Drugs -Device (e.g. fruit flies behaviour detection, sensor, audio restoration and speech enhancement, carbon nanotube) -Software (e.g. cognitive assessment) -Semiconductor -Medical materials (e.g. proteins -Chemical products -Power switching control -Trauma fixation system for fracture - 3D Imaging and Spectroscopy	- Assay service including drugs development service - Training - Consultancy - Licensing
London	- Birkbeck, University of London - Brunel University - City University - Goldsmiths, University of London	Creative, Digital, Business service, Financial service, property, tourism	38	127	30%	-Drugs (e.g. biologic drugs and novel oncology therapeutics) -Devices (e.g. turbo compressors, shell and heat tube exchanger, vacuum and condenser equipment, air purifier units, gas sensor, energy saving compressors, mass spectrometry, medical torniquet)	- Assay and testing service - Drugs development service - Training - Consultancy - Contract research

	- Imperial College London - King's College London - London South Bank University - Queen Mary University of London - Royal College of Art - University College London					-Software (e.g. GPS, visual search and image recognition, coffee maker) -Materials (e.g. fuel cell, material coating, nanocomposites) -Clothing -Cellular immunotherapeutic for infectious disease and cancer - Fire sprinkler	- Licensing
North East	- Durham University - Newcastle University - Northumbria University - Teesside University	Manufacturing and engineering-related industries–Automotives, Plastics, Electrical Industrial Equipment, Chemicals and Furniture	20	46	43%	- Chemical products - Software (e.g. computational stress analysis, radiography training) - Materials (e.g. 3D cell culture systems, proteins, peptides, antibodies and antigens) - Devices (e.g. nuclear detection, security screening, medical imaging - High-speed smart cameras - Drugs	- Assay and testing service - Training - Consultancy - Contract research - Licencing

						- Computer game for rehabilitation of the hand and arm - Dipsticks	
North West	- Lancaster University - University of Liverpool - University of Manchester - University of Salford	Aerospace, Chemical	2	56	4%	- Software (e.g. planning of cabling network, extract language DNA from digital source -Devices (e.g. measurements in waters, soils and sediments, spectrometer, mid-infrared LEDs, hydrocarbon monitor, laser gas sensor) -Drugs -Semiconductor nanoparticles - High quality TV contents - Skin treatment products - Photodynamic Therapy lamp - Fungal DNA extract kits	- Assay and testing service - Consultancy - Contract research - R&D services - Licensing
Northern Ireland	- University of Ulster - Queen's University Belfast	advanced engineering (including aerospace and other vehicles), agri-food, ICT, life and health sciences and advanced materials	23	33	70%	-Software (e.g. e-commerce, analytics engines accelerators, maths teaching, power station monitoring, data inspection security)	- Consultancy - R&D services - Assay and testing service

						-Devices (e.g. health monitoring) - Scientific camera, spectroscopy, microscopy system, fibre optic sensor) -Materials (e.g. extracellular matrix, textile, concrete) -Semiconductor -Chemical products (e.g. waste water treatment - Hardware engines for content and network processing - Manikins for medical training	- Licensing
Scotland	- Edinburgh Napier University - Glasgow Caledonian University - Heriot Watt University - Queen Margaret University - University of Aberdeen - University of	Financial Services, Electronics and ICT, Oil & Gas, Tourism, Whisky	50	174	29%	- Software (e.g. game, oil and gas industry, defence and security, visualising speech, intrusive sand monitoring, linguistics, capture facial expression, online education, training and assessment -Chemical products (e.g. pharmaceutical ingredients, protein polymer, enzyme, antibody -Devices (e.g. spectrometer, laser	- Assay and testing service - Consultancy - R&D services - Drugs development service - Licensing

	Abertay Dundee - University of Edinburgh - University of Glasgow - University of St Andrews - University of Strathclyde					and LEDs, gas sensor, gas monitor, photonics, allergen detection) -Materials (e.g. biofuel, reactor and crystalliser, "off grid" hydrogen fuel, synthetic bone graft substitutes, contact lens materials) -Drugs -Optical engine -Equipment for visually impaired person - Volumetric heating equipment - Power grid	
South East	- Cranfield University - Oxford Brookes University - University of Oxford - University of Surrey - University of Sussex	High-tech and ICT, Instrumentation (medical and electronic), pharmaceuticals and biotechnology	52	80	65%	Ultra-light energy efficient vehicles -Devices (e.g. wastewater treatment, optical imaging, automated normothermic liver perfusion, laser micromachining, nanopore sensing, needle-free drug delivery) -Materials (e.g. baculovirus protein, recombinant protein,	- Assay and testing service - Consultancy - Drugs development service - Training -Licensing

						bionanomaterials, natural protein) -Software (e.g. smart gas index, 3D motion capture for injury assessment, project management) -Drugs -Hardware accelerated products - Handheld scanner - Pest control - Earth observation satellites	
South West	- Bournemouth University - University of Bath - University of Bristol - University of Exeter - University of Plymouth - University of Southampton	Tourism, Aerospace, ICT and hi-tech value chain (from hardware and semiconductor manufacture to e-Commerce retailers and creative industries)	15	56	27%	-Devices (e.g. in vitro Point-of-Care testing, predictor of the fertile period, nutrient feeding, air dryer) -Software (e.g. power controller, TV and film, residual stress measurements, electrophysiology analysis, image processing and mesh generation, materials analysis, collaborative modelling -Materials (engineering and medical purposes) - Drugs - Flood defence	- Contract research - Consultancy - Assay and testing service -Licensing

						- Electrical travel pod - Optical glass and fibre	
Wales	- Aberystwyth University - Cardiff University - Swansea University - University of Glamorgan	Tourism, Electronics, Industrial manufacturing, Furniture/wood	8	27	30%	-Software -Vehicle (e.g. low carbon hydrogen car, electric car -Devices (e.g. orthopaedic trauma devices, high Temperature Superconductors, laser plastic welding) -Materials (e.g. ultra-fine metal)-Chemical products (e.g. dry liquid blends) -Visualisation products e.g. 3D system -Smoke alarms Ceramics Robust soil moisture sensors biosensors for the measurement of neuroactive chemicals -fingerprint scanning product	- Contract research - Training - Design service - Licensing
Yorkshire and Humberside	-Sheffield Hallam University - University of Bradford	Metal, furniture, chemical and renewable energy supply chain	2	54	4%	- Materials (e.g. polymer coatings, biocompatible patch for peripheral vascular reconstruction)	- Assay and testing service - Training - Contract

	- University of Hull - University of Leeds - University of Sheffield - University of York					- Chemical products - Devices (e.g. protein analysis, polymer bead cleaning, cervical cancer diagnostic) - Software (e.g. virtual reality for training, design visualisation, precision measurement, nuclear, chemical, mineral and pharmaceutical industries, Rolling stock planning, Performance & safety management, analytics, geology, structural fire engineering, aerospace and automotive electronics embedded, Risk and Claims Management)	research - Consultancy - Licensing

Table 6 shows that USOs have a significant presence in the East of England, Northern Ireland, and the South East compared to other regions. In the case of East of England and South East regions, where the University of Cambridge and University of Oxford are located, the high-tech sectors such as ICT, pharmaceutical and biotechnology reflect the research strengths of the universities. In contrast, in the North West and Yorkshire, the clusters are different and include sectors such as aerospace and chemicals, metal, furniture, and renewable energy. In both cases, USOs make only a 4% contribution towards regional clusters even when they do host Russell Group universities. London's cluster specifications focus on creative, digital, financial service, property, and tourism and USOs contribute only about 30% toward the regional cluster. London has a high proportion of universities in the Russell Group with their research output mainly related to STEM subjects rather than creative or financial services, which are sectors that make London one of the top three world cities. Hence, this study demonstrates that USO contributions to regional innovation ecosystems are wide ranging than the regional cluster specifications. Future research needs to evaluate the capability of USOs to generate exports or income from outside their region.

5. Conclusions

This paper provides a comprehensive understanding of USOs in UK regions—this study examines the location and diversity of actors within UK's innovation ecosystems. In answer to the first question which asked how USOs are distributed and characterised across different regions, the quantitative data show that the research-intensive universities produce the most USOs. Therefore, value creation (Adner and Kapoor 2010) is directly associated with particular kinds of universities. For example, Cambridge, Oxford, Imperial College London, UCL from the Golden Triangle region, and the University of Edinburgh (Scotland), respectively, are the leading research institutions in the UK and they are the top five universities that create high volumes of spin-off firms. The role of research excellence in USO formation relates to the study by Di Gregorio and Shane (2003), which argues that academics from leading research universities may find it easier to assemble resources owing to their ability to leverage the reputation of their institution and signal to the broader community of their excellence (see also Van Looy et al. 2004). Additionally, university-based resources play an important role as exemplified by the positive correlation between the number of full-time academic staff and the number of spin-off companies (see Lockett and

Wright 2005). This highlights the different scale and scope of knowledge production within innovation ecosystems within a region.

The evidence also shows the temporal pattern of USO development (e.g., firm size and age) (see Grandstrand and Holgersson 2019, Hite and Hesterly 2001, Lundvall and Battese 2000, Ortin-Angel and Vendrell-Herrero 2014) across UK regions. USOs in most UK regions are micro, small, or medium-sized firms that are still at the early stages of their life cycle. The exceptions are the South East (Oxford, Southampton) and Northern Ireland (Queen's Belfast) regions which contain larger USOs (250+ employees). Consequently, some patents and a small number of products and services are offered in each region. The findings agree with other academic studies which suggest that UK USOs have the tendency to start small and remain small (e.g., Harrison and Leitch, 2010). In general, it takes them at least a decade before significant growth starts to be noted (Lindholm Dahlstrand 1999, Lawton Smith and Ho 2006). Moreover, during the first 10 years of their operation, product development is also limited (Lerner 2005).

The second question posed seeks to answer how innovative products and services from USOs (Rasmussemn et al. 2011, 2012) contribute to the variety and scope of innovation opportunities in a region or the composition of innovation ecosystems (de Vasconcelos Gomes et al. 2018, Granstand and Holgersson 2019) at the regional level. The data show that USOs' contribution to the specific regional clusters is relatively low with the exception of the East of England (Cambridge University), Northern Ireland (Queen's Belfast), and the South East (Oxford and Southampton universities). The dominant combined location is the 'golden triangle region' of Oxford, Cambridge, and London universities. Thus, as Fini et al (2018) imply, identification of the context leads to a differentiated understanding of particular phenomena. In this study, the geographical context (UK regions) shows that dominant regions and others offer a varying bundle of products and services; some match local clusters well and others do not. This implies the potential for USOs to contribute to innovation ecosystems through value generation and then directly creating possibilities for commercial opportunities for other local firms with which they engage. A conceptual point is that USOs' contribution to innovation ecosystems per se is potentially significant in the short as well as long-term (Bolzani et al. 2014) given that their products and services reflect the expertise unique to their founding university (Carayannis and Campbell 2009).

Despite some methodological difficulties and limitations in putting together a comprehensive database of the UK's USOs, the contribution of this paper is summarized below. First, the results shed light on various aspects of firm characteristics by age and location, as well as value creation (products, services, and patents). The findings not only confirm previous patterns of USOs, but also present additional regional value creation by examining related and unrelated products and services to clusters at the regional level. Second, despite the small percentage contribution to specific regional clusters, USOs' product/service offerings provide a first step in understanding how USOs' innovations contribute and fit into regional clusters/markets. Third, the study adds to the analysis of the geography of entrepreneurship discipline by linking the outputs of USOs and their stage of development to the wider regional context. The study shows regional patterns of knowledge (e.g., patents) creation and product/service development, which in turn has the potential to strengthen local clusters and/or generate revenue from outside the local region.

Further research is needed to understand and explain the local and non-local effects of USOs (de Vasconcelos Gomes et al. 2018, Granstand and Holgersson 2019). Additionally, since this research has observed the out-migration of USOs from particular regions in the UK, further research is needed to provide an understanding of regional factors affecting the retention/departure of USOs. The study also provides a relatively comprehensive database from which to gauge shifts that may result in the near future from the impact of political decisions and policies affecting UK's universities in a post-Brexit world.

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Appendix

Summary of observed variables

Variables	Measurement scale
Demographic information of the USOs	
-Years in operation	- Continuous data
- Active in operation	- Binary data
- Number of employees	- Categorical data
- Sector	- Nominal data
- Number of patents	- Continuous data
- Firm category	- Categorical data
- Number of products and services	- Continuous data
- products/services specifications	- Nominal data
Regional data	
- Regions	- Nominal data
- Number of universities in the region	- Continuous data
- Number of full-time academic staff in each university	- Continuous data
- Cluster specifications	- Nominal data

Correlation between the number of universities, number of academic staff, and USOs

	No. of institutions	*No. of USOs created*	*No. of academic staff*
No. of institutions	1		
No. of USOs created	0.8994	1	
No. of academic staff	0.7525	0.5948	1