International Comparative Performance of the UK Research Base - 2011

A report prepared for the Department of Business, Innovation and Skills.

ELSEVIER

EXECUTIVE SUMMARY: INTERNATIONAL COMPARATIVE PERFORMANCE OF THE UK RESEARCH BASE - 2011

UK research is high-quality and efficient

The UK is a leading research nation in the world in terms of the number of articles that it publishes annually. It is also a leading research nation in the world in terms of the usage and citation of those articles, both of which indicate that its articles are high quality. While the UK has far fewer researchers than larger countries such as the US and China, as a country, it is far more efficient in terms of output per researcher: of the top five research nations (based on article output in 2010: US, China, UK, Japan, Germany), UK researchers generate more articles per researcher, more citations per researcher, and more usage per article authored as measured by global downloads of UK articles.

Similarly, while the UK spends far less in absolute terms on research than the US, China, Japan and Germany, recent trends indicate that it is becoming more efficient than all four in terms of output per unit spent. The UK is also becoming even more efficient over time in terms of output per researcher and per unit of research spend. The UK is the clear leader among all eight comparator countries (Canada, China, France, Germany, Italy, Japan, UK, US) on citations per unit spend on Gross Expenditure on Research & Development (GERD).

The UK's volume of articles published has grown by 2.9% per year since 2006, which is lower than the world average growth of 4% per year. As a result the UK's share of articles published declined slightly from 6.7% in 2006 to 6.4% in 2010. Conversely, in the same period citations to UK articles increased at 7.2% per year, faster than the world average of 6.3% per year. As a result the UK's share of global citations increased from 10.5% to 10.9%. The UK's share of the world's top 1% of most highly cited papers, which indicates its share of the highest quality published research, was 13.8% in 2010, 2nd only to the US.

The UK's field-weighted citation impact, an indicator of quality that adjusts for differing citation practices in different subject fields and therefore of the different subject emphases of comparator countries, is 2nd only to and closing in on the US among the comparator group. Within the UK, its constituent countries reflect the UK's overall positive trend in field-weighted citation, while Scotland shows a modest increase in article share relative to England, Wales and Northern Ireland.

UK research is mobile and international

The UK researcher population is highly mobile internationally: almost 63% of researchers that are or have been affiliated with UK institutions have also published articles while working at institutions outside the UK. Researchers who have returned to the UK after an extended time abroad are significantly more productive in terms of articles published than those who have never left the UK. The UK's leading position in terms of research efficiency is therefore in part due to its effectiveness in attracting productive and internationally mobile researchers to work in the UK, both those that began their research careers in the UK and those that began them elsewhere.

While the UK's researcher population is growing more slowly than the global average, it is fluid, dynamic and internationally collaborative: nearly 31% of all researchers that published work while affiliated with UK institutions during the period from 1996-2010 stayed in the UK for less than two years before moving abroad. These researchers, who were also more productive than average, were primarily senior and most often came from the US.

The proportion of UK researchers that publish articles with non-UK researchers is high and rising, reaching 46% in 2010. This proportion is far higher than in most other research-intensive nations and also accounts for the UK's high number of citations per researcher, because articles that have co-authors residing in more than one country are more highly cited. UK-based researchers' ability to move internationally and to collaborate with non UK researchers are therefore key drivers of the UK's leading global position in terms of research efficiency. Countries that the UK collaborates with also publish high-quality research which benefits those countries and the UK.

This document is an executive summary of the report that was commissioned by the UK's Department of Business, Innovation and Skills (BIS) to assess the performance of the United Kingdom's (UK) research base across multiple indicators compared with other research-focussed nations. The full report is available on the BIS website: http://www.bis.gov.uk

UK research is well-rounded

The UK's Activity Index (i.e. outputs of research papers) reveals the disciplinary emphasis of its research efforts versus the global average. Relative to the world average, the UK has generally a well rounded portfolio, with a strong and increasing emphasis in clinical sciences, health & medical sciences, social sciences, business and humanities. In the biological sciences and environmental science the UK's publishing activity, although relatively strong, fell back closer to the world average from 2000 to 2010. In mathematics, physical sciences and engineering the UK has a lesser focus, although its articles in these fields are cited considerably more than the global average. The UK's field-weighted citation impact shows the UK to perform better than the world average in all subject fields. Moreover, the UK's strong citation performance relative to the world average grew in all disciplines over the period 2000 to 2010.

UK research has mixed performance in knowledge transfer

In contrast to the UK's leading position in terms of articles published, and the usage and citations of those articles, UK researchers have a low and declining share of patents compared with other research-intensive nations. This probably reflects the relatively lower research spend in business enterprise as a proportion of UK research spend (GERD) compared to countries where patenting activity is high. While UK researchers move freely between the academic and corporate sectors, the UK's proportion of articles that are co-authored by researchers in both academic and corporate sectors is relatively low (1.3%) compared to other major countries. However, high usage by R&D-intensive corporations of articles authored by academic researchers suggests a productive knowledge flow between academic and corporate sectors.

UK research has some potential areas of vulnerability

While the UK is a world leader in terms of article and citation output per researcher and per unit of spend, its leadership position may be threatened by its declining share of researchers globally, and by its declining share of global spending on research. For while the number of UK researchers and the UK's spending on research are both growing in absolute terms, the growth rates of both are being outstripped by the growth rate of the global averages.

There are over four hundred niche areas of research in which the UK is distinctively strong. However, interviews with leading researchers in selected areas of strength (cognitive neuroscience, ecology, computer science, languages and education) revealed concerns about the difficulty of recruiting high quality post-graduate students. While thus far the UK has been highly effective in developing domestic and attracting non-domestic researchers, it is potentially at risk of falling behind relative to other research-intensive nations, especially when the relatively low underlying growth in the population and labour force are considered. Inability to develop, attract and retain enough researchers may have negative consequences for national R&D capacity.

In terms of spending on research, UK GERD is increasing but also remains below that of several key comparator countries both proportionally and in absolute terms. The UK's world share of GERD fell from 3.7% in 2006 to 3.0% in 2010. By contrast, China's share increased from 8.9% to 13.3% over the same period. Inability to sustain R&D spending at levels comparable to the global average may also have consequences for the UK's future research performance relative to other countries.

Summary

The UK is a world leader in research, and is a world leader in terms of article and citation output, both per researcher and per unit of research spending. However, the global landscape of research is fluid, dynamic and intensely competitive. Other countries are outpacing the UK in terms of growth in number of researchers and spending on research. The UK is well positioned, but its ability to sustain its leadership position is far from inevitable.

CONTENTS

INTRODUCTION AND KEY FINDINGS

This report has been commissioned by the UK's Department of Business, Innovation and Skills (BIS) to assess the performance of the United Kingdom's (UK) research base compared with seven other research-intensive countries (Canada, China, France, Germany, Italy, Japan, and the US), and, where data are available, with the EU27, the Organisation for Economic Co-operation and Development (OECD) member countries' groups, and three other fast growing nations (Brazil, Russia and India)[1]. It tracks investment and performance in the national research system in an international setting, combining bibliometric and other research measures across 22 international indicators to present a multifaceted view of the UK's comparative performance in research as well as the trends that may affect its position.

The main themes were explored through data analyses, literature reviews and researcher interviews. Themes pertain to research inputs such as R&D expenditures and human capital (including number of researchers, mobility and collaboration), and research outputs such as published articles, data about the citations and usage of those articles, and patents. Efficiency of research, such as output per researcher or per unit spend on research, is also a key theme.

We chose five highly specific sub-fields of research out of over 400 where the UK is strong. In each case, five to seven leading researchers were interviewed to gain insights about the area of research, why it became a UK strength, and what researchers say is required to sustain and develop that strength. Short summaries of these interviews appear throughout the report as *UK Strength Case Studies* and are intended to complement with more qualitative perspectives the quantitative analyses of UK inputs and outputs.

The UK has long held a leading position in the global research landscape. It is home to some of the oldest and most prestigious learned societies in the sciences (including the Royal Society, founded in 1660) and the social sciences and humanities (such as the British Academy, founded in 1902), and has produced some of the greatest thinkers of the last millennium.

Recent years have seen a dramatic shift in the research focus of emerging countries like China and Brazil as well as continued investment in science across traditional research-centric countries like Germany, France and the US. This report examines, within this context, how UK research compares internationally, and what trends may affect the UK's future standing in key areas such as research output, knowledge transfer, human capital and productivity.

1.1. Data Sources and Methodology

The majority of data presented in this report are derived from OECD (R&D expenditure and human capital), Scopus (articles and citations), and WIPO (patent applications). All three data sources aggregate information from a large number of disparate primary sources and as such, missing values and discrepancies in the data are to be expected. Please see Appendix C: Data Sources for additional detail about data sources used, and for a discussion of the limitations of data sources. Comparator countries are defined consistently across all data sources: a grouping of G7 (plus China) for charting, and G8, EU27 and OECD member countries as benchmarks. Standard ISO 3-character country codes are used throughout for visual clarity where required *(Table 1.1)*.

Table 1.1. Countries in this report and their ISO 3-character code.

Country	ISO 3-character code	Comparator Group
Brazil	BRA	
Canada	CAN	✓
China	CHN	✓
France	FRA	✓
Germany	DEU	✓
India	IND	
Italy	ITA	✓
Japan	JPN	✓
Russia	RUS	
United Kingdom	GBR (UK used throughout this report)	✓
United States	USA	✓

[1] For a full listing, see Appendix D: Countries Included in Data Sources. OECD membership is restricted to 34 countries. In this report the OECD data also include non-member countries Argentina, China, Romania, Russian Federation, Singapore, South Africa, and Chinese Taipei.
[2] Researcher as defined by the Frascati Manual (2002) *Proposed Standard Practice for Surveys on Research and Experimental Development.* OECD Publishing.

1.2. Key Findings

UK research is high-quality and efficient: The UK is a leading research nation in the world in terms of the number of articles that it publishes annually. It is also a leading research nation in the world in terms of the usage and citation of those articles, both of which indicate that its articles are high quality. While the UK has far fewer researchers *(Figure 1.1A)* than larger countries such as the US and China, as a country, it is far more efficient in terms of output per researcher: of the top five research nations (based on article output in 2010: US, China, UK, Japan, Germany), UK researchers generate more articles per researcher, more citations per researcher, and more usage per article authored as measured by global downloads of UK articles; *(Figure 1.1B).*

Similarly, while the UK spends far less in absolute terms on research than the US, China, Japan or Germany, recent trends indicate that it is becoming even more efficient than all four in terms of output per unit spent *(Figure 1.1C).* The UK is also becoming more efficient over time in terms of output per researcher and per unit of research spend. The UK is the clear leader among all eight comparator countries (Canada, China, France, Germany, Italy, Japan, UK, US) on citations per unit spend on Gross Expenditure on Research & Development (GERD; *Figure 6.4).*

The UK's volume of articles published has grown by 2.9% per year since 2006, which is lower than the world average growth of 4% per year. As a result the UK's share of articles published declined slightly from 6.7% in 2006 to 6.4% in 2010 *(Figure 4.1).* Conversely, in the same period citations to UK articles increased at 7.2% per year, faster than the world average of 6.3% per year. As a result the UK's share of global citations increased from 10.5% to 10.9% *(Figure 4.4).* The UK's share of the world's top 1% of most highly cited papers, which indicates its share of the highest quality published research, was 13.8% in 2010, 2nd only to the US *(Figure 4.9).*

The UK's field-weighted citation impact, an indicator of quality that adjusts for differing citation practices in different subject fields and therefore of the different subject emphases of comparator countries, is 2nd only to (and closing in on) the US among the comparator group *(Figures 1.2A and 4.7).* Within the UK, its constituent countries reflect the UK's overall positive trend in field-weighted citation, while Scotland shows a modest increase in article share relative to England, Wales and Northern Ireland *(Figure 4.2).*

UK research is mobile and international: The UK researcher population is highly mobile internationally: almost 63% of researchers that are or have been affiliated with UK institutions have also published articles while working at institutions outside the UK *(Figure 3.3).* Researchers who have returned to the UK after an extended time abroad are significantly more productive in terms of articles published than those who have never left the UK *(Figure 3.3).* The UK's leading position in terms of research efficiency is therefore in part due to its effectiveness in attracting productive and internationally mobile researchers to work in the UK, both those that began their research careers in the UK, and those that began them elsewhere.

While the UK's researcher population is growing more slowly than the global average, it is fluid, dynamic and internationally collaborative: nearly 31% of all researchers that published work while affiliated with UK institutions during the period from 1996-2010 stayed in the UK for less than two years before moving abroad. These researchers, who were also more productive than average, were primarily senior and most often came from the US *(Figure 3.3).*

The proportion of UK researchers that publish articles with non-UK researchers is high and rising, reaching 46% in 2010. This proportion is far higher than in most other research-intensive nations *(Figure 5.1)* and also accounts for the UK's high number of citations per researcher, because articles that have co-authors residing in more than one country are more highly cited. UK-based researchers' ability to move internationally and to collaborate with non UK researchers are therefore key drivers of the UK's leading global position in terms of research efficiency. Countries that the UK collaborates with also publish high-quality research which benefits those countries and the UK.

UK research is well-rounded: The UK's Activity Index[3] (i.e. outputs of research papers) reveals the disciplinary emphasis of its research efforts versus the global average.

[3] Hu, X. & Rousseau, R. (2009) "A comparative study of the difference in research performance in biomedical fields among selected Western and Asian countries" *Scientometrics* 81(2) pp. 475-491.

Relative to the world average, the UK has generally a well rounded portfolio, with a strong and increasing emphasis in clinical sciences, health & medical sciences, social sciences, business and humanities *(Figure 4.3)*. In the biological sciences and environmental science the UK's publishing activity, although relatively strong, fell back closer to the world average from 2000 to 2010. In mathematics, physical sciences and engineering the UK has a lesser focus, although its articles in these fields are cited considerably more than the global average. The UK's field-weighted citation impact shows the UK to perform better than the world average in all subject fields. Moreover, the UK's strong citation performance relative to the world average grew in all disciplines over the period 2000 to 2010 *(Figure 4.4)*.

UK research has mixed performance in knowledge transfer: In contrast to the UK's leading position in terms of articles published, and the usage and citations of those articles, UK researchers have a low and declining share of patents compared with other research-intensive nations *(Figure 7.1)*. This probably reflects the relatively lower research spend in business enterprise as a proportion of UK research spend (GERD) compared to countries where patenting activity is high. While UK researchers move freely between the academic and corporate sectors, the UK's proportion of articles that are co-authored by researchers in both academic and corporate sectors is relatively low (1.3%) compared to other major countries (see Appendix F: Supplementary Data, section 7). However, high usage by R&D-intensive corporations of articles authored by academic researchers suggests a productive knowledge flow between academic and corporate sectors *(Figure 7.8)*.

UK research has some potential areas of vulnerability: While the UK is a world leader in terms of article and citation output per researcher and per unit of spend, its leadership position may be threatened by its declining share of researchers globally, and by its declining share of global spending on research.

For while the number of UK's researchers and the UK's spending on research are both growing in absolute terms, the growth rates of both are being outstripped by the growth rate of the global averages *(Figure 1.3)*.

There are over four hundred niche areas of research in which the UK is distinctively strong. However, interviews with leading researchers in selected areas of strength (cognitive neuroscience, ecology, computer science, languages and education) revealed concerns about the difficulty of recruiting high quality post-graduate students. While thus far the UK has been highly effective in developing domestic and attracting non-domestic researchers, it is potentially at risk of falling behind relative to other research-intensive nations, especially when the relatively low underlying growth in the population and labour force are considered *(Figures 3.1, 3.2)*. Inability to develop, attract and retain enough researchers may have negative consequences for national R&D capacity[4].

In terms of spending on research, UK GERD is increasing but also remains below that of several key comparator countries both proportionally and in absolute terms. The UK's world share of GERD fell from 3.7% in 2006 to 3.0% in 2010. By contrast, China's share increased from 8.9% to 13.3% over the same period *(Figure 1.4)*. Inability to sustain R&D spending at levels comparable to the global average may also have consequences for the UK's future research performance relative to other countries.

Summary: The UK is a world leader in research, and is the world leader in terms of research efficiency per researcher and per unit of spending on research. However, the global landscape of research is fluid, dynamic and intensively competitive. Other countries are outpacing the UK in terms of growth in number of researchers and spending on research. The UK is well positioned, but its ability to sustain its leadership position is far from inevitable.

[4] Universities UK (July 2007) "Policy Briefing: Talent wars: the international market for academic staff". Available at http://www.universitiesuk.ac.uk/Publications/Documents/Policy%20Brief%20Talent%20Wars.pdf.

Figure 1.1. Radar charts of key input and output indicators for the UK and key comparators.

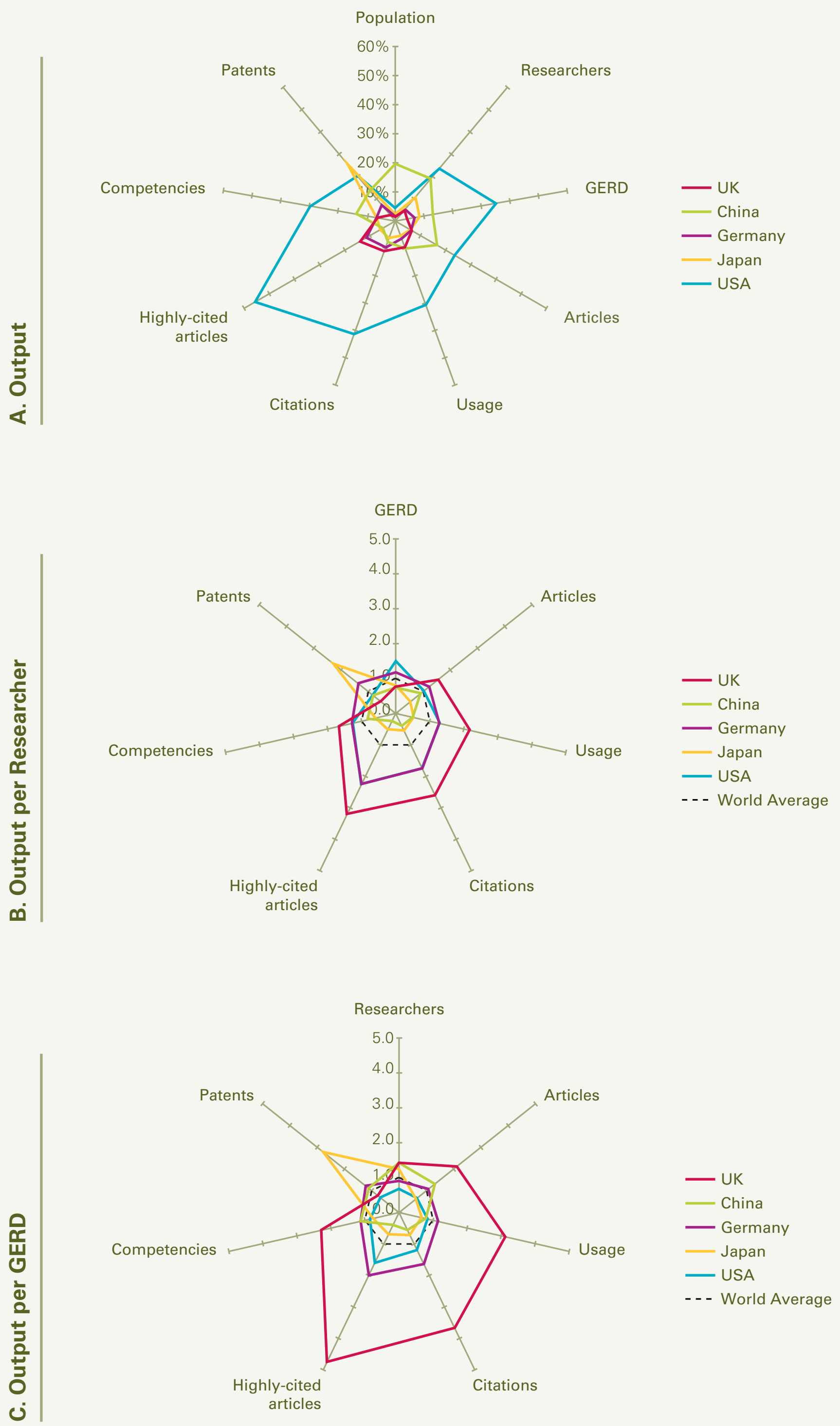


Figure 1.1 Radar charts of key input and output indicators for the UK and key comparators. **Panel A**: All data are expressed as worldz v share. **Panel B**: All data are expressed as world share divided by world share of researchers, giving a relative index that is normalised for each country's human capital input. A value of 1.0 implies that per researcher the outcome is equal to the world average. **Panel C**: All data are expressed as world share divided by world share of GERD, giving a relative index that is normalised for each country's R&D funding input. A value of 1.0 implies that per unit spend of GERD spent the outcome is the same as the world average. Sources: OECD MSTI: all population data 2010, all research data 2009, all GERD data 2010 except Germany (2009), with extrapolation where appropriate and where World totals are the sum of data for all countries with available data. WIPO Statistics Database: all patents data 2009. Scival Spotlight: all Competencies data 2010. Scopus: all Articles, Citations and Highly-cited articles data 2010. ScienceDirect: all Usage data 2010.

Figure 1.2A Changes in field-weighted citation impact and article share for UK and comparator countries (2006-2010).

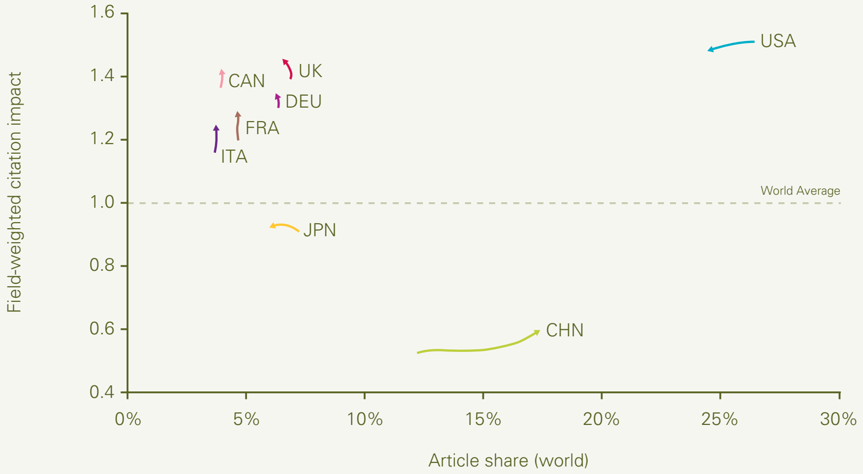


Figure 1.2B Changes in UK field-weighted citation impact and article share by disciplines (2000-2010).

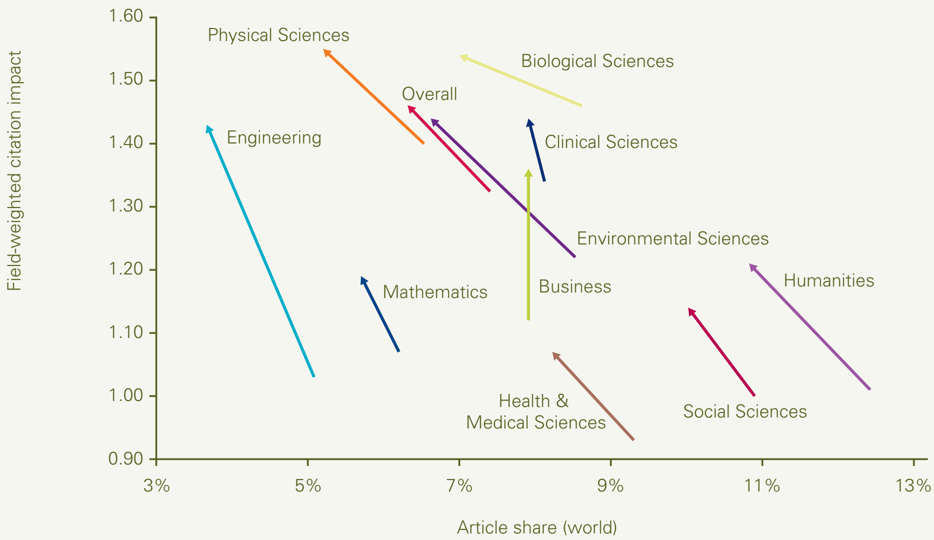


Figure 1.2C Changes in field-weighted citation impact and article share for UK constituent countries (2006-2010).

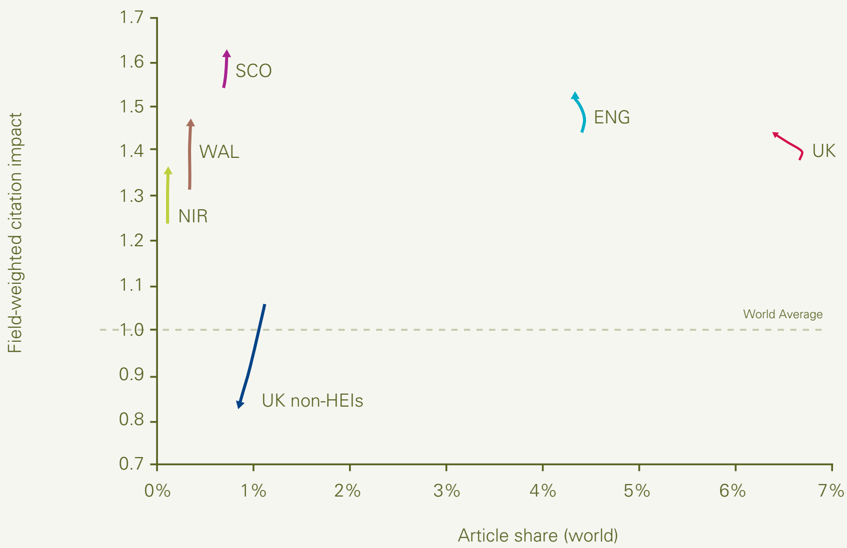


Figure 1.2 Changes in UK field-weighted citation impact shown by country, discipline and constituent countries. 2006-2010. Constituent countries (England = ENG, Scotland = SCO, Wales = WAL, Northern Ireland = NIR) data is for higher education institutions only (HEIs). UK data includes both HEIs and non-HEIs. The latter could not unambiguously be assigned to constituent countries. HEIs represent approximately 80% of UK articles published. Source: Scopus. Canada = CAN; China = CHN; France = FRA; Germany = DEU; Italy = ITA; Japan = JPN; United Kingdom = UK, United States = USA.

Figure 1.3: Changes in key input and output indicators for the UK and key comparators.

A: Changes in count (actual numbers) and world shares.

Counts	UK				China				Germany				Japan				US			
	2006	2010	Change	CAGR	2006	2010	Change	CAGR	2006	2010	Change	CAGR	2006	2010	Change	CAGR	2006	2010	Change	CAGR
Population	60.6m	62.3m	1.7m	0.7%	1.32b	1.35b	33.4m	0.6%	82.4m	82.8m	0.5m	0.1%	127.8m	127.2m	-0.6m	1.0%	298m	310m	11.8m	1.0%
Researchers	249k	256k	7.5k	0.7%		1.15m			272k	312k	39k	3.4%	681k	659k	-22k	1.3%	1.38m	1.45m	72k	1.3%
GERD (US$)	31.2b	32.2b	1.0b	0.8%	75.0b	144b	68.6b	17.6%	54.6b	62.4b	7.8b	3.4%	120b	94.7b	-25.7b	6.1%	299b	379b	80.2b	6.1%
Articles	110k	124k	13k	2.9%	198k	331k	133k	13.7%	102k	118k	15k	3.6%	117k	112k	-5k	1.9%	432k	465k	34k	1.9%
Usage	40m	100m	60m	25.9%	25m	105m	80m	43.5%	29m	70m	41m	25.0%	29m	62m	33m	25.4%	132m	327m	195m	25.4%
Citations	2.62m	3.46m	0.84m	7.2%	0.94m	2.43m	1.49m	26.9%	2.31m	2.97m	0.65m	6.4%	1.91m	2.08m	0.17m	4.4%	11.1m	13.2m	2.10m	4.4%
Highly-cited articles	9.1k	12.5k	3.4k	8.4%	1.5k	4.4k	3.0k	31.4%	7.7k	10.3k	2.6k	7.5%	4.7k	5.4k	0.7k	4.0%	42.7k	49.9k	7.2k	4.0%
Competencies		418				885				396				398				1817		
Patents	40.5k	37.6k	-2.9k	-1.8%	97.6k	240.3k	142.7k	25.3%	125.7k	118.4k	-7.2k	-1.5%	524.4k	423.3k	-101.1k	-1.9%	366.3k	339.5k	-26.8k	-1.9%

World share (%)	2006	2010	Change	CAGR	2006	2010	Change	CAGR	2006	2010	Change	CAGR	2006	2010	Change	CAGR	2006	2010	Change	CAGR
Population	0.9%	0.9%	0.0%	-0.5%	20.0%	19.6%	0.0%	-0.5%	1.2%	1.2%	-0.1%	-1.0%	1.9%	1.8%	-0.1%	-1.3%	4.5%	4.5%	0.0%	-0.2%
Researchers	4.4%	4.2%	-0.2%	-0.9%		18.9%			4.8%	5.1%	0.3%	1.7%	11.9%	10.8%	-1.1%	-2.4%	24.1%	23.8%	-0.4%	-0.4%
GERD (US$)	3.7%	3.0%	-0.7%	-5.4%	8.9%	13.3%	4.3%	10.4%	6.5%	5.8%	-0.7%	-2.9%	14.3%	8.8%	-5.6%	-11.6%	35.5%	35.0%	-0.5%	-0.4%
Articles	6.7%	6.4%	-0.3%	-1.1%	11.9%	17.1%	5.1%	9.4%	6.2%	6.1%	-0.1%	-0.4%	7.1%	5.8%	-1.3%	-4.9%	26.1%	24.0%	-2.0%	-2.0%
Usage	10.0%	9.4%	-0.6%	-1.4%	6.2%	9.9%	3.7%	12.3%	7.1%	6.6%	-0.6%	-2.1%	7.3%	5.9%	-1.4%	-5.3%	33.1%	30.7%	-2.3%	-1.8%
Citations	10.5%	10.9%	0.4%	0.9%	3.8%	7.6%	3.9%	19.4%	9.3%	9.3%	0.1%	0.1%	7.7%	6.6%	-1.1%	-3.8%	44.4%	41.4%	-3.0%	-1.7%
Highly-cited articles	12.3%	14.0%	1.7%	3.3%	2.0%	5.0%	3.0%	25.3%	10.4%	11.5%	1.1%	2.5%	6.4%	6.0%	-0.4%	-1.4%	57.6%	55.8%	-1.7%	-0.8%
Competencies		6.8%				14.4%				6.5%				6.5%				29.7%		
Patents	2.4%	2.2%	-0.2%	-1.8%	5.8%	14.3%	8.5%	25.3%	7.5%	7.0%	-0.4%	-1.5%	31.1%	25.1%	-6.0%	-5.2%	21.8%	20.2%	-1.6%	-1.9%

B: Changes in productivity measures.

World share per researcher (Relative Index)	UK				China				Germany				Japan				US			
	2006	2010	Change	CAGR	2006	2010	Change	CAGR	2006	2010	Change	CAGR	2006	2010	Change	CAGR	2006	2010	Change	CAGR
Population																				
Researchers																				
GERD (US$)	0.85	0.71	-0.14	-4.5%		0.70			1.36	1.13	-0.23	-4.6%	1.20	0.81	-0.39	-9.4%	1.47	1.47	0.00	0.0%
Articles	1.53	1.52	-0.01	-0.2%		0.90			1.29	1.19	-0.10	-2.1%	0.59	0.53	-0.06	-2.5%	1.08	1.01	-0.07	-1.6%
Usage	2.28	2.24	-0.05	-0.5%		0.52			1.50	1.28	-0.21	-3.8%	0.61	0.54	-0.07	-2.9%	1.37	1.29	-0.08	-1.5%
Citations	2.40	2.58	0.18	1.8%		0.40			1.94	1.82	-0.12	-1.6%	0.64	0.61	-0.04	-1.4%	1.84	1.74	-0.10	-1.4%
Highly-cited articles	2.82	3.33	0.51	4.2%		0.26			2.18	2.25	0.07	0.8%	0.53	0.56	0.02	1.0%	2.39	2.35	-0.04	-0.4%
Competencies		1.62				0.76				1.26				0.60				1.25		
Patents	0.55	0.53	-0.02	-0.9%		0.75			1.56	1.37	-0.19	-3.2%	2.61	2.32	-0.28	-2.8%	0.90	0.85	-0.05	-1.5%

World share per GERD (Relative Index)	2006	2010	Change	CAGR	2006	2010	Change	CAGR	2006	2010	Change	CAGR	2006	2010	Change	CAGR	2006	2010	Change	CAGR
Population																				
Researchers	1.18	1.41	0.24	4.7%		1.43			0.73	0.89	0.15	4.8%	0.83	1.23	0.40	10.3%	0.68	0.68	0.00	0.0%
GERD (US$)																				
Articles	1.80	2.14	0.35	4.5%	1.34	1.29	-0.05	-0.9%	0.95	1.06	0.10	2.7%	0.49	0.66	0.17	7.6%	0.73	0.69	-0.05	-1.6%
Usage	2.68	3.16	0.48	4.2%	0.69	0.74	0.05	1.7%	1.10	1.14	0.04	0.9%	0.51	0.67	0.16	7.1%	0.93	0.88	-0.05	-1.5%
Citations	2.82	3.65	0.83	6.6%	0.42	0.57	0.15	8.1%	1.43	1.62	0.19	3.2%	0.53	0.75	0.21	8.8%	1.25	1.18	-0.07	-1.4%
Highly-cited articles	3.31	4.70	1.39	9.2%	0.23	0.38	0.15	13.5%	1.60	2.00	0.39	5.6%	0.45	0.69	0.24	11.5%	1.62	1.59	-0.03	-0.4%
Competencies		2.29				1.09				1.12				0.74				0.85		
Patents	0.65	0.75	0.10	3.8%	0.65	1.07	0.43	13.5%	1.15	1.22	0.07	1.5%	2.17	2.87	0.70	7.2%	0.61	0.58	-0.04	-1.5%

-5 -1 +1 +5

Figure 1.3 Dashboard representation of key input and output indicators for the UK and key comparators. All data are for 2006 and 2010, and the absolute change and compound annual growth rate (CAGR) between them, except for all researchers and patents data and the values for GERD for Germany, which are for 2005 to 2009. **Panel A**: All data are expressed as counts or world share. **Panel B**: All data are expressed as world share divided by world share of researchers or world share of GERD, giving a relative index that is normalised for each country's human capital or R&D funding input. A value of 1.0 implies that per researcher or per unit spend of GERD is equal to the world average. No researcher trend data are shown for China owing to a rebasing of these figures in 2009 in the OECD data. Source: As per Figure 1.1.

RESEARCH INPUTS

RESEARCH INPUTS

2.1. R&D Expenditures

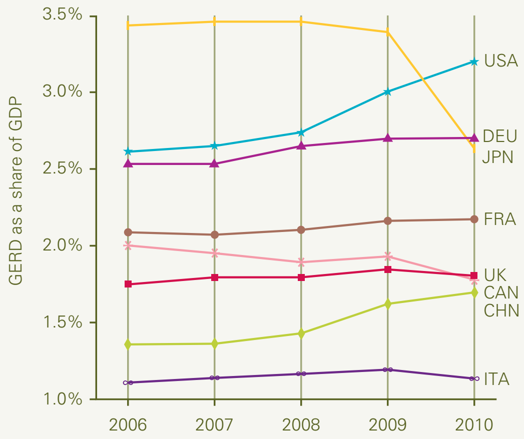
R&D expenditures are a key driver of research output. While countries vary in the efficiency and quality of their research output, Gross Expenditure on R&D (GERD), measured as a share of the country's Gross Domestic Product (GDP), is the measure also known as research intensity. The global financial crisis of 2008, however, has affected investment in R&D in most key countries in terms of both total GERD and the portions allocated to government, business enterprise, and higher education R&D sectors. The approach to R&D expenditures since 2008 has varied considerably by country, with the UK's investment remaining static as a percent of GDP, albeit with continuing focus on support to the academic sector *(Figure 2.1)*.

2.2. Key Findings

UK GERD is increasing but remains below that of several key comparator countries both proportionally and in absolute terms.

- The UK's GERD in 2010 was $32.2 billion[5].
- R&D intensity (GERD as a share of GDP) is a long-standing and widely-used metric for comparing the level of investment in research between countries[6]. The UK's R&D intensity was 1.8% in 2010.
- While growing modestly, the UK's R&D intensity remains below that of several key comparator countries and international benchmarks *(Figure 1.4; Figure 2.1)*. For example: in 2010, the UK ranked 5th among the G8 and the comparator group, below the G8 average of 2.4%; among all OECD countries, the UK ranked 16th, below the OECD average of 2.7%.
- In the period 2006-2010, the UK's R&D intensity increased on average by 1.1% per year, higher than the G8 average of -0.2% due mainly to a large decline in Japan, but below the annual growth of 1.5% on average across the EU27 and 4.6% for the OECD countries.
- The UK's Higher Education R&D (HERD) as a proportion of GERD, at almost 28%, is greater than that of all but one of the comparator countries (Canada).

Figure 2.1 R&D intensity (GERD as a share of GDP) for UK and comparators, 2006-2010.



	2006	2010	Change 06-10	CAGR 06-10	UK Rank 2006	UK Rank 2010
UK	**1.75%**	**1.82%**	**0.08%**	**1.07%**		
G8	2.41%	2.39%	-0.02%	-0.21%	6	5
EU27	1.78%	1.89%	0.11%	1.45%	9	10
OECD	2.25%	2.69%	0.44%	4.61%	17	16

G8: All 8 countries with available data (including Germany, for which the 2010 datapoint was assumed equal to 2009 for ranking purposes)

EU27: 21 (of 27) countries with available data (including Germany, for which the 2010 datapoint was assumed equal to 2009 for ranking purposes)

OECD: 38 (of 42) countries with available data (including Germany, for which the 2010 datapoint was assumed equal to 2009 for ranking purposes)

Figure 2.1 R&D intensity (GERD as a share of GDP) for UK and comparators, 2006-2010. For Germany, the 2010 data-point was assumed equal to that of 2009 for charting purposes. Source: OECD MSTI, with extrapolation where appropriate. Japan's R&D intensity dropped to 2.72% in 2010 (from 3.37% in 2009) as GDP rose sharply while GERD continued its recent decline.

[5] Financial data are given in constant US$ at 2000 prices and corrected for Purchasing Power Parity (PPP), allowing comparability over time and between countries.
[6] Godin, B. (2003) "The most cherished indicator: Gross Domestic Expenditure on R&D (GERD)" *Project on the History and Sociology of S&T Statistics*, Working Paper No. 22, Canadian Science and Innovation Indicators Consortium.

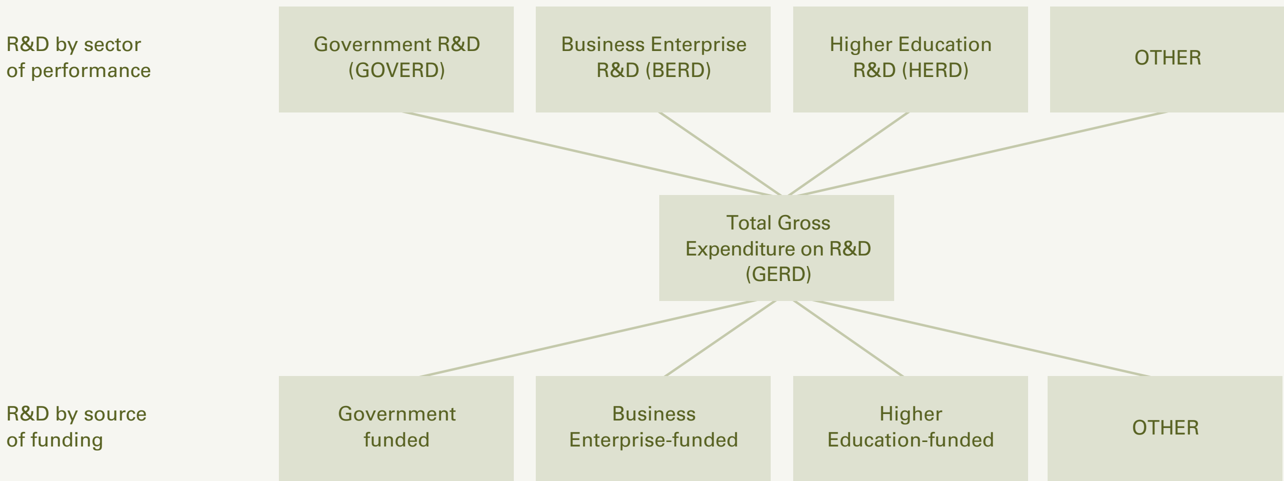
2.3. R&D Expenditures: Discussion

It has been suggested that the UK's relatively low R&D intensity, compared to other G8 countries, is due to a lack of large firms based in the UK, which are the major performers of business R&D. However, this has been shown not to be the case[7]. Instead, differences in R&D intensity between countries appear to reflect differences in their specialisation in R&D-intensive industries (such as pharmaceuticals, biotech, engineering and information & communication technologies industries)[8].

Research and development can be viewed through the lens of the 'performing sector', or the 'funding sector', that is carrying out the research' *(Figure 2.2)*. The distribution of GERD gives an important perspective on the emphasis placed on different types of R&D within a country, and so helps to explain the relative distribution of outputs from the R&D system as a whole.

In terms of R&D by sector of performance, the composition of GERD in the UK differs from that of several key comparator countries. The UK's Higher Education R&D (HERD) as a proportion of GERD, at almost 28%, is greater than that of all but one of the comparator countries (Canada) and is significantly higher than the G8 and EU27 averages *(Figure 2.3)*. It is possible that this reflects the UK's longstanding emphasis on university-centred research[10].

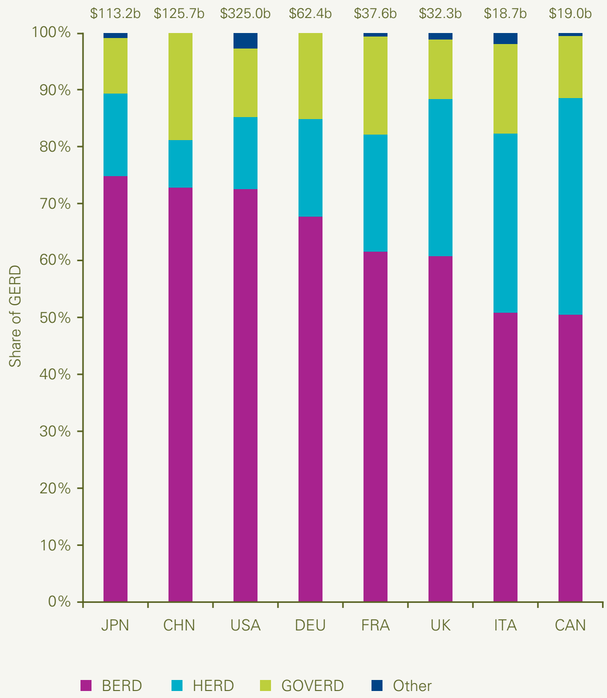
Figure 2.2 The distinction between performing and funding sector in establishing the composition of GERD.[9]



[7] Bulli, S. (2008) "Business Innovation Investment in the UK". Available at http://www.bis.gov.uk/assets/biscore/corporate/migratedd/publications/b/businessinnovationuk.pdf.
[8] van Pottelsberghe de la Potterie, B. (2008) "Europe's R&D: Missing the wrong targets?" *Bruegel Policy Brief*, Issue 2008/03.
[9] Adapted from Table 6.1 of the Frascati Manual (2002) *Proposed Standard Practice for Surveys on Research and Experimental Development*. OECD Publishing. This simplified chart shows only the main sources of funding and sectors of performance typical in most countries.
[10] The Haldane Report (1918) recommended that government departments should oversee only that research meeting the specific needs of those departments and that all other research should be under the control of autonomous Research Councils the first of which, the Medical Research Council, was created by Royal Charter in 1920. See also Hume, L.J. (1958) "The Origins of the Haldane Report" *Australian Journal of Public Administration* 17(4) pp. 344–352. The UK government position has been recently clarified in "The allocation of science and research funding, 2011/12 to 2014/15: Investing in world-class science and research" (December 2010), available at http://www.bis.gov.uk/assets/biscore/science/docs/a/10-1356-allocation-of-science-and-research-funding-2011-2015.pdf.

Conversely, Business Enterprise R&D (BERD), often considered a driver of short-term economic growth[11], stands at just 60% of GERD in the UK and is lower than that of all comparator countries (except Canada) and of the G8 average (but similar to the EU27 average). It has been suggested that this relates, at least in part, to diminished defence R&D expenditures in the UK in recent decades[12]. There is as yet no clear consensus on whether public expenditure on R&D (i.e. GOVERD+HERD) within a country acts as a complement to or a substitute for private sector R&D (i.e. BERD), or if this has a "crowding out" effect[13]. The UK's pattern of GERD expenditure distribution may, at least in part, explain its relative strength in productivity in terms of more "academic" research outputs such as publications and citations and its relative weakness in terms of technology outputs such as patents[14].

Figure 2.3. R&D by sector of performance for UK and comparators.



	Year	HERD	BERD	GOVERD	Other
UK	**2009**	**27.9%**	**60.4%**	**9.2%**	**2.5%**
G8	2009	15.5%	67.2%	5.3%	12.0%
EU27	2009	24.3%	60.8%	13.6%	1.3%

G8 BERD and GOVERD use 2008 datapoints for the USA

Figure 2.3. R&D by sector of performance for UK and comparators. For all countries, Other was estimated by subtraction. Values above bars are shown in billions of US dollars. The most recent complete data are used for each country, such that data are for 2009 in all countries except USA (2008) and Canada (2010). Source: OECD MSTI.

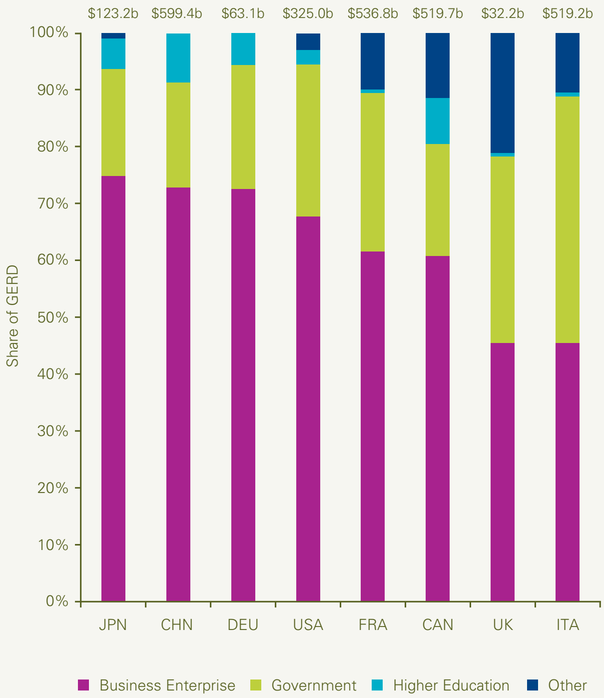
[11] Bloom, N. & Griffith, R. (2001) "The Internationalisation of UK R&D" *Fiscal Studies* 22(3) pp. 337–355.

[12] OECD (2003) "Steering and funding of research institutions. Country report: UK". Available at http://www.oecd.org/dataoecd/24/35/2507946.pdf.

[13] David, P.A., Hall, B.H., Toole, A.A. (2000) "Is public R&D a complement or substitute for private R&D? A review of the econometric evidence" *Research Policy* 29(4-5) pp. 497-529.

[14] Shelton, R.D. & Leydesdorff, L. (2009) "Publish or Patent: Bibliometric evidence for empirical trade-offs in national funding strategies". Available at http://arxiv.org/abs/1102.3047; Shelton, R.D. & Ali, H.B. (2011) "Scientometric Secrets of Efficient Countries: Turkey, Greece, Poland, and Slovakia". Available at itri2.org/lpaper/lpaper.doc.

Figure 2.4. R&D by source of funds for UK and comparators.



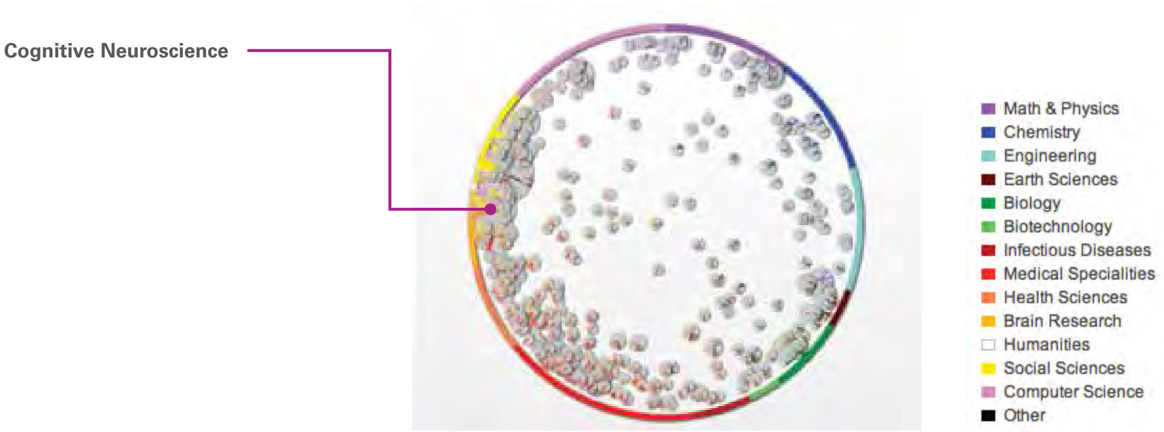
	Year	Higher Education	Business Enterprise	Government	Other
UK	**2010**	**1.2%**	**45.3%**	**30.6%**	**22.9%**
G8	2008	3.2%	65.0%	27.5%	4.4%

Figure 2.4. R&D by source of funds for UK and comparators. For all countries, Other was estimated by subtraction except for China and Germany, where no recent Higher Education data were available and so Other was assumed to equal zero in order to estimate Higher Education. Values above bars are shown in billions of US dollars. The most recent complete data are used for each country, such that data are for 2008 for all countries except Canada (2009) and UK (2010). Source: OECD MSTI.

In terms of R&D by source of funding, the UK's proportion of GERD funded by the Business Enterprise sector, at just over 45%, is lower than that of comparators and is much lower than that of the G8 average *(Figure 2.4)*. Conversely, almost 23% of the UK's GERD is funded by Other sources, greater than that of any comparator country or the G8 average. (Other sources include investment from abroad and from the non-profit sector, which in the UK consists primarily of charities such as the Wellcome Trust, the British Heart Foundation, and Cancer Research UK, all major funders of biomedical research[15]). According to a recent report[16], "Members of the Association of Medical Research Charities funded £1.1 billion of research in the UK in 2009-2010 alone. Approximately 15% of research income at UK universities comes from UK-based charities." This pattern of GERD by source of funds highlights the UK's strong dependency on foreign and research charity funding[17].

[15] Garau, M., Mordoh, A., Sussex, J. (2011) "Exploring the Interdependency between Public and Charitable Medical Research". Available at http://www.ohe.org/news/2011/04/20/public-and-charitable-medical-research-funding/.
[16] "Government support for charity funded research in universities. A joint statement from universities and charities in the UK" (July 2010). Available at http://www.amrc.org.uk/news-policy--debate_policies-positions-and-guidance_policy--position-statements.
[17] Leevers, H. & Dusic, N. (2009) "The Magic Number? Reaching 2.5% of GDP on R&D" *CaSE News* 62.

UK STRENGTH CASE STUDY 1: **COGNITIVE NEUROSCIENCE**



Country	Fractionalized articles	Total articles	RRS	SotA	Citation count
1. United States	5,288.5	14,195	1.06	-0.36	32,198.2
2. United Kingdom	4,698.4	8,563	0.94	0.24	28,921.8
3. Germany	2,047.6	4,530	0.43	1.65	10,172.7
4. Canada	1,609.3	3,486	0.26	-0.38	8,110.5
5. France	1,181.6	2,414	0.31	0.93	6,575.2
6. Italy	1,162.1	2,251	0.25	1.15	6,142.5
7. Netherlands	1,050.9	2,257	0.23	-0.40	6,008.2
8. Australia	1,044.5	2,101	0.17	-0.96	4,739.9
9. Japan	909.4	1,894	0.09	-2.01	2,196.7
10. Spain	575.8	1,174	0.06	1.09	1,554.3

Source: SciVal Spotlight, UK Country Map 2010.
RRS = Relative Reference Share; SotA = State of the Art. See Glossary for definitions.

Cognitive Neuroscience

The UK shows strength in a competency characterised by keywords such as "clinical neurophysiology", "memory and cognition" and "neuroimaging".

- UK rank:2 (US 1). The UK published 25% of the 19,000 (fractionalised) articles published in this interdisciplinary area of research during the period 2006-2010, which is remarkable given that UK researchers in all fields are just 4% of the global research population. This is a growing area of research (+6% per year), but UK article share has decreased slightly (by 0.55% per year) during this period.

- UK articles in the field were cited 28,922 times, vs. 32,198 times for US articles (2006-2010). The relative reference share (RRS) of cognitive neuroscience for the UK is 0.94. This means that the UK has almost as many reference papers as the US.

- Leading UK institutions include University College London (18% of UK articles, 28% of UK citations), University of Oxford (8% of UK articles, 11% of UK citations), University of Cambridge (5% of UK articles, 7% of UK citations), and University of Edinburgh (5% of UK articles, 5% of UK citations).

Cognitive neuroscience is the study of psychology and mental processes from the perspective of the brain sciences, from the basic understanding of how brain cells, neurons, communicate with each other to the large-scale anatomy of the brain and the interconnections between specialized brain regions that underpin certain cognitive functions. The fundamental goal of the field is to explain how the hardware of the brain runs the software of the mind. This broad endeavour includes studies on sensory perception and awareness, decision-making, language development, memory and learning, as well as aspects of social behaviour, such as the neural basis of empathy, trust and perceptions of fairness. The understanding of the healthy mind that cognitive neuroscience provides promises to shed light on what goes wrong in disorders of cognition from dyslexia and autism to dementia and schizophrenia.

Cognitive neuroscience tackles a very broad set of problems, with a correspondingly diverse set of tools – from brain-imaging techniques such as functional magnetic resonance imaging (MRI) to computational modelling of brain networks. Both the questions pursued by cognitive neuroscientists and the approaches they employ make the field inherently interdisciplinary, and people are drawn into this area not only from the obvious backgrounds of neuroscience and psychology, but also philosophy, computer science and engineering, as well as clinical disciplines such as psychiatry.

How did the UK become a global leader in Cognitive Neuroscience?

Building on History: By the 1960s, UK researchers were at the forefront of both experimental psychology and the then new field of neuropsychology, which draws on brain-damaged patients to identify brain regions crucial for specific psychological functions. This represented a break away from the previously dominant behaviourist paradigm in psychology, which focused on input–output relationships between various stimuli and behaviour, without much consideration on the intervening psychological processes. Experimental- and neuro-psychologists, by contrast, began to develop models of how various inputs and tasks were processed psychologically.

This work set the stage for the development of cognitive neuroscience when new imaging technologies, such as positron emission tomography and magnetic resonance imaging, became available in the late 1980s to the delight of the research community.

> *"When I was working in the 1970s, I was always imagining how interesting it would be to look inside someone's head. I never in my wildest dreams believed that I would actually be able to do it."*
> **Chris Frith, Emeritus Professor of Psychology at University College London**

And so with these new tools in hand, researchers could begin filling in the details of these box diagrams, and identifying which brain regions were involved – a project that scientists with a background in experimental and neuropsychology were well placed to pursue. "It's a lucky accident of history," says Sarah-Jayne Blakemore, a UCL Professor of Cognitive Neuroscience based at the university's Institute of Cognitive Neuroscience (ICN).

"The context was all there, ready – and then these technologies came along and enabled us to answer the questions we were trying to answer with brain-damaged patients."
Sarah-Jayne Blakemore, UCL Professor of Cognitive Neuroscience at the Institute of Cognitive Neuroscience

Yet the increasingly interdisciplinary nature of cognitive neuroscience has also posed some challenges to the traditional organisation of the university.

"In Cambridge, neuroscience has typically been pursued in several different academic departments – in experimental psychology, physiology, zoology, the clinical school and, more recently, in engineering. There's always been plenty of potential for collaboration; it's just been a matter of getting people together."
Trevor Robbins, Professor of Cognitive Neuroscience, University of Cambridge

Creating Critical Mass: In 1994 UCL created the Institute for Functional Imaging (IFI) in Queen's Square, drawing on the nascent tools of brain imaging, and two years later founded the Institute for Cognitive Neuroscience (ICN) next door. The following year, in 1997, the Institute of Neurology – a world-class centre for basic and clinical neuroscience, again based in Queen's Square – formally became a part of UCL. A year later the Gatsby Centre for Computational Neuroscience was set up, housed on the top floors of the IFI's building. In 2006, the IFI was awarded Wellcome Trust Centre status, and became the Wellcome Trust Centre for Neuroimaging at UCL.

"The geographical clustering of these centres of excellence in one square has been a major contributor to the success of cognitive neuroscience at UCL in the two decades," says Professor Geraint Rees, Director of the ICN. "Being neighbours, the ICN and the Wellcome Trust Centre for Neuroimaging have developed a close, synergistic relationship, working with and inspiring each other."

"Both are beacons of scientific excellence that attract an international cadre of world-class researchers from a wide variety of backgrounds," says Professor Karl Friston, Scientific Director of the Wellcome Trust Centre for Neuroimaging. "This creates an internal diversity that also nurtures synergistic interactions."

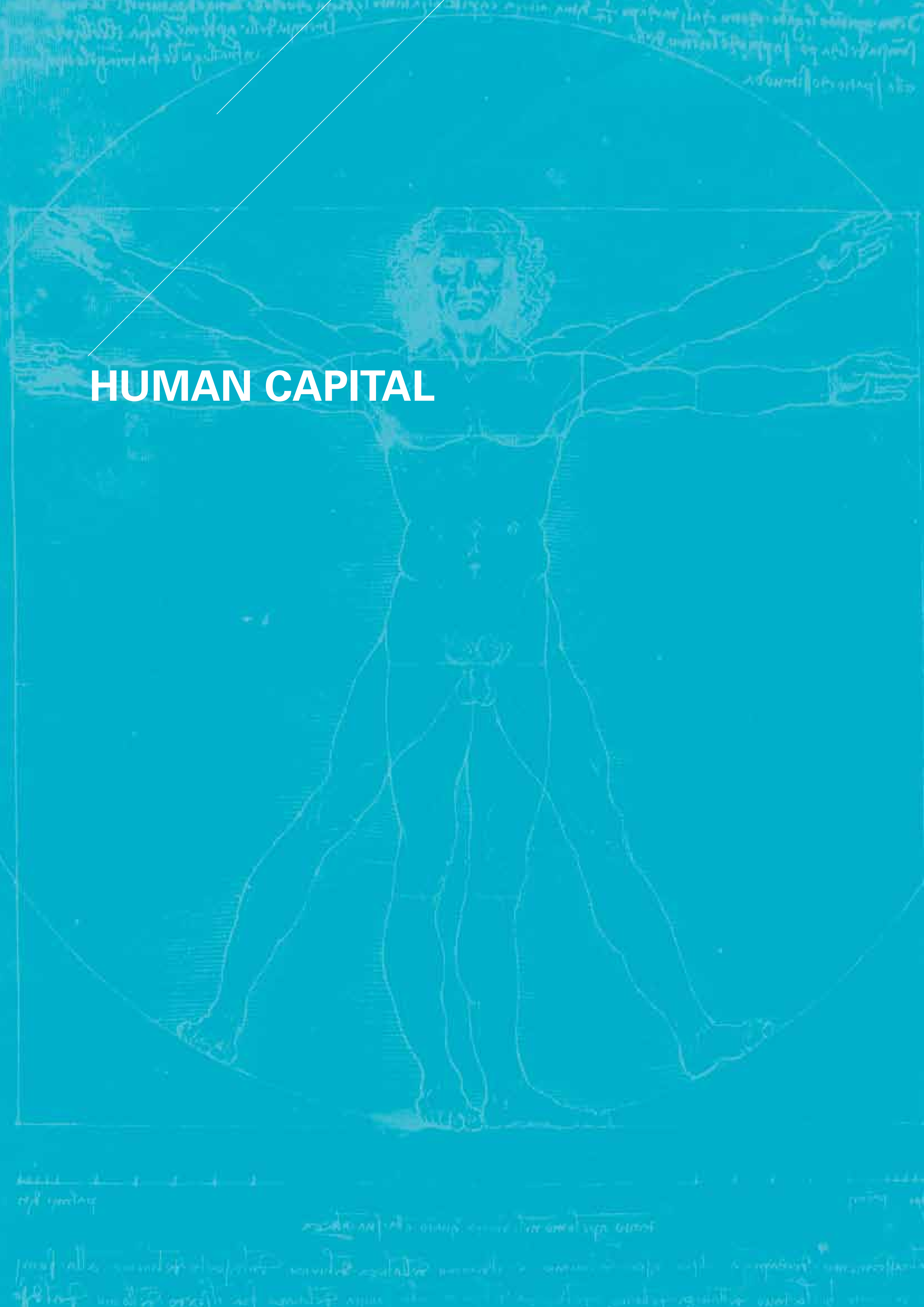
"You have this portfolio of eclectic expertise and different perspectives on similar issues, all in dialogue and working together."
Professor Karl Friston, Scientific Director of the Wellcome Trust Centre for Neuroimaging

In addition, researchers from other countries often bring their own sources of funding, creating a form of inward investment in the UK science base.

Friston says the inner life of the Wellcome Trust Centre for Neuroimaging is like a family, which is another key to its success. "Most of the key people here worked together in their 20s and 30s, and share a common culture. Science is social – it's about the organic evolution of relationships, attitudes and collaborations. And like in every growing family, there are new arrivals. Every new person brings new ideas, which keeps you fresh, it feeds the fire. But you've got to have a working culture sufficiently organic to be able to respond to shifts in emphasis."

One upshot of this is that successful scientific teams cannot easily be assembled anew from scratch as a response to top-down strategic needs. Instead, they develop bottom-up through frequent interactions, and depend on recruiting new people into a permissive research culture that allows individuals and collaborations to flourish over time.

"Not every university doing quality work in cognitive neuroscience has the critical mass of researchers that can be found in places like Queen's Square. As such, they have not had the luxury to explore the wide range of questions that are pursued at the ICN and Wellcome Trust Centre for Neuroimaging. Instead, they have developed excellence by specialising in specific niches within the field. And so our niche has been in perception and action, like motor control."
Glyn Humphreys, Professor of Cognitive Psychology at the University of Birmingham



HUMAN CAPITAL

HUMAN CAPITAL

It is clear that one factor in the UK's historic position of strength has been the excellence of individual researchers. The prestige of individual researchers or laboratories, historic centres of research and top-ranking universities has served not only to develop the next generation of UK researchers but also attract excellent researchers from abroad.

3.1. Key Findings

The UK's researcher population is growing more slowly than the global average; it is fluid, dynamic and internationally collaborative.

- The UK had 256,124 researchers[18] in 2009.
- The UK had very modest growth in researcher numbers over the period 2005-09 (at just 0.8% per year), below the rates seen in the G8 and OECD countries in the same period.
- The UK had some 2.4 million undergraduate and postgraduate students in 2008. While the UK has a large and growing population of undergraduate and postgraduate students, the growth rate in PhDs graduated has slowed to 2.1%, with 16,606 graduating in 2008.
- The UK had a highly mobile population of researchers during the period 1996 to 2010. More than 63% of researchers in the UK over this period have published articles while affiliated with non-UK institutions, and therefore can be presumed to have worked outside the UK at some point. This group of researchers is very productive. By contrast, the 37% of UK researchers who have not published with a non-UK institution during this period, and can therefore be assumed not to have conducted research outside of the UK, are 40% less productive in terms of articles published than the average for the UK.
- The most productive group of UK researchers in terms of articles published from 1996 to 2010 (66% more productive than average) were the 2.6% of researchers who left the UK for at least two years and then returned.
- 31% of researchers who were publishing while at UK institutions from 1996-2010 came to the UK for a year or less. Over their career, however, they are 35% more productive in terms of articles published than average. The reverse is not true. UK researchers who left the UK for a year or less (14% of the whole) were only slightly more productive than average over their careers.
- The findings suggest that UK researchers who returned after two or more years abroad benefited from the experience in terms of productivity. Similarly, non-UK researchers who came to the UK, even for a short period, also may have benefited from the experience in terms of productivity. However, it may also be the case that those researchers that are more productive are also more likely to get opportunities to work in different countries.

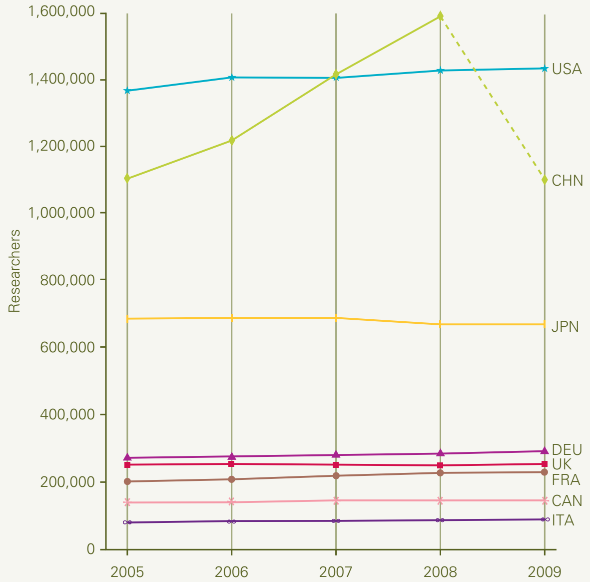
3.2. Human Capital: Discussion

The UK had very modest growth in researcher numbers over the period 2005-09 (at just 0.8% per year), below the rates seen in the G8 and OECD countries in the same period and outpacing only Japan amongst the comparator countries, which saw negative growth in this period *(Figure 3.1A)*. Indeed, when expressed per thousand population, UK growth is even more modest at just 0.1% per year since 2005, and when expressed per thousand labour force growth is negative at -0.2% in this period (see report Appendix F: Supplementary Data, section 3 for details).

A breakdown of the UK's researchers by sector of employment *(Figure 3.1B)*, shows that the UK's overall growth over the period 2005-09 was buoyed up by growth in the Higher Education sector (at 2.4% per year), which is also the largest sector (61% of UK researchers) while there was negative growth in the Business Enterprise sector (-3.4%, representing 34% of UK researchers) and relatively little change in the Government sector (-0.9%, representing 3% of UK researchers).

[18] Researcher as defined by the Frascati Manual (2002) *Proposed Standard Practice for Surveys on Research and Experimental Development*. OECD Publishing.

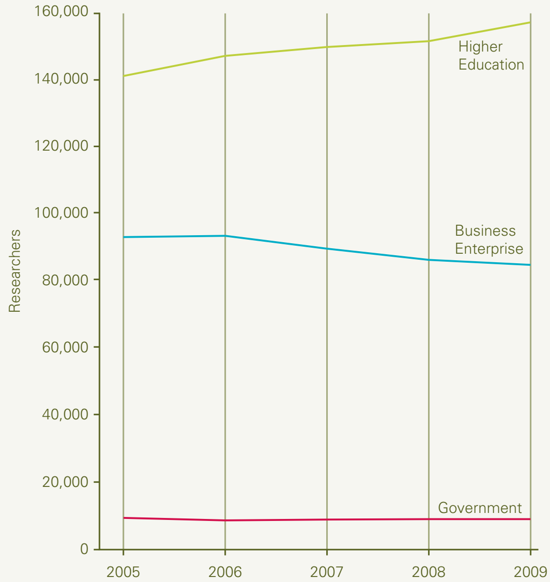
Figure 3.1A Researchers for UK and comparators, 2005-2009.



	2005	2009	Change 05-09	CAGR 05-09	UK Rank 2005	UK Rank 2009
UK	**248,599**	**256,124**	**7,525**	**0.75%**	-	-
G8	3,463,023	3,599,311	136,287	0.97%	5	5
EU27	1,369,123	1,544,660	175,537	3.06%	2	2
OECD	5,469,438	5,949,193	479,754	2.12%	6	6
World	5,605,045	5,991,085	386,040	1.68%	6	6

G8: 8 (of 8) countries with available data
EU27: 22 (of 27) countries with available data
OECD: 33 (of 42) countries with available data
World: 36 countries with available data

Figure 3.1B UK researchers by sector of employment, 2005-2009.



	2005	2009	Change 05-09	CAGR 05-09
Business Enterprise researchers	**93,717**	**84,554**	**-9,164**	**-2.54%**
Government researchers	**9,311**	**8,701**	**-609**	**-1.68%**
Higher Education researchers	**141,762**	**158,004**	**16,242**	**2.75%**

Figure 3.1 Researchers by country **(Panel A)** and sector of employment **(Panel B)** 2005-2009. Note that data for China were rebased in 2009 according to the Frascati Manual definition of Researcher; prior to this much of the data for China were collected according to the UNESCO concept of "scientist and engineer". Percentages show growth rates (CAGR) 2004-2008 for each sector. Source: OECD MSTI.

These data highlight a potential developing paucity of skilled human capital in the UK versus comparator countries, when the relatively low underlying growth rates in the population and especially the labour force are considered. There is a risk that failure to develop, attract and retain enough researchers may have consequences for national R&D capacity[19].

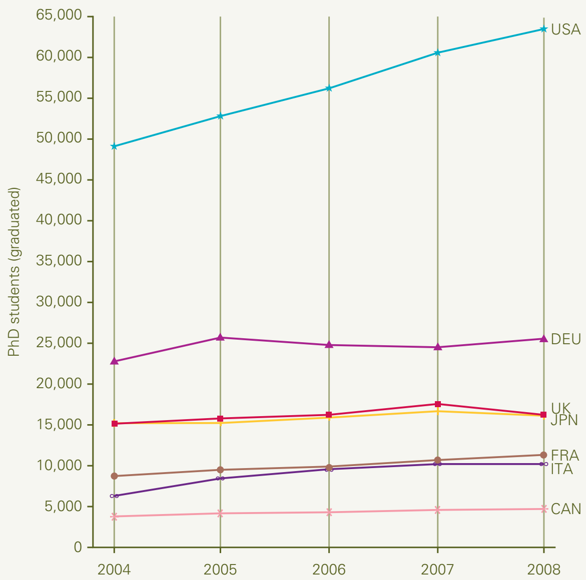
The UK has a broadly stable pipeline of research talent. The flow of people through higher education and into a research career can be characterised as a 'pipeline' of talent, but one that typically narrows as individuals pass through it and are 'siphoned off' into careers outside of research[20].

The UK has a large and growing population of undergraduate and postgraduate students (see Appendix F: Supplementary Data, section 3 for details). While the UK ranks 3rd (after the US and Germany) amongst its comparators in terms of number of PhD students graduated (with Japan a close 4th), it saw a downshift in 2008 to give a growth rate of just 2.1% per year since 2004, considerably lower than the G8 average growth of 6.1% per year and an EU27 average growth of 3.7% per year *(Figure 3.2).*

[19] Universities UK (July 2007) "Policy Briefing: Talent wars: the international market for academic staff". Available at http://www.universitiesuk.ac.uk/Publications/Documents/Policy%20Brief%20Talent%20Wars.pdf.

[20] Royal Society (2010) "The Scientific Century: securing our future prosperity". Available at http://royalsociety.org/policy/publications/2010/scientific-century/; Council for Science and Technology (2007) "Pathways to the future: the early career of researchers in the UK". Available at http://www.bis.gov.uk/assets/bispartners/cst/docs/files/whats-new/07-1503-pathways-early-career-researchers.

Figure 3.2 PhD students graduated for UK and comparators, 2004-2008.



	2004	2008	Change 04-08	CAGR 04-08	UK Rank 2004	UK Rank 2008
UK	**15,257**	**16,606**	**1,349**	**2.14%**	-	-
G8	80,774	102,479	21,705	6.13%	3	3
EU27	89,300	103,139	13,839	3.67%	2	2
OECD	215,667	228,266	12,599	1.43%	4	3

G8: 7 (of 8) countries with available data
EU27: 18 (of 27) countries with available data
OECD: 32 (of 42) countries with available data
Source: OECD Education

Figure 3.2 PhD students graduated for UK and comparators, 2004-2008. Source: OECD Education.

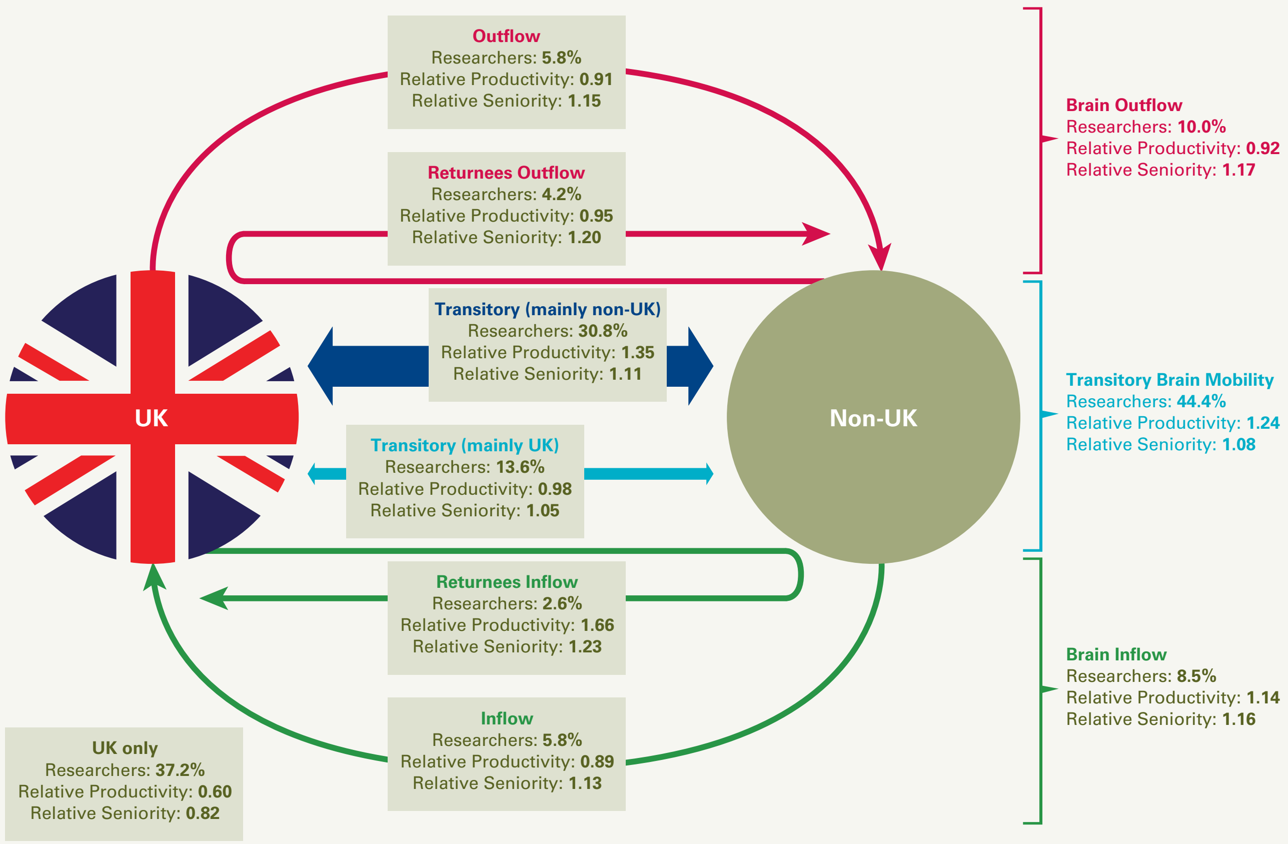
3.2.1 Brain Circulation

The concept of 'brain drain' has been discussed since the late 1950s, but has shifted in meaning and become more complex over time. Originally used to describe the net outflow of research talent from Europe to the US, the term then became used to describe the shift of researchers from any country (typically less research-intensive) to any other (typically more research-intensive). In recent years, the theoretical framework surrounding researcher mobility and migration has become sufficiently developed to require the coinage of a new term, brain circulation[21]. Within this framework, there are no longer clear winners and losers; instead, with return rates, network building and diaspora effects[22], brain circulation is seen as potentially beneficial to all parties involved, even when these benefits are difficult to quantify. It appears that very high mobility rates are associated with reduced productivity at both individual researcher and research group levels, suggesting that a certain level of stability is required for the greatest gain in international researcher migration. 'Push' and 'pull' factors acting on individual researchers in their migration patterns have been extensively studied[23]. Migration decisions are typically made on a complex set of social factors (personal criteria and relationships), coloured by cultural, historical and linguistic considerations, but also through active encouragement to return[24] and by visa and immigration controls[25].

According to our detailed analysis of Scopus data over the period 1996-2010, 37.2% of UK researchers appear never to have been affiliated with anything other than a UK institution, i.e. their career has been UK-based as indicated by their country listed in their published articles (see Appendix E: Elsevier Methodology for full details). It is possible that many of these researchers did travel and collaborate internationally, but such activities never resulted in published articles in which they listed their address as being outside the UK. These researchers have relatively low 'productivity'

[21] Cao, X. (1996) "Debating 'Brain Drain' in the Context of Globalisation" *Compare: A Journal of Comparative and International Education* 26(3) pp. 269-285.
[22] Ciumasu, I.M. (2010) "Turning brain drain into brain networking" *Science and Public Policy* 37 pp. 135–146.
[23] Breithaupt, H. (2000) "The flight from European science" *EMBO Reports*, 1(2) pp. 104–105; Saravia, N.G. & Miranda, J.F. (2004) "Plumbing the brain drain" *Bulletin of the World Health Organization*, 82 (8) pp. 608–615; Dodani, S. & LaPorte, E.R. (2005) "Brain drain from developing countries: how can brain drain be converted into wisdom gain?" *Journal of the Royal Society of Medicine* 98(11) pp. 487–491; Casper, S. & Murray, F. (2005) "Careers and clusters: analyzing the career network dynamic of biotechnology clusters, *Journal of Engineering and Technology Management* 22(1-2) pp. 51–74; Nerdrum, L. & Sarpebakken, B. (2006) "Mobility of foreign researchers in Norway" *Science and Public Policy* 33(3) pp. 217–229; Jöns, H. (2007) "Transnational mobility and the spaces of knowledge production: a comparison of global patterns, motivations and collaborations in different academic fields" *Social Geography* 2(2) pp. 97–114; Anas, M.U.M. & Wickremasinghe, S.I. (2010) "Brain drain of the scientific community of developing countries: the case of Sri Lanka" *Science and Public Policy* 37(5) pp. 381–388.

Figure 3.3 International mobility of UK researchers, 1996-2010.



Returnee Researcher = 2 or more years abroad.
Transitory Researcher = less than 2 years abroad.

Figure 3.3 International mobility of UK researchers, 1996-2010. This analysis is based on author affiliation addresses in the published literature and is restricted to a set of 210,923 researchers with a UK affiliation during this period that are 'active'; i.e. those with ≥1 article in the latest five-year period 2006-2010 and ≥10 articles in the entire 15-year period 1996-2010, or those with >3 articles in the period 2006-2010 but <10 articles in the period 1996-2010. Relative Productivity represents articles per year since the first appearance of each researcher as an author in the database during the period 1996-2010, relative to all UK researchers in the same period. Relative Seniority represents years since the first appearance of each researcher as an author in the database during the period 1996-2010, relative to all UK researchers in the same period. Both Relative Productivity and Relative Seniority are calculated for each author's entire output in the period (i.e. not just those articles listing a UK address). Source: Scopus. For further discussion on author naming and disambiguation see Appendix E: Elsevier Methodology.

[24] Kupfer, L., Hofman, K., Jarawan, R., McDermott, J., Bridbord, K. (2004) "Strategies to discourage brain drain" Bulletin of the World Health Organization 82(8) pp. 616–619. See also commentaries that follow this article in the same issue.
[25] Brumfiel, G. (2004) "As one door closes…", *Nature* 427 pp. 190–195.

(articles published per year since first appearance as an author), at just 0.60 (compared to an average score of 1.00 for all UK researchers over this period; see caption to *Figure 3.3*). They are also at an earlier stage in their (publishing) career, with a relative seniority (i.e. number of years since their first appearance as an author) of 0.82. This index is relative to the seniority of UK researchers overall, where 1.00 would represent the average across all researchers. In the period 1996-2010, 5.8% of UK researchers moved out of the UK and show no indication of having returned to the UK since as indicated by their country listed in their published articles, while 5.8% of UK researchers moved into the UK and showed no indication of having left the UK since. The actual difference in this period was a net inflow of just 61 researchers to the UK (of the 210,923 total researchers in the dataset). Of these categories the researchers moving out of the UK were slightly less productive than average (0.91) but also slightly more senior (1.15), and those moving to the UK had a very similar profile (0.89 and 1.13, respectively). The most common destination countries were the US, Australia, Canada, Germany and France, while the most common source nations were the US, Germany, Australia, France and Italy.

During 1996-2010, 2.6% of UK researchers moved out of the UK and subsequently returned after more than two years abroad ("returnees inflow"), while 4.2% of UK researchers moved into the UK and subsequently left after more than two years in the country ("returnees outflow"). While the latter group are slightly less productive than average (0.95), the former group are highly productive (1.66). Both groups have a very similar relative seniority, at 1.20 for the returnees outflow and 1.23 for the returnees inflow. The most common destination countries amongst the returnees outflow group were the US, Australia, Germany, France and Canada, while the most common source nations in the returnees inflow group were the US, Australia, Canada, Germany and Ireland (see Appendix F: Supplementary Data, section 3 for details). Owing to their small number, these two groups of "returnees" contributed a relatively small amount to the UK's brain circulation, compared to the whole. Despite this, returnees may contribute a great deal to their home country after their return. For example, a recent study focused on the cost and benefits of a 'return scholarship' program in Peru, showing a return on investment of about 27-fold in terms of research funding attracted[26]. However, the main challenge, especially in the developing world, is not the ability to produce important researchers but the ability to retain them[27].

Taking together the outflow and returnees outflow group and the inflow and returnees inflow group, the net brain outflow from the UK is about 1.5%. However, the inflow groups together constitute a more productive population than the outflow groups, despite their very similar seniority profiles. This outflow is in apparent contrast to the overall growth of UK researchers of 0.75% seen in *Figure 3.1A*, but as the figures here are taken from publication records for productive researchers (rather than a count of researcher full time employees [FTEs]) over a period of 15 years (and not 5 years) some discrepancy is to be expected.

The UK also attracts a large number of short-term "transitory" and productive researchers from abroad. The most prominent groups identified in this analysis are the large numbers of researchers with transitory mobility (with stays either in the UK, or out of the UK, of less than two years as indicated by their country listed in their published articles). In the period 1996-2010, 13.6% of researchers based mainly in the UK showed transitory mobility to non-UK countries (as indicated by their country listed in their published articles), while a very large number (30.8%) of researchers based mainly in non-UK countries showed transitory mobility into the UK. While the former group is about as productive as the average (0.98) and slightly more senior (1.05), the latter group is highly productive (1.35) and somewhat more senior (1.11). In contrast with these findings a limited study of US physicists has suggested that 'movers' and 'stayers' do not have different h-indices[28, 29]. In the current study, the most common destination countries for the mainly UK-based group were the US, Australia, Germany, Canada and France, while the most common source nations for the mainly non-UK-based group were the US, Germany, France, Italy and Australia (see Appendix F: Supplementary Data for details, section 3).

[26] Guerra, H. (2010) "La beca de retorno de la Universidad Peruana Cayetano Heredia" *Revista Peruana de Medicina Experimental y Salud Publica* 27(3) pp. 428–431.
[27] Weinberg, B.A. (2011) "Developing science: Scientific performance and brain drains in the developing world" *Journal of Development Economics* 95(1) pp. 95–104.
[28] Hirsh, J.E. (2005) "An index to quantify an individual's scientific research output" *PNAS* 102(46) pp.16569-16572.
[29] Hunter, R.S., Oswald, J., Charlton, B.G. (2009) "The elite brain drain" *The Economic Journal* 119(538) pp. F31–F251.

The analysis suggests that the UK research base is supported in large part by a population of senior and productive non-UK researchers with transitory connections to the UK (i.e. the overall transitory brain mobility group), implying that the UK is an attractive place for these individuals to do research. Three main reasons why this may be so have been put forward:

- "culture – the 'free-thinking' nature of UK researchers – and the dual-support system which promotes high levels of competition for money.
- co-investment by different partners – but there is multiple jeopardy in bringing together different funders for a particular project especially if each contributor/ funding agency has their own particular terms and conditions.
- recognition, transparency and reward – which is tied to excellence so the system has strong incentives to drive up productivity[30]."

Far from implying the UK 'loses the best and brightest' to the US and other countries, this analysis suggests that returnee inflow brings comparatively productive researchers back into the UK (presumably with an extended international network, diverse skills and knowledge) and that returnee outflow (representing the most productive group identified) is high, which may also serve to strengthen the position of the UK abroad through international network-building. It is of note that Japan, one of the largest research nations in the world, does not feature more prominently in the lists of source of destination countries for UK researchers. This may support earlier views that Japan runs an "intellectual closed shop" [31], characterised by a large proportion of 'stay-at-home' researchers and high return rates from abroad[32].

The most distinctive group identified in this analysis is the returnees inflow, who account for just 2.6% of the researchers studied but are the most productive and senior of all the groups. This group also displays a strong characteristic that their time spent abroad is spent in the US. It appears likely that these individuals represent those making long-lasting and productive connections with the world's largest research base (i.e. the US) to the apparent benefit of the UK's research capability.

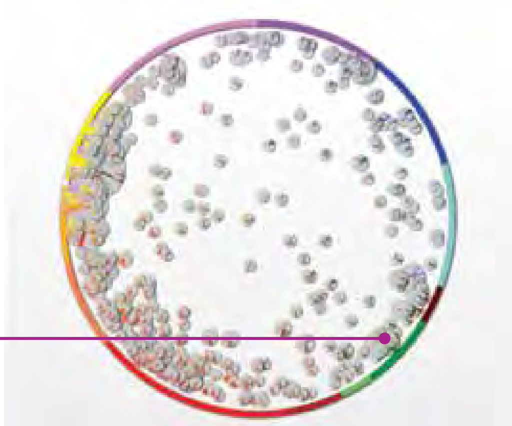
For comparison a similar brain circulation study was carried out for Germany (Appendix F: Supplementary Data, section 3). The overall pattern is largely similar to that for the UK but with a slightly higher proportion of stay homes (Germany only) and therefore a slightly lower proportion flowing in and out of the country.

[30] Council for Science and Technology (2010) "A Vision for UK Research". Available at http://www.bis.gov.uk/assets/bispartners/cst/docs/files/whats-new/10-584-vision-uk-research.pdf.

[31] Gaillard, A.M. & Gaillard, J. (1998) "The International Circulation of Scientists and Technologists: A Win-Lose or Win-Win Situation?" *Science Communication* 20(1) pp. 106–115.

[32] Marceau, J., Turpin, T., Woolley, R., Hill, S. (2008) "Innovation agents: The inter-country mobility of scientists and the growth of knowledge hubs in Asia" *25th DRUID conference on Entrepreneurship and Innovation - Organisations, Institutions, Systems and Regions.*

UK STRENGTH CASE STUDY 2: **ECOLOGY**



Country	Fractionalized articles	Total articles	RRS	SotA	Citation count
1. United Kingdom	1,409.4	2,813	1.88	-1.48	9,326.1
2. United States	1,025.5	3,227	0.53	0.26	7,490.1
3. Germany	545.9	1,363	0.30	3.09	3,344.8
4. France	378.5	955	0.27	3.16	2,723.0
5. Spain	325.5	809	0.12	2.31	2,301.2
6. Netherlands	310.6	718	0.20	-9.39	2,629.2
7. Canada	300.8	871	0.14	2.47	2,386.8
8. Sweden	298.3	675	0.14	-4.33	1,898.6
9. Switzerland	256.6	603	0.15	3.37	2,320.6
10. China	240.7	671	0.11	-0.96	597.9

Source: SciVal Spotlight, UK Country Map 2010.
RRS = Relative Reference Share; SotA = State of the Art. See Glossary for definitions.

Ecology

The UK shows strength in a competency characterised by keywords such as "biodiversity", "wildlife research" and "biological conservation."

- UK rank:1 (US 2). The UK published 25% of the 5,500 (fractionalised) articles published in this interdisciplinary area of research during the period 2006-2010. This is a growing area of research (+11% per year), but UK article share decreased 1% per year during this period.
- UK articles in the area were cited 9,326 times, vs. 7,490 times for US articles (2006-2010). The relative reference share (RRS) of this competency in ecology for the UK is 1.88. This means that the UK has almost twice as many reference papers in this area of research as the US.
- Leading UK institutions in this area of research include Centre of Ecology and Hydrology (16% of UK articles, 18% of UK citations), The Lodge RSPB (10% of UK articles, 10% of UK citations), University of Aberdeen (7% of UK articles, 6% of UK citations), and University of Oxford (6% of UK articles, 12% of UK citations).

In broadest terms, ecology studies the relationships between living organisms of all kinds, and their interaction with the natural environment in which they live. It has a broad scope and deals with life at many biological levels: from cells and organs, populations and species, to the entire biosphere. Ecology is an interdisciplinary endeavour, drawing on physiology, evolutionary biology, genetics and ethology (the study of animal behaviour in natural settings).

The UK's distinctive strength in ecology is directly relevant to global challenges that pertain to the effect of humans on the natural environment on a planetary scale. Ecology provides tools to assess the impact that humans have on the world's ecosystems, and what the effects of this are likely to be. Ecologists see the natural environment as providing a wide range of 'goods and services' that humans around the world depend on, from food and water to timber, air purification and pollination by various insects. Ecology helps to work out how to preserve these goods and services, and maximise the benefits to be obtained from them. While politics and demography are major causes of poverty and conflict in many parts of the developing world, these are often exacerbated by ecological factors. As populations increase and environments change, conflict may increasingly revolve around scarce environmental goods and services.

"Our dependence upon those ecosystem goods and services is becoming more and more apparent with a growing number of environmental challenges that people are facing. We need to know how those goods and services are actually distributed, and how to turn those into benefits, as well as identifying who benefits from them."
Kevin Gaston, Director of the Environment and Sustainability Institute at the University of Exeter

Gaston's research into ecosystem goods and services also provides insights into the capacity of both rural and urban environments to absorb and store carbon, an important component of the UK's national carbon accounting.

Humans affect the natural environment on a planetary scale. Ecology provides tools to assess the impact that humans have on the world's ecosystems. Will Cresswell, a Reader in Ecology at the University of St Andrews, studies the factors that determine the density and distribution of bird populations, which provide a convenient proxy measure of ecosystem health and the availability of ecosystem goods and services.

"Put very simply, if you've got high numbers of birds, and a high diversity of bird species, then the ecosystem is likely to be in good shape. So we can use bird populations to assess the impact of our activities of the environment, how this will affect our quality of life, and then use them to monitor our attempts to modify our impact. For example, changes in bird populations help us to identify more sustainable farming systems."
Will Cresswell, Reader in Ecology at the University of St Andrews

The insights of ecology are also central to projects aimed at conserving natural habitats and the species they house. Jos Barlow, a Research Fellow at the University of Leicester, studies 'forest corridors' that link small fragments of forest into larger networks, thereby connecting the populations in each patch of forest. This can effectively increase the population size of forest species, which is important because larger populations support greater biodiversity.

Likewise, Terry Burke of the University of Sheffield, uses the tools of molecular biology to study 'gene flow' through forest corridors, which arises as animals move between forest fragments and mate – a process that also helps support biodiversity. Similar techniques of molecular ecology can also help ecologists work out whether they're dealing with a single species, or several similar yet distinct species, an important issue in many conservation projects, and especially when dealing with plants.

Ecology can contribute to thinking about strategies for sustainable development in globally important ecosystems such as the Amazonian rain forests. Toby Gardner, a Natural Environment Research Council Fellow in Ecology at the University of Cambridge, studies different land-use systems in the Brazilian Amazon (such as cattle ranching, plantation forestry, selective logging of native forest, and maintaining arable cropland), and the costs and benefits that these land-use systems entail – especially conservation/development trade-offs – to determine their sustainability.

Another practical application of ecological research is on combating the ecologically damaging effects of non-native species that have been introduced in various countries. Xavier Lambin, Professor of Ecology at the University of Aberdeen, has worked with Scottish National Heritage and Cairngorms National Park Authority in the world's largest project to combat the damaging effects of the American mink, which was introduced in to the UK in the 1920s for fur and has been established in the wild since the 1950s. The American mink competes with, and preys on, native species, and is thought to be responsible for the 96% drop in numbers of native water voles observed since the '50s. The conservation project to tackle the threat of the American mink has recruited a large coalition of people with common interests, such as fishermen, gamekeepers, conservationists, land owners and farmers.

How did the UK become a global leader in ecology?
History: Ecology is closely related to evolutionary biology, which emerged from Charles Darwin's theories of evolution by natural selection. Darwin's ideas themselves emerged out of a Victorian culture fascinated by natural history, a national interest that persists to this day. This is partly evidenced by the membership figures for organisations such as the Royal Society for the Protection of Birds (more than 1 million in total, including 195,000 youth members), and many other wildlife and botanical societies. This not only creates a climate conducive to ecological research in general, but volunteer activity in these organisations actually produces data that scientists have drawn on.

Building on success: Institutions that currently excel in ecology have hired and retained leading researchers, who have subsequently attracted other scientists to join respected research groups. "The key has been to establish a critical mass of quality researchers, who can operate in a flexible research environment," says Barlow. Today's leading ecological departments, have simply hired good people, and given them freedom.

RESEARCH OUTPUTS

RESEARCH OUTPUTS

Scholarly communication is key to academic endeavour and research outputs are a traditional indicator of research intensity. Outputs can be assessed based on article quantity, article share, citations quantity, citation share and collaboration behaviour. At the same time, it is important to recognise that research outputs take many other forms, such as books, monographs, and non-textual media such as music (see Appendix E: Elsevier Methodology for further discussion on caveats and limitations of data sets used). Taken together over time, bibliometrics based on journal articles and citations offer a rich indicator of changes in research intensity and quality. Changes in global publishing and citation behaviour (such as increased mobility and collaboration) have created a flattening of differences between countries. This trend suggests that there may be a convergence of citation rates in countries that collaborate closely, as well as a distortion in the attribution of article share[33].

4.1. Key Findings

The volume of UK articles is growing, but not as fast as in other countries. The quality of UK articles as measured by citations is above average and increasing in all subject areas.

- UK researchers published 123,594 articles in 2010. The 588,334 articles published by UK authors in the period 2006-2010 generated 3,459,875 citations in the same period.

- The UK's article output has increased by an average of 2.9% per year since 2006, compared to the world average growth over the same period of 4% per year. As a result UK article share globally declined from 6.67% in 2006 to 6.38% in 2010.

- The UK shows high and increasing activity focus in clinical sciences, health & medical sciences, social sciences, business and humanities. A relative drop is seen in other areas (biological sciences and environmental sciences). The UK has relatively lower activity focus in mathematics, physical sciences and engineering.

- Citations to UK articles have grown at 7.2% per year since 2006 compared to the world average of 6.3% per year over the same period. As a result the UK's share of global citations increased from 10.5% in 2006 to 10.9% in 2010.

- The UK ranks 2nd in citations per paper – a key measure of quality -- both in the G8 and in the comparator group, marginally trailing the US. The UK has had a growth rate of 2.3% per year, since 2006.

- The UK's field-weighted citation impact -- also a key measure of quality that adjusts for the fact that different countries pursue different fields of research in differing proportions – is well above the world benchmark, but is slightly lower than that of the US, ranking it 2nd in the G8 and in the comparator group but with a growth rate of 1.1% compared to the US's -0.5% per year since 2006.

- The UK's share of articles in the 1st, 5th and 10th citation percentiles is high and growing (see Appendix F: Supplementary Data, section 4 for details), and in the 1st percentile, the UK with 13.8% is 2nd only to the US in share of highly-cited articles.

- The UK's field-weighted citation distribution across subject fields is above world average and rising in influence in all subjects. Interestingly, the UK is especially strong in fields where its Activity Index (i.e. outputs of research papers) is comparatively low – in particular mathematics, physical sciences and engineering.

- UK researchers are highly collaborative and work with a growing number of researchers abroad.

[33]Zitt, M., Barre, R, Sigogneau, A, Laville, F. (1999) "Territorial concentration and evolution of science and technology activities in the European Union: a descriptive analysis" *Research Policy* 28(5) pp. 545-562.

4.2. Research Outputs: Discussion

4.2.1. Articles

Measuring national research performance with the use of bibliometric indicators is an activity with a long tradition[34]. Godin (2005)[35] has presented a historical overview of the development of statistics on research, and a handbook of current approaches is available[36]. Nowadays many countries publish national research reports and analyse what bibliometric indicators express about the state of a nation's research system and about the level of its research performance. For instance, the Science and Engineering Indicators series[37] is produced every two years by the US National Science Board, the governing body of the National Science Foundation, using indicators derived from bibliometric and other databases. In Europe, the French Observatoire des Sciences et des Techniques[38] and the Netherlands Observatory of Science and Technology[39] also publish national science indicator reports, and present bibliometric indicators derived from specialist databases.

The UK's share of articles globally has declined from 6.7% in 2006 to 6.4% in 2010, *(Figure 4.1)*, because despite actual article outputs growing at 2.9% per year in the same period the world average growth in the same period was 4% per year (see Appendix F: Supplementary Data, section 4 for details). Growth in constituent countries of the UK has been similar, and the proportion contributed to the UK remains roughly the same *(Figure 4.2)*. With the even steeper decline of Japan's share of articles published in recent years, the UK has become the world's 3rd research nation by this indicator.

Most countries are seeing flat or slightly declining global shares due to the rise of new players, in particular China (see 'The rise of the BRICs'). This provides both challenges and opportunities for established research countries.

An examination of the UK's article output in its four constituent countries reveals that England constitutes the largest share, followed by Scotland, Wales and Northern Ireland *(Figure 4.2)*. In this analysis, articles are assigned to UK constituent countries where at least one of all UK-based authors listed belongs to a Higher Education Institute (HEI) as defined by HESA[40], while 'Non-HEIs only' represents articles where all UK-based authors cannot be unambiguously assigned to UK constituent countries in this way. Collectively the UK produced 123,594 articles in 2010, and growth over recent years is positive in all four countries.

Although this report is focused on the UK and selected international comparators and benchmarks, it is important to acknowledge that a proportion of global research is done outside these countries. Indeed, some of these so-called 'peripheral' research nations have seen dramatic rises in their article outputs in recent years, as illustrated in *Table 4.1*. Most notable of the countries shown are Malaysia[41] and Iran[42] which have both sustained extremely high rates of growth on relatively large output volumes, compared to G8 countries.

[34] Narin, F. (1976) *Evaluative bibliometrics: The use of publication and citation analysis in the evaluation of scientific activity.* Washington D.C.: National Science Foundation.; Price, D.J.D. (1978) "Towards a model for science indicators" In: Elkana, Y., Lederberg, J., Merton, R.K., Thackray, A., Zuckerman, H. (Eds.). *Toward a metric of science: The advent of science indicators.* New York: John Wiley, 69–95; Price, D.J.D. (1980) "Towards a Comprehensive System of Science Indicators" *Conference on Evaluation in Science and Technology – Theory and Practice;* Braun, T., Glänzel, W., Schubert, A. (1988) "World flash on basic research – The newest version of the facts and figures on publication output and relative citation impact of 100 countries 1981–1985" *Scientometrics* 13(5-6) pp. 181–188; King, D.A. (2004) "The scientific impact of nations" *Nature* 430 pp. 311–316.

[35] Godin, B. (2005). *Measurement and Statistics on Science and Technology: 1920 to the Present.* London: Routledge.

[36] Moed, H.F., Glänzel, W., Schmoch, U. (2004) (eds.). *Handbook of quantitative science and technology research. The use of publication and patent statistics in studies of S&T systems.* Dordrecht (the Netherlands): Kluwer Academic Publishers.

[37] National Science Foundation (2010) "Science and Engineering Indicators 2010". Available at http://www.nsf.gov/statistics/seind10.

[38] Observatoire des Sciences et des Techniques (2010). "Rapport Biennal 2010". Available at http://www.obs-ost.fr/fr/le-savoir-faire/etudes-en-ligne/travaux-2010/rapport-biennal-edition-2010.html.

[39] Netherlands Observatory for Science and Technology (2010). "2010 Rapport". Available at http://www.nowt.nl/nieuwste_rapport.php.

[40] HESA (Higher Education Statistical Agency) lists all UK HEIs per constituent country. This distribution has been used to aggregate article counts per constituent country.

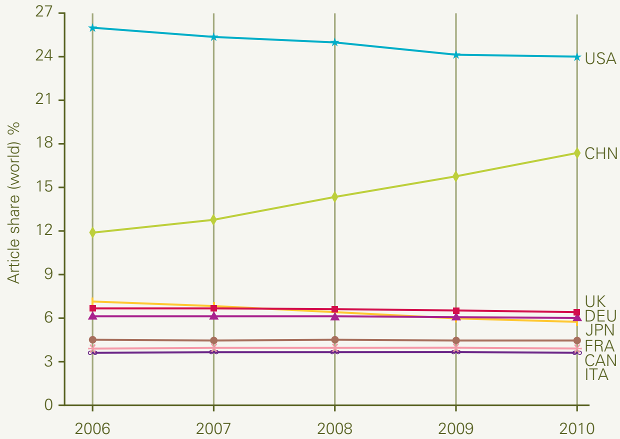
[41] Natalie Day, N. & Muhammad, A. (2011) "Malaysia: The Atlas of Islamic-World Science and Innovation Case Study No. 1". Available at http://royalsociety.org/aiwsi-malaysia-case-study/; Wong, C.-Y. & Goh, K.-L. (2010) "Growth behaviour of publications and patents: A comparative study on selected Asian economies" *Journal of Informetrics* 4(4) pp. 460-474.

[42] Plume, A. (2011) "A rebirth of science in Islamic countries?" *Research Trends*, Issue 21.

Table 4.1 Growth in article output (absolute article numbers and CAGR) from 2006-2010 in high-growth countries.

	Articles					Change (2006-2010)	
Country	2006	2007	2008	2009	2010	Absolute	CAGR
Malaysia	3,881	4,682	7,027	10,030	13,040	9,159	35.4%
Luxembourg	316	378	578	749	840	524	27.7%
Iran	10,321	13,844	17,984	21,638	25,346	15,025	25.2%
Bosnia & Herzegovina	268	355	414	480	647	379	24.6%
Romania	4,223	5,814	7,581	9,319	10,162	5,939	24.5%
Saudi Arabia	2,208	2,405	2,766	3,617	5,100	2,892	23.3%
Serbia	2,022	2,808	3,348	4,081	4,596	2,574	22.8%
Qatar	256	309	425	421	573	317	22.3%
Cyprus	521	649	758	995	1,114	593	20.9%
Azerbaijan	314	483	514	565	654	340	20.1%

Figure 4.1 Share of world articles for UK and comparators, 2006-2010.



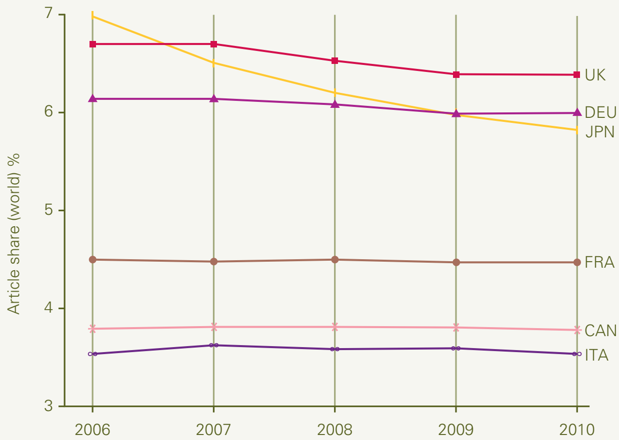
The rise of the BRICs

The emergence of new players is having a marked effect on the balance of power in the global research landscape. Four countries with large populations and dynamic economies were identified in 2001 as the BRICs (Brazil, Russia, India, and China). With strong growth in human capital and almost unbridled economic growth driving investments in R&D compared to G8 countries, Brazil, India and China have collectively destabilised the status quo of research in terms of the sheer volume of research outputs produced *(Table 4.2)*. As a result, global article shares of many other nations have trended downwards, even where underlying volume growth exists (for example, in the US, UK and many others).

Table 4.2 Increase in articles in the BRIC countries. Source: Scopus.

	Articles					Change (2006-2010)	
Country	2006	2007	2008	2009	2010	Absolute	CAGR
Brazil	29,682	33,058	37,569	40,745	43,188	13,506	9.8%
Russia	31,654	32,754	33,468	33,609	34,843	3,189	2.4%
India	41,200	45,958	51,128	56,923	65,487	24,287	12.3%
China	197,802	221,348	256,546	295,663	330,818	133,016	13.7%

Figure 4.1 A detailed view of the chart above (excluding USA and China).



	2006	2010	Change 06-10	CAGR 06-10	UK Rank 2006	UK Rank 2010
UK	**6.67%**	**6.38%**	**-0.28%**	**-1.07%**	-	-
EU27	30.54%	30.31%	-0.23%	-1.19%	1	1
OECD	85.48%	87.72%	2.25%	0.65%	4	3
World	100%	100%	-	-	4	3

Figure 4.1 Share of world articles for UK and comparators, 2006-2010. Source: Scopus.

Figure 4.2 Growth in UK publications 2006-2010, shown by constituent countries.

Figure 4.2. Growth in UK publications 2006-2010, shown by constituent countries. Constituent countries' data is for higher education institutions only (HEIs). UK data include both HEIs and non-HEIs. The latter could not unambiguously be assigned to constitutent countries. HEIs represent approximately 80% of UK articles published. Source: Scopus.

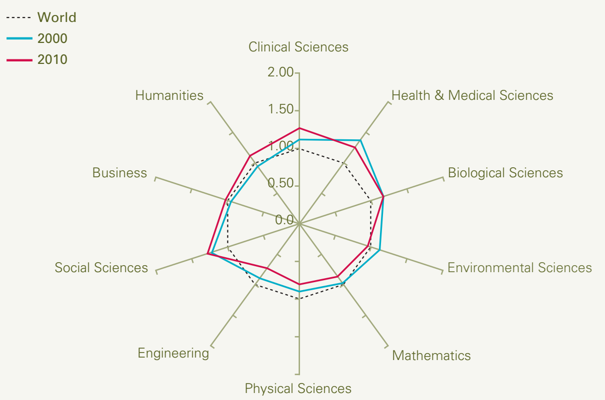
The UK continues to direct research efforts into the clinical & health sciences, social sciences, business and humanities. The UK's Activity Index[43] is each country's share of its total articles relative to the world's share of articles in each of the 10 research fields. A value of 1.00 indicates that a country's research effort in that field corresponds precisely with the world average. It reveals the emphasis of its research efforts versus the global average in 2000 and in 2010 and shows high and increasing share of world articles published in clinical sciences, health & medical sciences, social sciences, business and humanities *(Figure 4.3)*. A relative drop is seen in other emphasis areas (biological sciences and environmental sciences). The UK has lower share of articles published than the global average in mathematics, physical sciences and engineering, although share has grown slightly in mathematics. Other countries can be very broadly typified as generalists (Canada, France, US), technology-focused (China) or a composite of these types (Brazil, Germany, India, Japan).

[43] Hu, X. & Rousseau, R. (2009) "A comparative study of the difference in research performance in biomedical fields among selected Western and Asian countries" *Scientometrics* 81(2) pp. 475-491.

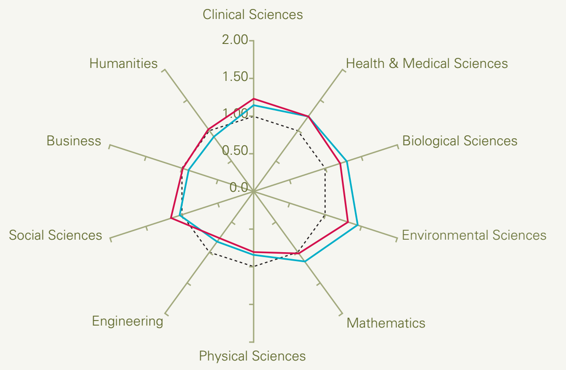
Figure 4.3 Activity Index for UK and comparators (also Brazil, India and Russia) across ten research fields in 2000 and 2010.

Figure 4.3 Activity Index for UK and comparators (also Brazil, India and Russia) across ten research fields in 2000 and 2010. The Activity Index is each country's share of its total articles relative to the world's share of articles in each of the 10 research fields. A value of 1.00 indicates that a country's research effort (indicated by article outputs) in that field corresponds precisely with the world average. Source: Scopus.

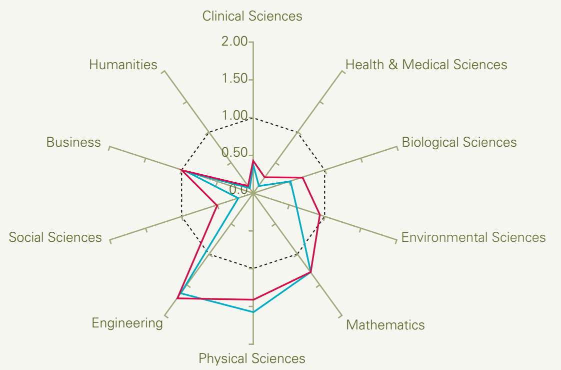
USA



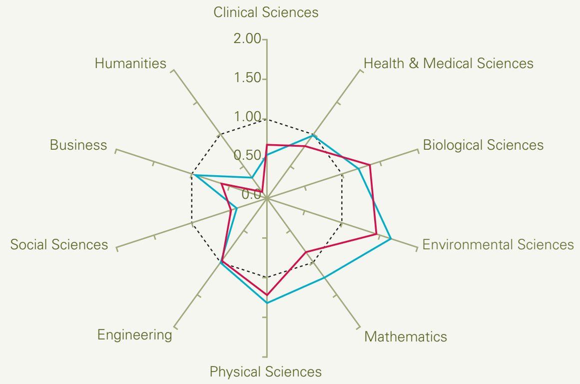
Canada



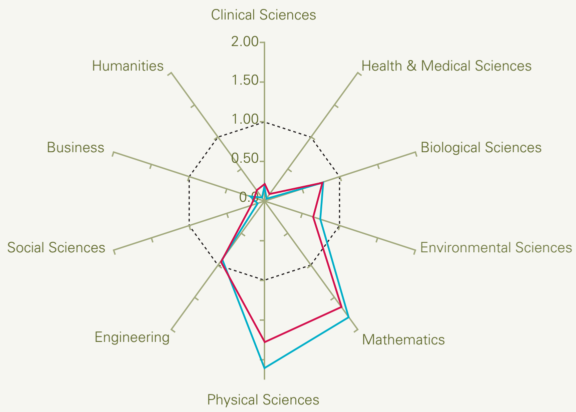
China



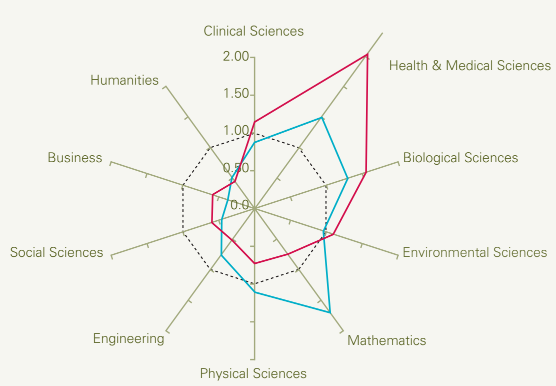
India



Russia



Brazil



4.2.2. Citations

Citations are typically understood to be an indicator of the quality or importance of scholarly work[44], where a document cited in an article is understood to act as a marker that may stand for a method, data or idea[45]. Since citations accumulate over time, citations are counted in overlapping five-year windows to allow comparisons over time; for example, the 2010 data-point relates to articles published in the period 2006-2010 inclusive, and the citations to these same articles in the same period (i.e. 2006-2010 inclusive).

UK research quality is world-class. Citations to UK articles have grown strongly at 7.2% per year since 2006 compared to 6.3% for the global average (see report Appendix F: Supplementary Data, section 4 for details). The UK ranks 2nd only to the US in the world in this indicator. The UK's share of citations also rose slightly (0.9% per year in the same period), strengthening its position relative to other comparator countries including the US *(Figure 4.4)*. This increase may be attributed, at least in part, to inflation as a result of incremental increases in the global volume of literature available for citation each year; much of it is understood to arise from the recent trend towards lengthening reference lists in published articles[46].

	2006	2010	Change 06-10	CAGR 06-10	UK Rank 2006	UK Rank 2010
UK	**10.49**	**10.87**	**0.38**	**0.90%**	-	-
EU27	38.61	39.27	0.66	0.42%	1	1
OECD	95.67	95.41	-0.25	-0.07%	2	2
World	100	100	-	-	2	2

Figure 4.4 Share of world citations for UK and comparators, 2006-2010.Each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. Source: Scopus.

Figure 4.4 Share of world citations for UK and comparators, 2006-2010.

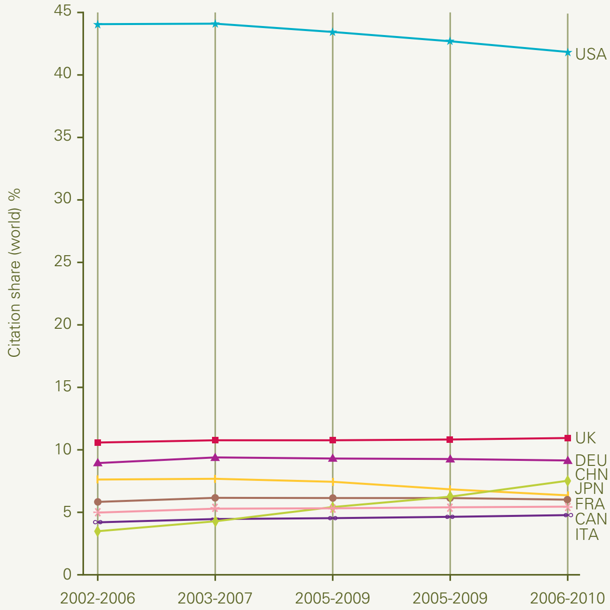
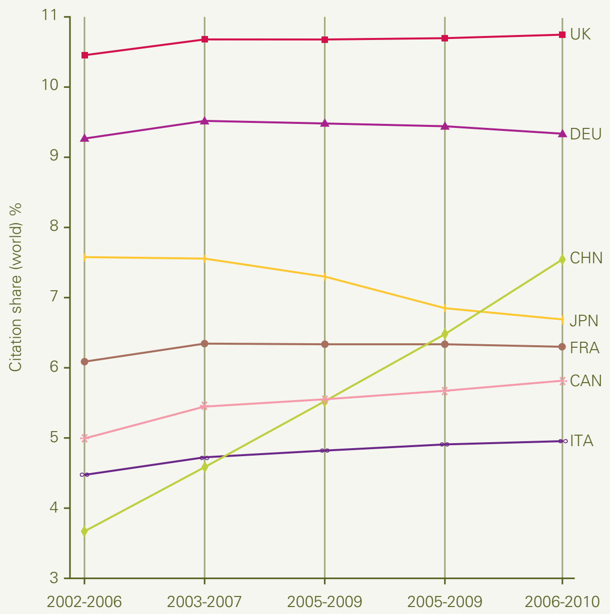


Figure 4.4 A detailed view of the chart above (excluding USA).

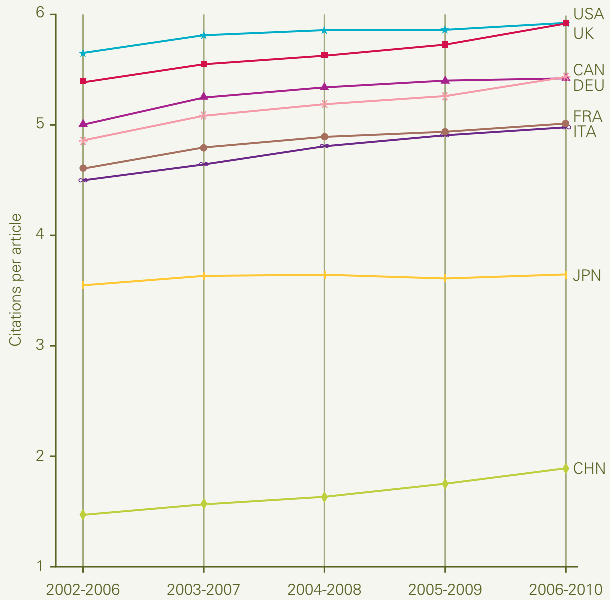


[44] Cronin B. (2005) "A Hundred Million Acts of Whimsy?" *Current Science* 89(9) pp. 1505-1509; Davis P.M. (2009) "Reward or persuasion? The battle to define the meaning of a citation" *Learned Publishing* 22(1) pp. 5-11.
[45] Small, H.G. (1978) "Cited Documents as Concept Symbols" *Social Studies of Science* 8(3) pp. 327-340.
[46] Althouse, B.M., West, J.D., Bergstrom, C.T., Bergstrom, T. (2009) "Differences in impact factor across fields and over time" *Journal of the American Society for Information Science and Technology* 60(1) pp. 27–34.

It is also important to note that, owing to differences in citation practices in different fields of research, citation counts may be biased in favour of those countries publishing large volumes of articles in highly-citing fields. Citations per article in the UK also continue to increase *(Figure 4.5)*.

An examination of the UK's citation output in its four constituent countries reveals that, as per article output, England constitutes the largest share, followed by Scotland, Wales and Northern Ireland. As with article output, citations are assigned to UK constituent countries where at least one of all UK-based authors listed on the cited article belongs to a HEI, while 'Non-HEIs only' represents articles where all UK-based authors cannot be unambiguously assigned to UK constituent countries in this way. Collectively, the UK received 3,459,875 citations in 2006-2010 to articles published in the same period and growth over recent years is positive in all four countries *(Figure 4.6)*.

Figure 4.5 Citations per article for UK and comparators, 2006-2010.



	2006	2010	Change 06-10	CAGR 06-10	UK Rank 2006	UK Rank 2010
UK	**5.42**	**5.94**	**0.52**	**2.33%**	-	-
G8	4.71	4.90	0.19	1.01%	2	2
EU27	4.35	4.60	0.25	1.41%	4	5
OECD	3.96	3.94	-0.02	-0.11%	7	8
World	3.48	3.57	0.09	0.66%	7	8

Figure 4.5 Citations per article for UK and comparators, 2006-2010. Each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. World data are for 229 countries with at least 1 article in 2010. World rankings out of 89 countries (of 229) with at least 500 articles in 2010. Includes all 42 OECD countries and accounts for over 99% of the world total output. Source: Scopus.

Figure 4.6 Growth in UK citations in overlapping five-year windows 2006-2010, shown by constituent countries.

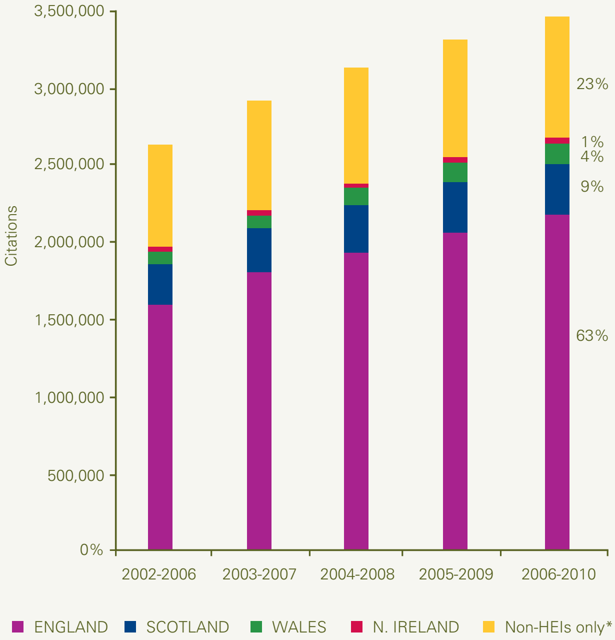
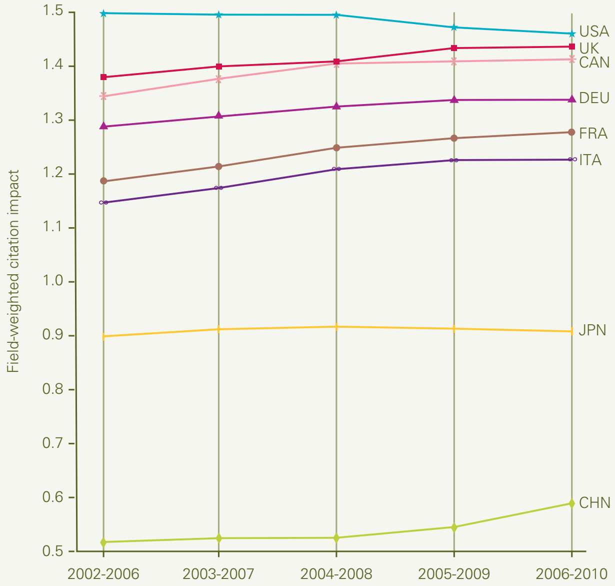


Figure 4.6 Growth in UK citations in overlapping five-year windows 2006-2010, shown by constituent countries. Constituent country data is for HEIs only. UK data includes both HEIs and non-HEIs. The latter could not unambiguously be assigned to constituent countries. HEIs represent approximately 80% of UK articles published. Source: Scopus.

Field-weighted citations account for the inherent differences in citation practices between fields and are preferable to citation counts or citations per article indicators for assessing research performance across countries of different size or research field focus. The UK's field-weighted citations are well above the world benchmark (which is defined as 1.00[47]), but are slightly lower than that of the US, ranking it 2nd in the G8 and in the comparator group *(Figure 4.7)*. Within the broader OECD and world groups the UK ranks lower (7th and 8th, respectively) but those nations ranking higher (including Iceland, Switzerland, Denmark, Netherlands, Sweden and Belgium) publish far fewer articles.

Figure 4.7 Field-weighted citations for UK and comparators, 2006-2010.



	2006	2010	Change 06-10	CAGR 06-10	UK Rank 2006	UK Rank 2010
UK	**1.38**	**1.44**	**0.06**	**1.14%**	-	-
G8	1.22	1.22	0.00	0.06%	**2**	**2**
EU27	1.12	1.15	0.03	0.68%	**4**	**5**
OECD	1.06	1.03	-0.03	-0.74%	**7**	**8**
World	1.00	1.00	-	-	**7**	**8**

Figure 4.7 Field-weighted citations for UK and comparators, 2006-2010. Field-weighted citations account for field-specific differences in citation practices. A value of 1.00 indicates that a country's field-weighted citations in that field corresponds precisely with the world average. Each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. World data are for 229 countries with at least 1 article in 2010. World rankings out of 89 countries (of 229) with at least 500 articles in 2010. Includes all 42 OECD countries and accounts for over 99% of the world total output. Source: Scopus.

[47] Bornmann, L. & Plume, A. (2011) "Is it necessary to consider suburbs (or small cities in the close proximity) and name variants in a citation impact analysis for bigger cities? An investigation using Munich as an example" *Journal of Informetrics* (in press).

An examination of the UK's field-weighted citation ratio in its four constituent countries reveals that Scotland and England have a consistently higher field-weighted citation impact than the UK average, and that Northern Ireland has a lower field-weighted citation impact than the UK average (but still significantly higher than the world average of 1.00; *Figure 4.8*). Wales has increased from below the UK average to above it in recent years. As for article output, field-weighted citations are assigned to UK constituent countries where at least one of all UK-based authors listed on the cited article belongs to a Higher Education Institute (HEI) as defined by HESA, while 'Non-HEIs only' represents articles where all UK-based authors cannot be unambiguously assigned to UK constituent countries in this way.

Citation distributions are extremely skewed, with a large proportion of articles never or seldom cited and a small proportion of articles receiving the majority of citations[48]. At the national level, highly-cited articles have been shown to be a good measure of research excellence[49]. The UK's share of articles in the 1st, 5th and 10th citation percentiles is high and growing (see Appendix F: Supplementary Data, section 4 for details), and in the 1st percentile, the UK is 2nd only to the US in share of highly-cited articles *(Figure 4.9)*. Some evidence exists to suggest that highly-cited articles are mostly research articles, are typically multi-authored and often involve international collaboration, and may be more likely to be interdisciplinary (or at least, relevant to more different research fields)[50].

Figure 4.8 UK field-weighted citation impact, in overlapping five-year windows 2006-2010, shown by constituent countries.

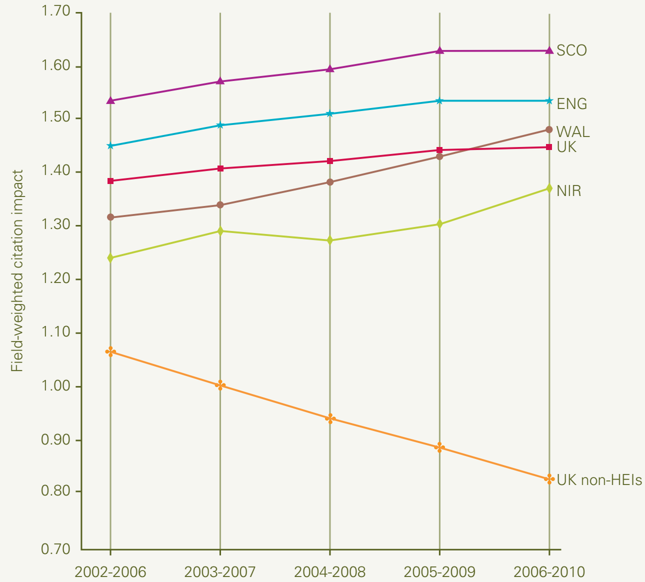


Figure 4.8 UK field-weighted citation impact, in overlapping five-year windows 2006-2010, shown by constituent countries. Constituent country data is for HEIs only. UK data include both HEIs and non-HEIs. The latter could not unambiguously be assigned to constituent countries. HEIs represent approximately 80% of UK articles published. Source: Scopus.

[48] de Solla Price, D.J. (1965) "Networks of Scientific Papers" *Science* 149(3683) pp. 510-515.
[49] Tijssen, R.J.W., Visser, M.S., van Leeuwen, T.N. (2002) "Benchmarking international scientific excellence: Are highly cited research papers an appropriate frame of reference?" *Scientometrics* 54(3) pp. 381–397; Aksnes, D.W & Sivertsen G. (2004) "The effect of highly cited papers on national citation indicators" *Scientometrics* 59(2) pp. 213-224.
[50] Aksnes, D.W. (2003) "Characteristics of highly cited papers" *Research Evaluation* 12(3) pp. 159-170.

Figure 4.9A Share of world highly-cited articles for UK and comparators, 2006-2010.

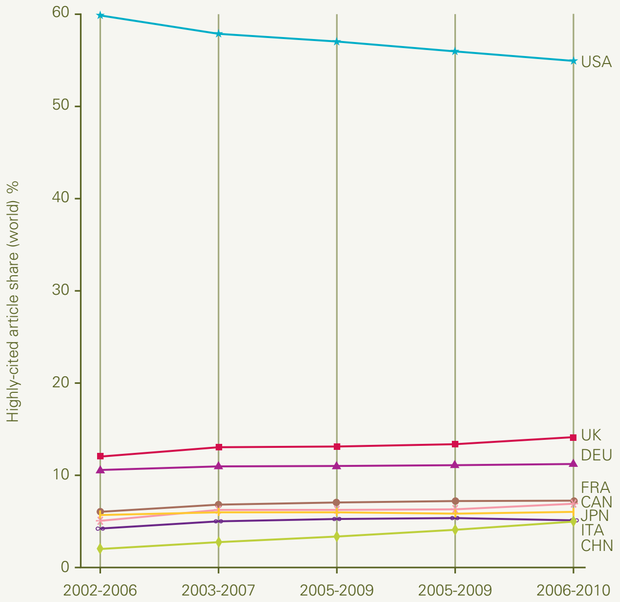
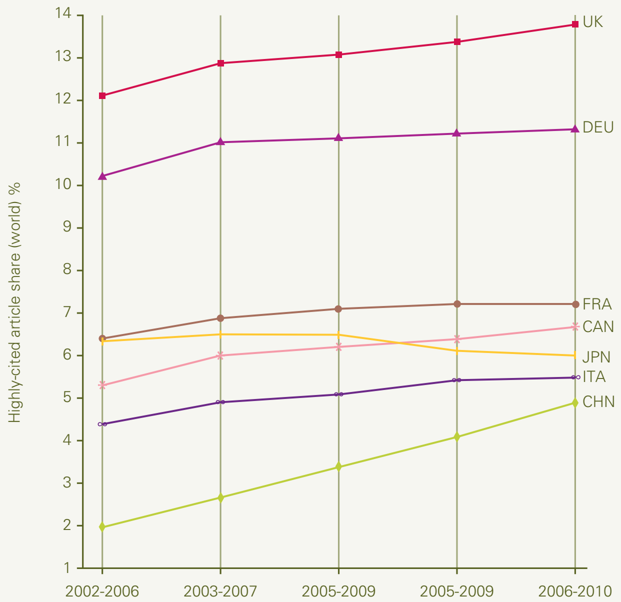


Figure 4.9B A detailed view of the adjacent chart (excluding USA).



	2006	2010	Change 06-10	CAGR 06-10
UK	**12.09**	**13.80**	**1.71**	**3.35%**

Figure 4.9 **Panel A**: Share of world highly-cited articles for UK and comparators, 2006-2010. **Panel B**: A detailed view of panel A (excluding USA). Highly-cited articles are those belonging to the 1% most cited articles (i.e. those in the 1st citation percentile). Each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. The top cited articles were selected from each of the subject areas considered in this study, effectively field weighting so that highly cited fields did not dominate the top 1%. Source: Scopus.

Figure 4.10 Highly cited articles (top 1% of the most cited articles) in constituent countries of the UK, 2006-2010.

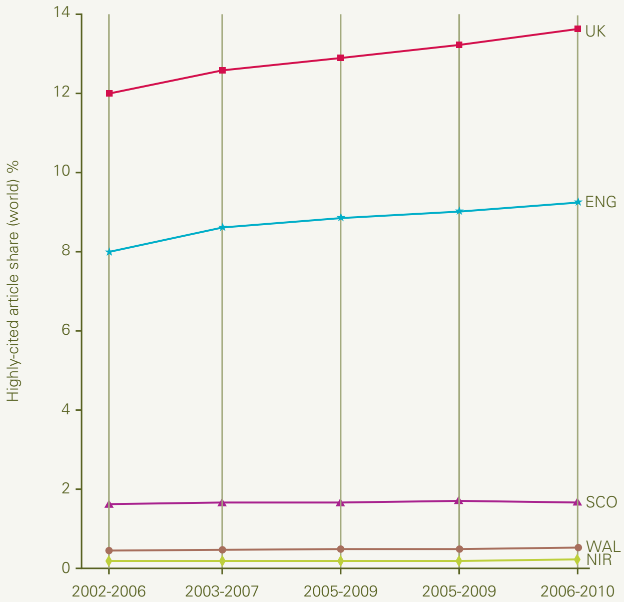


Figure 4.10 Highly cited articles (top 1% of the most cited articles) in constituent countries of the UK, 2006-2010. Data are shown in overlapping 5-year windows; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. The top cited articles were selected from each of the subject areas considered in this study, effectively field weighting so that highly cited fields did not dominate the top 1%. Constituent country data are for higher education institutions only (HEIs). UK data include both HEIs and non-HEIs. The latter could not unambiguously be assigned to constituent countries. HEIs represent approximately 80% of UK articles published Source: Scopus.

An examination of the UK's highly-cited article share compared with its four constituent countries reveals that England has the greatest share of these four, followed by Scotland, Wales and Northern Ireland *(Figure 4.10).*

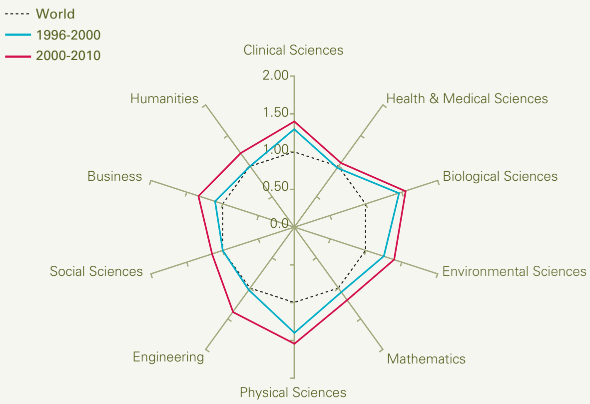
There is some evidence to suggest that the UK's high and rising share of highly-cited articles may be the result of UK HEIs competing for central funds based on assessment criteria where the quality of publications is taken as a proxy for the influence of research conducted at those institutions[51].

UK research quality is high across all subject fields. The UK's field-weighted citation impact across subject fields reveals high and rising influence *(Figure 4.11)*. Interestingly, the UK's field-weighted citation impact is especially strong in fields where it has relatively lower publishing activity – especially mathematics, physical sciences and engineering *(Figure 4.3).*

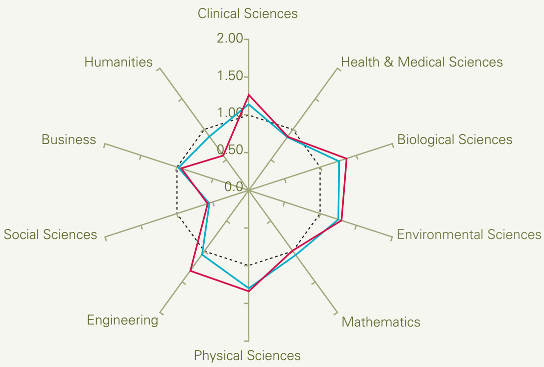
[51]OECD (2003) "Steering and funding of research institutions. Country report: UK". Available at http://www.oecd.org/dataoecd/24/35/2507946.pdf.

Figure 4.11 Field-weighted citation impact for UK and comparators (also Brazil, India and Russia) across ten research fields in 1996-2000 and 2006-2010.

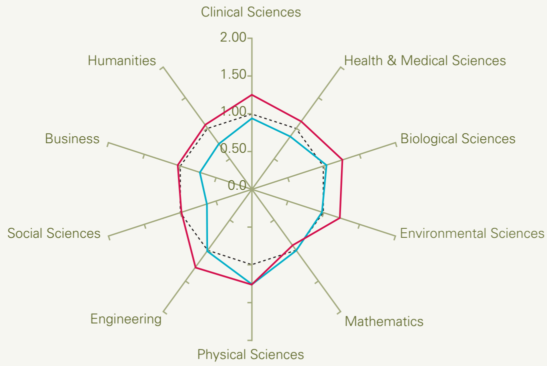
UK



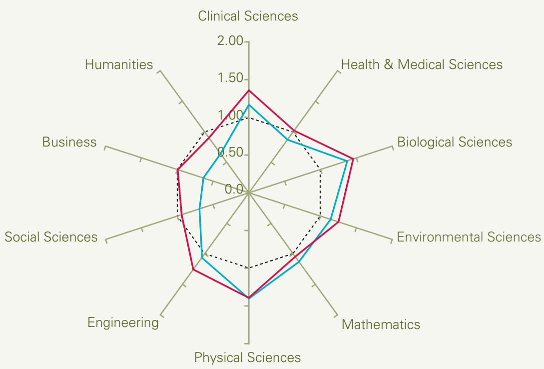
France



Italy



Germany



Japan

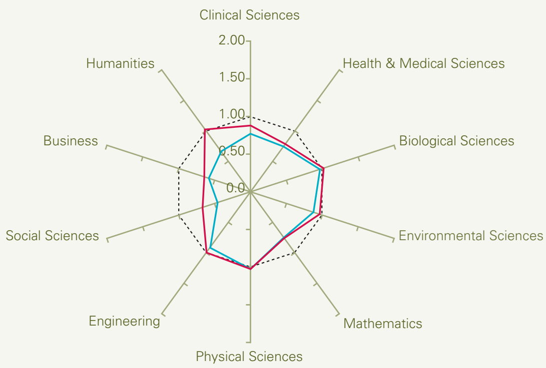
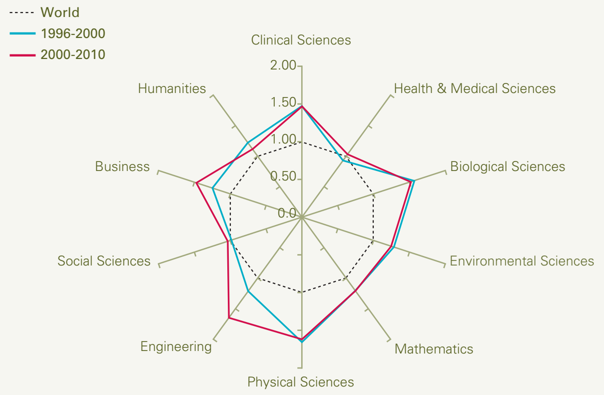
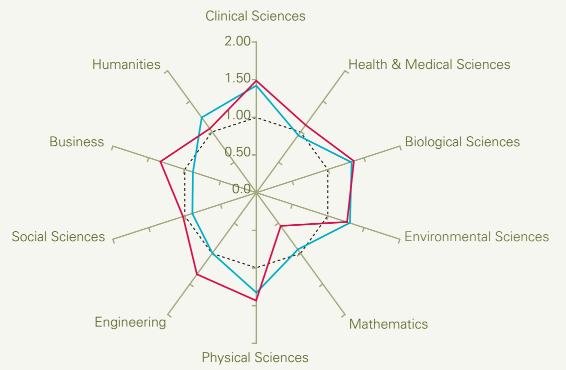


Figure 4.11 Field-weighted citation impact for UK and comparators (also Brazil, India and Russia) across ten research fields in 1996-2000 and 2006-2010. Field-weighted citation impact accounts for field-specific differences in citation practices. A value of 1.00 indicates that a country's field-weighted citation impact in that field corresponds precisely with the world average. Each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. Source: Scopus.

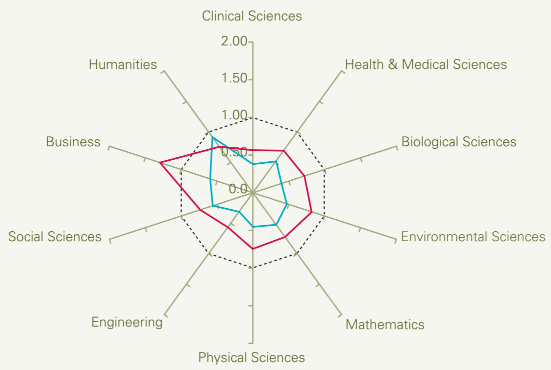
USA



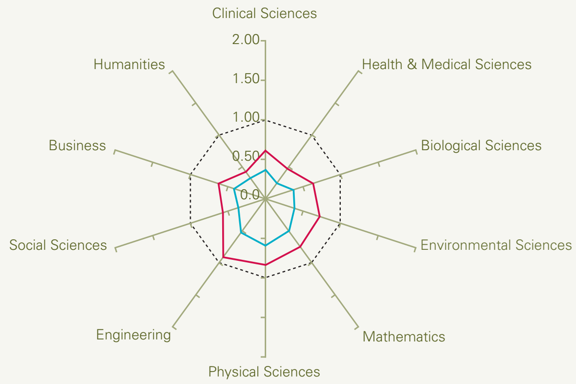
Canada



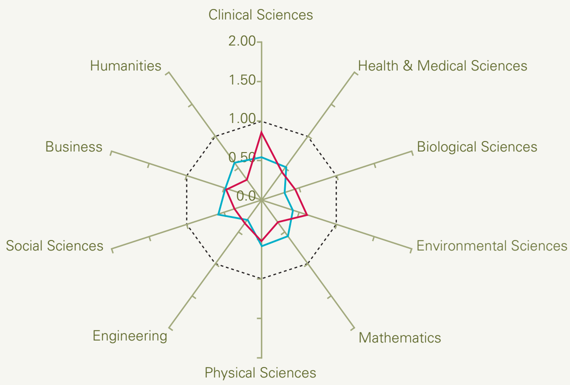
China



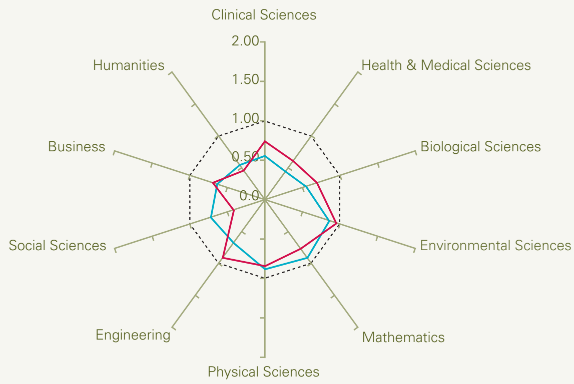
India



Russia



Brazil



The countries acting as sources of citations to UK articles have become more diverse over time, with citations from the UK itself proportionally reducing (as are 'traditional' sources such as the US, Japan, France and Germany) in favour of emerging research nations, especially China *(Figure 4.12)*. This increasing diversity could be the result of the increasing online availability of scholarly journals as countries beyond the UK have continued to adopt broad license agreements on a large scale that provide widespread access to journal articles. Recent findings have suggested that, as online availability of articles has increased, citations have tended to become concentrated on fewer different journals and articles[52]. However, these findings have since been refuted with data showing that the dispersion of citations across articles is increasing[53], an outcome in keeping with the pattern of dispersion across countries seen here.

Figure 4.12 Share of citations to UK articles, 1996-2000, 2002-2006 and 2006-2010.

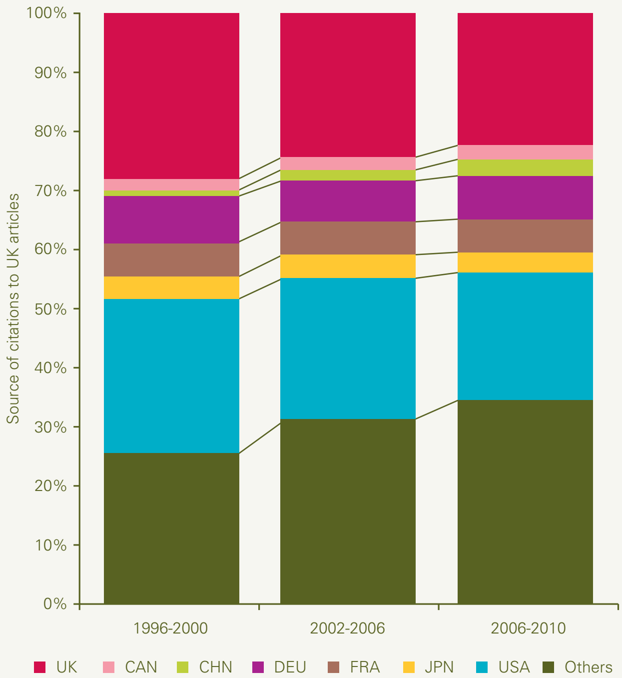


Figure 4.12 Share of citations to UK articles, 1996-2000, 2002-2006 and 2006-2010. The UK itself and the six other largest sources of citations are shown, in addition to an Others category. Each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. Source: Scopus.

Comparing the sources of citations to UK articles to the sources of citations of all articles globally, it is clear that UK authors cite UK authors disproportionately frequently, though have done so to a lesser extent in recent years. The pattern of national self-citation is in keeping with that observed for most other countries (see Appendix F: Supplementary Data, section 4 for details). However, it appears that while some comparator countries have begun to cite UK articles more often (France, Italy and Germany) some comparator countries (US, Japan and China) are strongly under-citing UK articles *(Figure 4.13)*. However, when country self-citations (i.e. citations to and from the same country) are excluded, citations from the US to UK are above average *(Figure 4.14)*.

Figure 4.13 Distribution of the source of citations to UK articles relative to the distribution of citations to world articles, 1996-2000, 2002-2006 and 2006-2010.

Figure 4.13 Distribution of the source of citations to UK articles relative to the distribution of citations to world articles, 1996-2000, 2002-2006 and 2006-2010. The UK and comparators are shown, in addition to an Others category. A value of 1.00 indicates that a country's share of citations going to the UK corresponds precisely with the world average share of citations to the UK. Each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. Source: Scopus.

[52] Evans, J.A. (2008) "Electronic Publication and the Narrowing of Science and Scholarship" *Science* 321(5887) pp. 395-399.
[53] Larivière, V., Gingras, Y., Archambault, E. (2009) "The decline in the concentration of citations, 1900–2007" *Journal of the American Society for Information Science and Technology* 60(4) pp. 858–862.

Figure 4.14 Distribution of the source of citations (less national self-citations) to UK articles relative to the distribution of citations to world articles (less national self-citations), 1996-2000, 2002-2006 and 2006-2010.

Figure 4.14 Distribution of the source of citations (less national self-citations) to UK articles relative to the distribution of citations to world articles (less national self-citations), 1996-2000, 2002-2006 and 2006-2010. The UK itself does not appear since national self-citations are excluded, so only comparators are shown, in addition to an Others category. A value of 1.00 indicates that a country's share of citations (less national self-citations) going to the UK corresponds precisely with the world average share of citations (less national self-citations) to the UK. Each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. Source: Scopus.

4.2.3. Usage

Article downloads (i.e. online usage of full-text documents) offer a different perspective from citations and may be interpreted as representing the interest in, or usefulness of, an article to the community it is aimed at:

> *"It can be hypothesized that the number of downloads primarily reflects a community's awareness of a paper, in terms of its availability and particularly its face value. Scientists may read – and in this sense use – many papers in their research, but during the research process and the writing their own papers, they sort out the articles worth citing and those that are less so. Thus, downloads and citations relate to distinct phases in the process of collecting and processing relevant scientific information that eventually leads to the publication of a journal article, the former being located more in the beginning, and the latter more towards the end of it."* [54]

Aside from "expressing different facets of impact" from citations[55], a primary advantage of usage data is to offer a more accurate measure of prestige in practitioner-oriented fields, where usage may be more important than citation[56]. Using data derived from Elsevier's ScienceDirect database (which provides usage data for approximately 25% of the world's published journal articles), it is possible to compare a country's field-weighted download impact (defined in an analogous way) with field-weighted citation impact across subject fields in a single time period *(Figure 4.15)*. The UK's field-weighted download impact distribution across subject fields is distinct from the field-weighted citation impact. The UK performs comparatively strongly in health & medical sciences and social sciences, but comparatively less well in all other fields. The UK's field-weighted download ratio is lower than the world average (defined as 1.00) only in the humanities (at 0.990) and mathematics (0.834).

[54] Moed, H. (2005) "Statistical relationships between downloads and citations at the level of individual documents within a single journal" *Journal of the American Society for Information Science and Technology* 56(10) pp. 1088–1097.

[55] Bollen, J., Van de Sompel, H., Rodriguez, M.A. (2008) "Towards Usage-based Impact Metrics: First Results from the MESUR Project" *JCDL '08 Proceedings of the 8th ACM/IEEE-CS joint conference on Digital libraries.*

[56] Shepard, P. (2011) "The Journal Usage Factor project: results, recommendations and next steps". Available at http://www.uksg.org/usagefactors.

Figure 4.15 Field-weighted citation impact (FWCI) and field-weighted download impact (FWDI) for UK and comparators (also Brazil, India and Russia) across ten research fields in 2006-2010.

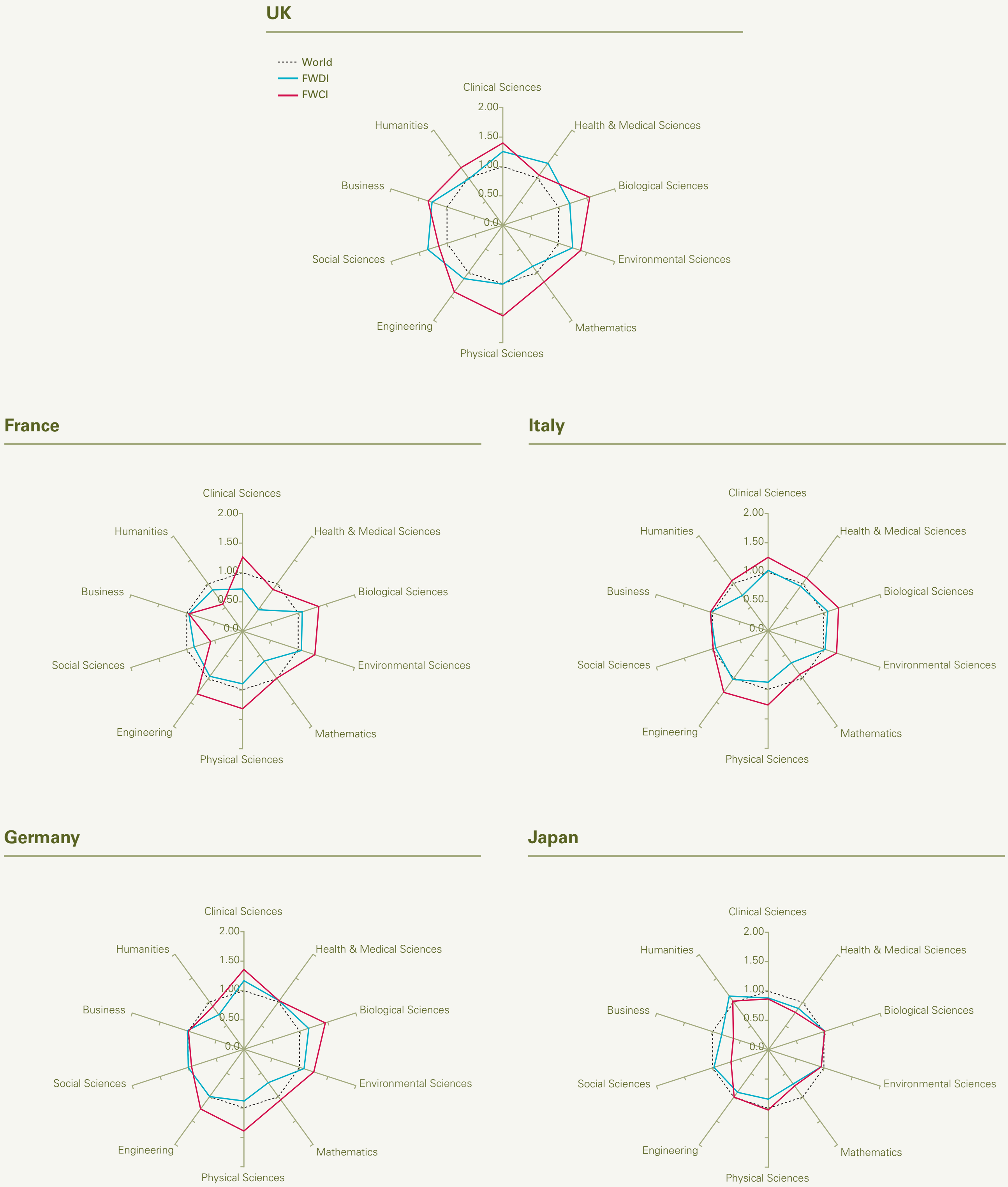
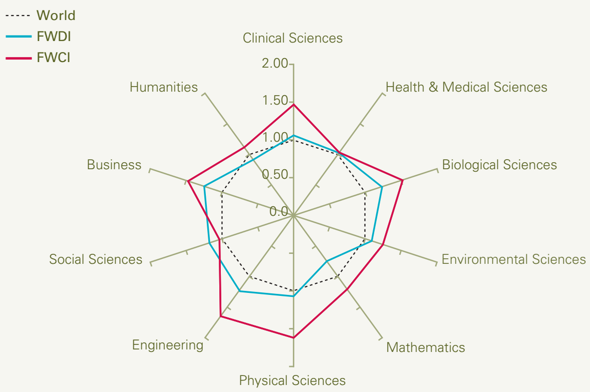
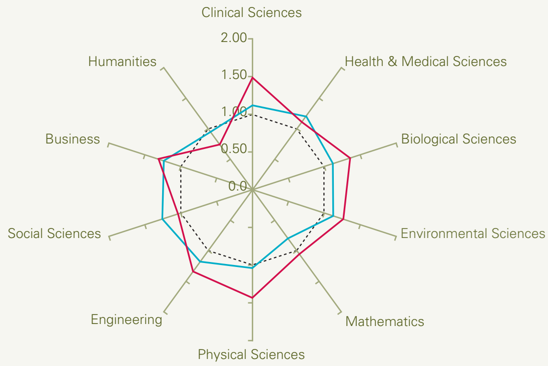


Figure 4.15 Field-weighted citation impact (FWCI) and field-weighted download impact (FWDI) for UK and comparators (also Brazil, India and Russia) across ten research fields in 2006-2010. Field-weighted impact accounts for field-specific differences in citation and download practices. A value of 1.00 indicates that a country's field-weighted impact in that field corresponds precisely with the world average. Each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. Source: Scopus and ScienceDirect.

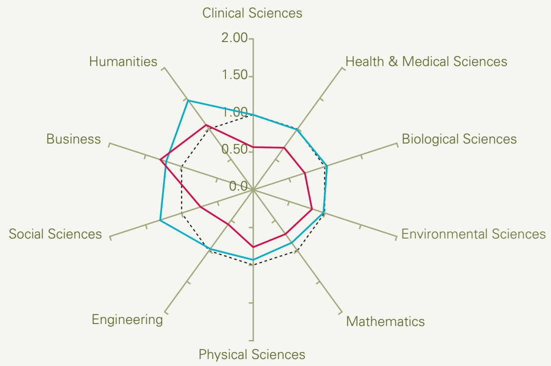
USA



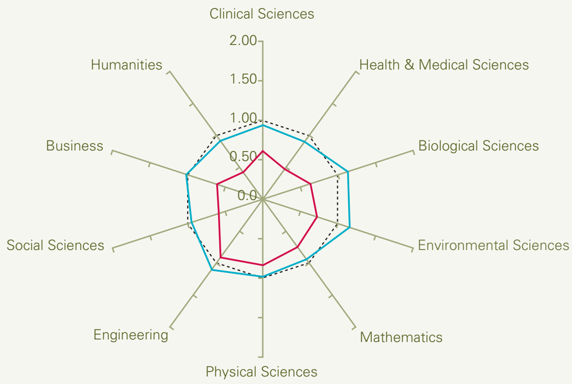
Canada



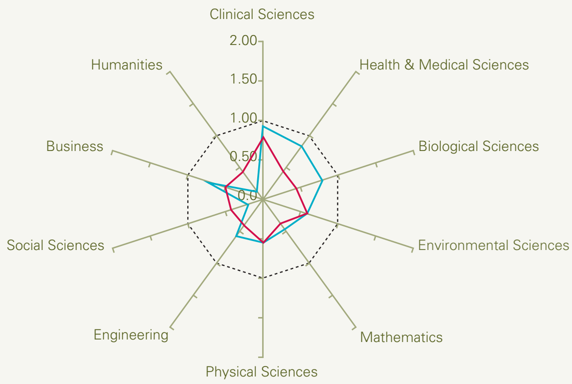
China



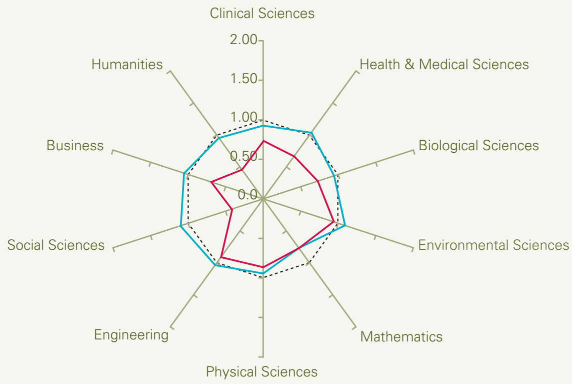
India



Russia



Brazil



4.2.4. Competencies

Elsevier has developed a new way of assessing the research strengths of a country that provides a complementary view to traditional citation-based indicators. This new research assessment methodology is enabled by Elsevier's SciVal Spotlight tool, which creates a visual map of the distinctive research strengths ("competencies") of a country. Rather than limiting analysis to individual subject areas, Spotlight considers a country's full article output as recorded in Scopus to show strengths that are truly interdisciplinary in nature.

The Spotlight map of UK research strengths for 2010 *(Figure 4.16)* shows over 400 areas of research in which the UK is very strong by international research standards. Each competency on the map represents an area of research, consisting of a set of topics that are strongly linked through co-citation, in which UK researchers are very prolific or highly-cited when compared to researchers from other countries. Competencies are placed at the average position of the mix of topics comprising the strength. Thus, competencies at the edge of the circle consist of groups of similar topics that fit neatly into traditional subject categories, while competencies that are closer to the centre consist of more disparate topics and have a multidisciplinary makeup.

The UK Spotlight map shows that the UK has strengths in all of the major areas of research. These strengths are not, however, evenly distributed. UK strengths are more concentrated in health sciences (orange), brain research (light orange), and social sciences (yellow) regions of the map. If one reads the map as one reads a clock, this comprises the area between eight o'clock and eleven o'clock. The largest UK strengths are also in this area of the map. UK strengths are far less concentrated in computer science, mathematics, physics, chemistry, and engineering (from eleven o'clock to four o'clock).

It is interesting to contrast the UK Spotlight map with those of several other countries *(Table 4.3)*. Maps for the United States, China, Japan and Germany are also shown in *Figure 4.16.*

Figure 4.16 2010 Spotlight Maps showing competencies for the UK, United States, China, Japan and Germany. Source: SciVal Spotlight.

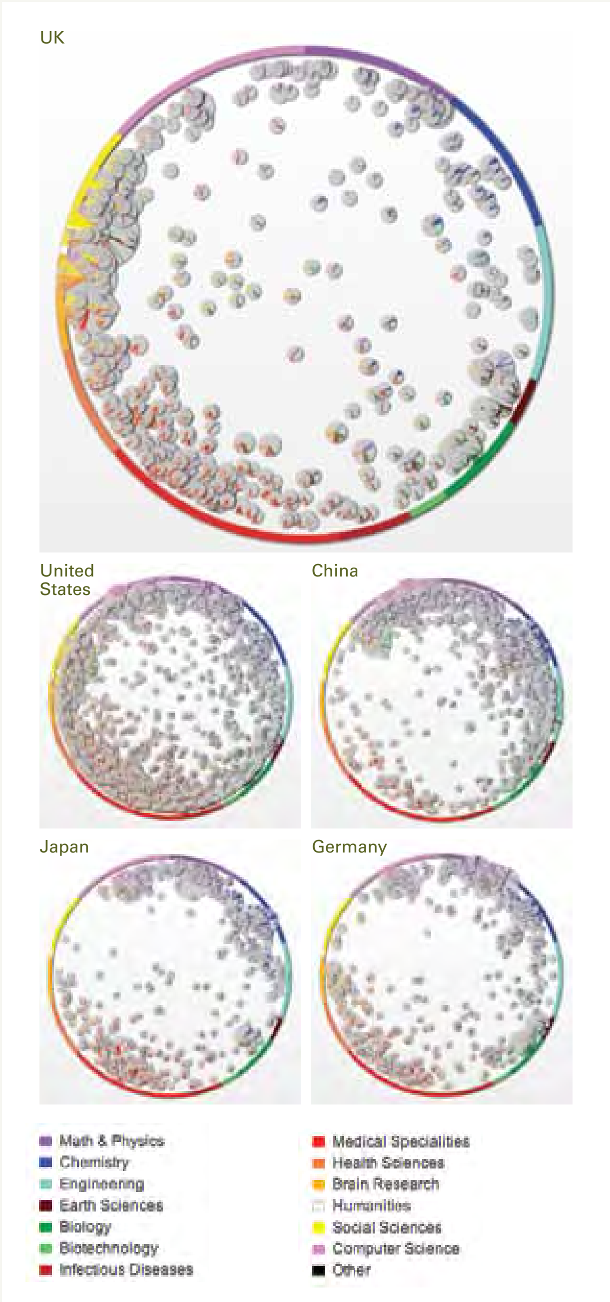


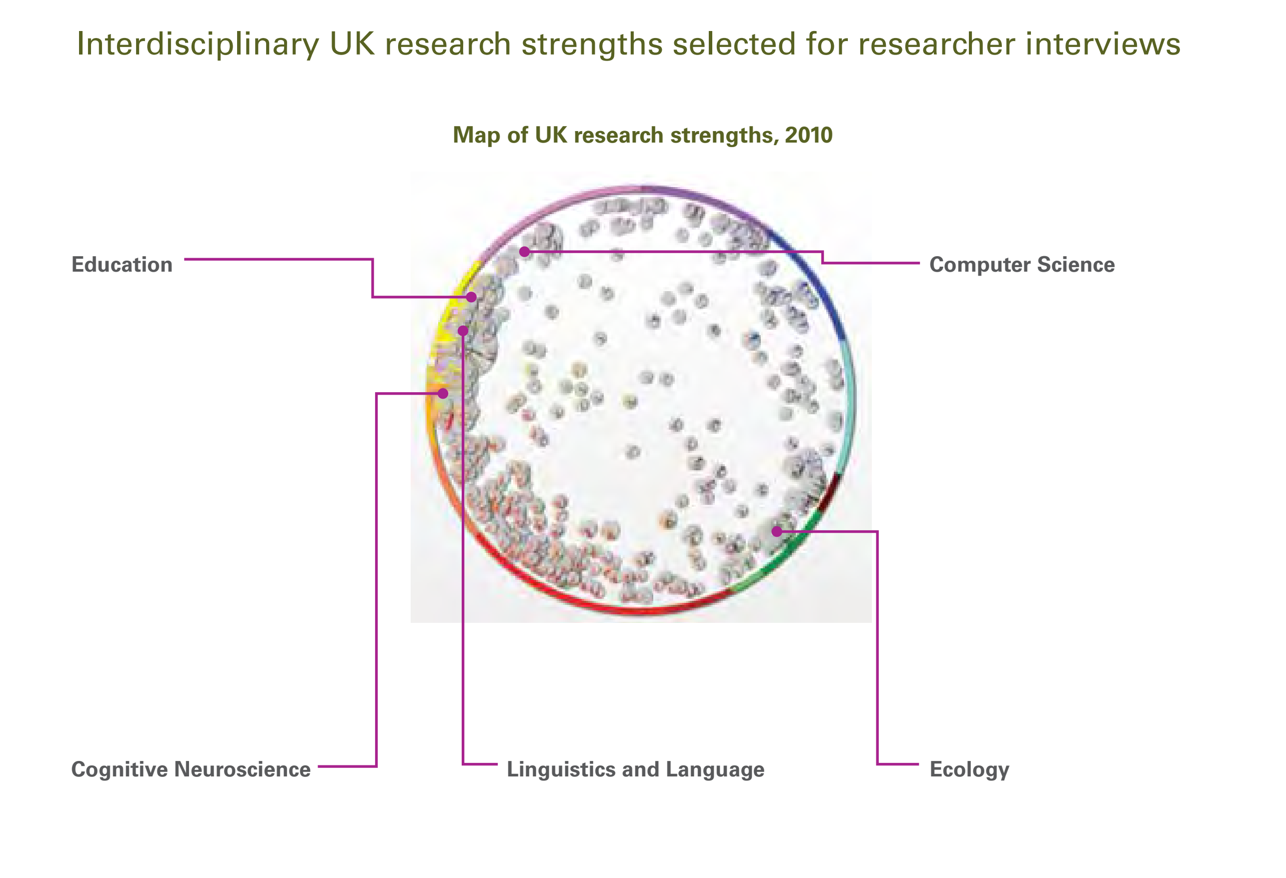
Table 4.3 Percentage of global competencies in subject areas held by the UK, US, Germany, Japan and China compared to the world average. All columns sum to 100%. Source: SciVal Spotlight.

Main Subject Areas	UK	USA	DEU	JPN	CHN	AVG
Computer Science	9.1%	7.2%	9.7%	7.3%	17.8%	10.0%
Mathematics & Physics	6.8%	5.8%	13.2%	13.8%	14.6%	9.3%
Chemistry	5.4%	7.9%	12.0%	14.5%	13.5%	9.9%
Engineering	7.5%	7.1%	8.7%	10.3%	19.1%	10.2%
Earth Sciences	3.5%	2.6%	3.0%	2.2%	4.5%	3.1%
Biology	5.3%	4.7%	4.8%	3.9%	4.5%	4.7%
Biotechnology	3.4%	5.4%	5.0%	4.5%	4.4%	4.8%
Infectious Diseases	8.2%	9.1%	7.4%	7.8%	2.8%	7.4%
Medical Specialities	16.1%	19.8%	15.8%	16.7%	6.6%	15.9%
Health Sciences	13.6%	12.7%	9.3%	9.7%	4.8%	10.5%
Brain Research	9.1%	10.9%	8.3%	8.5%	2.8%	8.5%
Humanities	2.0%	0.7%	0.1%	0.0%	0.0%	0.6%
Social Sciences	9.8%	6.0%	2.7%	0.7%	4.7%	5.3%

The UK holds more proportionally competencies in medical/health sciences and in humanities/social sciences than comparator countries. The UK has a very different research strength profile from China, Japan and Germany. China's strengths are nearly all in computer science, physics, chemistry and engineering, with very few strengths in the medical and social sciences. Japan and Germany each are very focused in physics and chemistry, and each has relatively more medical strengths than does China. However, neither have significant strengths in the social sciences. The UK and US maps are very different from those of Germany, Japan and China in that their strengths are not focused in the applied sciences, but are rather in the medical and social sciences. US strengths are more weighted toward the medical sciences while UK strengths are more weighted toward the social sciences. The UK and US maps are also similar in that they both have a significant number of strengths near the centre of the map, indicating that many of these strengths are highly multidisciplinary.

A deeper dive into the map of UK research strengths reveals some of the smaller disciplinary areas in which the UK has notable strengths relative to the other countries. In the social sciences these include strengths related to ethics (general ethics, bioethics, and business ethics), environmental and public policy, political geography, and pragmatics. In medical areas these include strengths in public health administration, pharmacoeconomics and tropical medicine. In the hard sciences these include strengths in conservation, archaeology and palaeogeography, topology (mathematics), and renewable energy.

Figure 4.17 Interdisciplinary UK Research strengths ("Competencies") chosen for the interviews.



Insights on selected UK competencies

In order to explore more fully some of the UK's distinctive competencies, *(Figure 4.17)*, 5-7 UK-based researchers were interviewed in each of five of the subject areas where the UK shows strong research performance. These 31 interviews covered 19 institutions across the UK and were primarily conducted with faculty at the level of professor. Interviewees were invited based on their comparative performance in their field and/or their role as an editor for a peer reviewed journal in their field. Further supporting the data on human capital suggesting that talent is attracted to the UK from outside the country, 19% of the researchers who agreed to be interviewed were not UK-born.

Key themes from interviews across five distinctive areas of UK research strength

- In the five selected interdisciplinary areas of UK research strength in which interviews were conducted, the UK is ranked 1st in the world or is a very close 2nd behind the US in terms of the volume of articles published and of citations to those articles. In all cases the fields of research are growing, but the relative share of UK articles is decreasing.

- The history of the area of research contributes to the UK's current strength. This does not necessarily mean that the field itself has been long-established, but that it built upon areas of historical strength. For instance, theoretical computer sciences has drawn upon the UK's long history in philosophy.

- Strength generates further strength, for example by making it easier to recruit top quality senior researchers. It is easier for universities who are successful in specific areas of research to further develop them in terms of recruitment and funding than to develop a new area of expertise.

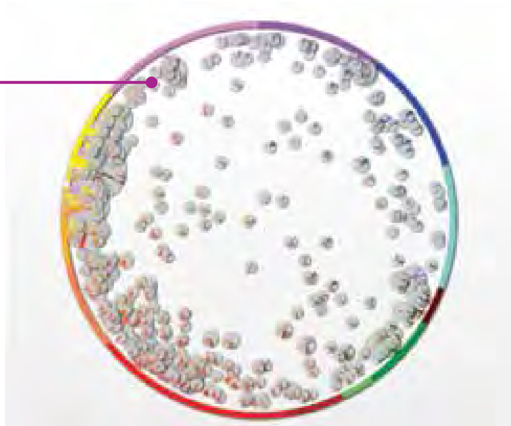
- Researchers in all disciplines expressed the opinion that key elements of their field's success were the ability to recruit excellent staff and then to ensure that they are free to pursue their chosen interests, whether self-directed "blue sky" endeavour or to work with more practical applications.

- Researchers in most areas expressed concerns regarding the availability of funding and the difficulty in recruiting good doctoral students in the UK.

- UK researchers collaborate with non-UK researchers across a wide range of countries that also pursue high quality research in the sub-field in question.

UK STRENGTH CASE STUDY 3: **COMPUTER SCIENCE**

Computer Science



Country			Fractionalized articles	Total articles	RRS	SotA	Citation count
	1.	United Kingdom	185.5	312	2.42	1.31	494.7
	2.	United States	81.8	233	0.05	-2.01	68.3
	3.	France	73.8	122	0.41	0.64	121.5
	4.	Netherlands	73.7	118	0.13	-0.98	182.8
	5.	Argentina	49.1	64	0.17	1.22	64.4
	6.	Spain	46.0	81	0.09	1.70	80.7
	7.	Canada	44.7	85	0.02	-0.82	98.8
	8.	Italy	42.1	79	0.22	1.24	100.7
	9.	Germany	35.0	77	0.13	1.06	80.2
	10.	China	30.4	65	0.00	0.30	6.5

Source: SciVal Spotlight, UK Country Map 2010.
RRS = Relative Reference Share; SotA = State of the Art. See Glossary for definitions.

Computer Science

The UK shows strength in a competency characterised by keywords such as "data mining", "semantic web" and "argumentation frameworks".

- UK rank:1 (US 2). The UK published 27% of the 689 (fractionalised) articles published in this interdisciplinary area of research during the period 2006-2010. This is a growing area of research (+6% per year), but UK article share decreased by 0.64% per year during this period.

- UK articles in this competency were cited 495 times, vs. 68 times for US articles (2006-2010). The relative reference share (RRS) of this competency in computer sciences for the UK is 2.42 (2006-2010). This means that the UK has more than double the reference papers in the set as the US.

- Leading UK institutions in this competency include: University of Liverpool (29% of UK articles, 34% of UK citations), University College London (12% of UK articles, 5% of UK citations), University of Edinburgh (12% of UK articles, 12% of UK citations) and Imperial College London (10% of UK articles, 21% of UK citations).

Computer science – the study of the theoretical foundations of information and computation, and the development of practical techniques to implement and apply these concepts in computer systems – is highly interdisciplinary. Computer scientists collaborate with economists to study the dynamics of financial markets, epidemiologists to model the spread of diseases, biologists to analyse genomic data, chemists to develop new drugs, and physicists to study the cosmos. Researchers also frequently draw on seemingly unrelated fields, such as philosophy and linguistics, in developing theories, models and practical applications.

"Computer science has broad applications in all aspects of the economy. Information technology now plays an essential role in managing, optimising, and coordinating productive activities, from mining and raw materials to manufacturing and agriculture. For example, the output of mines and oil wells can be optimised through the use of advanced techniques from artificial intelligence."
Peter McBurney, Professor of Computer Science at King's College London

Computer science is also currently being applied to develop the infrastructure and software technologies to facilitate the UK's transition from an economy mainly based on physical products towards a digital economy. In the area of financial markets, in which interconnected and automated trading systems are increasingly replacing human traders, computer science provides not only the tools to make trades, but also the means to analyse the dynamics of how automated trading systems interact and affect global financial stability.

The dynamics of 'multi-agent systems', in which thousands or even millions of autonomous 'computational agents' interact, is of broad interest to computer scientists. As computers become more and more integrated into our daily lives, the study of multi-agent systems is becoming increasingly important.

"For example, by 2020 most households in the UK will have 'smart energy meters', each of which can be considered as an agent. These will collect data that will enable more efficient energy consumption by homeowners, and allow energy providers to optimise the delivery of resources, but making sense of the data produced by 25 million households presents a big computational challenge."
Nick Jennings, Professor of Computer Science at Southampton University

Agents that interact in these complex computational ecologies need to have some rules or guidance for how to interact with other agents they encounter. This has led to the development of argumentation theory, in which agents exchange 'arguments' about certain courses of action and reach conclusions on the basis of rules that govern what counts as a persuasive argument.

"Beyond applications in the financial and energy sectors, argumentation theory has other potential applications whenever information is complex or incomplete – such as diagnosing a medical condition, or analysing security threats," says Francesca Toni, Reader in Computational Logic in the Department of Computing at Imperial College, London.

> *"Computer science is also highly relevant to data-intensive scientific fields, such as genomics, drug discovery, and astronomy. UK researchers have had a leading role in developing the 'Semantic Web', which aims to make online scientific data more meaningful to, and therefore more analysable by, computers. As such, advances in computer science are deeply connected to scientific progress."*
> **Carole Goble, Professor of Computer Science at the University of Manchester**

"Increasingly, data storage is shifting from a local computer (the home or office PC, for instance) to remote 'clouds' of computer networks," says Paul Watson, Professor of Computer Science and Director of the Digital Institute at Newcastle University. These are often provided by private companies, such as Amazon, and users pay for storage space. In addition, resource-intensive applications and programs that would overwhelm smaller computers can also be run on these clouds. "By offloading the storage and processing requirements from a local computer to a massive and powerful cloud, users no longer need to invest in expensive hardware to store huge amounts of data or carry out complex computational procedures, bringing down the costs of scientific research." Computer scientists address the many challenges involved in developing efficient, secure cloud networks.

How did the UK become a global leader in computer science?

History: The UK has a long history of developing core theoretical and practical ideas in computer science, from Charles Babbage and George Boole in the 19th century to Alan Turing and Tim Berners-Lee in the 20th. Today's researchers build on this historical momentum.

Mixing theory and practice: Computer science can be a very theoretical, mathematical discipline, and the UK has long excelled in this aspect of the field. Yet in the UK theoretical work has typically been carried out in the context of solving practical problems, such as code breaking, and has long been allied with applied disciplines such as engineering, which has led to synergistic interactions between disciplines.

Attracting the best and brightest: As the UK has been home to some of the world's first computers, it has long had a reputation as a leader in the field.

> *"This has made the UK an attractive destination to study and work and has enabled institutions to create diverse, high-quality research teams. The success of these centres of excellence has bred further success, and maintained the UK's lead in this competitive field. In addition, the ability to apply for research funding for a wide range of projects has made the UK a good place to pursue the many facets of computer science."*
> **Francesca Toni, Reader in Computational Logic in the Department of Computing at Imperial College, London**

COLLABORATION

COLLABORATION

Research collaboration may take many forms, some of them obvious (such as co-authorship of articles or acknowledgement within them) and some of them less so (such as informal discussions and informal information sharing, which account for as much as half of all collaborations)[57]. The rise of collaboration as measured by co-authorship of articles by authors residing in separate countries – the most commonly-used proxy – is a consequence of the professionalisation of research and has shown considerable expansion in recent decades[58]. Most methodologies to address the question of the extent and patterns in international collaboration have employed co-authorship data from publication databases[59].

5.1. Key Findings

The UK's rate of international co-authorship is high and rising.

- 46% of UK authored-articles were co-authored with a non-UK researcher, a rate of international collaboration 2nd only to France in the comparator group.
- In most cases, there is a clear citation advantage that accumulates to internationally co-authored papers, over and above that of institutionally-authored or nationally co-authored articles.
- UK articles co-authored with a non-UK researcher have more citations per paper than domestically authored articles, regardless of where the non-UK author resided.
- Acting in concert with the effects of brain circulation and international citation described in section 3 it is likely that the UK's global influence and reputation for research is related to its wide - and widening - collaboration with diverse parts of the world.

5.2. Collaboration: Discussion

UK researchers are highly collaborative. The UK's rate of international co-authorship is high and rising, reaching 46% in 2010 (2nd only to France in the comparator group), with low and decreasing rates of national and institutional co-authorship (of 38% and 16% respectively; *Figure 5.1)*. UK international co-authorship is associated with a 2.0-fold increase in citations per article over institutional co-authorship (and 1.4-fold for national co-authorship over institutional co-authorship); these rates are broadly in line with those seen in most other comparator countries except the US (which sees a lower increase for international co-authorship), China (which sees a much higher increase for international co-authorship), and also India (which sees lower increases for both national and international co-authorship).

Comparator countries show different patterns based upon their emphasis on collaboration as measured by co-authorship which fall into three main categories: (a) high and rising rates of international co-authorship with low and falling institutional co-authorship rates (Canada, Germany, France, and the UK); (b) high but falling rates of institutional co-authorship with low and steady international co-authorship rates (China, India, Japan); (c) high but falling rates of institutional co-authorship with low but rising international co-authorship rates (US). France has a notably high rate of international collaboration, and India is the only country in the comparator set showing a clear increase in national co-authorship over time. In most cases, there is a clear citation advantage that accumulates to internationally co-authored papers, over and above that of institutionally-authored or nationally co-authored articles.

Collaboration can be considered to be a form of 'collabetition', (i.e. part collaboration, part competition) insofar as it is unlikely that the costs of collaborating are borne without advantages accumulating to both collaborators in a partnership. One such benefit may be the increased citations for internationally co-authored papers[60], which has been shown to exist over and above a multi-authorship effect[61]. Another may be the observed

[57] Beaver, D.deB. (2001) "Reflections on scientific collaboration (and its study): past, present, future" Scientometrics 52(3) pp. 365–377; Laudel, G. (2002) "What do we measure by co-authorships?" *Research Evaluation* 11(1) pp. 3–15.
[58] He, T. (2009) "International scientific collaboration of China with the G7 countries" *Scientometrics* 80(3) pp. 571–582.
[59] Melin, G. & Persson, O. (1996) "Studying research collaboration using co-authorships" *Scientometrics* 36(3) pp. 363–377.
[60] Glänzel, W. (2001) "National characteristics in international scientific co-authorship relations" *Scientometrics* 51(1) pp. 69–115; Levitt, J.M. & Thelwall, M. (2010) "Does the higher citation of collaborative research differ from region to region? A case study of Economics" *Scientometrics* 85(1) pp. 171–183.
[61] Persson, O., Glänzel, W., Danell, R. (2004) "Inflationary bibliometric values: The role of scientific collaboration and the need for relative indicators in evaluative studies" *Scientometrics* 60(3) pp. 421–432.

productivity boost for individual authors[62], although this may be associated in part by their appearance as a 'fractional author' on more papers. Despite the underlying trend towards collaborative research in recent decades, the extinction of the single-authored article (predicted since the 1960s[63]) is unlikely[64].

With the obvious advantage to UK research of high citations, national growth benefits from even greater rates of international collaboration and removal of barriers to establishing and maintaining such collaborations. Very recent work has demonstrated that networks of co-authorship overlap strongly with networks of acquaintanceship, suggesting that collaborations arise from interpersonal interactions[65]. This has implications for programmes aimed at encouraging collaboration operating at the institutional or national level.

Since research collaboration occurs among individuals, observed patterns of international collaboration are simply an emergent property of complex networks of researchers interacting in self-interested ways. Indeed, research collaboration operates via small-world networks, and as such the well-known principle of 'six degrees of separation' (made famous by the network of connections between movie actors) holds[66].

With rising international collaboration rates globally, research is being done in an increasingly distributed way that blurs the lines between countries[67]. International collaboration rates are strongly influenced by cultural, historical, linguistic, and geopolitical factors[68]. Conceptual frameworks have been developed to explain these differences, and also the positioning of the different partners in bilateral collaborations: e.g. co-option, solidarity, and 'master-pupil'[69]. It appears that this may be levelling out differences between countries in the collaborative core: there is an apparent convergence of citations in highly-collaborating countries[70]. The core collaborating countries are becoming fewer and fewer, defining the centre in a more and more pronounced centre-periphery model arranged around growing peripheral hubs that act as the centre for their periphery[71]. Collaborations in the periphery are rare[72]. Given the increasingly distributed nature of research, it has been suggested that it will become more and more difficult to relate R&D inputs to outputs at national level, and that public accountability for research may need to shift to a global scale[73].

A network mapping approach has been used to visualise the UK's most frequent international collaboration partners, their field-weighted citation impact, and the field-weighted citation impact of the co-authored articles that result *(Figure 5.2)*. Countries are mapped as 'nodes' in the network overlaid on a projection of the globe, with node size for all countries (except the UK, which is reduced to a point) proportional to the number of co-authored articles with the UK. Collaborative relationships are mapped as 'edges' (lines connecting nodes) of equal thickness. Colours reflect the field-weighted citation impact of either the country (nodes) or the co-authored articles (lines) represented (see *Figure 5.2* for definition of colour scheme).

[62] Lee, S. & Bozeman, B. (2005) "The Impact of Research Collaboration on Scientific Productivity" *Social Studies of Science* 35(5) pp. 673–702.
[63] de Solla Price, D.J. (1963) *Little Science, Big Science.* Columbia Univ. Press New York.
[64] Abt, H.A. (2007) "The future of single-authored papers" *Scientometrics* 73(3) pp. 353–358.
[65] Pepe, A. (2011) "The relationship between acquaintanceship and coauthorship in scientific collaboration networks" *Journal of the American Society for Information Science and Technology* (in press).
[66] Newman, M.E.J. (2001) "The structure of scientific collaboration networks" *PNAS* 98(2) pp. 404–409.
[67] Nagpaul, P.S. (2003) "Exploring a pseudo-regression model of transnational cooperation in science" *Scientometrics* 56(3) pp. 403–416.
[68] Luukkonen, T., Persson, O., Sivertsen, G. (1992) "Understanding Patterns of International Scientific Collaboration" *Science Technology & Human Values* 17(1) pp. 101–126.
[69] Zitt, M., Bassecoulard, E., Okubo, Y. (2000) "Shadows of the past in international cooperation: Collaboration profiles of the top five producers of science" *Scientometrics* 47(3) pp. 627–657.
[70] Persson, O., Glänzel, W., Danell, R. (2004) "Inflationary bibliometric values: The role of scientific collaboration and the need for relative indicators in evaluative studies" *Scientometrics* 60(3) pp. 421–432.
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[73] Leydesdorff, L. & Wagner, C.S. (2008) "International collaboration in science and the formation of a core group" *Journal of Informetrics* 2(4) pp. 317–325.

Figure 5.1 Share of articles for UK and comparators (also Brazil, India and Russia) by co-authorship type, 2006-2010.

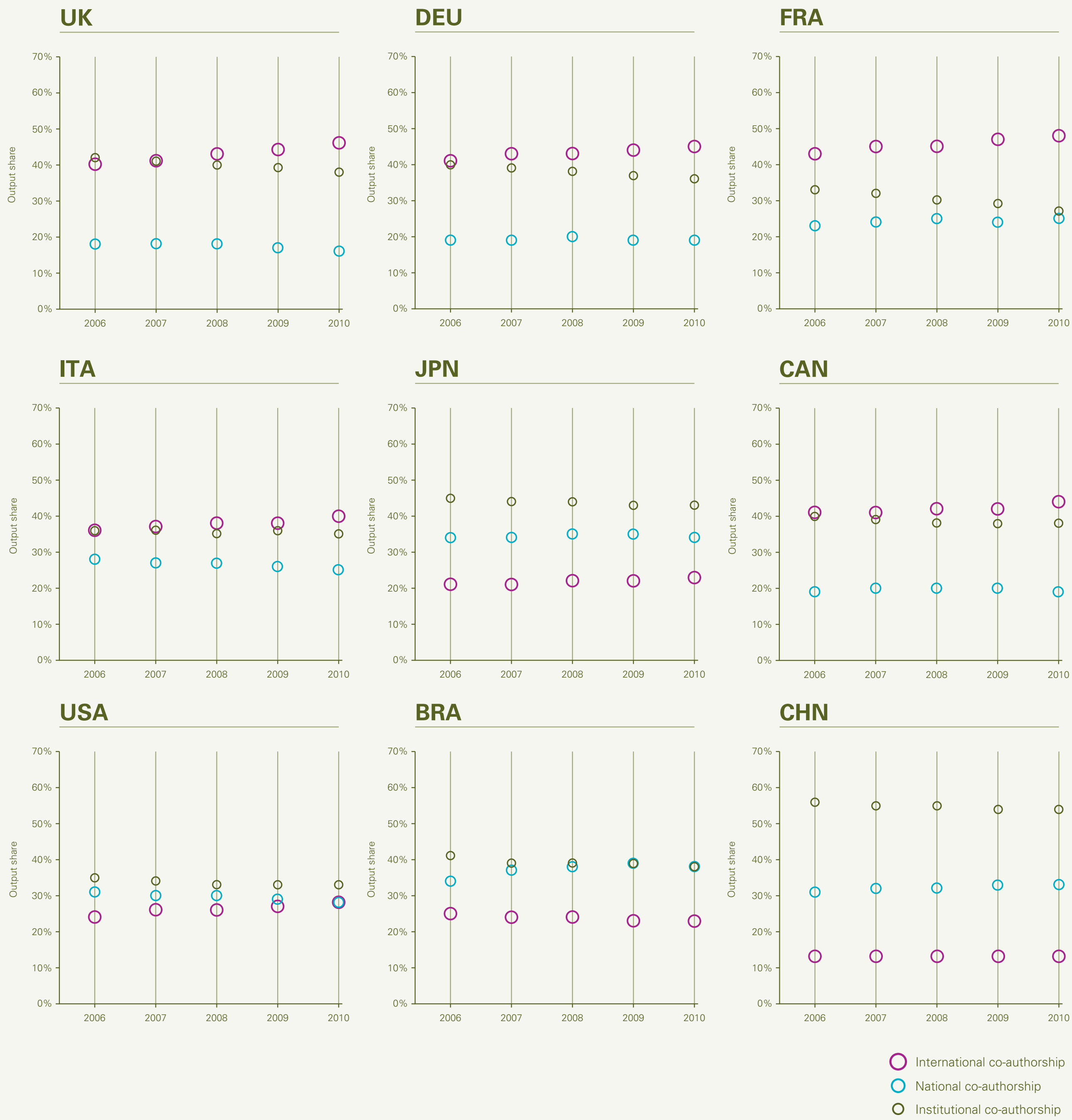


Figure 5.1 Share of articles for UK and comparators (also Brazil, India and Russia) by co-authorship type, 2006-2010 (cont.).

	Citations per article fold increase over institutional co-authorship		
	Institutional	National	International
UK	**1.0**	**1.4**	**2.0**
CAN	1.0	1.4	2.1
DEU	1.0	1.2	2.0
FRA	1.0	1.5	2.3
ITA	1.0	1.4	2.4
JPN	1.0	1.4	2.4
USA	1.0	1.5	1.7
BRA	1.0	1.1	2.6
CHN	1.0	1.2	3.1
IND	1.0	0.8	1.8
RUS	1.0	1.2	5.9
G8	1.0	2.3	1.6
EU27	1.0	1.4	2.0
OECD	1.0	1.6	1.3

	Downloads per article fold increase over institutional co-authorship		
	Institutional	National	International
UK	**1.0**	**1.1**	**1.1**
CAN	1.0	1.0	1.1
DEU	1.0	1.0	1.1
FRA	1.0	1.2	1.6
ITA	1.0	1.0	1.2
JPN	1.0	1.0	1.2
USA	1.0	1.1	1.1
BRA	1.0	1.0	1.2
CHN	1.0	1.0	1.3
IND	1.0	0.9	1.0
RUS	1.0	1.1	1.7
G8	1.0	1.1	1.1
EU27	1.0	1.0	1.2
OECD	1.0	1.1	1.0

Figure 5.1 Share of articles for UK and comparators (also Brazil, India and Russia) by co-authorship type, 2006-2010. Bubble sizes represent citations per article, where each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. Institutional co-authorship: all authors have the same institutional affiliation within the country of interest (includes articles with only a single author). National co-authorship: authors have different institutional affiliations but are all within the country of interest. International co-authorship: authors have institutional affiliations in different countries, at least one of which is within the country of interest. Data for G8, EU27 and OECD treats these as single countries. Source: Scopus.

Over the period 2006-2010, the UK's most frequent collaboration partners were also among the largest producers of articles: the US, Germany, France, Italy, Netherlands, Australia, Canada, Spain, China and Switzerland comprise the top 10. In almost all collaborations shown on this map, the field-weighted citation impact of the co-authored articles is more than 10% greater than the world average (i.e. 1.100 or above), even where the field-weighted citation impact of the collaborating country is not. It is clear that UK collaborations are typically of high quality regardless of the partner, with 78% of collaborative papers with countries whose overall field-weighted citation impact (FWCI) is greater than the world average and virtually all collaborative papers resulting in FWCI greater than the UK's average.

Of the 109 collaborating countries shown in *Figure 5.2 A and B*, 69 have an average FWCI lower than the world average. Even here, 90% of the resulting collaborative articles have a FWCI greater than the world and UK averages. In this latter case the UK may be seen as taking the role of 'master' in the 'master-pupil' view of collaboration.

Acting in concert with the effects of brain circulation and international citation it is likely that the UK's global influence and reputation for research is related to its wide - and widening - recognition from diverse parts of the world.

Figure 5.2 A: International collaboration map for the UK in the period 2006-2010, world excluding Europe.

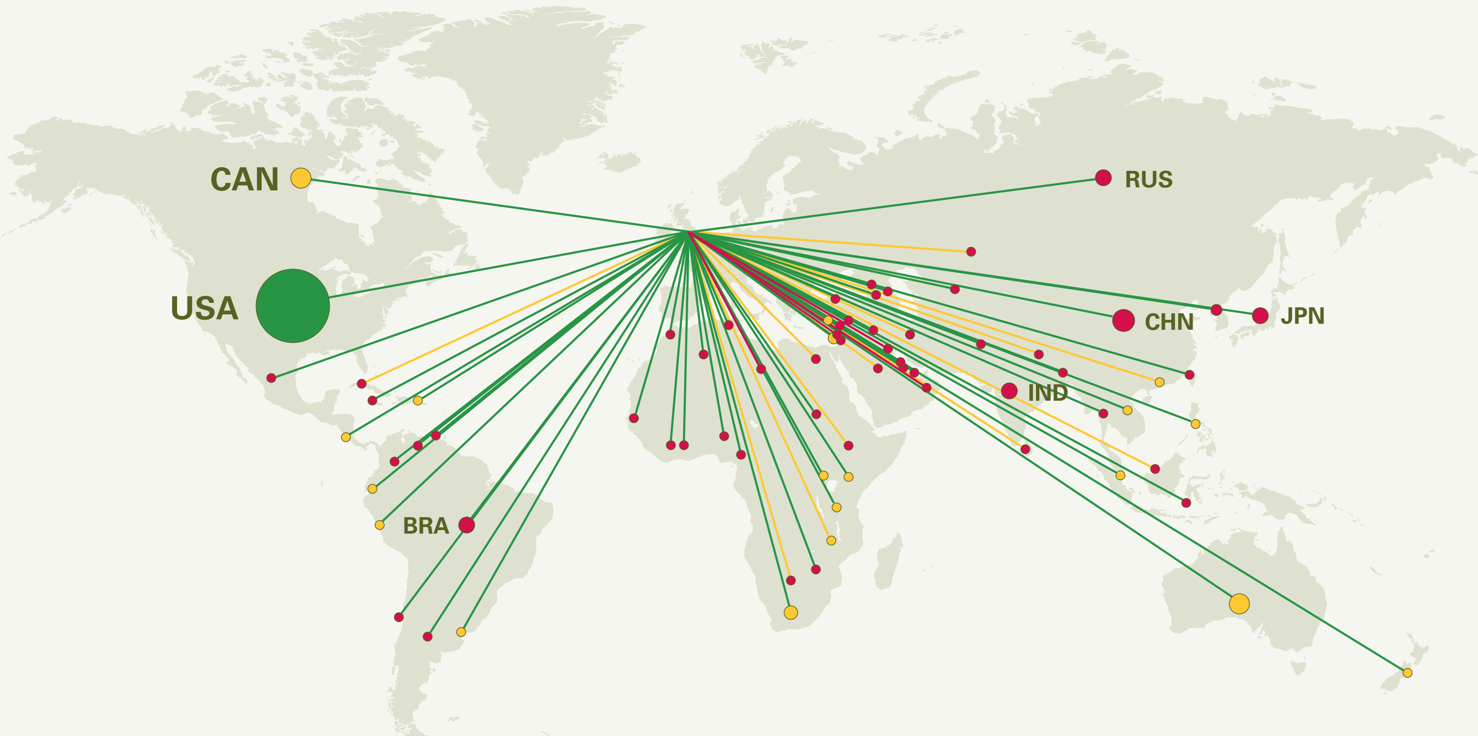


Figure 5.2 B: International collaboration map for the UK in the period 2006-2010, Europe only.

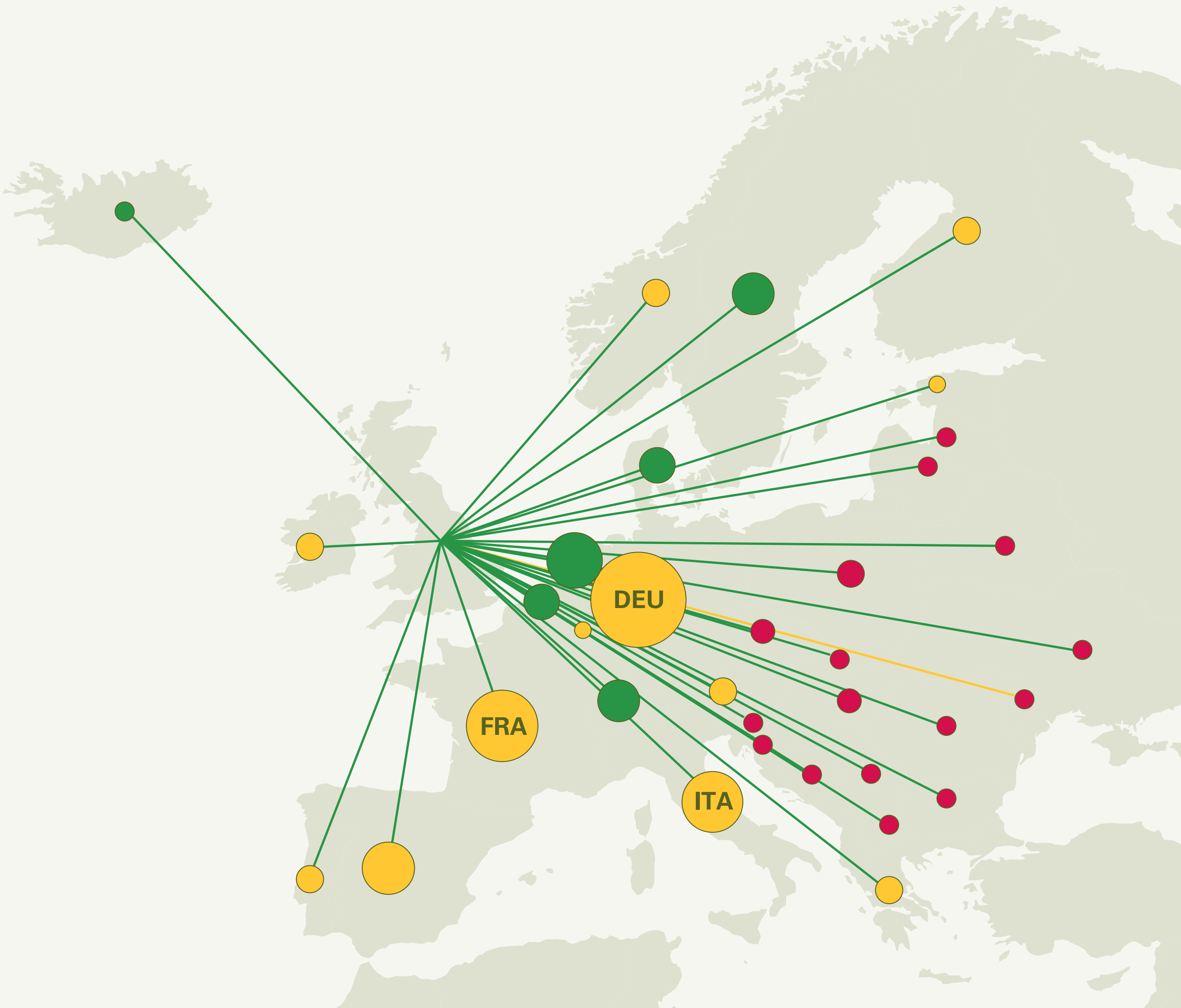
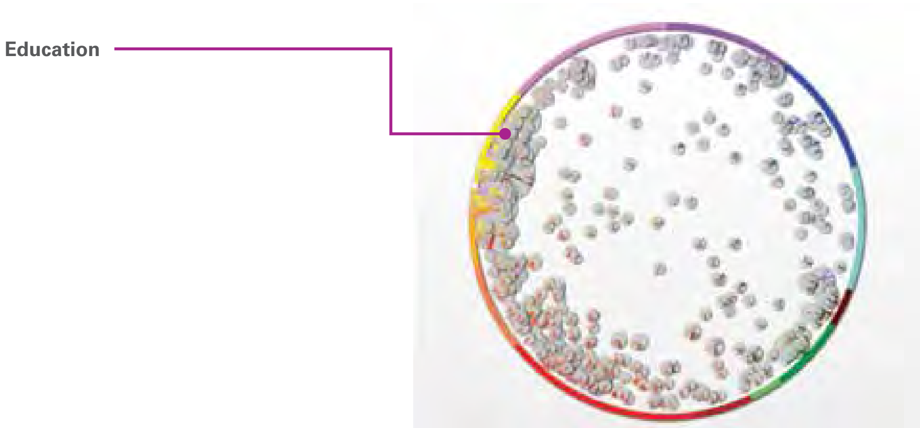


Figure 5.2 International collaboration map for the UK in the period 2006-2010. (A) World (excl Europe); (B) Europe only. Mapped countries include only those with at least 1,000 publications in this period (i.e. 109 countries, representing 99.8% of the UK's internationally co-authored articles). Bubble sizes (within each map only) represent the relative volume of collaboration between the two countries; Bubble colour represents the Field-Weighted Citation Impact (FWCI) of each country for all its papers: Green = FWCI greater than UK; Yellow = FWCI less than UK but greater than world average; Red = FWCI less than UK and less than world average. Line colour represents the Field-Weighted Citation Impact of collaborative papers relative to all papers where: Green = FWCI greater than UK average for all papers; Yellow = FWCI less than UK average but greater than world average; Red = FWCI less than UK and less than world. Source: Scopus (Map generated using Gephi 0.8 alpha with Miller cylindrical projection layout and coordinates from the CIA World Factbook. The exported network was placed over a blank world map image[74]).

[74]World_map_(Miller_cylindrical_projection,_blank).svg (attribution: Felipe Menegaz) via Wikimedia Commons.

UK STRENGTH CASE STUDY 4: **EDUCATION**



Country			Fractionalized articles	Total articles	RRS	SotA	Citation count
	1.	United Kingdom	2,797.4	6,392	1.60	-1.02	4,648.8
	2.	United States	1,792.2	6,072	0.62	-5.11	2,831.9
	3.	Australia	680.0	1,884	0.19	4.53	763.2
	4.	Canada	484.4	1,481	0.20	-0.38	659.1
	5.	Sweden	216.1	558	0.07	4.43	283.8
	6.	Germany	188.5	506	0.05	4.89	188.3
	7.	Netherlands	184.7	519	0.09	4.40	338.3
	8.	South Africa	166.3	447	0.01	4.59	94.3
	9.	New Zealand	162.5	417	0.03	4.43	173.9
	10.	Spain	141.1	349	0.01	5.10	93.9

Source: SciVal Spotlight, UK Country Map 2010.
RRS = Relative Reference Share; SotA = State of the Art. See Glossary for definitions.

Education

The UK shows strength in a competency characterised by keywords such as "comparative education" and "international education".

- UK rank:1 (US 2). The UK published 35% of the 8,000 (fractionalised) articles published in this interdisciplinary area of research during the period 2006-2010. This is a growing area of research (+10.5% per year), but UK article share has decreased by 1.72% per year during this period.
- UK articles in the field were cited 4,649 times, vs. 2,832 times for US articles (2006-2010). The relative reference share (RRS) of this competency in education for the UK is 1.60. This means that the UK has approaching twice as many reference papers than the US.
- Leading UK institutions in this area of research include: Institute of Education, University of London (6% of UK articles, 7% of UK citations), University of Manchester (4% of UK articles, 6% of UK citations), University of Birmingham (3% of UK articles, 3% of UK citations), and the University of Cambridge (3% of UK articles, 5% of UK citations).

Education research focuses on all aspects of learning, from the school classroom and university lecture hall to the development of professional expertise. Education researchers also study different educational systems around the globe, as well as the role of education in developing countries and how it can contribute to economic growth, better health, and the emergence of stable democracies.

Fundamentally, education research helps identify which teaching tools and techniques work in which contexts, and which don't. Therefore it directly impacts on educational practice and policy across a wide age range, and applies to many different situations (from schools to corporations).

In recent years, the issue of how technology can aid effective teaching and learning has become increasingly acute. Jean Underwood, Professor of Psychology at Nottingham Trent University, has studied the use of interactive whiteboards (IWBs), which are now replacing traditional blackboards – IWBs are already present in 1 in every 7 classrooms in the UK. Underwood's research suggests that while IWBs can provide a more engaging and stimulating multimedia experience for students, they do not fundamentally transform current pedagogic practice. Many schools are also developing web-based 'learning platforms' – online services that provide teachers and students with information, tools and resources to support and enhance education. Such learning platforms can be used to increase the range and accessibility of learning resources that can be accessed outside the school and at home, and which also enable parents to become better informed about their child's education and increase involvement with their learning.

"Our research has shown that collaborative learning is very effective if it's well organised, and a waste of time when it's not. So we've been trying to help teachers help the children to organise themselves effectively to work and think together. It's about enabling children to learn how to think collectively in an effective way, which is obviously a life skill as well as being useful for their actual endeavours in the classroom."
Neil Mercer, Professor of Education at the University of Cambridge

Learning platforms can also enhance students' digital literacy, provide opportunities for collaborations between students within and across schools, and provide additional routes to deliver support to those with particular educational needs.

Education researchers such as Anne Edwards, Professor of Educational Studies and Director of the Department of Education at the University of Oxford have also explored the development of organisational change and professional expertise. In the context of meeting the educational needs of children, this work underscores the need for professionals working in different fields – teachers and social workers in child-support services, say – to understand each other's perspectives on their shared concern with children's well-being and flourishing.

"Over the past 10 or so years, educationalists have begun to recognise and think about the links between the individual class context, the school and beyond. We need to build relationships across disciplines and reach a common understanding so that we can work on these complex problems together".
Anne Edwards, Professor of Educational Studies and Director of the Department of Education at the University of Oxford

Education research in the UK also has a strong international dimension. Simon McGrath, Professor of International Education and Development at the University of Nottingham, studies education in the context of developing nations, which is central to tackling many of the issues they face. Education in the context of development also means much more than learning the traditional subjects taught in schools.

"This is about teaching people to become critical, democratic thinkers, and particularly about thinking of themselves as global citizens. It's about nurturing the civic virtues on a global scale. As such, education research can contribute to the UK's international aid strategy by demonstrating how education can promote development goals like reducing poverty and boosting economic growth, promoting safe sex and other health-related activities, nurturing democracy, and encouraging sustainable development."
Michele Schweisfurth, Reader in Comparative and International Education and Director of the Centre for International Education and Research at the University of Birmingham

How did the UK become a global leader in education research?
History: "There's a culture of critique in the social sciences in the UK, which has been facilitated by the academic autonomy that we've historically enjoyed", says Michele Schweisfurth.

In addition, UK education researchers have tended to mix psychology with sociology, whereas research in education in other countries has tended to draw more on one or the other. "We've got a mixed method, and that interdisciplinarity is absolutely critical", says Jean Underwood.

RESEARCH PRODUCTIVITY

RESEARCH PRODUCTIVITY

Researcher productivity is a measure of the ability of researchers to convert GERD into publications and citations. An efficient country will have more publications per GERD unit input per researcher per year.

6.1. Key Findings

The UK is highly productive in terms of articles and citations.

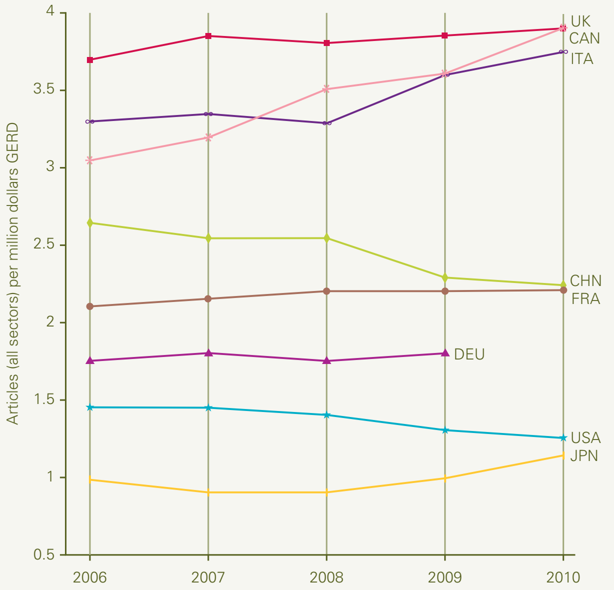
- The UK is highly productive in terms of articles produced per unit spend on GERD (growth 2.1% per year since 2006), as well as in citations per spend on GERD (growth 4.9% per year since 2006), ranking it 1st amongst the comparator group on both counts.
- The UK's performance on articles per researcher is strong, ranking 3rd in the comparator group (behind Italy and Canada) and growing strongly at 2.8% per year since 2006.
- Performance in terms of citations per researcher is even stronger, with the UK ranking 2nd amongst its comparators and with growth at 4.8% per year since 2006.

6.2. Research Productivity: Discussion

In the input-output model of R&D evaluation[75], inputs (such as R&D Expenditures or Human Capital) must precede outputs (such as articles and citations). At the lowest level of aggregation, the results of a research grant awarded in 2011 may not be published in the peer-reviewed literature for several years, and a patent application may follow after an even longer delay from the time of the R&D funding that enabled the invention[76]. Such lags will vary by indicator, country and subject field, and may even shift in magnitude over time.

The UK demonstrates high R&D productivity. In terms of articles per unit spend on GERD, the UK performs very well but with Canada closing on its top rank amongst the comparator group. Growth has been at 2.1% per year since 2006 *(Figure 6.1)*.

Figure 6.1 Articles (all sectors) per unit spend on GERD for UK and comparators, 2006-2010.



	2006	2010	Change 06-10	CAGR 06-10	UK Rank 2006	UK Rank 2010
UK	3.54	3.84	0.30	2.05%	-	-
EU27	2.37	2.57	0.20	2.06%	10	10

EU27 rankings out of 22 (of 27) countries with available data

Figure 6.1 Articles (all sectors) per unit spend on GERD for UK and comparators, 2006-2010. Missing data-points are due to missing GERD values for some countries in recent years. Source: Scopus and OECD MSTI.

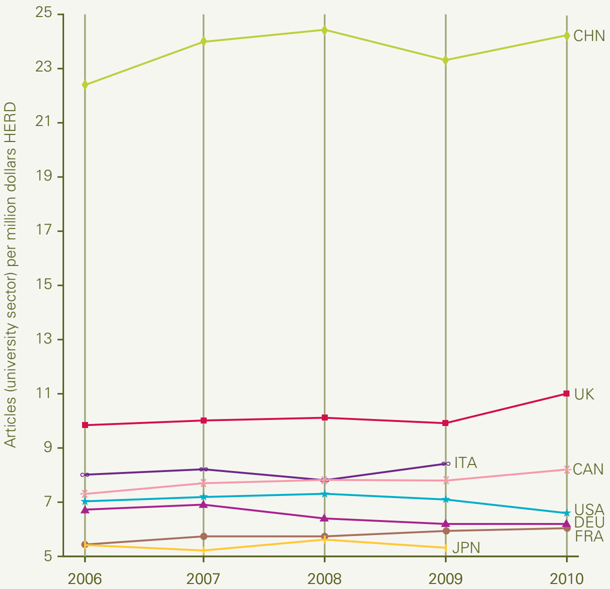
[75] Godin, B. (2005) "Science, Accounting and Statistics: The Input-Output Framework" *Project on the History and Sociology of S&T Statistics,* Working Paper No. 31, Canadian Science and Innovation Indicators Consortium.

[76] Shelton, R.D. & Leydesdorff, L. (2009) "Publish or Patent: Bibliometric evidence for empirical trade-offs in national funding strategies". Available at http://arxiv.org/abs/1102.3047; Shelton, R.D. & Ali, H.B. (2011) "Scientometric Secrets of Efficient Countries: Turkey, Greece, Poland, and Slovakia". Available at itri2.org/lpaper/lpaper.doc.

Since the higher education sector is the biggest single contributor to article output worldwide[77], an alternative way of measuring national productivity is to express this as articles authored by researchers in the university sector per unit spend on HERD *(Figure 6.2)*. Doing so reveals a very different picture and emphasises the high productivity of the UK (with proportionally high HERD inputs in relation to GERD), but also the very high productivity of China owing to the low cost of performing research[78].

The UK is also a clear first amongst comparator countries on citations per unit spend on GERD and has sustained strong growth at 4.9% per year since 2006, but with Canada showing notable increases in recent years moving from 3rd to 2nd place *(Figure 6.3)*.

Figure 6.2 Articles (university sector) per unit spend on HERD for UK and comparators, 2006-2010.

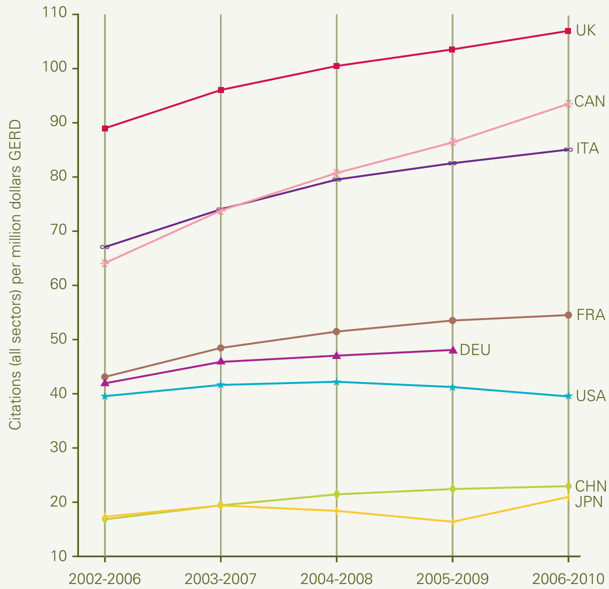


	2006	2010	Change 06-10	CAGR 06-10	UK Rank 2006	UK Rank 2010
UK	[illegible]	[illegible]	[illegible]	[illegible]	-	-
EU27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

EU27 rankings out of 22 (of 27) countries with available data

Figure 6.2 Articles (university sector) per unit spend on HERD for UK and comparators, 2006-2010. University sector articles are those where at least one author listed on the article is affiliated with a degree-granting institute that also engages in research, e.g. Harvard University. Missing data-points are due to missing HERD values for some countries in recent years. Source: Scopus and OECD MSTI.

Figure 6.3 Citations (all sectors) per unit spend on GERD for UK and comparators, 2006-2010.



	2006	2010	Change 06-10	CAGR 06-10	UK Rank 2006	UK Rank 2010
UK	[illegible]	[illegible]	[illegible]	[illegible]	-	-
EU27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

EU27 rankings out of 22 (of 27) countries with available data

Figure 6.3 Citations (all sectors) per unit spend on GERD for UK and comparators, 2006-2010. Missing data-points are due to missing GERD values for some countries in recent years. Each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. Source: Scopus and OECD MSTI.

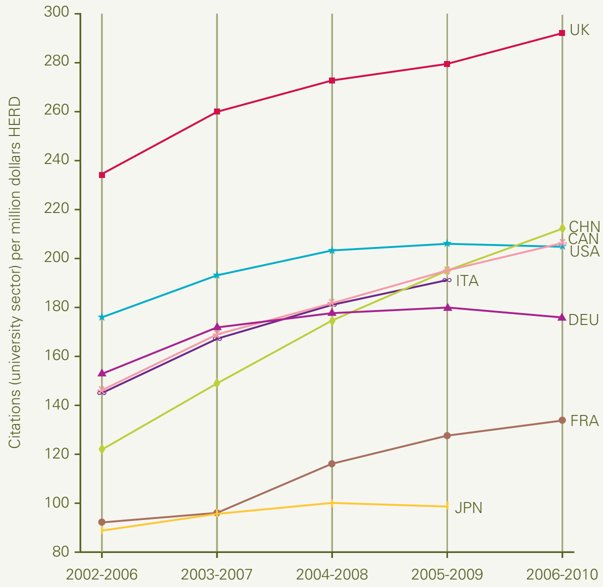
[77] Grimaki, R., Kenney, M., Seigel, D.S., Wright, M. (2011) "30 years after Bayh–Dole: Reassessing academic entrepreneurship" *Research Policy* 40(8) pp. 1045-1057; Shelton, R.D. & Leydesdorff, L. (2009) "Publish or Patent: Bibliometric evidence for empirical trade-offs in national funding strategies". Available at http://arxiv.org/abs/1102.3047; Shelton, R.D. & Ali, H.B. (2011) "Scientometric Secrets of Efficient Countries: Turkey, Greece, Poland, and Slovakia". Available at itri2.org/lpaper/lpaper.doc.

[78] Chen, K. & Dean, J. (2006) "Low Costs, Plentiful Talent Make China a Global Magnet for R&D" *The Wall Street Journal*, March 13, 2006.

Again, a somewhat different perspective is revealed when expressing this as citations to university-authored articles per spend on HERD, but once again this emphasises the high productivity of the UK *(Figure 6.4)*.

Assessment of raw output measures favours large countries. When output is assessed per researcher, a different set of countries emerges as highly productive. Similarly, citations per researcher can give a more normalised view of quality of research. The UK performs strongly in terms of both outputs and citations per researcher, suggesting that researchers are efficient in using the resources available to them to produce a comparatively large amount of high quality content.

Figure 6.4 Citations (university sector) per unit spend on HERD for UK and comparators, 2006-2010.



	2006	2010	Change 06-10	CAGR 06-10	UK Rank 2006	UK Rank 2010
UK	**234.51**	**292.52**	**58.02**	**5.68%**	**-**	**-**
EU27	135.14	162.31	27.17	4.69%	**2**	**1**

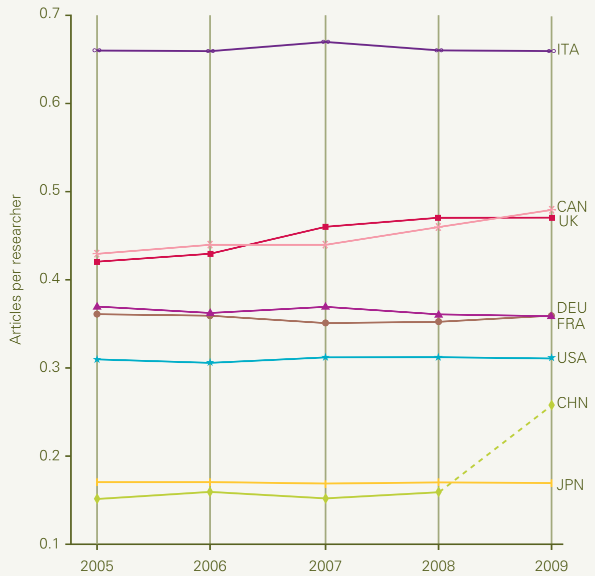
EU27 rankings out of 22 (of 27) countries with available data

Figure 6.4 Citations (university sector) per unit spend on HERD for UK and comparators, 2006-2010. Citations (university sector) per unit spend on HERD for UK and comparators, 2006-2010. University sector citations are those where at least one author listed on the cited article is affiliated with a degree-granting institute that also engages in research, e.g. Harvard University. Missing data-points are due to missing HERD values for some countries in recent years. Each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2006-2010 corresponds to citations in this period to articles published in the same period. Source: Scopus and OECD MSTI.

UK Researchers are highly productive. The UK's performance in terms of articles per researcher is strong, ranking 3rd in the comparator group (behind Italy and Canada) and growing strongly at 2.8% per year since 2006 *(Figure 6.5)*. Performance in terms of citations per researcher is even stronger, with the UK ranking 2nd amongst its comparators and with growth at 4.8% per year since 2006 *(Figure 6.6)*.

Analysis of reported Italian researcher numbers suggests that these are likely to be underestimated and less suitable for such comparative use. The researcher-based efficiency measures for Italy shown here are therefore likely to be overestimated (see Appendix F: Supplementary Data, section 6).

Figure 6.5 Articles per Researcher for the UK and comparators, 2005-2009.



	2005	2009	Change 05-09	CAGR 05-09	UK Rank 2005	UK Rank 2009
UK	**0.42**	**0.47**	**0.05**	**2.80%**	-	-
G8	0.25	0.26	0.01	1.01%	3	3
EU27	0.35	0.37	0.02	1.19%	8	9
OECD	0.24	0.28	0.04	3.80%	12	12
World	0.28	0.31	0.04	3.13%	12	13

EU27: 22 (of 27) countries with available data

OECD: 36 (of 42) countries with available data in 2005 and out of 33 in 2009

World: 39 countries with available data in 2005 and out of 36 in 2009

Figure 6.5 Articles per Researcher for the UK and comparators, 2005-2009. The dashed line between the 2008 and 2009 data-points for China indicates a rebasing of these figures in 2009 in the OECD data. The higher values seen for Italy may be caused by a divergence on the way Researchers are counted compared to other countries (see Appendix F: Supplementary Data for an analysis of the issue). Source: Scopus and OECD MSTI.

Figure 6.6 Citations per Researcher for the UK and comparators, 2005-2009.

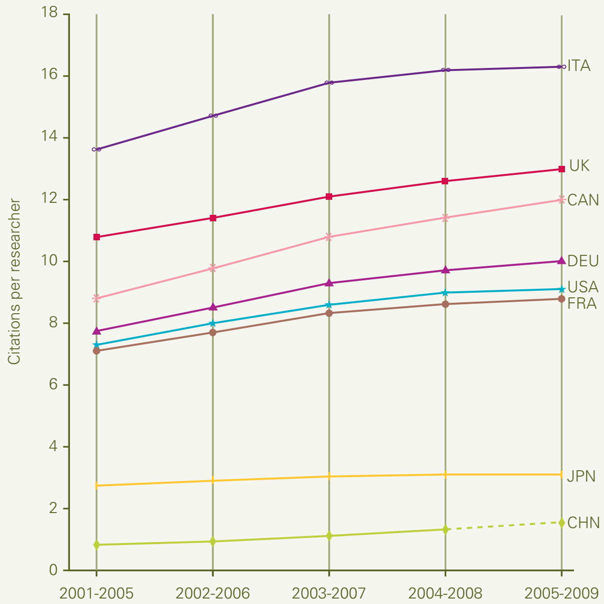


Figure 6.6 Citations per Researcher for the UK and comparators, 2005-2009. The dashed line between the 2008 and 2009 data-points for China indicates a rebasing of these figures in 2009 in the OECD data. The comparatively high values seen for Italy may be caused by a divergence on the way Researchers are counted compared to other countries (see Appendix F: Supplementary Data for an analysis of the issue). Each data-point corresponds to a five-year window of publications and citations; i.e. data-point 2005-2009 corresponds to citations in this period to articles published in the same period. Source: Scopus and OECD MSTI.

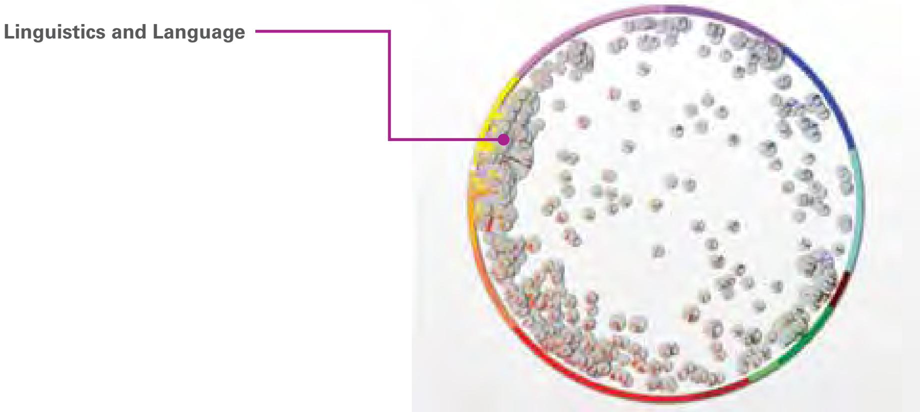
	2005	2009	Change 05-09	CAGR 05-09	UK Rank 2005	UK Rank 2009
UK	**10.81**	**13.04**	**2.23**	**4.79%**	**-**	**-**
G8	5.13	6.25	1.12	5.06%	3	3
EU27	6.88	8.23	1.35	4.57%	4	7
OECD	4.21	4.95	0.74	4.15%	5	8
World	4.31	5.05	0.74	4.03%	5	8

EU27: 22 (of 27) countries with available data in 2005 and out of 21 in 2009

OECD: 36 (of 42) countries with available data in 2005 and out of 32 in 2009

World: 39 countries with available data in 2005 and out of 35 in 2009

UK STRENGTH CASE STUDY 5: **LINGUISTICS AND LANGUAGE RESEARCH**



Country	Fractionalized articles	Total articles	RRS	SotA	Citation count
1. United States	589.3	1,584	1.05	-1.81	1,221.7
2. United Kingdom	428.8	878	0.95	2.02	913.5
3. Germany	251.7	515	0.41	-5.44	387.9
4. Netherlands	135.9	310	0.39	2.27	289.2
5. France	123.0	245	0.09	1.09	58.4
6. Canada	107.7	266	0.16	1.55	184.8
7. Spain	98.8	190	0.03	1.97	42.6
8. Belgium	97.8	157	0.15	2.15	93.1
9. Japan	90.5	176	0.10	1.75	122.3
10. Italy	56.2	128	0.02	1.82	37.6

Source: SciVal Spotlight, UK Country Map 2010.
RRS = Relative Reference Share; SotA = State of the Art. See Glossary for definitions.

Linguistics and Language Research

The UK shows strength in a competency characterised by keywords such as "corpus linguistics" and "English language teaching".

- UK rank:2 (US 1). The UK published 19% of the 2,275 (fractionalised) articles published in this interdisciplinary area of research during the period 2006-2010. This is a growing area of research (+9% per year), but UK article share decreased by 1.3% per year during this period.
- UK articles in the area were cited 913 times, vs. 1,222 times for US articles (2006-2010). The relative reference share (RRS) of this competency in language for the UK is 0.95. This means that the UK has almost as many reference papers in the set as does the US.
- Leading UK institutions in this area of research include: University of Edinburgh (15% of UK articles, 18% of UK citations), University of Manchester (12% of UK articles, 11% of UK citations), University of Cambridge (7% of UK articles, 15% of UK citations) and University College London (5% of UK articles, 7% of UK citations).

This specific competency falls within language research, which broadly includes linguistics (itself a sub-field that studies all aspects of how languages work, and how they change over time), as well as research on language learning (both as a primary and secondary language), bi- and multilingualism, and the means by which language can be used to negotiate and define social relationships.

Language research in the UK has a strongly applied focus that links theory with real-world concerns. One strand in which the UK has been particularly strong is corpus linguistics, which involves analysing huge datasets (corpora) of everyday language collected from newspapers, diaries and recorded conversations, among other sources, to illuminate language use and other linguistic phenomena. "Corpus linguistics now underpins the design and development of new dictionaries and grammars of English", says Hilary Nesi, Professor of English Language at the University of Coventry. Nesi is also using corpora of academic writing by both students and researchers to identify the key characteristics of particular kinds of writing, such as essays, reviews or critiques. The insights generated by this research are intended to help students and researchers better understand the writing process, and to write more effectively.

The applied nature of UK language research has also led to engagement with the challenges posed by the rise of multicultural societies, in which many people grow up speaking more than one language. Marilyn Martin-Jones, Emeritus Professor at the University of Birmingham, has studied bilingualism and multilingualism in different regions of Britain, including urban and rural settings, and in schools, colleges, and in the wider community. This work has looked at bilingual and multilingual discourse in face-to-face settings and multilingual literacy, and the ways in which gender, language and literacy contribute to the construction of social and cultural identities.

Language researchers in the UK are world-leaders in the development of approaches to teaching English as a foreign language, which attracts many overseas students and provides many opportunities to forge links with foreign institutions with an interest in teaching English.

"As teaching usually requires testing, UK researchers are also very active in the development of tools for assessing proficiency in English – an expertise that contributes to the UK's economy. The English Language Teaching (ELT) industry generates an enormous amount of money for the UK. Research on language teaching is key to sustaining a strong ELT industry."
Paul Thompson, Senior Lecturer and Director of the Centre for Corpus Research at the University of Birmingham

How did the UK become a global leader in linguistics and language research?

History: The UK has a deep history of language studies, and played a significant role in the birth of modern linguistics during the 18th century. In the 20th century, the applied focus of UK language research and the emphasis on the social context of language use acted as a counter-balance to the abstract, decontextualised approach to language predominant in the US.

Capitalising on the widespread use of English: The prominence of English as a global language has provided UK language researchers with many opportunities for study, and to develop practical tools for assessing English proficiency, an area in which the UK has a leading position.

Pioneering research: The UK has been at the forefront of developing new fields of linguistics, such as corpus linguistics (using large samples of real-world text to analyse language usage).

"Corpus linguistics got going in the 1980s, and is very much a UK speciality, which is why we're way ahead of the game."
Hilary Nesi, Professor of English Language at the University of Coventry

Differentiation: Language research in the UK has largely had an applied focus, with theoretical frameworks being used to illuminate real-world problems (such as how a second language is learned, and the best ways to assess proficiency). As such, the UK has carved out an applied niche in which it excels.

KNOWLEDGE TRANSFER

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Knowledge transfer refers to the movement of knowledge from one part of an organisation, sector or country to another. Knowledge transfer as a specialised discipline seeks to organise, create, capture or distribute knowledge and ensure its availability for future users. As a bilateral process that benefits both parties, consideration is given here to disembodied (explicit and written) and embodied (non-explicit and behavioural) knowledge transfer in the form of patent, licensing income and startup companies as well as corporate-academic cross-sector mobility, co-authorship and article usage. Knowledge transfer can also include teaching and other dissemination of information to the public, but this element is not addressed in the current research-focused report.

7.1. Key Findings

The UK shows low levels of patenting and industry co-authorship but positive knowledge flow between the sectors.

- UK researchers accounted for 37,644 patent applications in 2009.
- UK researchers have relatively low levels of patenting (2.2% of the global share in 2009) and average levels of researcher exchange between the academic and corporate research sectors.
- The UK's proportion of corporate – non-corporate co-authored papers (where both have UK affiliations) is relatively low (1.3%) compared to other major countries (see Appendix F: Supplementary Data, section 7 for details).
- The UK shows a strong but not overwhelming focus on startups and spin-offs over Intellectual Property (IP) income per Knowledge Transfer Office (KTO). This preliminary view suggests that licensing income and start-up data may provide a more complete picture of the UK's knowledge transfer activities than patenting alone.
- While the UK does not show strong co-authorship between sectors, cross-sectoral article usage in the corporate sector is high, suggesting good flows of information.

7.2. Knowledge Transfer: Discussion

7.2.1. Patents

Knowledge transfer is the conduit between investment in research and its commercialisation via innovation, which leads ultimately to economic growth. As such, patents – being an indicator of innovation – do not accurately measure knowledge transfer activity but instead reflect its existence. Indeed, a recent study of UK academics has shown that there is a positive correlation between patenting activity and engagement in more direct forms of university-industry knowledge transfer[79], which may include licensing agreements and income, the generation of spin-offs, networking and collaborative research (including joint publication), staff exchange and joint student supervision, contract research and consulting, and teaching[80]. Recent work suggests that barriers to effective knowledge transfer may remain, including lack of time, differing timescales, lack of incentives, low prioritisation of knowledge transfer, intellectual property rights, mutual issues with perception, and issues with the 'cutting edge' status of research[81]. The potential to commercialise their research since the introduction of the 1980 Bayh-Dole Act in the US (designed to encourage academic entrepreneurship[82]) has been shown to stimulate both basic and applied research productivity in a subset of US university researchers[83].

UK researchers have relatively low patenting rates. Patent applications filed by UK inventors appear to have been in decline in recent years, although there may be lags in the completeness of data for recent years, and a recent decline in patenting activity may be expected as a result of the recent global financial crisis[84]. In terms of global share of patent applications filed, the UK's share in 2009 was just 2.2%, while the largest shares go to four countries: Japan, US, China, and Germany *(Figure 7.1)*. It is important to note that these patent application counts are totals, aggregated across all fields of research and all sectors of R&D performance. However, not all fields and sectors have the same propensity to patent. Indeed, the physical sciences (including computer science) and engineering, which have a high propensity to patent, are areas of relatively low publication activity for the UK *(see Figure 4.3)*. As such, the low number of UK patent applications relative to other countries may – at least in part – be caused by differences in field specialisation[85].

79 Crespi, G., D'Este, P., Fontana, R., Geuna, A. (2011) "The impact of academic patenting on university research and its transfer" *Research Policy* 40(1) pp. 55–68.

80 Leydesdorff, L., & Wagner, C. (2009) "Macro-level indicators of the relations between research funding and research output" *Journal of Informetrics* 3(4) pp. 353-362.

81 Lockett, N., Kerr, R., Robinson, S. (2008) "Multiple Perspectives on the Challenges for Knowledge Transfer between Higher Education Institutions and Industry" *International Small Business Journal* 26(6) pp. 661–681.

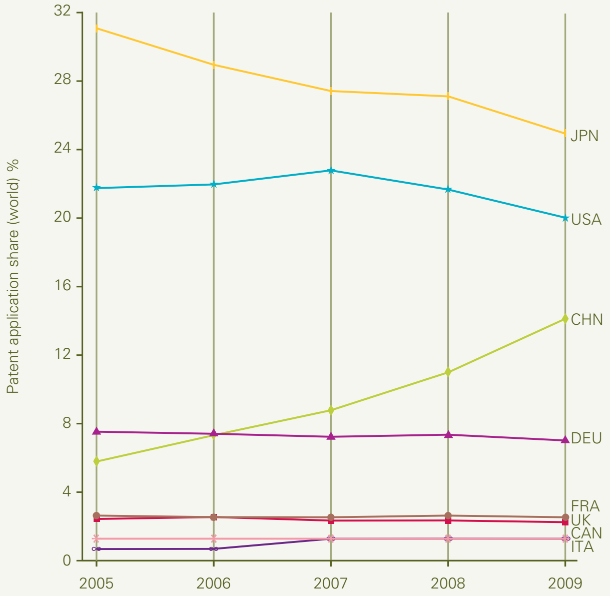
82 Grimaki, R., Kenney, M., Seigel, D.S., Wright, M. (2011) "30 years after Bayh–Dole: Reassessing academic entrepreneurship" Research Policy 40(8) pp. 1045-1057.

83 Thursby, J.G. & Thursby, M.C. (2011) "Has the Bayh-Dole act compromised basic research?" *Research Policy* 40(8) pp. 1077-1083.

84 Grimaki, R., Kenney, M., Seigel, D.S., Wright, M. (2011) "30 years after Bayh–Dole: Reassessing academic entrepreneurship" *Research Policy* 40(8) pp. 1045-1057.

85 Fu, X. & Yang, Q-G. (2009) "Exploring the cross-country gap in patenting: A Stochastic Frontier Approach" *Research Policy* 38(7) pp. 1203-1213. "The gap in patent production between the UK and the world leaders is substantial and lies in both basic patenting capacity [i.e. financial R&D inputs and human capital resources] and the patenting efficiency [i.e. capability to transform innovation inputs into innovation outputs, such as government policy and support for innovation, openness of the economy, the relative involvement of the business sector and public sector in R&D, the linkages between the research base and industries, the information infrastructure of the economy, and the strength of protection for intellectual property] of the national innovation system. Both the generation of inputs and greater efficiency appear to be required. The results from our study also suggest that institutional factors, such as the involvement of universities in the national innovation system, the proportion of R&D funded by the private sector which reflects the effectiveness of the institutional system in encouraging industrial R&D investment, as well as the development level of the economy each have identifiable effects on patenting."

Figure 7.1 Share of world patent applications for UK and comparators, 2005-2009.



	2005	2009	Change 05-09	CAGR 05-09	UK Rank 2005	UK Rank 2009
UK	**2.40%**	**2.21%**	**-0.19%**	**-2.04%**	-	-
G8	68.74%	60.45%	-8.29%	-3.16%	5	5
EU27	18.40%	17.65%	-0.75%	-1.04%	3	3
OECD	92.92%	91.96%	-0.96%	-0.26%	7	7
World	100%	100%	0.00%	0.00%	7	7

Figure 7.1 Share of world patent applications for UK and comparators, 2005-2009. Source WIPO

On the point of the relative involvement of the business sector and public sector in R&D, it is clear that for the UK and key comparator countries (including the top-patenting countries globally: Japan, US, Germany and China), there is a good correlation between the share of patent applications globally and the proportion of GERD financed by industry (i.e. source of funds; *Figure 7.2*), and a slightly stronger correlation between the share of patent applications globally and the proportion of GERD performed in the Business Enterprise sector (i.e. sector of performance; *Figure 7.3*). This latter correlation has also been observed over time[86]. Since these shares by source of funds and sector of performance are relatively low for the UK, this is reflected in a low share of patent applications globally[87].

Another recent study of UK universities suggests that patents are not favoured since other forms of intellectual property protection confer "specific advantages not available by patenting"[88].

Unlike other forms of research output (such as publication in international peer-reviewed journals), the process of applying for a patent and having it granted is complicated by diverse national and international patenting offices and agreements. The process is associated with different regulatory frameworks and different costs in each country, and by policy initiatives (such as the Bayh-Dole Act in the US[89]) to encourage patenting activity. In the UK, budgetary constraints in the HE sector in the mid-1980s resulted in an increased focus on entrepreneurial activities for revenue generation, and these activities were actively supported by government policy encouraging such "third mission" activities from the mid-1990s[90].

[86] Lombardo, L. (2011) "New indicators linking patenting and business R&D expenditure" *Scientometrics* 76(2) pp. 201-224.
[87] This finding is alluded to, but not directed examined, in Félix, B. (2006) "Statistics in focus, Science and Technology. Patents and R&D expenditure". Available at http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-NS-06-016/EN/KS-NS-06-016-EN.PDF.
[88] Anderson, B. & Rossi, F. (2011) "UK universities look beyond the patent policy discourse in their intellectual property strategies" *Science and Public Policy* 38(4) pp. 254-268.
[89] Grimaki, R., Kenney, M., Seigel, D.S., Wright, M. (2011) "30 years after Bayh–Dole: Reassessing academic entrepreneurship" *Research Policy* 40(8) pp. 1045-1057.
[90] Geuna, A & Rossi, F. (2011) "Changes to university IPR regulations in Europe and the impact on academic patenting" *Research Policy* 40(8) pp. 1068-1076.

Figure 7.2 Share of world patent applications for UK and comparators versus share of GERD funded by the Business Enterprise sector.

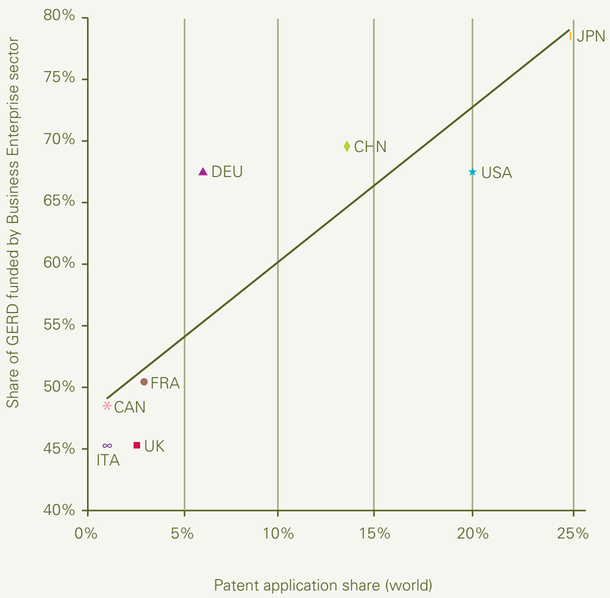


Figure 7.2 Share of world patent applications for UK and comparators (2009) versus share of GERD funded by the Business Enterprise Sector. Data from 2008 for all countries except Canada (2009) and UK (2010). The square of the correlation coefficient (R^2) of the linear regression is 0.8242 (i.e. the regression explains 82.42% of the variance), suggesting a relationship between them. Source: WIPO Statistics Database and OECD MSTI.

Figure 7.3 Share of world patent applications for UK and comparators versus share of GERD performed in the Business Enterprise sector (BERD).

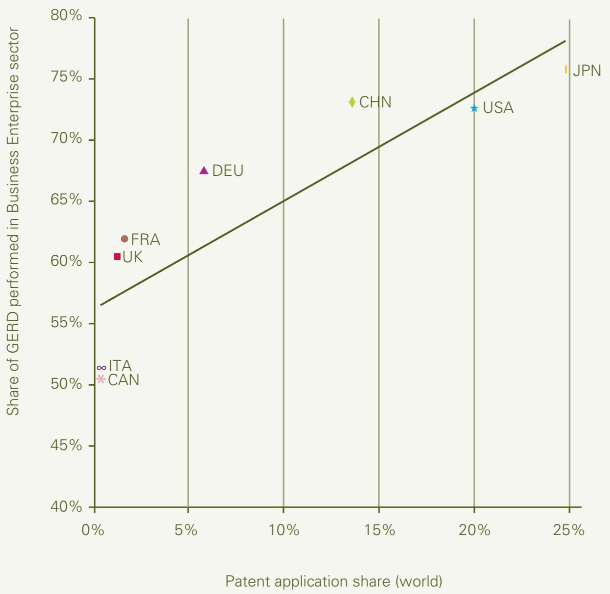


Figure 7.3 Share of world patent applications for UK and comparators (2009) versus share of GERD performed in the Business Enterprise sector (BERD). Data from 2009 for all countries except USA (2008) and Canada (2010). The square of the correlation coefficient (R^2) of the linear regression is 0.7768 (i.e. the regression explains 77.68% of the variance), suggesting a relationship between them. Source: WIPO Statistics Database and OECD MSTI.

7.2.2. Licensing income and startups

Along with patents, innovation can be monetised via commercial licensing and the creation of commercial companies. Analysis of changes in licensing income and startup or spin-off company creation adds a further dimension to knowledge transfer activities. Due to international differences in incentives, regulations and tracking these activities, it is difficult to make comparisons based on these data alone.

Furthermore, while patent count includes the private sector, this measure is narrower and also a less representative view of university disembodied transfer.

Various bodies are active in surveying KTOs (knowledge transfer offices dedicated to identifying and exploiting university technology for the creation of new products, processes, applications, materials or services), for data on IP income (i.e. licensing income) and startups/spin-offs[91].

[91] These include HESA's Higher Education - Business and Community Interaction (HE-BCI) Survey in the UK, the Association of University Technology Managers (AUTM) Licensing Activity Survey for the USA and Canada, and ProTon Europe's Annual Survey Reports for several countries within and beyond Europe.

[92] Aldridge, T.T. & Audretsch, D. (2011) "The Bayh-Dole Act and scientist entrepreneurship" *Research Policy* 40(8) pp. 1058-1067.

Despite the possibility that data collection and coverage may not yield internationally comparable results, it is informative to contrast the available data for several countries. Doing so reveals the apparent focus of the US (and to a lesser extent Canada) on IP income per KTO over startups and spin-offs per KTO, versus the much stronger focus on the latter activity in China, Japan and Italy *(Figure 7.4)*.

However, a recent study suggests that the data for the US and Canada (compiled by the Association of University Technology Managers [AUTM] from surveys of KTOs) systematically under-counts startups in those countries[92]. The UK falls between these groups, with a strong but not overwhelming focus on startups and spin-offs over IP income per KTO. This preliminary view suggests that licensing income and start-up data may provide a more complete picture of the UK's knowledge transfer activities than patenting alone.

7.2.3. Cross-sector linkages

Cross-sector co-operation within the UK has previously been identified as a weakness in the country's innovation system[93]. UK researchers move to and from the corporate sector at an appreciable rate. Migration of researchers between research sectors (for example, between the higher education and corporate sectors) has been proposed as a proxy for knowledge transfer between such sectors. The number of researchers moving to and from the corporate sector in different countries can be measured using author affiliation profiles in Scopus. In the UK, more than 8,500 authors with a non-corporate affiliation moved to a corporate entity in the period 1996-2010 *(Figure 7.5)*. The largest proportion of these (about 66%) moved from university affiliations, a proportion in line with those seen in most of the comparator countries. In the same period, just over 7,200 authors with a corporate affiliation moved to a non-corporate entity. The most common destination was a university affiliation (at about 65%), and this is again in line with the pattern observed in most comparator countries.

Figure 7.4 IP income and startups/spin-offs per surveyed Knowledge Transfer Office (KTO), 2009.

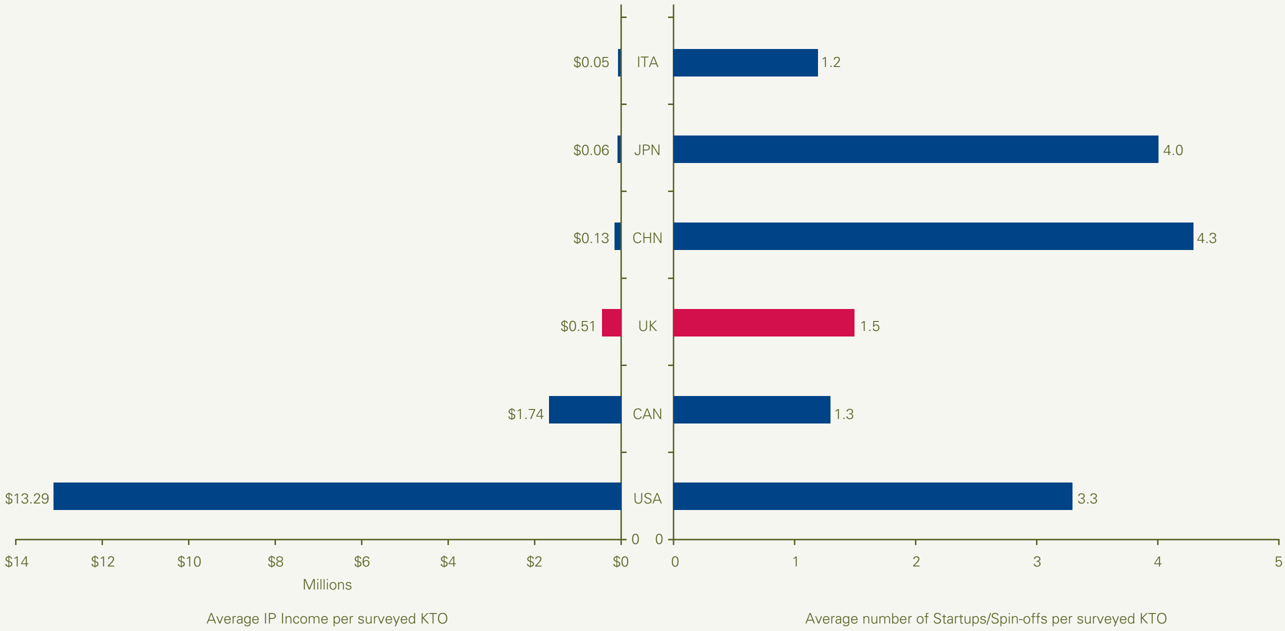


Figure 7.4 IP income and startups/spin-offs per surveyed Knowledge Transfer Office (KTO), 2009. Sources: AUTM Licensing Activity Survey for the USA and Canada and ProTon Europe Annual Survey Reports for the UK, China, Japan and Italy.

[93] OECD (2008) "OECD Science, Tecnology and Industry Outlook 2008. Science and Innovation: Country Notes: UK". Available at http://www.oecd.org/dataoecd/18/51/41559425.pdf.

Figure 7.5 Cross-sector migration of UK researchers, 1996-2010.

Figure 7.5 Cross-sector migration of UK researchers, 1996-2010. This analysis is based on author affiliation addresses in the published literature and on movements from one affiliation type to another during that period. Corporate authors are those affiliated with commercial entities (typically for-profit), e.g. IBM. Other sectors are defined as: **univ** (university): degree-granting institutes that also engage in research, e.g. Harvard University; **hosp** (hospital): organisations that provide healthcare and that may also engage in research, e.g. Johns Hopkins Hospital; **resi** (research institute): organisations that engage in research and that may also conduct educational activities. e.g. Salk Institute; **meds** (medical school): medical degree-granting institutes that also engage in research, e.g. Harvard Medical School; **other**: typically government and non-governmental organisations, e.g. UN, US Department of Energy, Red Cross. Source: Scopus.

Survey data from Spain suggest that mobility of researchers from the public (i.e. university) sector to the corporate sector is shown to accrue positive benefits for firms' innovation processes. They confirm that society's primary stock of knowledge resides in its public R&D system, and that mobility of personnel from there to private enterprise may result in greater societal outcomes[94].

The UK has relatively low levels of co-authorship between corporate and non-corporate authors. Article co-authorship between the corporate and other sectors has been shown in a number of recent studies to be an effective method of determining the extent of cross-sector collaboration and thus, to some degree, of knowledge transfer[95].

The UK's proportion of corporate – non-corporate co-authored papers (where both have UK affiliations) is relatively low (1.3%) compared to other major countries (see Appendix F: Supplementary Data, section 7 for details). A similar proportion was found in an earlier independent study[96]. Out of the comparator countries, high performers are Japan and the US, and poor performers Italy and Canada.

Although causality cannot be inferred, the data do suggest a link between cross-sector collaboration and patenting activity for most comparator countries, with China a clear outlier. Japan and the US are losing share in both of these metrics, while China is showing large growth in patenting but is fairly static in corporate – non-corporate co-authorship *(Figure 7.6).*

A recent study has shown that academic researchers in the US who have co-authored articles with researchers working for a company are more likely to become entrepreneurs (i.e. exemplified by starting a new firm)[97]. Within the UK, other studies have confirmed that the interaction of academic researchers with industry is more dependent on the characteristics of the individual researcher (such as collaborative productivity and collaborative grants) than on departmental or institutional factors[98].

Usage of UK corporate-authored articles by researchers in other sectors suggests strong cross-sector knowledge flows. More than 70% of all downloads of corporate-authored articles came from users in the academic sector. *(Figure 7.7)*. Users in the corporate sector themselves were responsible for 25% of downloads of corporate-authored articles. More than 40% of all downloads by corporate users were for university-authored articles, with the rest of their downloads made up in equal shares of research institute-, hospital-, and corporate-authored articles *(Figure 7.8).* Government-authored articles make up a very small share of corporate downloads. Overall, this points to dynamic information exchange between the sectors.

[94] Herrera, L. Muñoz-Doyague, M.F., Nieto, M. (2010) "Mobility of public researchers, scientific knowledge transfer, and the firm's innovation process" *Journal of Business Research* 63(5) pp. 510–518.

[95] Sun, Y., Masamitsu, N., Masaki, N. (2007) "Coauthorship linkages between universities and industry in Japan" *Research Evaluation*, 16(4) pp. 299-309; Sun, Y. & Masamitsuk N. (2010) "Measuring the relationships among university, industry and other sectors in Japan's national innovation system: a comparison of new approaches with mutual information indicators" *Scientometrics* 82(3) pp. 677–685; Tijssen, R.J.W., van Leeuwen, T.N., van Wijk, E. (2009) "Benchmarking university-industry research cooperation worldwide: performance measurements and indicators based on co-authorship data for the world's largest universities" *Research Evaluation* 18(1) pp. 13-24; Leydesdorff, L. & Sun, Y. (2009) "National and International Dimensions of the Triple Helix in Japan: University–Industry–Government Versus International Coauthorship Relations" *Journal of the American Society for Information Science and Technology,* 60(4) pp. 778-788.

[96] Calvert, J. & Patel, P. (2003) "University–industry research collaborations in the UK: bibliometric trends" *Science and Public Policy* 30(2) pp. 85–96.

[97] Aldridge, T.T. & Audretsch, D. (2011) "The Bayh-Dole Act and scientist entrepreneurship" *Research Policy* 40(8) pp. 1058-1067.

[98] D'Este, P. & Patel, P. (2007) "University–industry linkages in the UK: What are the factors underlying the variety of interactions with industry?" *Research Policy* 36(9) pp. 1295–1313.

Figure 7.6 Share of world patent applications for UK and comparators versus share of each country's articles representing corporate/ non-corporate co-authorship (where both are affiliated with institutions within that country), 2006-2009.

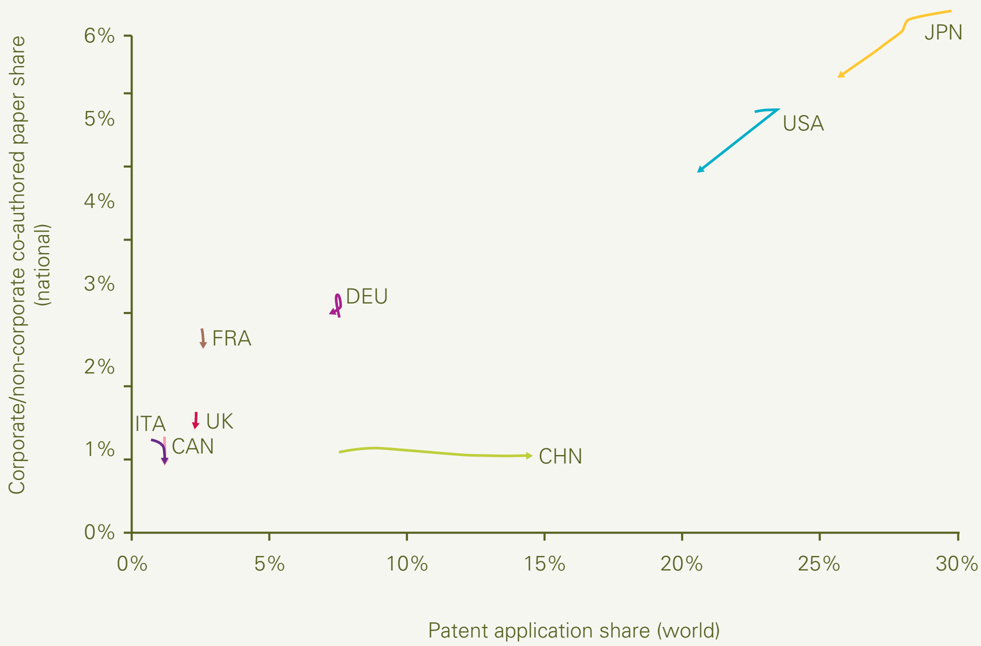


Figure 7.6 Share of world patent applications for UK and comparators versus share of each country's articles representing corporate/ non-corporate co-authorship (where both are affiliated with institutions within that country), 2006-2009.The square of the correlation coefficient (R^2) of the linear regression is 0.7768 for the 2009 data-points alone (i.e. the regression explains 77.68% of the variance), suggesting a relationship between them. Source: WIPO Statistics Database and Scopus.

Figure 7.7 Downloads (usage) of articles with at least one corporate author by downloading account type, 2006-2010.

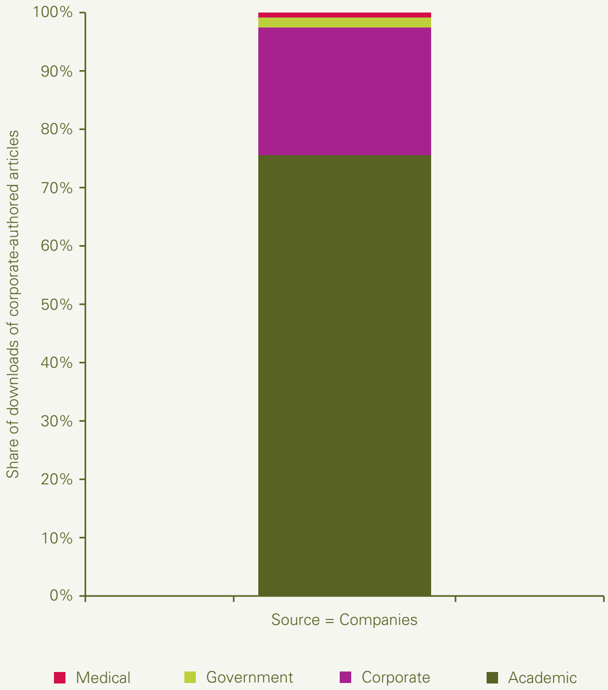


Figure 7.8 Downloads (usage) of articles by corporate accounts of articles by sector of article authorship, 2006-2010.

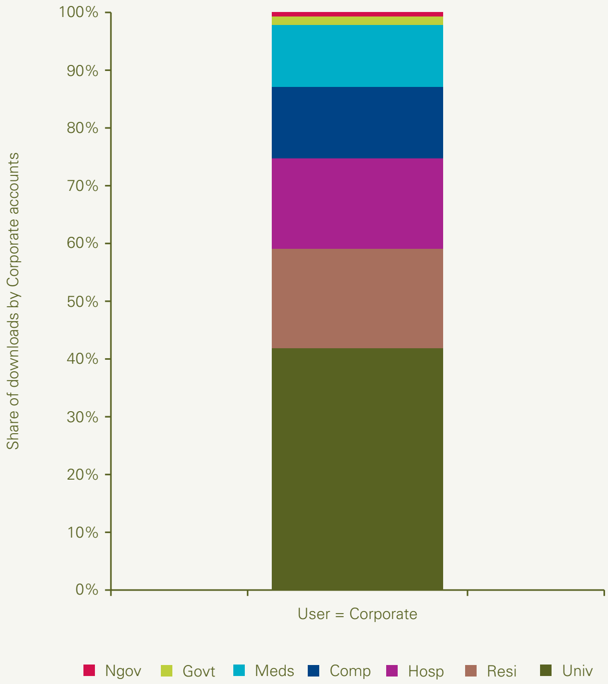


Figure 7.7 Downloads (usage) of articles with at least one corporate author by downloading account type, 2006-2010. Corporate authors are those affiliated with commercial entities (typically for-profit), e.g. IBM. Accounts are defined as: Academic, Corporate, Government, Medical. Source: Scopus and ScienceDirect.

Figure 7.8 Downloads (usage) of articles by corporate accounts of articles by sector of article authorship, 2006-2010. Corporate accounts are as defined in Figure 7.7, and author affiliations by sector are as follows: **univ** (university): degree-granting institutes that also engage in research; **hosp** (hospital): organisations that provide healthcare and that may also engage in research; **resi** (research institute): organisations that engage in research and that may also conduct educational activities; **meds** (medical school): medical degree-granting institutes that also engage in research; **comp** (companies) corporate sector that engages in research; **govt** government organisations that engage in research such as the Rutherford Appleton laboratory; **ngov** non-governmental organisations that engage in research such as NIESR
Source: Scopus and ScienceDirect.