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INDUSTRY RESEARCH PRODUCTION AND LINKAGES WITH ACADEMIA: EVIDENCE FROM UK SCIENCE PARKS

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Abstract

The aim of this study is to identify the research areas, geographic regions, university-industry (U-I) collaborations, quality, and impact of the research associated with the research-intensive organisations based in the UK science parks. An analysis of scholarly publications (1975-2010) revealed three main research domains: food-biotechnology and bio-pharmacology; physics and material engineering; and agro-biotechnology. These three types of research were mainly produced in East England, South East England, and Scotland, respectively. Only a quarter of the research results from inter-institutional cooperation. The high involvement of private sector in the physics and material engineering domain involves the highest rate of U-I collaboration but the lowest citation impact. The research quality, defined in terms of the journals where research is published, is significantly higher than the average across research areas, although its impact is not significantly higher than the national average. In terms of inter-sector differences, the higher the involvement of Higher Education Institutions (HEIs) and Research Institutions (RIs) the greater the impact of the publications produced. The low level of impact of private research suggests that citations may not be the best indicator to assess academic researchers with close and operational linkages with industry.

Conference Topic

Technology and Innovation Including Patent Analysis (Topic 5); Scientometrics Indicators: Relevance to Science and Technology (Topic 1).

Introduction

The sustainability of socio-economic development among developed countries increasingly depends on the capacity to foster dynamic and strong research-based industries. In this regard, European and national policies highlight the potential role of university as a main source of research, technology and innovation, and actively promotes closer links with industry (Dyson, 2010; Hauser, 2010; Lambert, 2003). However, this university-industry (U-I) collaboration is not always a straightforward process as the academic and private communities belong to systems that differ in their identity and mission, bringing about transaction costs associated with the efforts employed to bridge the gap between both communities (Abramo, et al., 2009; Arvanitis, Kubli, & Woerter, 2008). In fact, this interaction barrier has led to create an entire constellation of actors oriented to encourage and facilitate the multidimensional and complex process of capitalisation and transference of academic knowledge (Minguillo & Thelwall, 2011; Suvinen, Konttinen, & Nieminen, 2010).

One of the most important and long-standing members of this support constellation are intermediary infrastructures: incubators, science parks, research and technology parks, and innovation parks. These policy tools are widely known as science parks (SPs), and are basically physical infrastructures established in partnerships between research-intensive universities, public authorities and private investors to create favourable conditions to facilitate U-I collaboration and boost technological innovation, and ultimately generate local socio-economic growth (Link & Scott, 2007; UKSPA, 2012; Vedovello, 1997). Yet the pivotal role of SPs in the commercialisation of academic research and technology (R&T) obviously has a significant impact on the goals and functions of universities, and in turn on part of the scientific community. The assessment of SPs mainly focuses on finding out to what extent the links with universities are able to stimulate the growth of cutting-edge industries and a competitive advantage for businesses located on SPs in comparison to their off-park counterparts (Quintas, Wield, & Massey, 1992; Rothaermel & Thursby, 2005; Schwartz & Hornych, 2010; Siegel, Westhead, & Wright, 2003; Westhead & Storey, 1995).

A growing interest in studying factors that may strengthen U-I interaction and encourage a stronger research-orientation in industry has led to suggestions that the use of a scientometric approach may give a fuller understanding of the impact of SPs on the synergy between industry and academia (Bigliardi, et al., 2006; Fukugawa, 2006; Link & Scott, 2003; Siegel et al., 2003). Although, there are two relevant studies regarding the Hsinchu SP in Taiwan, employing bibliographic (Hu, 2011) and patent data (Hung, 2012), and a third one using web-based data to study the SPs in the region of Yorkshire and the Humber in the UK (Minguillo & Thelwall, 2012), it is necessary to conduct further studies that map the research capability and properties of on-park businesses across regions and countries. This could shed new light on the intermediary role of SPs, provide empirical evidence for the literature regarding U-I collaboration in general (Teixeira & Mota, 2012), and most importantly guide and support more effective U-I collaboration processes in developed countries.

With this in mind, this study mainly analyses the capacity of the UK SP movement to encourage and generate R&T. The focus is on providing a better understanding of two specific aspects; (1) the research areas that attract most of the on-park research and the contribution of the geographic regions and U-I collaboration across different areas; and (2) whether the research production associated with SPs has a greater quality and impact than the average research across the different areas. These aspects provide an insight into the R&D activities and U-I links that are expected to be fostered by the different support infrastructures, and to what extent the on-park research is integrated into the wider scientific community.

Data and methodology

Publications associated with UK SPs were retrieved from Elsevier's Scopus database covering a period of 35 years (1975-2010). We used two different approaches to retrieve the records of the research publications produced by any organisation located within a SP in the UK. First, with the help of the SP list provided by the United Kingdom Science Park Association (UKSPA) and the electronic version of the *Atlas of Innovation* created by the *World Alliance for Innovation* (Wainova) we identified the names of 82 full members across the country. This allowed for the creation of queries with the specific names of the different SPs (e.g., *AFFIL ("norwich research park") AND (LIMIT-TO(AFFILCOUNTRY, "United Kingdom"))*). Second, to extend the first search and identify non-members of the UKSPA we used truncated queries with terms that are broadly used to name research-based infrastructures in the country, such as science-, technology-, innovation park, and incubator, as well as terms for commercial-based infrastructures, such as business-, industrial-, enterprise park, and business centre (i.e. *AFFIL("sci* park") AND (LIMIT-TO(AFFILCOUNTRY, "United Kingdom")*). Both specific and truncated queries were restricted to the year 2010 covering journals, book series, and conference proceedings, while excluding editorials, erratum, letters, and notes.[84] The search yielded 10,920 records.

A similar search strategy was used on the *Web of Science* (WoS) database (Thomson Reuters) but approximately two thousand fewer records were retrieved using this method. Note that not all onsite organisations mention the SPs where they are located as part of their affiliation addresses in research publications, so this search approach may not take all the relevant publications into account. Data cleaning and standardisation was used to identify all publications listing at least one author address referring to a UK SP, and the author address was checked for a correct assignment to the organisation stated by the author. The research produced by departments, sub-units, or company groups was assigned to the parent entity, and only research centres associated with HEIs were treated independently in order to get more fine-grained results. In the case of firms, name changes, mergers, or acquisitions were taken into account where possible but in most cases organisations with different physical locations were treated separately to quantify the impact of SPs on the immediate environment. Most hospitals in SPs are teaching hospitals and were classified as HEIs, as recommended in the *Frascati Manual* (2002).The organisations were grouped into six groups (higher education, industry, government, on-park organisation, non-profit organisation, and research institute), and other main attributes (type of organisation, location, type of location, and district). We obtained 9,771 publications produced by at least one onsite-organisation.

[84] This selection of document types is based on their relevance as public communication channels for industry research outputs (Cohen, Nelson, & Walsh, 2002).

The research subject areas were taken from the Scopus journal classification scheme, and publications placed in journals indexed in more than one subject area are counted in each one. These areas are also used to identify the degree of participation of the private and academic sectors, of the regions, and of the U-I collaboration. Reputation, in form of citations given by the research community, was used to determine the popularity and impact of the research. The prestige was determined in two ways. First, quality was approximated by the number of citations received by the journals of the publications. This is quantified by the two citation based indicators; Scimago Journal Ranking (SJR) and Source Normalised Impact per Paper (SNIP), as both are designed to evaluate the prestige and visibility of journals in relation to the particular characteristics of a research area. Second, impact was approximated by the number of citations received by each individual publication. Finally, the Wilcoxon signed-rank test, which is the non-parametric equivalent of the t-test, was applied to assess if there is a significant difference between the observed and expected quality and impact of the research across subject areas.

Results

As background information, the data set extracted from *Scopus* outperforms the *Web of Science* in terms of representing the heterogeneous publication output of a mainly private oriented research community associated to the SP movement (see Figure 1).

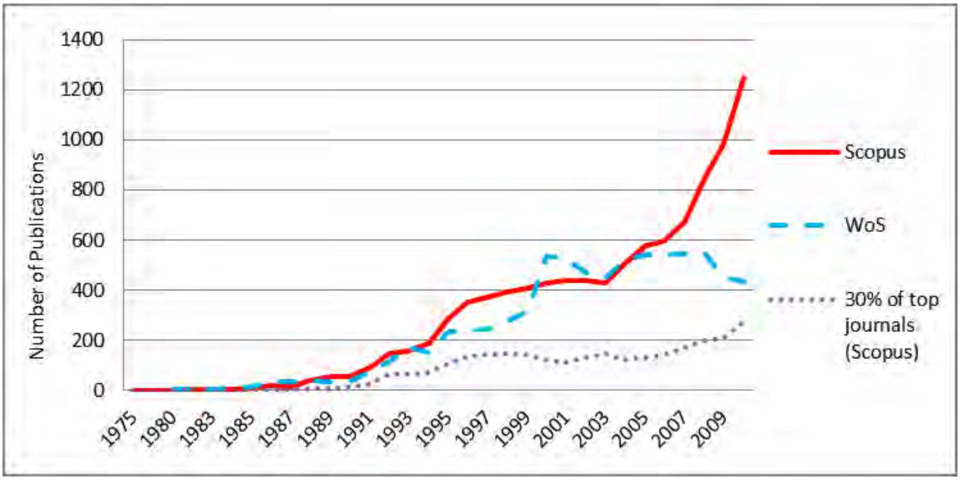

Figure 1. Publications from the UK SP movement from 1975 to 2010.

The coverage of WoS and Scopus seem to be very similar until the mid 90s, after which Scopus exhibits an exponential growth compared to the flat and even decreasing WoS coverage. No bias that would account for the difference could be identified by the publication sources or type of sources indexed by Scopus, as

demonstrated by the normal distribution of the top 30% largest journals in Scopus. The WoS output trend confirms previous findings indicating that WoS-indexed research produced by industry is steadily declining (Tijssen, 2004). These findings strongly suggest that the publication output of the SP movement is underrepresented in WoS.
The chronological development of the SP movement reported in Figure 2 contains the number of infrastructures which have been research-active every year of their existence in terms of research publication output. This shows that the constant growth of the output, shown in Figure 1, coincides with an increase in SPs that are involved in research activities. Before the 1990s there were, on average, 4.5 research-active SPs every year. During one decade this number increased to 24.5, resulting in a more than a two-fold increase by 2010 to a total of 61 SPs. Similarly, the output trend started to become substantial in the beginning of the 1990s, reaching over 400 publications in 2000 with a further three-fold increase by 2010.

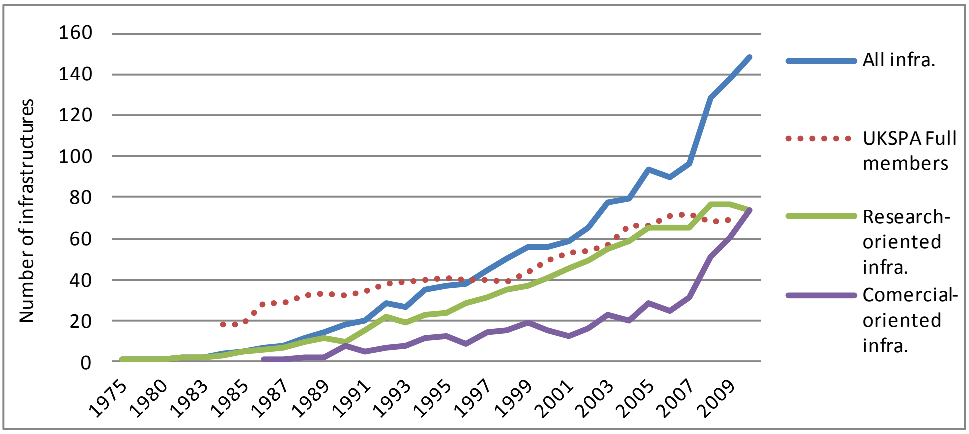

Figure 2. Number of research- and commercial infrastructures producing research publications in each year (Scopus data).

Figure 2 also illustrates that one of the reasons for the remarkable increase of records in Scopus could be an increase in the number of commercial-oriented infrastructures producing research in the last years. The distribution followed by the research-oriented infrastructures publishing every year shows a similar distribution to the records in WoS (see Figure 1).

Research subject areas, collaborative efforts, quality and impact of the SP movement

Scholarly journals are the main venues for formal interaction and communication for different scientific communities, making it possible to identify the intellectual and social aspects shared. These two aspects provide the framework that forms each knowledge domain, and the distance between domains can be determined by the degree of similarity between their cognitive and reputational systems, which in turn shapes the structure of science as a whole (Minguillo, 2010). Hence, the output of the SP movement helps, among other things, to shed light on their degree of intellectual and social integration into the wider scientific community. To do this, the research areas with the largest number of publications were identified based on the journals where the research is frequently disseminated.

Research subject areas and Collaborative efforts

The most frequent Scopus-indexed type of source for the research generated by SPs is journals (91%), in comparison to conference proceedings (7%), serials (1%), and generic (1%). The low rate of conference proceedings is somewhat surprising because conferences are considered as potential venues of interaction for industry and academia (D'Este & Patel, 2007; Lee & Win, 2004), and indeed, in the last ten years there has been an increasing trend for participating in conferences, as shown by the fact that 83% of all conference publications were published between 2005-2010, representing 12% of all publications over the last five years. This growth is the result of the intensification of R&D activities in technology areas, such as *Engineering*, *Physic and Astronomy*, and *Materials Science*.

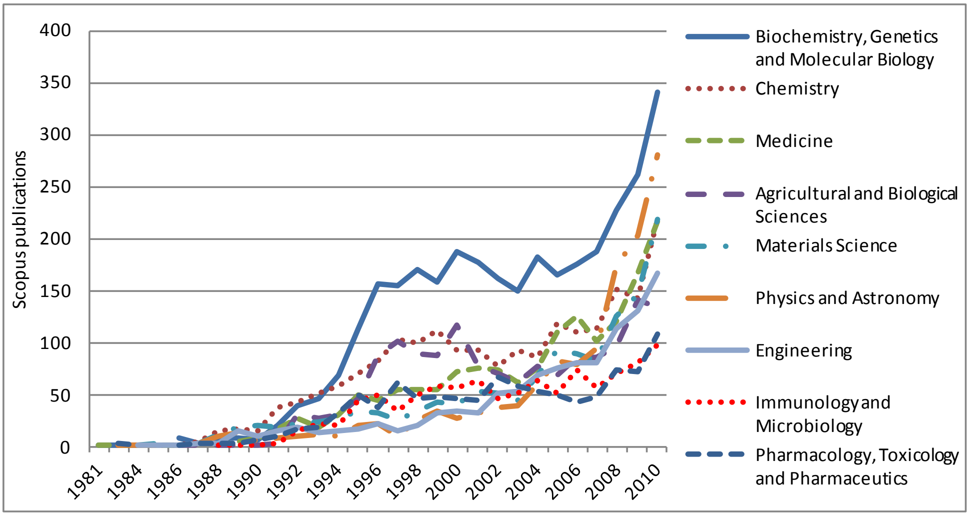

Figure 3. Chronological development of the top nine subject areas for the SP movement.

Regarding the most important research fields, the chronological development of the top nine subject areas, covering 80% of the total output, shows that *Biochemistry, Genetics and Molecular Biology* is the largest research area with 18% of the total output (Figure 3). It started in the mid 80s and has its first breakthrough in the mid 90s due to the establishment of RIs (e.g. Institute of Food Research, and the John Innes Centre), the parallel relocation of the pharmaceutical industry (e.g. GlaxoSmithKline) and the emergence of new spin-outs. In 2005 it again had exponential growth partially caused by the diversification and maturity of the industry and new emerging RIs (e.g. Babraham Institute). This trend differs from the relative decline suffered by *Chemistry*, and *Agricultural Biological Sciences* during 2000 and 2007. The other top subject areas have followed a constant growth and have similarly achieved a remarkable upward increase since 2005. Three related subject areas have been subject to recent exponential growth, namely *Physics and Astronomy*, *Material Science*, and *Engineering*, and this is partially caused by the RIs *Rutherford Appleton Laboratory* and the private sector (e.g. AkzoNobel R&D, Diamond Light Source, TWI). On one hand, these two sets of fields represent the emerging physics and material engineering industrial sector and, on the other hand, the partially weakening health and life science industrial sector, consisting of three subject areas: *Biochemistry, Genetics and Molecular Biology*, *Chemistry*, and *Agricultural Biological Sciences*. Both groups also differ in terms of research and technology producers as the first is slightly dominated by firms (64%) and the second by public RIs & HEIs (72%) (see Table 1), suggesting the maturity of new research-based industrial sectors, mostly produced by the private sector, that coexists with the well-established and publicly backed bio-tech industry within the SP movement.

The ranking of the top 15 subject areas in output (Table 1) illustrates characteristics of the research associated with the SP movement, the research profile of the three regions with the greatest research-intensive innovation structures, and the collaboration between on-park organisations (firms or HEIs/RIs) with on- or off-park organisations (firms or HEIs/RIs). At the regional level, the most productive is the East of England with the top subject area *Biochemistry, Genetics and Molecular Biology*. This depends upon the high concentration of small and large biotech firms (Birch, 2009), that in turn are highly dependent upon public RIs, as shown by the low share of private research (38%). This region also produces significant research in *Agricultural Biological Sciences* and *Chemistry*, and despite generating considerable research in other research fields, the region seems to be public science-based and specialised in food-biotechnology and bio-pharmacology. The research and technology from the South East is framed within four important areas *Physics and Astronomy*, *Materials Science*, *Engineering* and *Chemistry*, and even though there are public RIs that support the two first research areas, the role of industry as a research producer is significant (63%). Another region with a similar profile is the North East. Hence, the South East region seems to rely on private research to develop an industrial sector around physics and material engineering. Finally, Scotland, with a reduced private research capacity (35%), relies on public research (e.g. *Moredun RI, Roslin Institute, Veterinary Laboratories Agency*) to concentrate research related to *Immunology*, *Medicine*, *Veterinary* and *Biochemistry, Genetics and*

Molecular Biology, which in turn is exploited by the agro-biotech industry, confirming previous findings (Cooke, 2001). On the other hand, the subject areas with the highest rate of private participation are *Pharmacology* (81%), *Materials Science* (67%), and *Engineering* (66%); conversely the highest academic contribution is found in *Agricultural and Biological Sciences* (85%) and *Immunology* (80%).

Table 1. Distribution of the top subject areas according to private and academic output, regions, and inter-institutional collaborative efforts.

		Output						Three main regions' Output						Collaboration			
#	Research area	*n* = 17,341	%	#	Industry *n* (45%)	#	HEIs/Ris *n* (52%)	#	a	#	b	#	c	#	All *n* (25%)	#	U-I *n* (56%)
(1)	Biochemistry, Genetics & Molecular Biology*	3182	18%	(10)	36%	(5)	62%	(1)	26%	(5)	9%	(4)	10%	(11)	18%	(9)	46%
(2)	Chemistry*	2009	12%	(6)	58%	(9)	41%	(3)	12%	(4)	12%	(12)	2%	(6)	34%	(5)	67%
(3)	Medicine***	1572	9%	(9)	39%	(7)	55%	(4)	8%	(7)	5%	(2)	15%	(12)	15%	(12)	44%
(4)	Agricultural and Biological Sciences*	1535	9%	(15)	12%	(1)	85%	(2)	13%	(13)	2%	(5)	8%	(13)	14%	(14)	32%
(5)	Physics and Astronomy**	1334	8%	(7)	58%	(11)	39%	(7)	4%	(2)	13%	(11)	4%	(7)	33%	(2)	73%
(6)	Materials Science**	1300	7%	(2)	67%	(13)	32%	(8)	4%	(1)	20%	(10)	4%	(1)	52%	(1)	74%
(7)	Engineering**	1097	6%	(3)	66%	(14)	31%	(9)	4%	(3)	12%	(9)	5%	(5)	35%	(3)	71%
(8)	Immunology and Microbiology***	1015	6%	(13)	18%	(2)	80%	(6)	7%	(16)	1%	(1)	15%	(14)	14%	(13)	33%
(9)	Pharmacology, Toxicology & Pharmaceutics	1006	6%	(1)	81%	(15)	17%	(5)	7%	(9)	4%	(8)	5%	(8)	20%	(7)	65%
(10)	Chemical Engineering	551	3%	(5)	58%	(10)	41%	(10)	3%	(10)	3%	(14)	1%	(3)	38%	(6)	65%
(11)	Environmental Science	484	3%	(11)	34%	(6)	62%	(11)	2%	(12)	2%	(7)	6%	(9)	20%	(10)	45%
(12)	Computer Science	391	2%	(4)	64%	(12)	33%	(14)	1%	(6)	5%	(13)	1%	(4)	36%	(4)	68%
(13)	Mathematics	294	2%	(8)	55%	(8)	44%	(16)	1%	(8)	4%	(15)	1%	(2)	39%	(8)	63%
(14)	Veterinary***	287	2%	(14)	16%	(3)	80%					(3)	12%	(15)	10%	(15)	25%
(15)	Earth and Planetary Sciences	285	2%	(12)	33%	(4)	63%			(11)	2%	(6)	8%	(10)	18%	(11)	44%

a East of England (n=54%; I=38%); *b* South East (n=14%; I=63%); *c* Scotland (n=12%; I=35%)

* Food-biotechnology and Bio-pharmacology; ** Physics and Material engineering; *** Agro-biotechnology

Regarding inter-institutional collaboration, only 25% of all the research output has been co-authored by two or more different institutions, with *Material Science* being the area with the highest collaborative effort. From these collaborations, more than half (56%) are U-I, and there is a strong relationship (r_s=0.86) between the ranking of private output and U-I collaboration across the research areas. This shows that the research-intensive industries within the SP movement are able, to some extent, to capitalise on academic knowledge. Interestingly, the comparison between research areas in terms of U-I collaboration shows that the three top areas belong to the physics and material engineering industry, implying that the South Eastern agglomeration is the most successful in fostering U-I interaction. On the other hand, the low ranking of the other two main industrial agglomerations, food-biotechnology and bio-pharmacology, and agro-biotechnology – mainly based in East of England and Scotland respectively - is affected by the central role of the public research and especially RIs. Although most RIs are meant to closely support and cooperate with local businesses, they are industry-related and the outcome of the cooperation with private sector may not necessarily lead to the publication of research articles.

Quality and Impact

The quality is basically defined by capacity to place publications in journals that attract a considerable amount of citations from its research area. The quality of the output was obtained through comparing the expected quality (the average value of the SJR and SNIP given to each subject area in 2010) with the observed quality (the average value of the 2010 SJR and SNIP of the journals where on-park organisations publish). If the observed quality is higher than the expected quality then this is evidence that the research of on-park organisations is good enough to be disseminated among the most prestigious journals in the area. On the other hand, the impact of the output, defined by the number of citations that each publication receives, is obtained through comparing the expected impact (the average number of citations received by the publications in each subject area), with the observed impact (the average number of citations received by on-park organisations' publications). Then, if the observed impact is higher than the expected one it is assumed that the on-park research is relevant and attracts the attention of the research community.

Table 2. Quality and impact of the top subject areas.

	Quality				Impact (1996-2010)		
	SNIP		SJR		Observed		Expected
	Observed	Expected	Observed	Expected	n=18.44	St dev	n=16
Biochemistry, Genetics and Molecular Biology*	1.42	0.78	0.68	0.42	25.12	40.66	28.46
Chemistry*	1.35	0.88	0.23	0.15	16.50	27.45	18.76
Medicine***	1.26	0.77	0.41	0.13	18.75	33.88	17.86
Agricultural and Biological Sciences*	1.33	0.64	0.25	0.10	23.21	36.97	18.51
Materials Science**	1.15	0.91	0.14	0.10	11.06	23.35	11.57
Physics and Astronomy**	1.12	1.14	0.13	0.11	8.01	21.48	15.18
Engineering**	1.34	0.80	0.12	0.06	7.52	21.35	8.12
Immunology and Microbiology***	1.39	1.45	0.63	0.40	21.45	28.98	24.01
Pharmacology, Toxicology and Pharmaceutics	1.03	0.49	0.29	0.15	18.87	30.52	17.72
Chemical Engineering	1.42	0.63	0.28	0.09	15.43	29.65	10.7
Environmental Science	1.37	0.67	0.13	0.08	15.03	27.04	18.55
Computer Science	1.62	1.49	0.70	0.06	6.56	43.30	10.23
Mathematics	1.20	1.01	0.07	0.05	6.36	49.56	9.95
Veterinary***	1.02	0.56	0.10	0.06	13.12	24.71	9.23
Earth and Planetary Sciences	1.40	0.51	1.10	0.07	10.13	17.09	17.96

* Food-biotechnology and bio-pharmacology; ** Physics and material engineering; *** Agro-biotechnology
SNIP Source: www.journalindicators.com
SJR Source: www.scimagojr.com

Table 2 illustrates that the SP movement as a whole is capable of publishing in the most influential journals and these publications have a higher impact than the national average. Based on the SNIP indicator, the difference between the observed and expected quality suggests that the areas with highest quality are *Earth and Planetary Sciences*, *Chemical Engineering*, and *Agricultural and Biological Sciences*, while those with lower quality are *Immunology and Microbiology* and *Physics and Astronomy*. The comparison based on the SJR supports the high quality of on-park research, with the areas of highest quality being *Earth and Planetary Sciences* and *Computer Science*. In terms of impact of the output, between the period 1996 and 2010, 79% of the publications have been cited and the observed impact is higher (18.44) than the expected one (16). However, only five areas seem to have higher impact than expected, the highest being; *Chemical Engineering*, *Agricultural and Biological Sciences*, and

Veterinary. On the other hand, the areas with the lowest relative impact are: *Earth and Planetary Sciences* and *Physics and Astronomy*.

The Wilcoxon signed-rank test compares the expected and observed values, confirming that the quality measured by the SNIP (z=-3.238, p<.05) and SJR (z=-3.409, p<.05) of the journals within the different subject areas is significantly higher than the expected. On the other hand, the level of impact obtained by the publications is only slightly higher than expected with a difference that is not statistically significant (z=-.966, p>.05). This reveals that the organisations associated to the SP movement are able to publish in high-quality journals, although the impact of these publications on the scientific community varies across areas and tends to be only slightly greater than the average.

Different factors may lead areas with high quality to have low impact and vice versa. When the top quality research areas are compared based on the three main regional agglomerations (non shown), the observed quality reveals that research in food-biotechnology and bio-pharmacology industries in the East of England has a much higher value (2.63) than the agro-biotech industry in Scotland (2.40), and the physics and material engineering industry primarily located in the South East (2.0). The citations, however, show that only the agro-biotech sector has a positive impact (0.74), whereas the impact of food-biotechnology and bio-pharmacology (-0.3) and physics and material engineering sectors (-2.75) are below the expected values. The main reason for this could be the nature of the research. As Godin (1996) claims, basic research produced by industry in biotechnology and chemistry is more useful for the research community and thus more cited than the applied research produced by industry in physics. The applied nature of the research generated in physics and material engineering is reflected in the greater dissemination of research in the form of conference proceedings, for example. Another reason could be that the private-oriented sectors have only experienced a strong increase over the last ten or five years, and thus, have had less time to be cited.

Table 3. Citation rates of regions, infrastructures, and organisations.

Citations per publication									
Region	**IN** #	*n=19.2*	**OUT** #	*n=22.1*	**Infrastructure**	**IN** n=19.7	**Organisation**	**IN** *n=19.7*	**OUT** *n=21.2*
East of England	1	26.9	1	30.2	Research Camp	48.6	Research Institutes	25.7	25.6
North West England	2	16.0	2	29.4	Research Pk	27.8	Firms	15.2	17.4
Scotland	3	13.3	3	28.2	Incubator	16.0	HEIs	14.3	19.9
North East England	4	13.3	4	27.1	Science Pk	14.8	Government	6.3	10.2
South West England	5	12.4	5	19.9	Innovation Pk	13.8	Non-profit organisations	5.8	182.0
East Midlands	6	11.7	6	19.1	Science & Innovation Cent	12.6	**% of uncited publications**	**IN**	**OUT**
London	7	10.4	7	17.7	Industrial Pk	8.9	Organisation	*n=0.21*	*n=0.21*
West Midlands	8	9.7	8	16.8	Business Pk	8.6	Research Institutes	0.13	0.15
Yorkshire and the Humber	9	8.5	9	15.5	Technology Pk	8.3	Firms	0.27	0.25
South East England	10	7.9	10	15.3			HEIs	0.29	0.21
Wales	11	7.3	11	12.3			Government	0.40	0.23
Northern Ireland	12	3.4	12	11.0			Non-profit organisations	0.43	0.26

To find the reason for the inconsistency between the quality and impact of the output the characteristics of the impact across regions, infrastructures, and types of organisations were examined. First, Table 3 reports the citation rates of the on- and off-park organisations. Interestingly, at the national level the evidence indicates that on-park research production, chiefly conducted by the private sector, had a slightly lower impact (19.2) than the off-park production (22.1) which is chiefly conducted by HEIs. At the regional level, the low impact of the private research base in the South East, which occupies the tenth position, differs from the top positions of the primarily public research generated in the East of England and Scotland. The impact of the off-park organisations shows that the exchange of research with off-park organisations located in the North East, London, and the East of England attracted the interest of the research community, increasing its impact.
Similarly, the level of impact of the infrastructures and organisations (see Table 3), clearly shows that the closer the research production is to public RIs the greater the research impact. Infrastructures whit a greater part of the output generated by RIs, research- campuses (48.6) and parks (27.8), and, to a lesser extent, incubators (16), and science parks (14.8), have a greater impact than the business-oriented infrastructures, namely industrial- (8.9) and business- parks (8.6). Most of these RIs are recognised centres of excellence and the research produced by RIs, regardless of being on (25.7) or off park (25.6), leads to the highest impact for the on-park research community. On the other hand, it is difficult to argue that the research produced with the participation of either firms or HEIs could receive more citations due to the high level of collaboration between both.

Discussion

The result showed that Scopus provides a wider coverage of the research output of the SP movement in comparison with WoS. Scopus' broad coverage policy, with about 70% more sources than WoS (López-Illescas, Moya-Anegón, & Moed, 2008), offers a more comprehensive representation of the industrial research. This is especially true when conference proceedings are important (Meho & Rogers, 2008). The likely underrepresentation of private research in WoS represents a significant limitation for U-I studies, as any conclusions drawn are related to the properties of the bibliographical database used.
Overall, the SP movement prefers to publish in journals and the expansion of technology fields has recently increased the use of conference proceedings as source of communication. Besides this, the growing interest from commercial-oriented business parks to promote R&D activities as a means to add value to the products and services of their tenants involves new opportunities for further expansion of the SP movement, as it has been able to redefine itself to nurture a greater research production in the last two decades.
Quantitatively speaking, the interdisciplinary field of *Biochemistry, Genetics and Molecular Biology* is the main research field of the movement, and the East of

England possesses the main private and public agglomeration across the country, which in turn is related food-biotechnology and bio-pharmacology, in line with other findings (Birch, 2009). Despite two closely related areas (*Chemistry*, and *Agricultural Biological Sciences*) to the food-biotech and bio-pharma sector suffering a slight decline between 2000 and 2007, the research output of this important sector is underpinned by the convergence of recognised centres of research excellence that form an important public science base, along with a considerable group of international companies and spin-outs. The high visibility of this sector is also partially the result of the heavy publishing activity of bio-related companies (Cockburn & Henderson, 1998). The other two sets of top agglomerations are tightly related with either the South East or Scotland; the first is configured by an emerging private and multidisciplinary research base that is exploited by the physics and material engineering sector, while the latter is characterized by a considerable public research base focused on agro-biotechnology. The characteristics of both agglomerations also have been highlighted by Cooke (2001), while the slight decline in research of areas considered within food-biotechnology and bio-pharmacology may reflect the important weakening of the pharmaceutical industry in the UK and Europe (Rafols et al., 2012). The chronological trend followed by, at least, these three main agglomerations illustrates the potential influence of public strategy in the establishment of research units and partnerships within SPs as a way to support the emergence of new industries. Link and Scott (2003), also show how the historical development of SPs in the United States is influenced by public policies, promoting an early emergence of medical centres and aerospace technology that are then replaced by a biotechnology and biomedical industry. This policy-driven development may also be the reason for the difference between the subject areas distribution of the SP movement with those found among patenting off-park firms where *physics*, *engineering*, *clinical medicine*, *chemistry*, and *biomedical science* are the most popular fields, for example (Godin, 1996).

In terms of collaborative efforts, only a quarter of the output is the result of an inter-institutional collaboration, of which more than half is between HEIs/RIs and industry. This national rate of U-I collaboration is considerable low in comparison with the 34% found on the Hsinchu science park, for example (Hung, 2012). The significant involvement of the private sector in the research production related to physics and material engineering, in turn leads this domain to be the most successful in bridging the U-I gap and represents an attractive market niche for the commercialisation of academic R&T. The explanation for the active participation of industry in R&D activities in this domain is that industry needs to develop their own expertise in physics, while the life science sector relies more on external research (Godin, 1996). However, the central role of the public research infrastructure, mostly RIs, in the high visibility of the other two main domains (Food-biotechnology and bio-pharmacology, and Agro-biotechnology), seems to generate an unexpectedly low rate of U-I collaboration. Most RIs tend to have a lower publication average in comparison with Universities, as factors such as, human resources, value to publishing, and rewarding system differ between HEIs and RIs (Hayati & Ebrahimy, 2009; Noyons, Moed, & Luwel, 1999). In fact, the top position for the areas related to *Physics and Material engineering*, in terms of U-I collaboration, coincides with the study of Abramo and his colleagues (2009) who found that U-I collaboration in Italy is chiefly established in *Electronic and engineering*, outperforming other domains, such as *Chemistry* and *Agro-biotechnology*. The authors' explanation is the low level of development of the Italian industry, however this finding suggests that this domain is more likely to encourage a closer interaction between both sectors.

In terms of quality and impact, the publications of the SP movement have the quality to appear in leading journals and may have a slightly higher impact than the national average (not significant), being consistent with the higher quality (Cockburn & Henderson, 1998) and impact (Marston, 2011) of private research in biomedicine, for example. Thus, the observed quality and impact on the different fields do not seem to be related to each other, even though a journal's prestige is the most important factor for future impact in some science and technology areas (Bornmann & Daniel, 2007). The evidence suggests that the degree of impact, is determined by the public or private origin of the research. Hence, the regions with a greater public research base, such as the East of England and Scotland, have a higher impact on the research community, while those with a higher rate of private research, such as the South East, have less impact. In support of this, the output related to research oriented infrastructures and organisations (e.g. Research- campuses and Parks, and RIs) draws greater interest from the scientific community. This difference is also apparently linked to the applied nature of the research conducted by the private sector, and which has less scientific impact (Godin, 1996). This finding also reflects the distance between basic and applied research, as it is widely considered as one of the main interaction barriers between the public and private sectors (Bruneel, D'Este, & Salter, 2010). Thus, despite the private sector tending to establish collaborations with research leaders; they tend not to be able to publish their publication in top quality journals (Abramo et al., 2009), however this fact is partially contradicted as the on-park research in general have a significant higher quality. For this reason, the use of citations as a proxy to assess the quality of private research may not be suitable, as the diverse objectives of both communities from research differ in terms of intellectual and reputational goals, undermining to some extent the interest of private research in the actions of the scientific community.

Conclusions

This study draws on bibliographic data from at least one on-park organisation in the UK with the aim of expanding the knowledge of the SP movement as a whole. In particular, the focus has been on; (1) identifying the research areas that attract most of the on-park research and the contribution of the geographic regions and U-I collaboration across the different areas, and (2) finding out whether the quality and impact of the research production associated with SPs have a greater quality and impact than the average research.

In answer to the first goal, the findings reveal that the R&D activities are frequently generated in four subject areas: *Biochemistry, Genetics and Molecular Biology*, *Chemistry*, *Medicine*, and *Agricultural and Biological Sciences*, and the mass of research accumulated in the three top regions are characterised by; (1) public science-based research specialised in food-biotechnology and bio-pharmacology in the East of England, (2) private science-based research specialised in physics and material engineering in the South East, and (3) public science-based research specialised in the agro-biotech sector in Scotland. *Pharmacology*, *Engineering*, and *Materials Science* are the areas with the highest rate of private participation. The synergy expected within SPs is again questioned here as it is found that inter-institutional collaboration is only limited to a quarter of the output, of which more than half are U-I collaborations. The domain with the highest U-I interaction is private research-oriented physics and material engineering, while the rate of knowledge transference from the other two main domains seems to be punished for their high reliance on on-park RIs and then, their different approach to get involved into the research and dissemination process.

In answer to the second goal, the findings regarding the quality and impact of the output, reveal that in general on-park organisations publish in significantly higher quality journals, and that the research has similar impact to the national average. The relationship between quality and impact varies for the same research area, especially among the set of areas related to the three top domains and regions. A closer look at the impact produced by the regions, infrastructures, and organisations reveals that the closer the output is to HEIs and RIs the greater the impact, while the closer the output is to firms the lower the impact. This is a sign of the interaction barriers between the public and private sectors that are usually caused by the focus on either basic or applied research, which is also illustrated by the limited impact of the private research on the scientific community.

In conclusion, this study provides evidence that research impact is likely to be associated with the nature of the organisation producing the research rather than its relation to a physical intermediary infrastructure. The low level of interest in private research from the scientific community suggests that citation-based indicators may not be the best tools to assess the private research community and especially the academic research organisations, such as, schools, departments and RIs, which have built up strong links with industry. Furthermore, that important aspects, such as geographically high concentrations of on-park research activities, low U-I collaboration rates, and limited integration into the research community, question the idea of SPs as the catalysts behind a knowledge-based development across regions, and policy tools intended to support the transition from declining to innovative industries as a way of reducing the unequal distribution of research-intensive industry across the UK. Thus, this evidence is helpful for policy makers

in assessing the actual impact of policies and in guiding the directions of a more effective and realistic transfer policy for SPs and U-I collaboration in general.
An important limitation is that the results here are only indicative because although the main goal of SPs is to facilitate R&T transfer, formal research dissemination only uncovers part of this transference, and not all U-I interactions result in (co-authored) articles (Katz & Martin, 1997). Another important limitation is that it might not cover all the research generated within the SP movement due to the fact that not all on-park organisations mention the name of the infrastructures where they are based as part of their affiliation address. In addition, the rapid increase of the output over recent years can generate bias against part of the publications as they have less time to be cited. Similarly, the results could also favour the visibility of some research intensive industrial sectors where publications are more important. Finally, the identification of the research community associated with the SP movement allows qualitative studies that should disclose interesting insights into the real impact of support infrastructures on effective knowledge transfer. The central role of most RIs in supporting local industries makes it necessary to map their research performance and links with the private sector. There are also other interesting aspects of on-park research output which suggest that the development of the UK SP movement is characterised by a constant increase in the research production from the 90s with exponential growth since 2000. On the other hand, the coverage gap found in the WoS database suggests that the sources where industry in general is able to publish and interact with the wide scientific community might be less likely to be indexed in the WoS. It is therefore necessary to empirically examine the bias of this database against private research.

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