INTERNATIONAL COMPARATIVE PERFORMANCE OF THE UK RESEARCH BASE 2016

A report prepared by Elsevier for the UK's Department for Business, Energy & Industrial Strategy (BEIS)

Department for Business, Energy & Industrial Strategy

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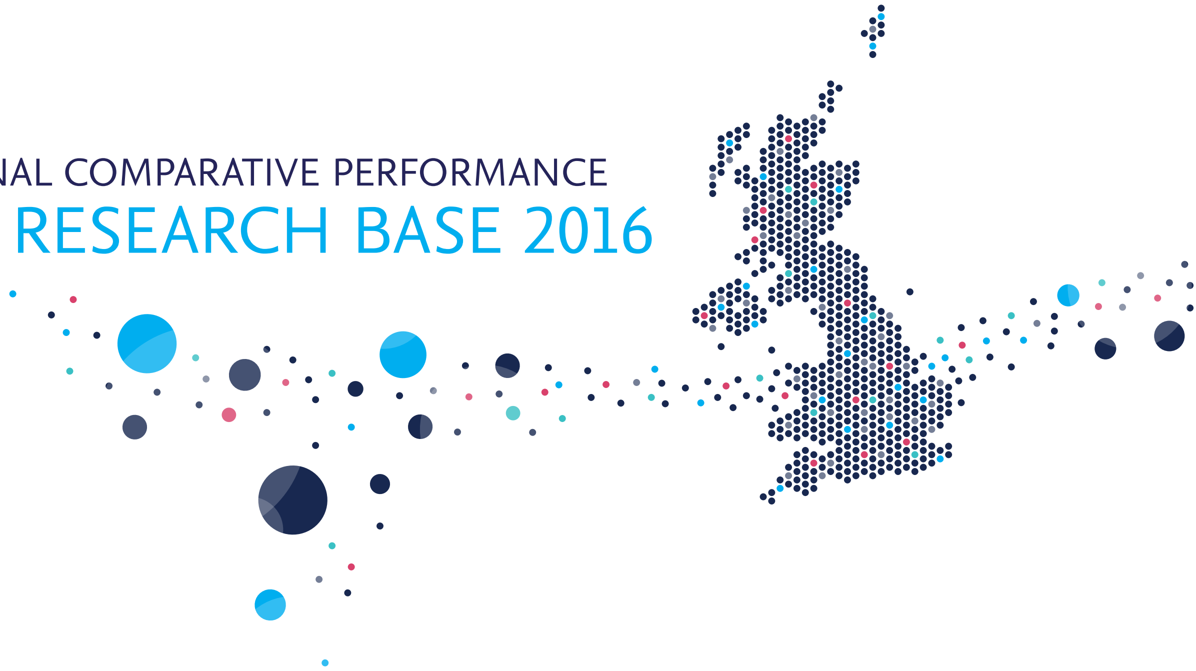

This report has been commissioned by the UK's Department for Business, Energy & Industrial Strategy (BEIS) to assess the performance of the United Kingdom's (UK) research base compared with seven other research-intensive countries (Canada, China, France, Germany, Italy, Japan, and the US), four other fast growing nations (Brazil, India, Russia and South Korea), and international benchmarks. Emerging research nations such as China, Brazil and India have been striving to emulate the performance of long-standing research-intensive countries such as the UK, Germany, France and the US. Within this context, this report tracks investment in, and performance of, the national research system in an international setting, combining a variety of indicators to present a multifaceted factual view of the UK's comparative performance in research as well as data about the trends that may affect, or indeed are already affecting, its position.

The UK punches above its weight as a research nation

In 2014, the UK represented just 0.9% of global population, 2.7% of R&D expenditure, and 4.1% of researchers, while accounting for 9.9% of downloads, 10.7% of citations and 15.2% of the world's most highly-cited articles. While there is no change in the percentages of the UK's representation of global population or researchers compared to 2012, its representation in three of these indicators is lower in 2014 than in 2012: R&D expenditure by 0.5 percentage points (p.p.), citations by 0.9p.p., and highly-cited articles by 0.7p.p.

The UK ranks first amongst its comparator countries by field-weighted citation impact, an indicator of research impact and quality, even though its annual rate of growth slowed down from 1.3% over the period 2008-2012 to 0.6% over 2010-2014 – this was at the same time as other key comparator countries, such as Germany, were growing at a much faster rate. The UK's share of global patents has risen as a result of an increase in the number of its patents in force, and the share of global patents citing UK articles is similar to its global publication share. However, shares in both these indicators are smaller than seen in the last report in this series – down from 2.4% to 2.0% and from 10.9% to 9.1% respectively.

The UK remains well-rounded across most fields of research, and is a highly productive research nation in relation to articles and citation outputs per researcher and per unit of R&D expenditure. The sustained upward trend in UK research productivity may be correlated to its continued increase in international research collaboration, an activity that is generally associated with greater citation impact than research co-authored institutionally or nationally, while its national inputs are broadly stable in relative terms.

Taking all these factors into account, particularly the pressures placed upon it and other research-intensive countries by emerging nations, the UK continues to punch above its weight as a research nation.

The UK research base is well-rounded and demonstrates excellence in diverse research fields

The UK is a well-rounded research nation, with activity (as indicated by article outputs) across all major research fields. Its field-weighted citation impact (FWCI) is well above the world average and it continues to rank first amongst the comparator countries, despite a slowdown in its rate of growth and a relatively unchanged share of global articles. Most of the UK's research fields saw an increase in FWCI over 2010-2014, with the exceptions of Mathematics, Humanities and Social Sciences. However, most fields experienced a reduced share of global articles, the exceptions being Health and Medical Sciences, Business and Social Sciences.

With high FWCI and, in most cases, high field-weighted download and readership impact, the UK demonstrates excellence in diverse research fields. UK research is increasingly cited internationally, and the UK is leading the world in making its articles available under a variety of different access models.

The UK has robust cross-sector knowledge exchange

UK academic and corporate users increasingly are downloading articles produced in the other sector, further strengthening an already robust cross-sector knowledge exchange within the country. Internationally, the UK's share of global patents has risen as a result of an increase in the number of its patents in force, and the share of global patents citing UK articles is similar to its global publication share. However, the UK's share of global patents in force ranked third lowest amongst the comparator countries.

The UK is a key partner for global research collaboration and researcher mobility

International research collaboration and international researcher mobility are interrelated and interdependent, and shaped by collaborative interactions that take place across multiple institutions, borders, continents, and time zones. The UK's most prolific international partnerships are associated with greater FWCI per article, relative to the overall international collaborative output of either the UK or its partner countries, including the Newton Fund partners.

Countries that exhibit high levels of research collaboration typically have high levels of researcher mobility, and the UK is no exception. As a whole, UK researchers are highly mobile internationally, although two groups are likely to be less mobile: short publication history researchers, i.e., those with less than 10 years since their first appearance as an author, who are likely to have had less time in which to move between countries; and women researchers, at any stage in their careers, are likely to be less mobile than men researchers. UK researchers are also mobile across sectors, both nationally and internationally, with industry gaining most researchers from UK academia and from international industry. Although the UK's level of growth in overall researcher numbers is generally low and slowing down, the growth rate of UK PhD graduate numbers is high and increasing faster than many comparators.

While the UK leads in many worldwide rankings, the world is changing

The UK punches above its weight in delivering increasingly high-quality research outputs, being highly productive, impactful and well-rounded. It holds a central position in the global collaboration network, is an attractive destination for researchers from other countries, and there is active cross-sector knowledge exchange within the UK and by the UK internationally. All of this is achieved on broadly stable levels of R&D expenditure and human capital inputs.

However, the global research landscape in recent years has become increasingly complex and fluid, and it can only become more so as emerging research nations grow their research bases. The UK is seeing, as are other research-intensive nations including the US, its global shares in key research indicators eroded by emerging countries, especially by China. As China and other rising research nations succeed in their desire to emulate and even surpass the research performance of countries like the US and the UK, their shares will naturally become larger while the erstwhile powerhouses see theirs shrink. Although there is no doubt that the UK is well-positioned to remain a leader on the global research stage, this can only be sustained by continued investment in its national research base.

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CHAPTER 1

Key Findings

1.1 Introduction

This report has been commissioned by the UK's Department of Business, Energy & Industrial Strategy (BEIS) 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), four other fast growing nations (Brazil, India, Russia and the Republic of Korea (hereafter referred to by its more commonly used name of "South Korea")), and international benchmarks. As has been shown in previous analyses in this series of reports, emerging research nations such as China, Brazil and India have been striving to emulate the performance of long-standing research-intensive countries such as the UK, Germany, France and the US. Within this context, this report tracks investment in, and the performance of, the national research system in an international setting, combining a variety of indicators to present a multifaceted factual view of the UK's comparative performance in research as well as data about the trends that may affect, or indeed are already affecting, its future position.

Six elements of the research base are discussed in chapters two through seven: research funding and expenditure (research inputs), numbers and mobility of researchers (human capital), numbers of journal articles published and citations received (research outputs), collaboration (research collaboration), ratio of research outputs to expenditure (productivity), and knowledge exchange.

This is the third consecutive report in this series to be delivered by Elsevier, the first having been published in October 2011[1] and the second in December 2013[2]. Comparisons between analyses in this report and the previous report, where provided, are noted in the context of the years of analysis of the reports. Details of those involved in the production of this report and further acknowledgements are given in *Appendix A: Author Credits, Advisory Groups, and Acknowledgements.*

Table 1.1 *— Comparator countries in this report, their ISO 3-character code and key for charting in this report. A full list of all countries included in data sources for this report is shown in Appendix D. Countries with a tick are included in the comparator group.*

Brazil	BRA	
Canada	CAN	✓
China	CHN	✓
France	FRA	✓
Germany	DEU	✓
India	IND	
Italy	ITA	✓
Japan	JPN	✓
South Korea	KOR	
Russia	RUS	
United Kingdom	UK	✓
United States	US	✓

Russia used instead of Russian Federation.
South Korea used instead of Republic of Korea.
UK used instead of GBR.
US used instead of USA.

1 International Comparative Performance of the UK Research Base – 2011. Available at https://www.bis.gov.uk/assets/BISCore/science/docs/I/11-p123-international-comparative-performance-uk-research-base-2011.pdf

2 International Comparative Performance of the UK Research Base – 2013. Available at https://www.gov.uk/government/publications/performance-of-the-uk-research-base-international-comparison-2013

DATA SOURCES AND METHODOLOGY

The majority of data presented in this report are derived from the OECD[3] (R&D expenditure and human capital), Scopus[4] (articles and citations), and WIPO[5] (patents). 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. A number of other data sources have been gathered to add to the review of knowledge exchange presented in this report. More information on data sources used in this report can be found in *Appendix C: Data Sources*, and full methodological details are discussed in *Appendix E: Methodology*.

Period studied in this report

At the time of writing, data for 2015 were not complete enough to be used for yearly figures. However, they were reliable enough to be used in five-year blocks. When yearly figures are presented in this report, data for the period 2010-2014 are used, and when blocks of years are presented, data for the period 2011-2015 are used.

Measuring change

A standard method of measuring change over time is used throughout this report: Compound Annual Growth Rate (CAGR). CAGR is defined as the year-on-year constant growth rate over a specified period of time. Starting with the earliest value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series.

Changing measures

The main data sources used in this report *(see above)* represent dynamic databases with regular updates throughout the year. Therefore, the indicators presented here are a snapshot taken of the data at a point in time; in some cases, the most recent values may be provisional, while earlier data may have been revised as a result of initiatives to expand data completeness and coverage. For example, OECD data on research inputs and human capital for some countries may relate to periods some years in the past, while for others much more recent figures are available. In Scopus, a significant expansion of journal coverage in the Arts & Humanities beginning in 2009 has resulted in a more robust view of journal articles and related output indicators in this report. Such changes have necessitated careful extrapolation of missing data points or rebasing of indicators to account for coverage changes; these are noted where appropriate throughout the report. Nevertheless, in Social Sciences and Arts & Humanities, the bibliometric indicators presented in this report and conclusions drawn from analysing these indicators for these fields must be interpreted with caution, because a reasonable proportion of research outputs in such fields take the form of books, monographs and non-textual media. As such, analyses of journal articles, their usage and citation, provides a less comprehensive view than in other fields, where journal articles comprise the vast majority of research outputs.

Defining a comparator country group

Comparator countries are defined consistently across all data sources: unless otherwise indicated, a grouping of the G7 plus China (G8), the European Union (EU28) and the OECD member and non-member countries (OECD41) are used as benchmarks. Standard ISO 3-character country codes are used throughout for visual clarity where required *(see Table 1.1)*; in some figures, additional countries are referred to by their ISO 3-character code, and a full listing of these codes is included in *Appendix D: Countries Included in Data Sources*.

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3 Organisation for Economic Co-operation and Development, an international economic organisation founded in 1961 and representing 34 member countries. In this report the OECD data also typically include the non-member countries Argentina, China, Romania, Russia, Singapore, South Africa, and Taiwan.

4 Scopus is the largest abstract and citation database of peer-reviewed literature, covering 62 million documents published in over 22,500 journals, book series and conference proceedings by some 6,000 publishers.

5 World Intellectual Property Organization, an agency of the United Nations created in 1967 to promote the protection of intellectual property globally.

In most analyses presented in this report that are based on size-normalised indicators (such as field-weighted citation impact or articles per researcher), rather than absolute numbers or volumes, smaller research nations often out-perform many or all of those included in the comparator set (for example, the Netherlands and Switzerland on field-weighted citation impact). However, owing to their small size, such countries do not represent meaningful comparators for the relatively large UK research base and hence are not included in the figures and tables (but are included, where appropriate, when indicating the UK's rank for a given indicator).

Publication types

Three types of documents are included as publications in this report: articles, reviews and conference proceedings. Book reviews are not included. "Publications" and "articles" are used interchangeably and both refer to the total of the three publication types.

Research field delineation

The proper delineation of research fields is a central issue in quantitative approaches to research assessment. In this report, article and citation data have been aggregated to 10 main research fields. However, for the calculation of field-weighted citation or download impact, a more granular scheme encompassing more than 300 subjects based on Scopus journal classification has been used.

Time lags between inputs and outputs

In the input-output model of R&D evaluation[6], inputs (such as R&D expenditure or human capital) must precede outputs (such as journal articles and citations). At the lowest level of aggregation, the results of a research grant awarded in 2014 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[7]. Such lags will vary by indicator, country and subject field, and may even shift in magnitude over time. Determining and accounting for the time lags between input and output has not been attempted in this report, owing to the complexities in calculating them.

Field-weighted citation impact (FWCI)

One of the most sophisticated and most widely recognised indicators in the modern bibliometric toolkit is field-weighted citation impact (FWCI). FWCI overcomes some of the challenges presented by the time lag between input and output, as discussed above, as well as differences between publication and field-specific differences in citation frequencies. FWCI divides the number of citations received by a publication by the average number of citations received by publications in the same field, of the same type, and published in the same year. The indicator is always defined with a world average baseline of 1.0.

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6 Godin, B. (2007) "Science, accounting and statistics: The input-output framework" *Research Policy* 36 (9) pp. 1388-1403.
7 Shelton, R.D. & Leydesdorff, L. (2012) "Publish or patent: Bibliometric evidence for empirical trade-offs in national funding strategies" *Journal of the American Society for Information Science and Technology* 63 (3) pp. 498-511.

1.2 Key Findings

1.2.1 The UK punches above its weight as a research nation

In 2014, the UK represented 0.9% of global population, 2.7% of R&D expenditure, and 4.1% of researchers, while accounting for 6.3% of articles, 9.9% of downloads, 10.7% of citations, 15.2% of the world's most highly-cited articles *(see Table 1.2 and Figure 1.1 Panel A)*. While there was no change in the percentages of the UK's representation of global population compared to 2010 and 2012, its share in four of these indicators in 2014 was lower than or equal to that seen in 2010 and/or 2012: R&D expenditure, researchers, articles, and citations. Its world share of highly-cited articles was higher in 2014 than in 2010, but lower than seen in 2012, while downloads was the only indicator where the percentage share in 2014 was higher than seen in both 2010 and 2012.

The UK ranks first amongst its comparator countries by field-weighted citation impact (FWCI), an indicator of research impact, even though its annual rate of growth in this indicator slowed down from 1.3% over the period 2008-2012 to 0.6% over 2010-2014. This was at the same time as a number of other key comparator countries were improving their performance in this indicator; a particular example of which is Italy, which rose to second place behind the UK in 2012 and, based on current trajectories, is set to overtake the UK in the near future. The global share of patent applications and share of citations from patents (both applications and granted) of the UK are smaller than seen in 2012 – down from 2.4% to 2.0% and from 10.9% to 9.1% respectively.

The UK remains well-rounded across most fields of research, and is a highly productive research nation in relation to articles and citation outputs per researcher and per unit of R&D expenditure, despite broadly stable or decreasing inputs in relative terms *(see Figures 1.1 Panel B and 1.1 Panel C, respectively)*. The sustained upward trend in citation-based UK research productivity may be correlated to, at least in part, its continued increase in international research collaboration, an activity that is, generally, associated with greater citation impact than those co-authored institutionally or nationally, while its national inputs are broadly stable in relative terms *(see Figure 5.1 and Table 5.1)*.

Taking all these factors into account, and especially the pressures placed upon the rankings of it and other research-intensive countries by the emerging nations, the UK continues to punch above its weight as a research nation. However, as discussed later, these pressures from the often-improving performance of the emerging countries, especially of China, threaten the UK's leadership position in the longer-term.

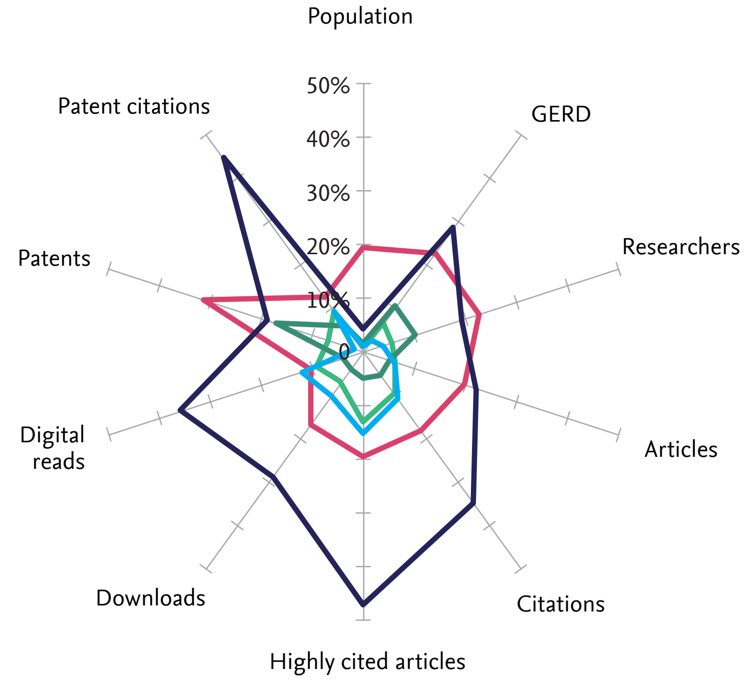
Table 1.2 — *World share of the UK for key indicators in the three reports in this series.*

	Report 2011 *Data 2010*	**Report 2013** *Data 2012*	**Report 2016** *Data 2014*
Population	0.9%	0.9%	0.9%
R&D expenditure	3.0%	3.2%	2.7%
Researchers	4.2%	4.1%	4.1%
Articles	6.4%	6.4%	6.3%
Downloads	9.4%	9.5%	9.9%
Citations	10.9%	11.6%	10.7%
Highly-cited articles	14.0%	15.9%	15.2%

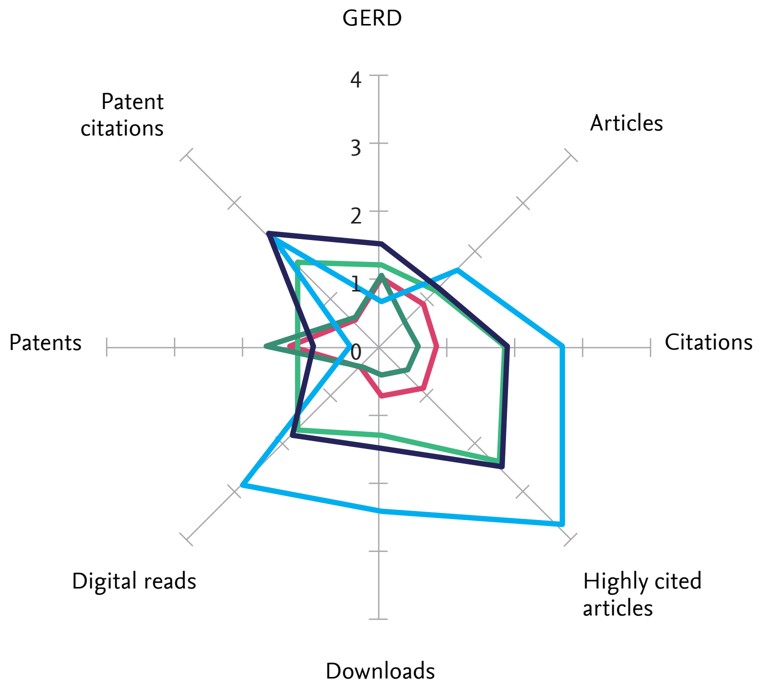
__Figure 1.1__ — Key input and output indicators for the UK and four key comparator countries (China, Germany, Japan and the US). Sources: OECD MSTI for Population 2013, Researchers 2014 (extrapolated for US), GERD 2014 (extrapolated for US); world totals are the sum of data for all countries with available data. Scopus for Articles 2014, Citations 2014, Highly-cited articles 2014. ScienceDirect for Downloads 2014. Mendeley for Digital reads 2014. WIPO Statistics Database for Patents 2014. LexisNexis Univentio and Scopus for Patent citations 2014.

China
Germany
Japan
UK
US

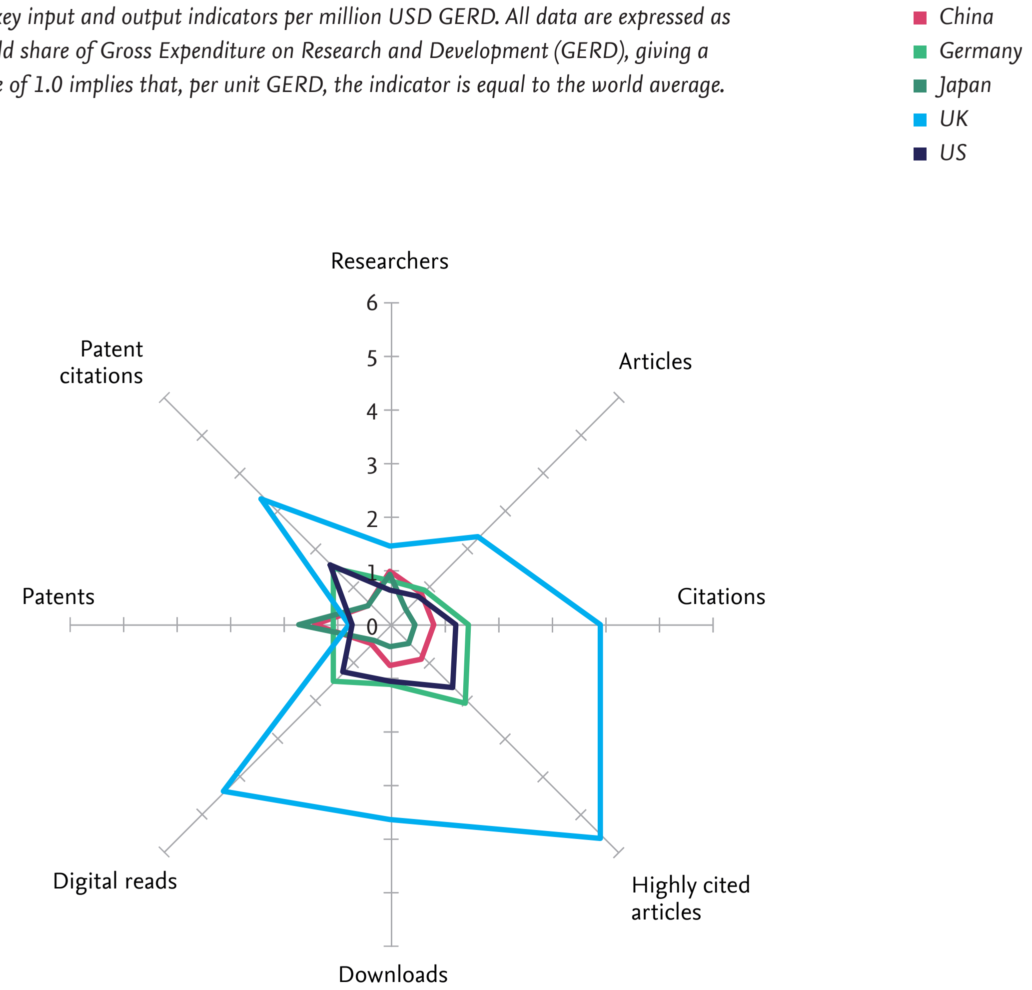
***Panel A:** Absolute share of key input and output indicators. All data are expressed as world share.*



***Panel B:** Relative share of key input and output indicators per researcher. All data are expressed as world share divided by world share of researchers, giving a relative index where a value of 1.0 implies that, per researcher, the indicator is equal to the world average.*



Panel C: *Relative share of key input and output indicators per million USD GERD. All data are expressed as world share divided by world share of Gross Expenditure on Research and Development (GERD), giving a relative index where a value of 1.0 implies that, per unit GERD, the indicator is equal to the world average.*



1.2.2 The UK research base is well-rounded and demonstrates excellence in diverse research fields

The UK is a well-rounded research nation, with substantial activity *(as indicated by article outputs; see Figure 4.3)* across all major research fields. Its field-weighted citation impact (FWCI) is well above the world average and it continues to rank first amongst the comparator countries, despite a slowdown in its rate of growth and a relatively unchanged share of global articles *(see Figure 1.2 Panel A(1))*. However, many smaller countries, such as Denmark, Switzerland, the Netherlands, and Belgium, have much higher FWCI than the UK and the other comparators *(see Figure 1.2 Panel A(2))*.

The FWCI of all of the UK's research fields is above the world average throughout the reporting period. Most of the UK's research fields saw an increase in FWCI, with the exceptions of Mathematics, Humanities and Social Sciences. However, the majority of fields experienced a reduced share of global articles *(see Figure 1.2 Panel B)*, the exceptions being Health and Medical Sciences, Business and Social Sciences. The FWCI of each of the UK's four constituent countries has been consistently higher than the UK overall since 2012, due to higher relative shares of international collaborations positively affecting their overall FWCI, but with each nation seeing static or slightly lower world article shares *(see Figure 1.2 Panel C and Figure 4.7)*.

With high FWCI and, in most cases, high field-weighted download and readership impact, the UK demonstrates excellence in diverse research fields, and UK research is increasingly cited internationally. The UK is above the world averages in making its articles available under a variety of different access models, with 20% of its articles freely accessible at time of publication, rising over time as embargoes and delays expire to 35% within 24 months after publication. These factors, when taken together, reinforce the UK's central position in the global collaboration network and also emphasise the attractiveness of the UK as a destination for researchers from other countries.

1.2.3 The UK is a key partner for global research collaboration and researcher mobility

International research collaboration and international researcher mobility are interrelated and interdependent, and shaped by collaborative interactions that take place across multiple institutions, borders, continents, and time zones. The UK's most prolific international partnerships are associated with greater FWCI per article, relative to the overall international collaborative output of either the UK or its partner countries, including the Newton Fund partners *(see Figure 5.5)*.

It is generally expected that countries that exhibit high levels of research collaboration also have high levels of researcher mobility, and the UK is no exception *(see Figures 5.1 and 3.4 & 3.5 respectively)*. As a whole, UK researchers are highly mobile internationally, although two groups are likely to be less mobile: those with short publication histories, less than 10 years since their first appearance as an author, who are, therefore, still establishing their networks; and women researchers, at any stage in their careers, are likely to be less mobile than men researchers. UK researchers are also mobile across sectors, both nationally and internationally, with the Business Enterprise sector gaining most researchers from UK academia and from international industry *(see Figure 7.11)*. Although the UK's level of growth in overall researcher numbers generally is low and slowing down, the growth rate of UK PhD graduate numbers is high and increasing faster than many comparators.

1.2.4 The UK has a robust cross-sector knowledge exchange

The UK's income derived from intellectual property (IP) has grown as percentage of total research resource since 2010, although the number of spin-off companies reduced significantly. UK academic and corporate users increasingly are downloading articles from each other's sector *(see Figures 7.9 and 7.10 respectively)*, further strengthening an already robust cross-sector knowledge exchange within the country. Internationally, the UK's share of global patents has risen as a result of an increase in the number of its patents in force, and its share of global patents citing UK articles is similar to its global publication share *(see Figures 7.7 and 4.1 respectively)*. However, the UK's share of global patents in force ranked third lowest amongst the comparator countries *(see Figure 7.5)*.

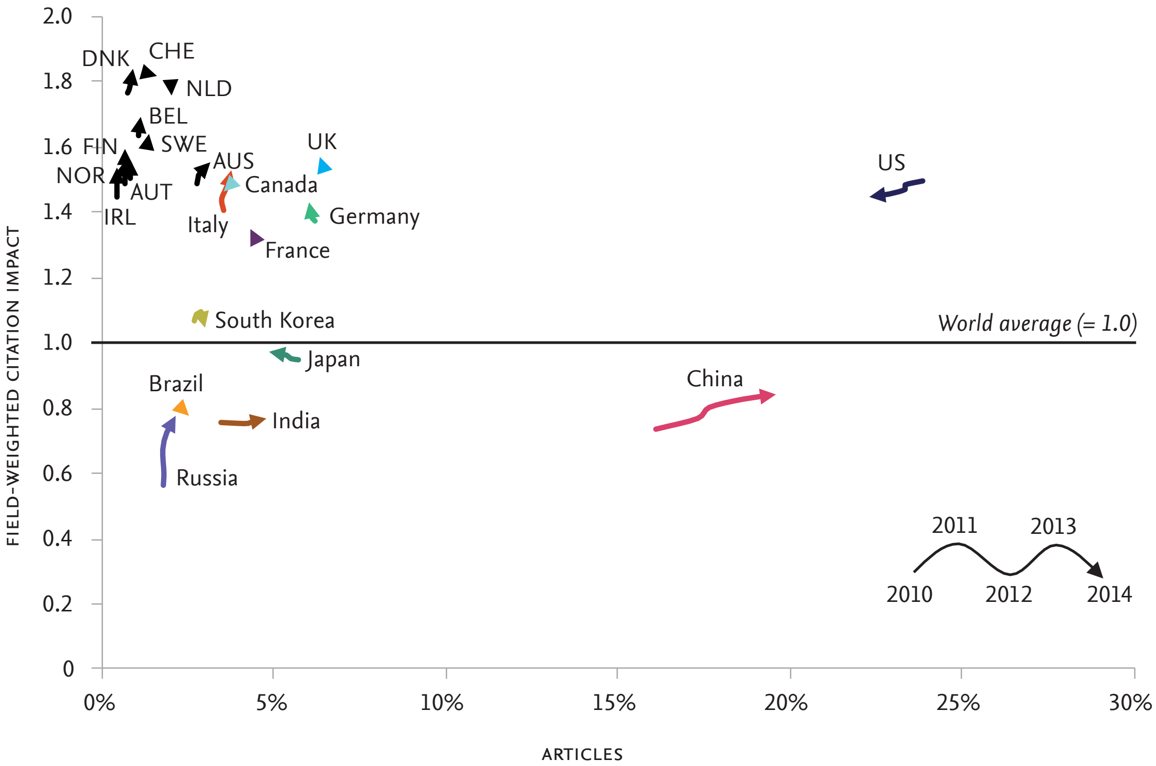
1.2.5 While the UK leads in many worldwide rankings, the world is changing

There are growing indications that the UK is losing ground in the research leadership stakes and may not be able to sustain its position as a world-leading research nation in the long term. Despite punching above its weight in delivering increasingly high-quality research outputs on broadly stable or decreasing R&D expenditure and human capital inputs, the UK, along with other research-intensive nations, including the US, are seeing their global shares in key research indicators eroded by other countries. Italy now has more articles per researcher *(see Figure 6.5)* than the UK and all other comparator countries; it has also increased its share of international collaboration *(see Figure 5.1)* and its field-weighted citation impact is set to rise above both the UK and Canada if current trends are maintained *(see Figure 5.2)*. However, the biggest pressure on the UK and others continues to be China. The quality of China's research in terms of field-weighted citation impact, alongside an increased share in the number of publications, has improved *(see Figure 4.9)*. As China and other emerging nations succeed in their desire to emulate and even surpass the research performance of countries like the US and the UK, their shares will naturally become larger while the erstwhile powerhouses see theirs shrink *(see Table 1.3)*.

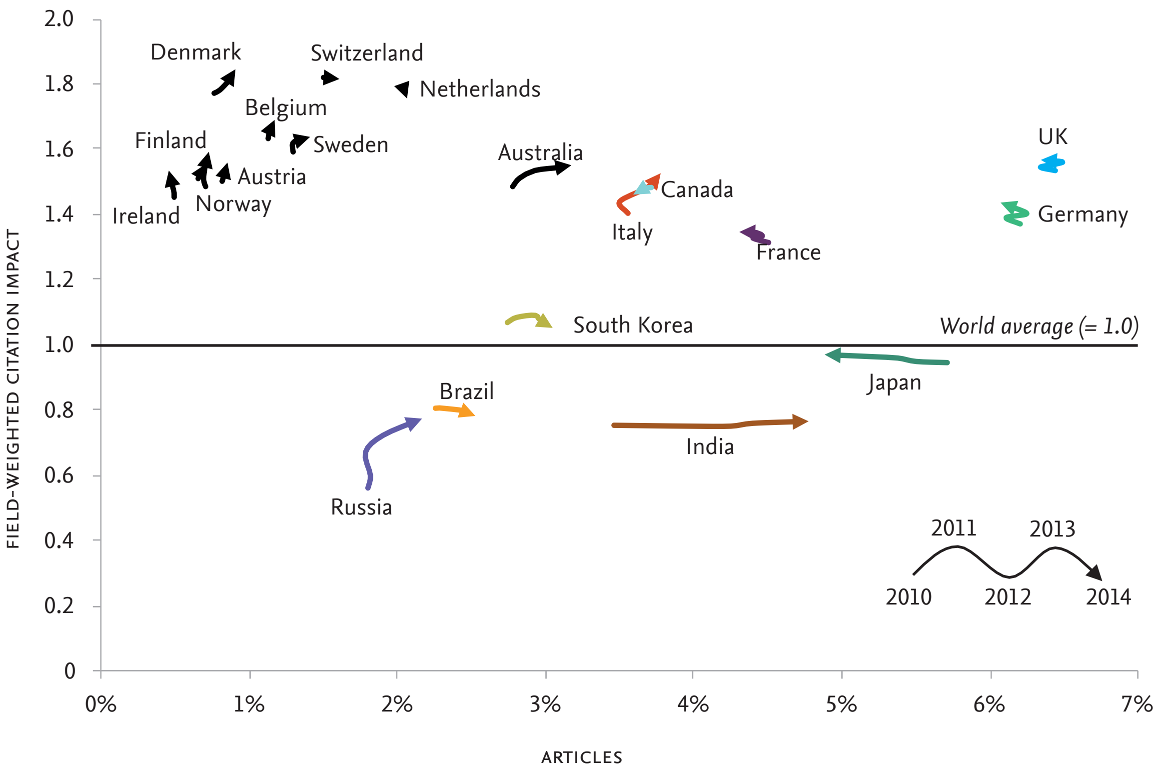
The global research landscape in recent years has become increasingly complex and fluid, and it can only become more so as the emerging research nations grow their research bases. Although there is no doubt that the UK is well-positioned to remain a leader on the global research stage, this can only be sustained by continued investment in its national research base.

__Figure 1.2__ — Article share and field-weighted citation impact, 2010-14. Source: Scopus.

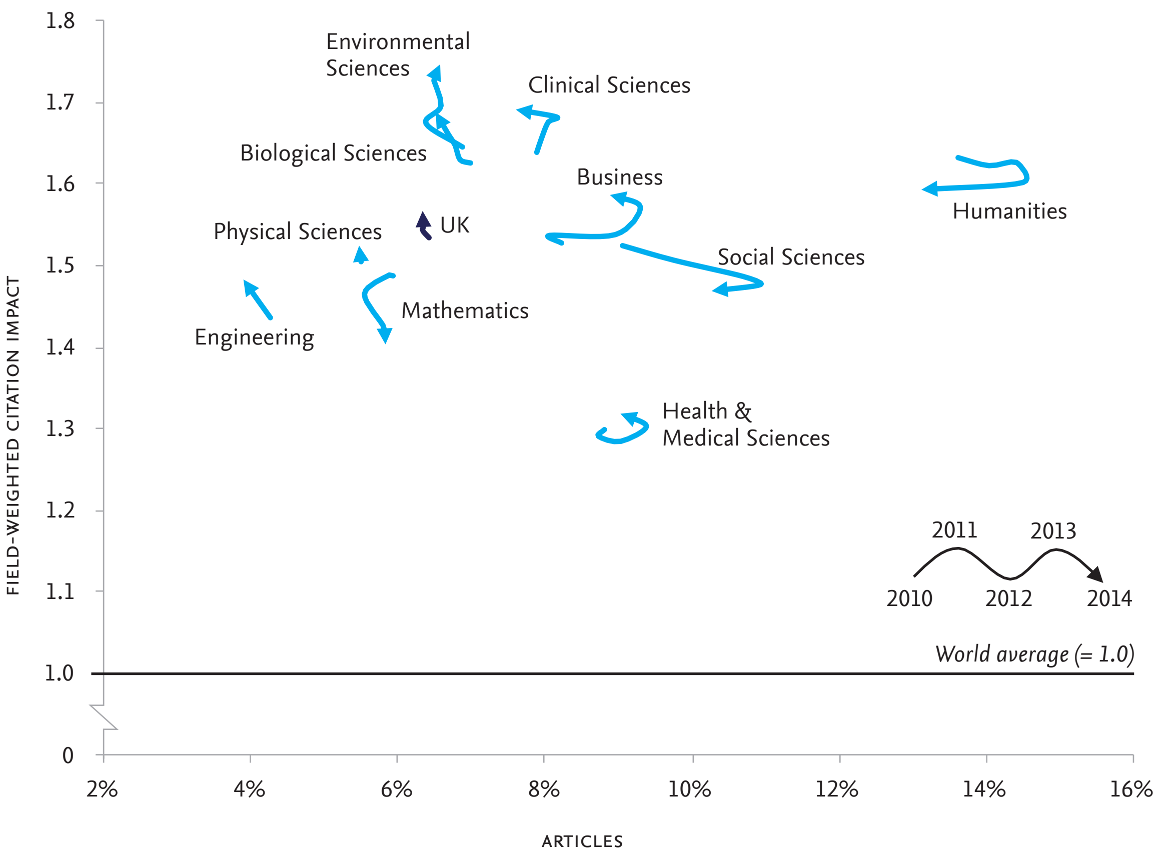
***Panel A(1):** The UK and comparator countries plus top ten countries with the highest field-weighted citation impact in 2014 among OECD countries with at least 5,000 publications in 2014 (including the US and China).*



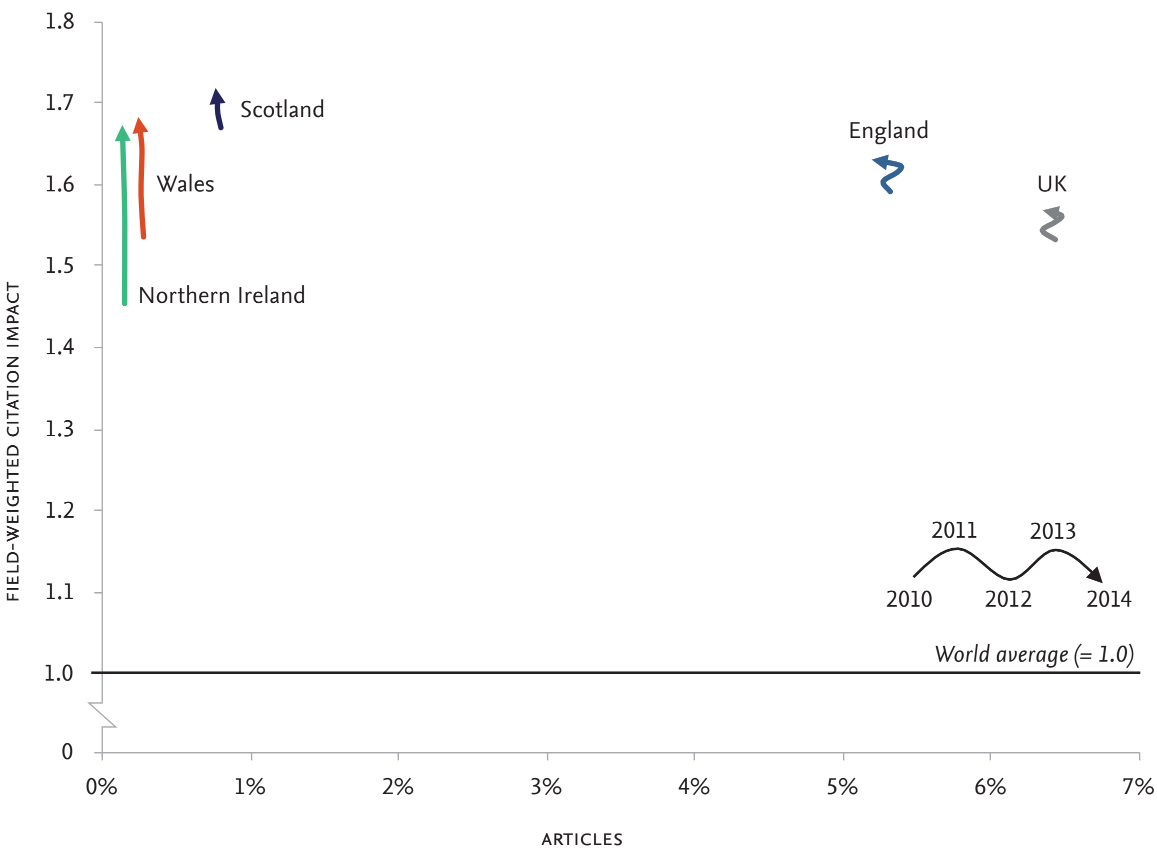
***Panel A(2):** The UK and comparator countries plus top ten countries with the highest field-weighted citation impact in 2014 among OECD countries with at least 5,000 publications in 2014 (excluding the US and China).*



Panel B: Research fields within the UK. For Humanities, OECD share instead of world share is used.[8]



Panel C: The UK's constituent countries.



8 Scopus has increased its coverage in Humanities considerably in recent years, and this expansion has come largely from OECD countries. Therefore, benchmarking for the Humanities is shown against OECD countries only and not the world, as these countries are similarly affected by the coverage issue.

Table 1.3 (continues next page) — Dashboard representation of key input and output indicators for the UK and key comparators. All data are for 2010 and 2014, and the absolute change and compound annual growth rate (CAGR) between them, except for all population data, which are for 2010 to 2013.

***Panel A:** All data are expressed as counts or world share. **Panel B:** All data are expressed as both absolute numbers, and world share divided by world share of researchers or world share of GERD. CAGR of citations, downloads, digital reads and patent citations are not used in conditional formatting of cell colours because the changes are expected to be negative for these indicators. Source: OECD for population, researchers and GERD, Scopus for articles, citations, highly-cited articles, downloads, Mendeley for digital reads, WIPO for patents and LexisNexis Univentio and Scopus for patent citations.*

A Changes in count and world shares

	UK				China			
Counts (actual numbers)	**2010**	**2014**	**Change**	**CAGR**	**2010**	**2014**	**Change**	**CAGR**
Population *(million)*	61.9	63.2	1.3	0.7%	1,359.8	1,385.6	25.7	0.6%
Researchers *(thousand)*	256.6	273.6	17.0	1.6%	1,210.8	1,524.3	313.4	5.9%
GERD *(billion USD, in 2010 price)*	38.2	41.6	3.4	2.2%	213.5	344.7	131.2	12.7%
Articles *(thousand)*	138.7	154.7	15.9	2.8%	347.3	478.2	130.9	8.3%
Highly-cited articles *(thousand)*	3.2	4.1	0.8	5.9%	2.0	5.3	3.2	26.9%
Patents *(thousand)*	50.9	52.6	1.7	0.8%	308.3	837.9	529.6	28.4%
World share (%)								
Population	0.9%	0.9%	0.0p.p.		19.6%	19.3%	-0.3p.p.	
Researchers	4.3%	4.1%	-0.2p.p.		20.1%	22.6%	2.5p.p.	
GERD *(USD, in 2010 price)*	3.0%	2.7%	-0.3p.p.		16.6%	22.5%	5.9p.p.	
Articles	6.4%	6.3%	-0.1p.p.		16.1%	19.6%	3.5p.p.	
Citations	11.0%	10.7%	-0.3p.p.		11.0%	18.1%	7.1p.p.	
Highly-cited articles[10]	14.9%	15.2%	0.3p.p.		9.4%	19.6%	10.2p.p.	
Downloads	9.8%	9.9%	0.0p.p.		11.4%	16.8%	5.4p.p.	
Digital reads	11.4%	11.8%	0.4p.p.		7.4%	10.5%	3.1p.p.	
Patents	2.5%	2.0%	-0.6p.p.		15.4%	31.3%	15.8p.p.	
Patent citations	9.3%	9.1%	-0.2p.p.		9.4%	12.4%	3.0p.p.	

B Changes in productivity measures

	UK				China			
Ratio of values to researchers (x / researchers)	**2010**	**2014**	**Change**	**CAGR**	**2010**	**2014**	**Change**	**CAGR**
GERD *(USD, in 2010 price)*	0.149	0.152	0.003	0.5%	0.18	0.23	0.05	6.4%
Articles	0.54	0.57	0.02	1.1%	0.29	0.31	0.03	2.3%
Highly-cited articles	0.01	0.01	0.00	4.2%	0.0017	0.0035	0.0018	19.8%
Patents	0.20	0.19	-0.01	-0.8%	0.25	0.55	0.30	21.2%
Ratio of values to GERD (x / GERD)								
Researchers	6.72	6.58	-0.14	-0.5%	5.67	4.42	-1.25	-6.0%
Articles	3.63	3.72	0.09	0.6%	1.63	1.39	-0.24	-3.9%
Highly-cited articles	0.08	0.10	0.01	3.7%	0.01	0.02	0.01	12.5%
Patents	1.33	1.27	-0.07	-1.3%	1.44	2.43	0.99	13.9%

9 Absolute numbers for citations, downloads, digital reads and patent citations are not included. These indicators require time to accumulate and, as a result, counts from earlier years will always be higher than recent years. Shares for these indicators are included, as they are relative to world counts.

10 Summing the shares of highly-cited articles of each comparator country will be over 100% due to collaboration between countries. This report using whole-counting of publications, not fractional counting. See *Appendix C: Data Sources* for a more detailed description of counting methods employed in this report.

Table 1.3 (continued)

CAGR: Lowest negative growth · Middling negative growth · Middling positive growth · Highest positive growth

Germany				Japan				US			
2010	**2014**	**Change**	**CAGR**	**2010**	**2014**	**Change**	**CAGR**	**2010**	**2014**	**Change**	**CAGR**
81.8	80.6	-1.1	-0.5%	128.1	127.3	-0.8	-0.2%	309.3	316.5	7.2	0.8%
328.0	359.6	31.6	2.3%	656.0	682.9	26.9	1.0%	1,198.3	1,278.6	80.3	1.6%
87.9	97.7	9.8	2.7%	140.6	159.2	18.6	3.2%	410.1	435.4	25.3	1.5%
133.9	148.2	14.4	2.6%	123.2	119.2	-4.0	-0.8%	513.5	544.2	30.7	1.5%
2.7	3.5	0.8	6.5%	1.1	1.4	0.3	5.6%	11.6	12.7	1.1	2.2%
173.6	179.5	5.9	0.8%	468.4	466.0	-2.4	-0.1%	433.2	509.6	76.4	4.1%
1.2%	1.1%	-0.1p.p.		1.8%	1.8%	-0.1p.p.		4.5%	4.4%	-0.1p.p.	
5.5%	5.3%	-0.1p.p.		10.9%	10.1%	-0.8p.p.		19.9%	19.0%	-0.9p.p.	
6.8%	6.4%	-0.4p.p.		10.9%	10.4%	-0.5p.p.		31.8%	28.4%	-3.4p.p.	
6.2%	6.1%	-0.1p.p.		5.7%	4.9%	-0.8p.p.		23.8%	22.3%	-1.5p.p.	
9.4%	9.5%	0.1p.p.		5.6%	5.1%	-0.4p.p.		39.4%	35.0%	-4.4p.p.	
12.4%	13.0%	0.5p.p.		5.1%	5.2%	0.0p.p.		53.5%	47.2%	-6.3p.p.	
6.9%	7.0%	0.1p.p.		4.8%	4.2%	-0.6p.p.		30.2%	28.9%	-1.3p.p.	
9.3%	9.4%	0.0p.p.		4.7%	4.3%	-0.4p.p.		38.0%	35.6%	-2.4p.p.	
8.7%	6.7%	-2.0p.p.		23.5%	17.4%	-6.1p.p.		21.7%	19.0%	-2.7p.p.	
10.3%	9.4%	-0.9p.p.		6.8%	5.8%	-1.0p.p.		42.7%	44.7%	2.0p.p.	
0.268	0.272	0.004	0.3%	0.21	0.23	0.02	2.1%	0.342	0.341	-0.002	-0.1%
0.408	0.412	0.004	0.3%	0.19	0.17	-0.01	-1.8%	0.429	0.426	-0.003	-0.2%
0.008	0.010	0.00	4.1%	0.0017	0.0020	0.0003	4.5%	0.010	0.010	0.000	0.6%
0.53	0.50	-0.03	-1.5%	0.71	0.68	-0.03	-1.1%	0.36	0.40	0.04	2.5%
3.73	3.68	-0.05	-0.3%	4.67	4.29	-0.38	-2.1%	2.92	2.94	0.01	0.1%
1.52	1.52	-0.01	-0.1%	0.88	0.75	-0.13	-3.9%	1.252	1.250	0.00	0.0%
0.03	0.04	0.00	3.7%	0.008	0.009	0.001	2.4%	0.028	0.029	0.001	0.7%
1.98	1.84	-0.14	-1.8%	3.33	2.93	-0.40	-3.2%	1.06	1.17	0.11	2.6%

CHAPTER 2

Research Inputs

2.1 Highlights

UK R&D EXPENDITURE

The UK spent	Increased at	Ranks	Represents
£30.6b	**2.2%**	**7th**	**2.7%**
on R&D in 2014	growth per year in the period 2010-2014	amongst comparator countries in 2014	of the global total in 2014

UK R&D INTENSITY

R&D intensity	Displayed	Ranks
1.7%	**No growth**	**7th**
in 2014	growth per year in the period 2010-2014	amongst comparator countries in 2014

The UK's level of R&D spending has increased at a similar rate as its GDP, which is also the case for most of the comparator countries.

The UK's R&D expenditure predominantly occurs in the Business Enterprise sector, although the sector contributes less than half of GERD funding.

The UK's R&D expenditure by sector of funding is more balanced across the sectors than that of the comparator countries.

2.2 Introduction

There is an widely accepted relationship between the development and maintenance of national research capabilities, and a country's underlying economic growth[11]. A country's expenditure on Research & Development (R&D) creates a market that extends far beyond the active R&D community: the R&D expenditure does not just pay the salaries of skilled researchers and provide the necessary infrastructure to support them in their work, it generates supply and demand for services and products across many industries.

Gross Domestic Expenditure on R&D (GERD) represents the total expenditure on R&D within a country, regardless of the sector of performance or sector of funding; it includes domestically-conducted R&D financed from overseas, but excludes R&D funding that is paid abroad (for example, to international agencies). GERD, measured as a share of the country's Gross Domestic Product (GDP), is also known as research intensity.

R&D expenditure can be viewed from two complementary perspectives: by the sector of performance (i.e., the sector in which the money was spent) or by the sector of funding (i.e., the sector from which the money originated); the sum of either equals GERD *(see Figure 2.1)*. A comparison of the distribution of GERD by sector within a country offers a measured assessment of the emphasis placed on different forms of R&D, and so can help to explain the relative distribution of outputs from the national research base. It should be noted, however, that the lag between spending on R&D and the outcomes of research means that any potential changes associated with the current trends in spending described in this chapter will not be reflected in the outcomes described in other chapters of this report.

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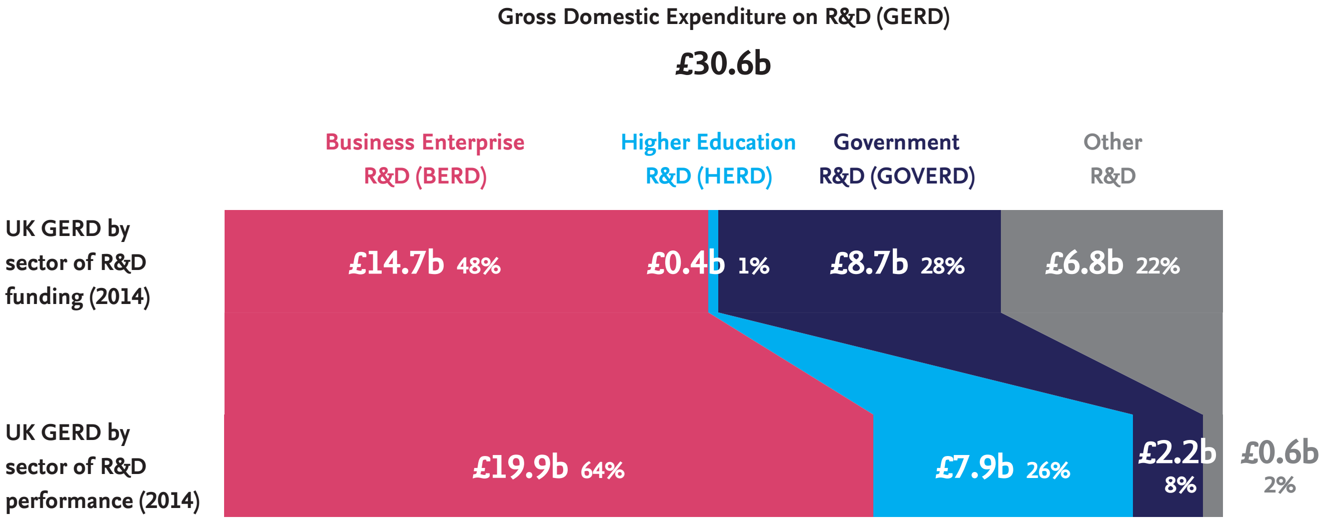
11 Godin, B. (2003) "The most cherished indicator: Gross Domestic Expenditure on R&D (GERD)" Project on the History and Sociology of S&T Statistics, Working Paper No. 22, Canadian Science and Innovation Indicators Consortium.

2.3 Key Findings

2.3.1 The large majority of UK's R&D is performed by the Business Enterprise (65%) and Higher Education (26%) sectors

According to the UK's Office for National Statistics, UK GERD amounted to £30.6 billion in 2014 *(see Figure 2.1)*. Nearly two thirds of expenditure was in the Business Enterprise sector (although the sector contributed 48% to the GERD by funding), and just over a quarter was in the higher education sector. The Government provided 28% (down from the 30% shown in 2012) of R&D expenditure (£5.3bn of that £8.7bn was funded through research and higher education councils) but 7% was performed in the Government sector. The 'Other' category, which includes investment from overseas (for example, grants from the European Union, the UK being one of the largest recipients of EU funding[12]) and from the non-profit sector[13], funded nearly a quarter of the total research expenditure, although only a small percentage of performance took place in this sector.

Figure 2.1 *— Composition of UK GERD by sectors of R&D performance and sectors of R&D funding, 2014. In this figure only, monetary values are shown in billions GBP and in nominal terms. Sectors of performance and funding are shown per OECD categorisation for comparability with other countries. For performing sectors, 'Government' includes expenditure by government, research councils and higher education funding councils, and 'Other' includes expenditure by private non-profit and overseas parties. For funding sectors, 'Government' includes funding by research councils and higher education funding councils, and 'Other' includes funding from private non-profit and overseas parties. Source: Office for National Statistics.*



12 European Commission 2015, Seventh FP7 Monitoring Report 2013 https://ec.europa.eu/research/evaluations/pdf/archive/fp7_monitoring_reports/7th_fp7_monitoring_report.pdf and EU Cohesion Funding, Available Budget 2014-2020. https://cohesiondata.ec.europa.eu/

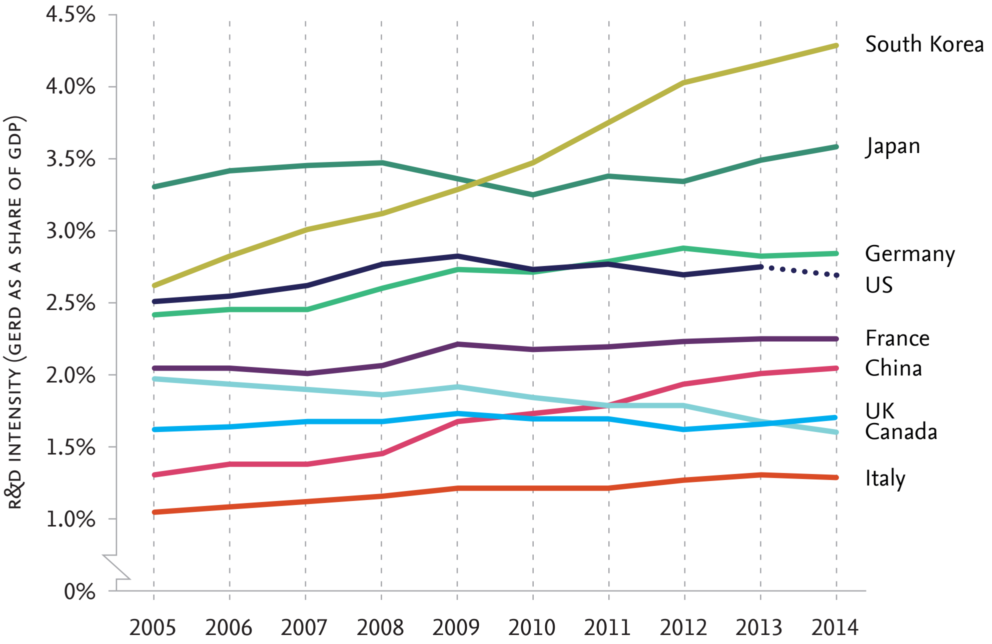
13 In the UK, the non-profit sector includes major medical research charities such as the Wellcome Trust, the British Heart Foundation, and Cancer Research UK.

2.3.2 The UK's level of R&D spending has remained flat as a proportion of GDP

R&D intensity is a relative indicator of national investment in the research base; it equals GERD as a percentage of GDP. The UK's R&D intensity remained broadly flat at 1.7% over the period 2010 to 2014, as well as over the period 2005 to 2014 *(see Figure 2.2)*.

Among the comparator countries, Germany's level of R&D intensity was static in the latter part of the reporting period, while Canada showed a downward trend overall. The US's level was projected to fall between 2013 and 2014. China, after overtaking the UK in 2010, continued to increase its R&D spending relative to GDP to a level well above the UK in 2014. South Korea showed the most significant proportional increase over the period, to be nearly two and a half times higher than the UK, and Japan reversed a decrease in the middle of the studied period to end at approximately twice the UK's level.

***Figure 2.2** — R&D intensity (GERD as a share of GDP) for UK and comparators, 2005-2014. The 2014 value for the US is extrapolated from OECD data (Appendix E). UK ranking in EU28 is amongst 21 (of 28) countries with available data and in OECD is amongst 37 (of 41) countries with available data. Source: OECD MSTI 2015/2.*



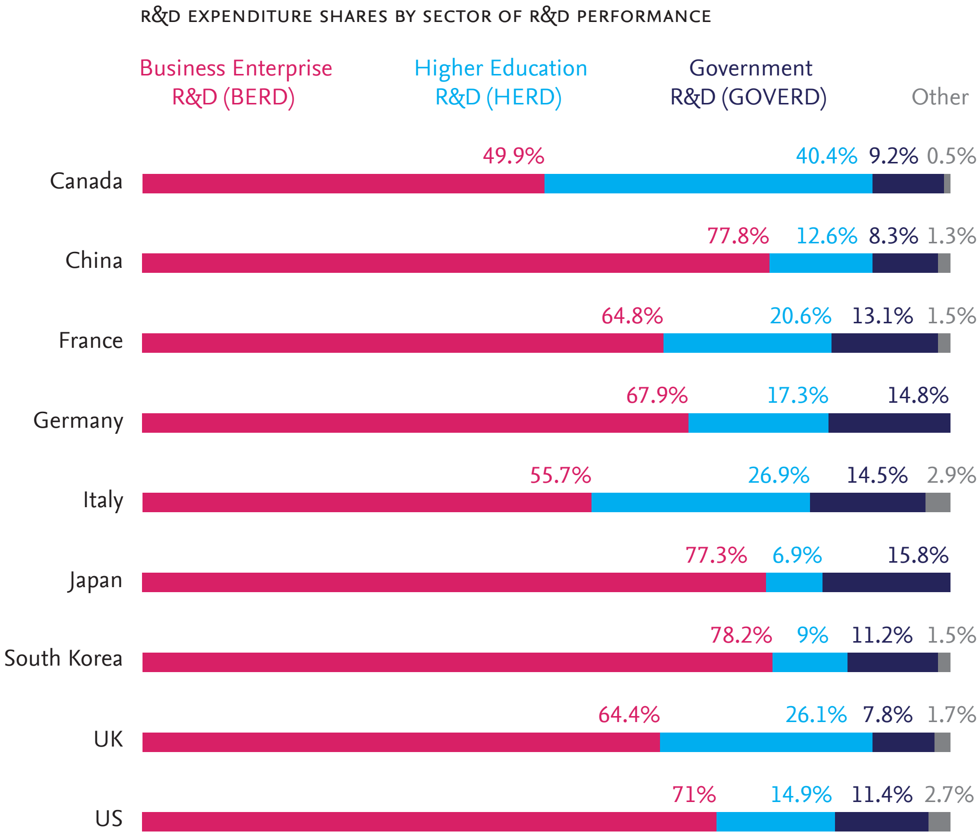
	2010	2014	Change	CAGR	UK rank 2010	UK rank 2014
UK	1.69%	1.70%	0.01p.p.	1.6%	–	–
G8	2.42%	2.46%	0.04p.p.	1.5%	6	5
EU28	1.90%	2.00%	0.10p.p.	2.5%	10	11
OECD41	2.11%	2.22%	0.11p.p.	3.0%	19	20

2.3.3 The share of UK R&D performed in the Higher Education and the Business Enterprise sectors combined is higher than any other comparator country

The UK's R&D expenditure shares by performance sector was proportionally greater in the Higher Education sector, and lower in the Business Enterprise sector than those for most of the comparator countries. But, when the two sectors are combined, the share was higher for the UK than for any of the other comparator countries at over 90% *(see Figure 2.3)*. Those countries that saw the largest increase in R&D expenditure (China, South Korea and Japan) had the greatest proportion of R&D performed in the Business Enterprise sector, in the range of 77-79%, and much smaller proportions in the Higher Education sector (6-13%).

The UK's financial contribution to R&D performance by the Higher Education sector, which is proportionally much greater than the average of the G8, the OECD41 and, to a lesser extent, the EU28 country groups, highlights the UK's long-standing emphasis on, and support for, university-centred research[14]. Canada and Italy, the only two comparator countries with a lower level of R&D intensity than the UK *(see Figure 2.2)*, were also the only comparator countries with proportionally greater R&D expenditure in the Higher Education sector than the UK.

Figure 2.3 — *R&D expenditure shares by sector of R&D performance for the UK and comparators, 2014. For the US, 2014 value was extrapolated (Appendix E). For all countries, 'Other' is estimated by subtraction from the total and includes mostly R&D performed by private non-profit organizations. Countries are shown left to right by descending proportion of Business Enterprise as sector of performance. UK ranking in EU28 is amongst 22 (of 28) countries with available data. Source: OECD MSTI 2015/2.*



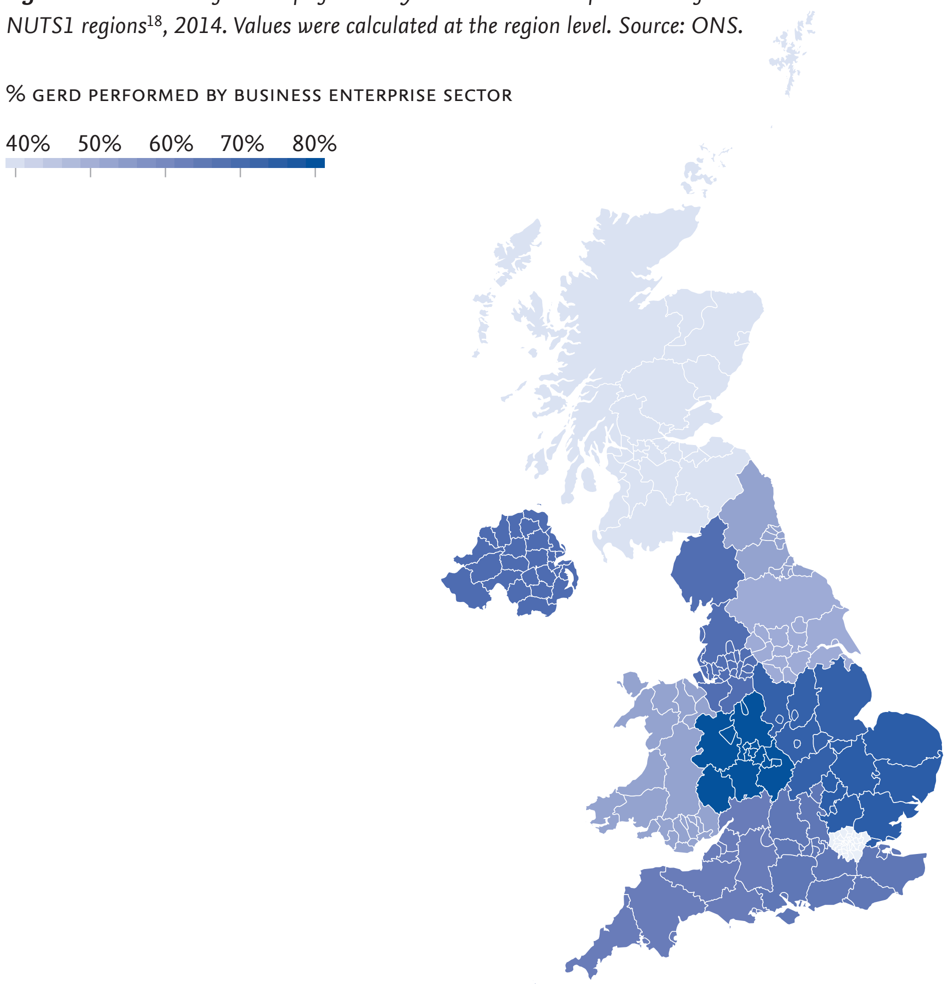
	HERD	UK rank	BERD	UK rank	GOVERD	UK rank	Other	UK rank
UK	26.1%	–	64.4%	–	7.8%	–	1.7%	–
G8	16.5%	3	69.7%	5	12.0%	8	1.9%	3
EU28	23.1%	11	63.4%	10	12.7%	17	0.8%	3
OECD41	15.6%	23	70.3%	17	12.9%	33	1.2%	7

14 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 and Department for Business, Innovation and Skills (2014) "The allocation of science and research funding 2015/16: Investing in world-class science and research".

2.3.1.1 Across the UK's regions, the highest share of GERD performed in the Business Sector occurs in the West Midlands, East England and the East Midlands

The composition of the industrial sectors of a region affects the percentage of R&D performed by the Business Enterprise sector in that region. In other words, a region that has a high proportion of R&D-intensive industry is likely to have a high proportion of GERD performed by its Business Enterprise sector. Across the UK, 65% of GERD is performed by the Business Enterprise sector. The regions that outperformed this average most were the West Midlands (84%), East England (78%) and the East Midlands (77%) *(see Figure 2.4)*. The West and East Midlands regions have a high proportion of employee jobs in the Manufacturing sector[15], where a large portion of the UK's R&D expenditure takes place[16]. The Greater London region had the second lowest share across the UK at just 43%, reflecting the prevalence of employee jobs in professional, scientific and technical activities[17], including those in higher education and government, rather than in R&D-intensive industries in this region.

Figure 2.4 *— Share of GERD performed by the Business Enterprise sector for UK NUTS1 regions[18], 2014. Values were calculated at the region level. Source: ONS.*



15 The information is drawn from "ONS workforce jobs by industry (SIC 2007) - seasonally adjusted", available at https://www.nomisweb.co.uk/reports/lmp/gor/2013265924/report.aspx#tabwfjobs

16 ONS. 2012. "Business Enterprise Research and Development, 2011." Available at https://www.google.com/search?q=Business+Enterprise+Research+and+Development,+2011

17 https://www.nomisweb.co.uk/reports/lmp/gor/2013265927/report.aspx

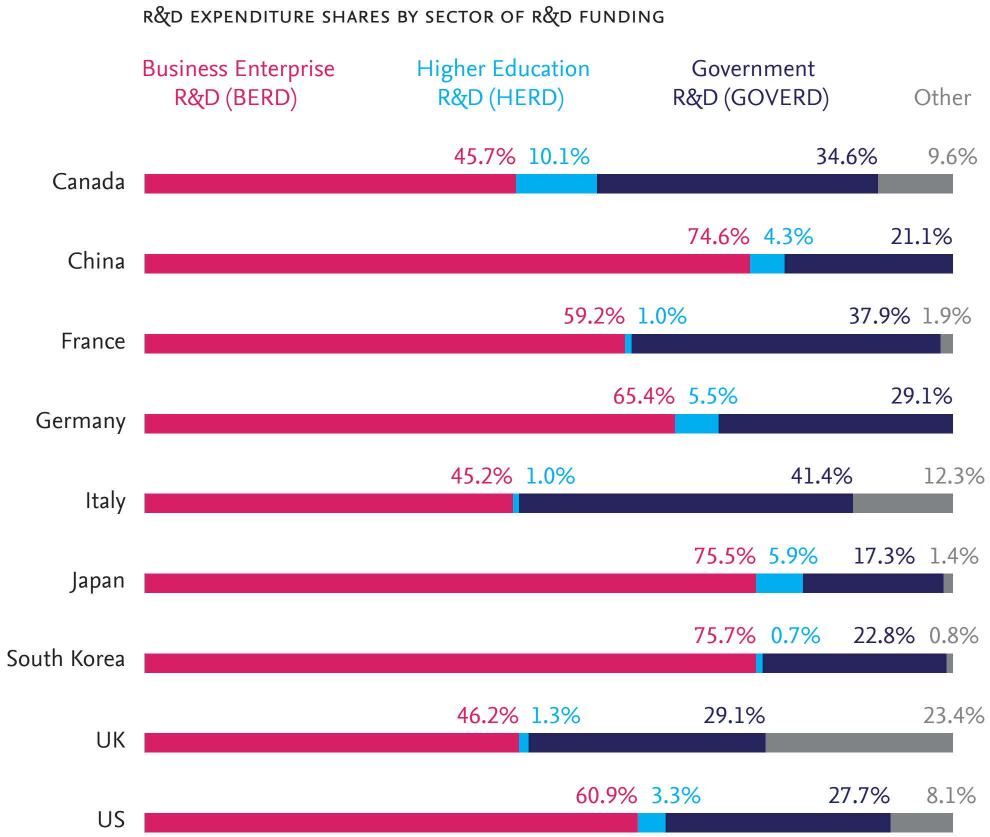
18 The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU. More information is available at http://ec.europa.eu/eurostat/web/nuts/overview

2.3.4 UK R&D expenditure by sector of funding is more balanced across sectors than most comparator countries

Research funding across sectors varies country by country, influenced by national priorities, culture and history. The UK's R&D expenditure by sector of funding was more balanced across the sectors than most of the comparator countries, making it less reliant on any one funding sector *(see Figure 2.5)*. Although its funding from the Higher Education and Business Enterprise sectors was proportionally lower than among comparators, funding sourced from non-profit organisations and from overseas (Others) was the highest across the comparator group.[19] The UK's funding from Others, which partly reflects the UK's unique mix of high EU funding and funding by medical research charities, was ranked first in the G8 group, and third and fourth highest among the EU28 and OECD41 countries, respectively.

Italy and France had the greatest proportions of R&D expenditure funded by Government. In contrast, Japan, South Korea and China had the greatest proportions funded by their respective Business Enterprise sectors, and saw higher percentage increases there than in the Government sector.

Figure 2.5 *— R&D expenditure by sector of R&D funding for the UK and comparators, 2013. Data are shown for 2013 as this is the most recent year for which data are available for the majority of countries. For all countries, 'Other' is estimated by subtraction from the total including mostly funding from private non-profit organizations and overseas, except for China, Denmark, Germany, Hungary and Iceland, for which no recent Higher Education data are available so 'Other' is assumed to equal zero in order to instead estimate Higher Education. Countries are shown left to right by descending proportion of Business Enterprise as sector of funding. UK ranking in EU28 is amongst 22 (of 28) countries with available data. Source: OECD MSTI 2015/2.*



	Higher Education-funded	UK rank	Business Enterprise-funded	UK rank	Government-funded	UK rank	Other	UK rank
UK	1.3%	–	46.2%	–	29.1%	–	23.4%	–
G8	3.8%	5	60.9%	5	29.0%	5	6.2%	1
EU28	0.9%	10	55.3%	13	33.5%	16	8.3%	3
OECD41	3.6%	21	63.6%	22	27.9%	27	4.8%	4

19 According to ONS UK data, out of the 6.8 billion GBP R&D expenditures funded by "Others" in 2014 private non-profit and overseas contributed 1.47 and 5.37 billion GBP, respectively.

2.3.5 The UK's R&D expenditure by field can be linked to high Activity Index

Funding plays an important role in driving the direction of a nation's research, since its reward structure influences the performance and evaluation of research[20]. According to OECD data[21], in 2012 the UK spent one third of all GERD (for which fields of science are classified) on Social Sciences and on Humanities, significantly higher than the US, which spent just over 8%[22]. The UK spent 23% of its GERD on Life Sciences, while the US had a high share at nearly 57%, South Korea was much lower at 12% and Russia at 3%. Both Russia and South Korea spent a high proportion of their GERD on Engineering and Technology (73% and 69% in 2014 respectively), with the corresponding proportions for the UK and the US being only 15 and 16% respectively. Chapter 4 presents how this relates to a country's research focus in terms of Activity Index in different fields (Activity Index is defined as a country's share of its total article output across different subject fields relative to the global share of articles in the same subject fields).

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20 Benner M., Sandström U. (2000) "Institutionalizing the triple helix: research funding and norms in the academic system" *Research Policy* 29 (2000) 291-301

21 OECD MSTI 2015/2.

22 http://www.nsf.gov/statistics/infbrief/nsf14303/

CHAPTER 3

Human Capital

3.1 Highlights

UK RESEARCHERS

Researchers	Increased at	Ranks	Represents
273,560	**1.6%**	**6th**	**4.1%**
in 2014	per year in the period 2010-2014	by absolute number, amongst comparator countries in 2014	of the global total in 2014

UK PHD GRADUATES

PhD graduates	Increased at	Ranks	Represents
21,240	**3.2%**	**4th**	**6.7%**
in 2014	per year in the period 2010-2014	by absolute number, amongst comparator countries in 2014	of the OECD total in 2014

UK RESEARCHER MOBILITY

Share	Ranks
72.2%	**2nd**
of active researchers were internationally mobile in the period 1996-2015	amongst comparator countries

The UK researcher population of 273,560 represents 4.1% of the global total in 2014. It ranks fifth among the comparator countries by number of researchers per thousand population.

The UK's total of 21,240 PhD graduates in 2014 is lower than in the US, China and Germany in absolute terms, but ranks second only to Germany when considered as a rate of PhD graduates per researcher or per capita of the overall population.

Women researchers, at all stages of their careers, are slightly less likely to be mobile than men researchers.

The UK has a highly mobile researcher population. Researchers with short publication histories are relatively less mobile than those with a longer publishing record. Researchers coming to the UK have the highest citation rates among the mobility classes, indicating that the UK attracts high quality researchers.

The UK, like many established research nations, has seen low, steady growth in the number of researchers; whereas the emerging nations have seen greater growth.

3.2 Introduction

The most important resource of any country's research base is its researchers, and so a country's contribution to the advancement of knowledge, nationally and globally, is critically dependent on the contributions of the researchers within its research infrastructure. This infrastructure of individual researchers, research laboratories, centres of excellence in research, and high-ranking universities, not only creates the next generation of home-grown researchers, but stellar researchers from other countries are attracted to the prestige associated with it.

MEASURING INTERNATIONAL RESEARCHER MOBILITY

Discussion around the international mobility of researchers has shifted considerably from the 1950s' view of a 'brain drain' phenomenon – coined to describe the net outflow of research talent from Europe to the US after the Second World War – to the more nuanced concept of 'brain circulation'. In this view, the skills and networks built by researchers while abroad accrue benefits to their home country's research base when they eventually return, and, often, even if they do not return but remain instead as a diaspora. The movement of researchers between countries can be analysed using a variety of data sources, from census or migration data[23], surveys of researchers[24], CV analysis[25], or a combination of methods[26]. The availability of comprehensive publication databases containing articles with complete author affiliation data has enabled the development of a systematic approach to researcher mobility analysis, through the use of authors' addresses listed in their published articles as a proxy for their location and so allowing tracking of their mobility patterns over time.

The approach presented here uses Scopus author profile data to derive a history of active UK author affiliations recorded in their published articles and to assign them to mobility classes defined by the type and duration of observed moves. Around 90% of Scopus publications include information on affiliations. However, it should be noted that, since a reasonable proportion of research outputs in Social Sciences and Arts and Humanities take the form of books, monographs and non-textual media, the affiliation history of active UK authors may be less complete for these fields.

How are individual researchers unambiguously identified in Scopus?

Scopus uses a sophisticated author-matching algorithm to precisely identify articles by the same author. The Scopus Author Identifier gives each author a unique ID and groups together all the documents published by that author, matching alternate spellings and variations of the author's last name and distinguishing between authors with the same surname by differentiating on data elements associated with the article (such as affiliation, subject area, co-authors, and so on). This is enriched with manual, author-supplied feedback, both directly through Scopus and also via Scopus' direct links with ORCID (Open Researcher & Contributor ID).

What is a 'UK researcher'?

To define the initial population for study, UK authors were identified as those that had listed a UK affiliation on at least one publication (articles, reviews and conference proceedings) published across the sources included in Scopus during the period 1996–2015. These researchers may fall into any of the mobility classes described below.

What is an 'active researcher'?

The 1.1 million[27] UK authors identified include a large proportion with relatively few articles over the entire 20-year period of analysis. As such, it was assumed that they are not likely to represent career researchers, but individuals who have left the research system. A productivity filter was therefore implemented to restrict the analysis to those authors with at least 1 article in the latest 5-year period (2010–2014) and at least 10 articles in the entire 20-year period (1996–2015), or those with fewer than 10 articles in 1996–2015, but at least 4 articles in 2010–2014. After applying the productivity filter, a set of 334,437 active UK researchers was defined and formed the basis of the study.

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23 Johnson, J.M. & Regets, M.C. (1998) "International mobility of scientists and engineers to the United States—brain drain or brain circulation?" Issue Brief (National Science Foundation), NSF 98-316, pp. 98–316.

24 Marceau, J. *et al.* (2008) "Innovation agents: the inter-country mobility of scientists and the growth of knowledge hubs in Asia" Paper presented to the 25th DRUID conference, Copenhagen;
Auriol, L. (2010). "Careers of doctorate holders: employment and mobility patterns" OECD Science, Technology and Industry Working Papers.

25 Dietz, J.S. *et al.* (2000) "Using the curriculum vitae to study the career paths of scientists and engineers: an exploratory assessment" *Scientometrics*, 49 (3), pp. 419-442; Cañibano, C. *et al.* (2008) "Measuring and assessing researcher mobility from CV analysis: the case of the Ramón y Cajal programme in Spain" *Research Evaluation*, 17 (1), pp. 17-31.

26 Fontes, M. (2007) "Scientific mobility policies: how Portuguese scientists envisage the return home" *Science and Public Policy*, 34 (4), pp. 284-298. 20 Science Europe & Elsevier (2013) Comparative Benchmarking of European and US Research Collaboration and Researcher Mobility.
Available at info.scival.com/research-initiatives/science-europe.

27 The number of UK authors is smaller than previous analyses in this series of reports due to merging of multiple author profiles from the same author.

What is a 'short publication history researcher'?

Short publication history researchers are defined as active researchers with less than 10 years since their first appearance as an author during the period 1996-2015. Among the 334,437 active UK researchers, 98,808 are identified as short publication history researchers. However, it should be noted that, in some research fields, researchers' first publications are often not the types of publications included in this report, and so their publishing history may be longer than observed here.

How are mobility classes defined?

The measurement of international researcher mobility in the published literature is complicated by the difficulties involved in teasing out long-term mobility from short-term mobility (such as doctoral research visits, sabbaticals, secondments, etc.), which might be deemed instead to reflect a form of collaboration. In this study, researchers who stayed overseas for 2 years or more were considered **migratory**,[28] and were further subdivided into those where the researcher remained abroad or where they subsequently returned to their original country. Researchers who stayed overseas for less than 2 years were deemed **transitory**, and were also further subdivided into those who mostly published under a UK or a non-UK affiliation. Since author nationality is not captured in article or author data, authors are assumed to be from the country where they first published (for migratory mobility) or from the country where they published the majority of their articles (for transitory mobility). In individual cases, these criteria may result in authors being assigned migratory patterns that may not accurately reflect the real situation, but such errors are assumed to be evenly distributed across the groups and so the overall pattern remains valid. Researchers without any apparent mobility based on their published affiliations were considered **non-migratory**. [Note: the data for subdivisions of the mobility classes are shown in *Appendix F*]

What indicators are used to characterise each mobility group?

To better understand the composition of each group defined above, three aggregate indicators were calculated for each to represent the productivity and seniority of the researchers they contain, and the field-weighted citation impact of their articles.

Relative Productivity — represents a measure of the articles per year since the first appearance of each researcher as an author during the period 1996–2015, relative to all UK researchers in the same period. This measure does not include research outputs that are not in the form of articles, proceedings and reviews.

Relative length of service — represents years since the first appearance of each researcher as an author during the period 1996–2015, relative to all UK researchers in the same period

Field-weighted citation impact (FWCI) — is calculated for all articles in each mobility class. All three indicators are calculated for each author's entire output in the period (i.e., not just those articles listing a UK address for that author).

What are some limitations of this methodology?

This mobility analysis is based on each author's output for the period 1996-2015, which captures a mixed cohort of researchers. Some researchers may publish articles during the entire period, others have become active only relatively recently, and yet others may have (mostly) stopped publishing. This means that researchers who have entered the cohort relatively recently will not have had as many opportunities to be included in the Migratory and Transitory groups. Moreover, the set of short publication history researchers also includes PhD students, who typically do not move between different institutions. Therefore, as a consequence of the methodology, and not necessarily any behavioural differences, the relative mobility of the short publication history researchers will be lower.

28 Crawford, E. et al. (1993) "The Nationalization and Denationalization of the Sciences: An Introductory Essay" in Crawford, E. et al. (eds.), *Denationalizing Science* (Dordrecht: Kluwer).

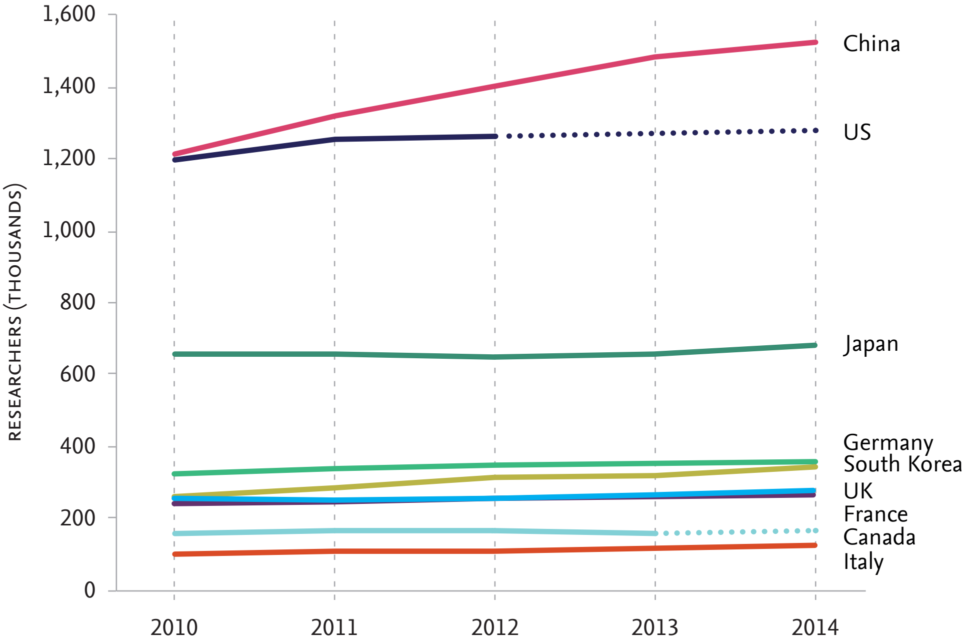
3.3 Key Findings

3.3.1 The UK researcher population represents 4.1% of the global total and its annual growth in researchers is comparatively low and steady

A critical factor in determining a country's capacity to conduct research is the total number of researchers working in higher education, business, government, or charity or other non-profit contexts *(see box "What is a 'researcher'?")*. In 2014, the UK had 273,560 researchers accordingly to OECD data[29] (expressed as full-time equivalents rather than as headcount). equating to 4.1% of the global researcher population. Normalised per capita, the UK had 4.3 researchers per thousand population, ranking fifth among the comparators. South Korea and Japan had the highest number of researchers per thousand of the population at 6.9 and 5.4 respectively. China and Italy had the lowest at 1.1 and 2.0 respectively.

Over the period 2010-2014, the UK's researcher population had an annual growth rate of 1.6% *(see Figure 3.1)*, which was higher than the 0.9% growth shown in 2012, and higher than the average of the G8 in this reporting period. When expressed per thousand population, UK growth was steady at 0.5% per year over the period 2010-2014, and, when expressed per thousand labour force, growth was 0.9% per year in the same period. The UK's steady growth in this indicator was similar to that of other established research nations, such as Germany, France, Canada and Italy, reflecting that there are a finite number of researchers that can be employed in R&D. The emerging nations saw greater growth, as might be expected as they expand their research infrastructures. The most dramatic growth in researcher numbers was shown by China at nearly 6%, so much so that it usurped the US from its position as leader among the comparators in 2010.

Figure 3.1 — *Researchers for the UK and comparators, 2010-2014. For Canada, 2014 values are extrapolated from OECD data. For the US, both 2013 and 2014 values are extrapolated (see Appendix E).[30] UK ranking in EU28 is amongst 22 (of 28) countries with available data and in OECD is amongst 39 (of 41) countries with available data. Source: OECD MSTI 2015/2.*



	2010	2014	Change	CAGR	UK rank 2010	UK rank 2014
UK	256,585	273,560	16,975	1.6%	–	–
G8	3,386,582	3,590,579	203,997	1.5%	5	5
EU28	1,568,920	1,729,686	160,766	2.5%	3	3
OECD41	5,909,966	6,657,734	747,768	3.0%	7	7

29 https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB
30 The most recent release of the OECD data (OECD MSTI 2016/1) shows a higher growth rate for the US in the number of researchers than is extrapolated here, reaching 1,307,973 in 2013.

This reporting period saw three out of the four main R&D sectors experiencing negative growth in the numbers of researchers; with only Business Enterprise sector seeing positive growth *(see Figure 3.2)*. Consequently, the distribution of researchers between the UK's Higher Education and Business Enterprise sectors narrowed. The Higher Education sector, while retaining the largest share, saw a drop in numbers with a partial recovery in 2011, and the Government and Other sectors saw their annual growth rates decline to an even greater extent. This shift in the distribution of researcher numbers across sectors may be caused in part by the moves seen in the distribution of GERD funding by sector of performance, as discussed in Chapter 2, particularly by the relative reduction in the proportion of GERD that is funded by Government.

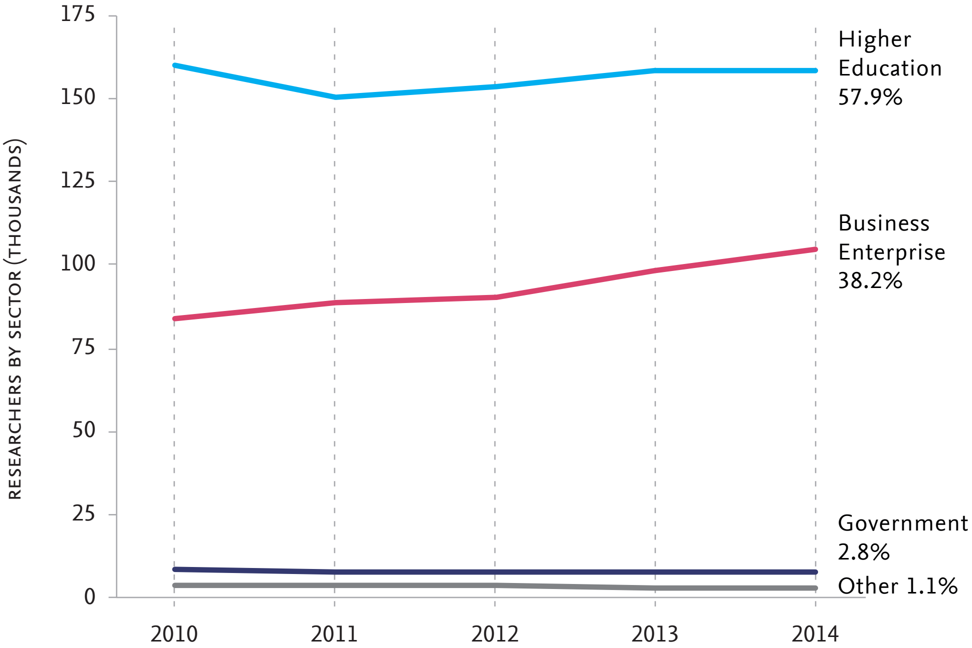
WHAT IS A 'RESEARCHER'?

The OECD data on research inputs used in this report are compiled from data supplied by national statistical agencies, such as The Office for National Statistics (ONS) and various government bodies in the UK. Agencies collect data according to definitions provided in the Frascati Manual, first published in the early 1960s and updated periodically ever since. According to the latest (2015) edition[31]:

"Researchers are professionals engaged in the conception or creation of new knowledge. They conduct research and improve or develop concepts, theories, models, techniques instrumentation, software or operational methods."

This definition includes members of the armed forces who perform R&D, managers and administrators engaged in the planning and management of the scientific and technical aspects of a researcher's work, and PhD students engaged in R&D.

Figure 3.2 — *UK researchers by sector of employment, 2010-2014. Source: OECD MSTI 2015/2.*



Sector	2010	2014	Change	CAGR
Higher Education	159,941	158,491	-1,450	-0.2%
Business Enterprise	84,074	104,484	20,410	5.6%
Government	8,620	7,640	-980	-3.0%
Other	3,950	2,945	-1,005	-7.1%

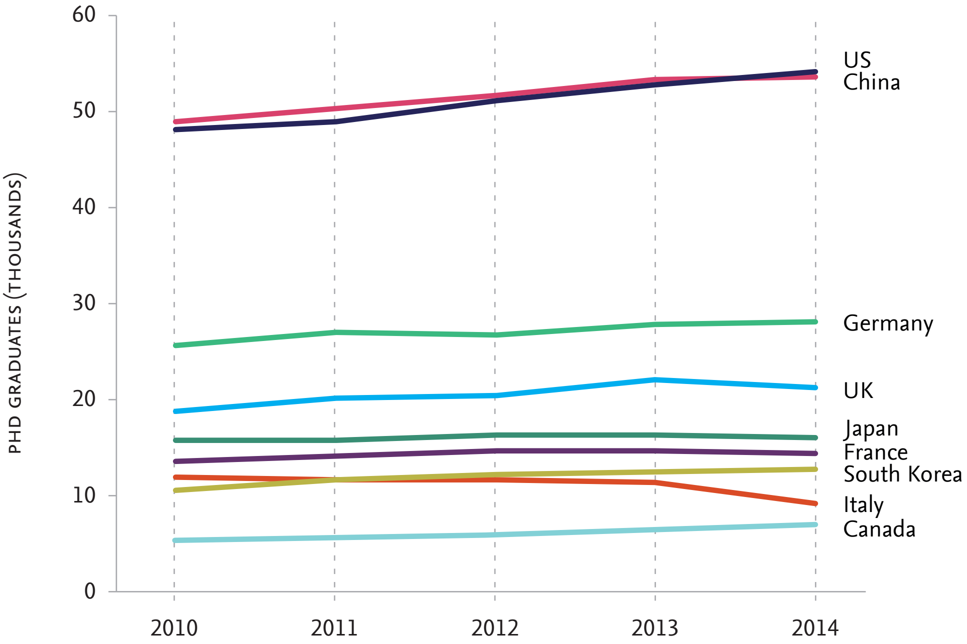
31 OECD (2015) "Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development." OECD Publishing, Paris.

3.3.2 The UK has a rapidly increasing number of PhD graduates

The pipeline of research talent is one that flows through higher education and into a research career, but which narrows as individuals pass through and siphon off into careers outside research[32]. The culmination of formal training for researchers who hope to go on to play a leading role in the conception or creation of new knowledge is typically a higher research degree, which would be a PhD in most research fields. The number of PhD graduates produced from a national research system each year, therefore, may be used as an indicator of the volume of new talent generated within that country, irrespective of the national origin or destination of those graduates.

The UK's number of PhD graduates increased over the reporting period to 21,240, in 2014, according to the data from Higher Education Statistical Agency (HESA)[33] *(see Figure 3.3)*. Whilst in the US and China, the absolute number of PhD graduates produced over the period outperformed all other comparator countries. In terms of PhD graduates per researcher and per capita of the overall population, the UK ranked second, behind Germany. The UK growth of PhD graduates per thousand population was 2.4% per annum (2010-2014), which is in line with the US (2.2%), Canada (2.6%) and Germany (2.9%). Furthermore, the UK's overall rate of growth across the reporting period was higher than the average of each of the G8, EU28 and OECD41 groups, and much higher than the rate of growth for all researchers shown in Figure 3.1[34].

Figure 3.3 *— PhD graduates for the UK and comparators, 2010-2014. The UK values are from the Higher Education Statistical Agency. Values for other comparator countries are from their respective agencies: China - Ministry of Education; France - Ministère de l'Enseignement supérieur et de la Recherche; Germany - Federal Statistical Office (Destatis); Italy - Agenzia Nazionale di Valutazione del Sistema Universitario e della Ricerca; Japan - Ministry of Education, Culture, Sports, Science and Technology; South Korea - Educational Development Institute, Ministry of Education; the US - National Science Foundation. UK ranking in G8 is amongst 7 (of 8) countries with available data, in EU28 is amongst 20 (of 28) countries with available data, and in OECD is amongst 35 (of 41) countries with available data. Source: OECD education and training data, and the sources listed above.*



	2010	2014	Change	CAGR	UK rank 2010	UK rank 2014
UK	18,755	21,240	2,485	3.2%	–	–
G8	139,524	150,182	10,658	1.9%	3	3
EU28	110,181	115,475	5,294	1.2%	3	3
OECD41	262,594	285,808	23,214	2.1%	4	4

32 Royal Society (2010) "The Scientific Century: securing our future prosperity";
Council for Science and Technology (2007) "Pathways to the future: the early career of researchers in the UK"

33 https://data.gov.uk/dataset/hesa-qualifications-in-uk-level-mode-of-study-domicile-gender-class-of-1st-degree-subject

34 The UK's growth of PhD graduates would have been even greater had the number of graduates not dropped to 21,240 in 2014 from 22,160 in 2013. However, it appears this drop is not indicative of a declining trend, as HESA reports the number of PhD graduates in 2015 to reassert itself at 22,780.

3.3.3 The UK researcher population is highly mobile

Figures 3.4 and 3.5 (pages 42-43), along with Table 3.1 (page 40), represent researcher mobility patterns as a snapshot of researcher headcount based on available data at author level between 1996 and 2015, which is aggregated into mobility classes at a country level *(see box "Measuring international researcher mobility" at beginning of chapter)*[35]. The same approach was used recently to compare patterns of European and US researcher mobility[36].

Figure 3.4 illustrates a high-level analysis of all active researchers and, new for this report, Figure 3.5 illustrates the high-level analysis of the international mobility of active UK researchers with less than 10 years since their first appearance as an author during the period 1996-2015 ("UK researchers with short publication history set"). In both Figure 3.4 and 3.5, the percentage of women among the researchers has been added to the data analysis. A more detailed analysis of the mobility classes (Outflow/Returnees Outflow; Transitory (mainly non-UK/mainly UK); and Inflow/Returnees Inflow) can be found in *Appendix F*.

3.3.3.1 UK researchers are highly mobile internationally, but women researchers are less mobile than men researchers

In the period 1996-2015, UK active researchers were highly mobile internationally, with over 72% of active researchers having published at least one article under a non-UK affiliation(s) *(see Figure 3.4)*[37]. The researchers classified as Non-migratory, who made up the remaining percentage, may well have travelled and collaborated internationally during this period, but their activities did not lead to peer-reviewed publication(s) in which they listed their address as being outside the UK. As well as being more senior, the relative productivity rate (articles published per year since first appearance as an author) of all active researchers averaged 1.0 over this period, which was about twice that of the non-migratory researchers; this may be explained by the former being more established in their publishing careers than their non-migratory counterparts. The origin and destination countries most associated with the mobile researchers moving in or out of the UK were the US, Germany, Australia, France, Canada and Italy. Worthy of particular note is the finding that women researchers were less likely to be mobile at any stage in their careers than men researchers.

3.3.3.2 Researchers leaving the UK (Outflow) are likely to be senior but associated with lower productivity and citation impact than those who come to the UK for short (Transitory) or long (Inflow) periods

Researchers in the Outflow group (i.e., those researchers who relocated from the UK to another country (or countries) for at least two years, or those who migrated into the UK for at least two years and who subsequently moved abroad for at least another two years) were amongst the most senior of all active researchers but their relative productivity rate was low, and their average field-weighted citation impact was higher than only that of the Non-migratory researchers. This group had the smallest percentage of women among researchers.

3.3.3.3 Nearly half of the UK active researcher population is transitory

The Transitory group (i.e., those researchers who either stayed in the UK for less than two years, or temporarily stayed outside it for a similar period, as indicated by the countries listed in their published articles) accounted for nearly half of all the active researchers. These researchers were, on average, the most productive, relatively higher in terms of seniority, and associated with high field-weighted citation impact. The majority of the transitory researchers were those who published mostly with non-UK affiliations, and the percentage of women who temporarily stayed outside the UK before returning to it was slightly higher than those who transited through the UK. The Transitory (mainly non-UK) researchers tended to be more productive and senior, and have a higher field-weighted citation impact, than their UK-based counterparts *(see Appendix F for more details.)*

35 It should be noted that the present analysis includes two additional years of publication data compared to the 2013 BIS analysis; active researchers included in the present analysis may or may not have been included in the previous analysis owing to the application of productivity filters; and the accuracy of Scopus author profiles has been substantially improved in the data used for the present analysis compared with the previous analysis. For the same reasons, it is also not meaningful to attempt to conduct trend analyses within these results by limiting to subsets of author profile data on shorter time windows. Finally, owing to the fact that researchers may publish across more than one research field, or move between fields over time, it is very difficult to create robust views of researcher mobility per subject field.

36 Science Europe & Elsevier (2013) Comparative Benchmarking of European and US Research Collaboration and Researcher Mobility. Available at https://www.elsevier.com/research-intelligence/research-initiatives/science-europe

37 Note that a non-UK affiliation is not equivalent to non-UK nationality. The Scopus data do not capture information on the nationality of authors. Other data sources cover this information. According to HESA data (https://www.hesa.ac.uk/data-and-analysis/staff), in 2014/15 academic staff in the UK were comprised of 139,195 UK nationals, 31,635 were nationals of other EU countries, and 9,040 were nationals of countries in Asia.

3.3.3.4 Researchers coming to the UK are productive, senior and have the highest citation rates among the mobility classes

Those researchers who made up the Inflow group (i.e., those who relocated from the UK for at least two years and subsequently returned to the UK for at least a further two years, and those who migrated to the UK from another country for at least two years without leaving) were among the most senior of all active researchers and had the second highest average productivity rate of the groups. The field-weighted citation impact for this group was the highest overall, indicating that, although there seems to be a net total outflow from the UK in terms of the quantity of researchers, the quality measured by the citation impact of the talent it attracts is high.

3.3.3.5 The UK researcher population is more mobile internationally than most comparator countries, but has the greatest net Outflow

The UK had the highest proportion of transitory researchers between 1996 and 2015 among the comparator countries *(see Table 3.1)*. A low proportion of UK researchers were Non-migratory, whereas the proportions in China, South Korea and Japan were significantly higher. Japan's high proportion of Non-migratory researchers supports the view that Japan runs an "intellectual closed shop", with low migration rates and high return rates from abroad[38].

The UK's total Net Outflow (the difference between the Outflow and the Inflow) was greater than any of the other comparator countries, Germany being the next highest; all the comparators experienced net losses with the exceptions of South Korea and China[39]. For the UK, the difference between the Outflow and Inflow was due mainly to the two groups of Returnees – there was a greater percentage of researchers who migrated into the UK from abroad for more than two years before relocating elsewhere for at least the same period, than those who relocated from the UK for more than two years before returning to the UK for a similar or longer time *(see Appendix F for more details)*.

Table 3.1 — *Summary of international mobility of researchers for the UK and comparator countries, 1996-2015. Source: Scopus.*

Comparator	Non-migratory	Transitory	Outflow	Inflow	Net Outflow (Outflow minus Inflow)
UK	27.8%	49.3%	13.3%	9.6%	3.8%
Canada	27.6%	48.5%	13.2%	10.7%	2.5%
China	78.3%	15.2%	2.6%	3.9%	-1.4%
France	35.3%	46.1%	9.8%	8.7%	1.1%
Germany	36.3%	43.5%	11.4%	8.7%	2.7%
Italy	50.8%	36.6%	6.8%	5.8%	0.9%
Japan	62.1%	27.3%	5.6%	5.0%	0.6%
South Korea	61.1%	25.7%	4.5%	8.7%	-4.3%
US	47.4%	35.5%	9.3%	7.8%	1.5%

38 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. 106–11;
Marceau, J. et al. (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.

39 Note: The apparent discrepancy between the UK's outflow discussed here and the overall growth of UK researchers seen in Figure 3.1 is to be expected due to the fact that these mobility figures are derived from the author profiles of active researchers over 20 years, rather than from a count of FTE researchers in a single year.

3.3.4 The UK *short publication history* researcher population is relatively less mobile

The UK's short publication history researchers tended to be relatively less mobile with only 56% being mobile internationally *(see Figure 3.5 on page 43)* between 1996 and 2015. A possible explanation for this could be that it takes time for this group to build up the research networks that give them opportunities to go abroad. The researchers classified as Non-migratory had the highest percentage of women among their peer group, and had a low relative productivity rate (articles published per year since first appearance as an author), due, no doubt in large part, to their being at an early stage in their publishing careers.

Of those short publication history researchers with international affiliations, the highest proportion (43%) was to be found in the Total Transitory group, and the second highest percentage of women researchers was also found here. The Total Inflow group was the most productive and associated with the highest field-weighted citation impact; indeed, the impact of publications from researchers with less than 10 years of publishing history was higher than the UK all-researcher set, an indication that the UK has a good stock of talented researchers.

The trend of a net outflow of researchers from the UK was also evident among the short publication history researchers, although the percentage was lower than the all-researcher group, at just under 2%.

3.3.5 The UK's four constituent countries each have a net outflow of researchers

Researchers in all four of the UK's constituent countries are highly mobile, with Wales having the lowest share of non-migratory researchers and the highest share in the transitory group *(see Table 3.2)*. Each country has a net outflow of researchers, with Northern Ireland and Wales having the highest rates.[40]

Table 3.2 — *Share of active researchers in mobility groups for UK constituents, 1996-2015. Source: Scopus.*

UK constituent	Non-migratory	Transitory	Outflow	Inflow	Net Outflow
Wales	11.3%	59.7%	17.1%	11.9%	5.2%
Scotland	13.1%	57.3%	17.3%	12.3%	5.0%
England	22.1%	51.8%	15.5%	10.7%	4.8%
Northern Ireland	16.3%	54.7%	17.1%	11.8%	5.3%

40 Compared to the UK, the constituent countries have a lower proportion of non-migratory researchers and higher proportions in the Outflow, Inflow and Net Outflow categories. This is because of migration of researchers across UK constituent countries. These movements are not counted in *Figures 3.4* and *3.5*.

Figure 3.4 *— International mobility of UK researchers, 1996-2015 ("UK all-researcher set"). This analysis is based on Scopus author data and a set of 334,437 active UK researchers.*

Relative Productivity, Relative length of service, and FWCI:

- < 0.50
- 0.50–0.75
- 0.75–1.25
- 1.25–1.75
- > 1.75

UK

334,437 ACTIVE RESEARCHERS

Of whom women: 30.7%

FWCI: 1.97

1996–2015

Inflow TOTAL

Researchers: 9.6%

Of whom women: 28.2%

Relative Productivity: 1.03

Relative length of service: 1.11

FWCI: 2.22

Transitory TOTAL

Researchers: 49.3%

Of whom women: 28.6%

Relative Productivity: 1.24

Relative length of service: 1.05

FWCI: 2.01

Outflow TOTAL

Researchers: 13.3%

Of whom women: 26.6%

Relative Productivity: 0.92

Relative length of service: 1.11

FWCI: 1.87

Non-migratory

Researchers: 27.8%

Of whom women: 37.2%

Relative Productivity: 0.49

Relative length of service: 0.82

FWCI: 1.67

MOBILITY CLASSES & INDICATORS

Mobility classes are defined as:

Migratory — researchers who stay abroad or in the UK for two years or more (Total Outflow and Total Inflow), further subdivided into those where the researcher remained abroad (Outflow and Inflow) or where they subsequently returned to their original country (Returnees Outflow and Returnees Inflow).

Transitory — researchers who stay abroad or in the UK for less than two years (Total Transitory), further subdivided into those who mostly published under a UK (Transitory (mainly UK)) or a non-UK (Transitory (mainly non-UK)) affiliation.

Non-migratory — researchers with only UK affiliations in Scopus during the period 1996–2015.

Indicators are defined as:

Relative Productivity — researchers who stay abroad or in the UK for two years or more (Total Outflow and Total Inflow), further subdivided into those where the researcher remained abroad (Outflow and Inflow) or where they subsequently returned to their original country (Returnees Outflow and Returnees Inflow).

Relative length of service — researchers who stay abroad or in the UK for less than two years (Total Transitory), further subdivided into those who mostly published under a UK (Transitory (mainly UK)) or a non-UK (Transitory (mainly non-UK)) affiliation.

Field-weighted citation impact (FWCI) — researchers with only UK affiliations in Scopus during the period 1996–2015.

All three indicators are calculated for each author's entire output in the period (i.e., not just those articles listing a UK address for that author). For further detail on the approach used, see box "*Measuring international researcher mobility*". Source: Scopus.

Figure 3.5 — *International mobility of UK short publication history researchers, 1996-2015. This analysis is based on an extracted corpus of the Scopus author data and a set of 98,808 active UK researchers with less than 10 years since the first appearance of each researcher as an author during the period 1996–2015.*

Relative Productivity, Relative length of service, and FWCI:

- *< 0.50*
- *0.50 – 0.75*
- *0.75 – 1.25*
- *1.25 – 1.75*
- *> 1.75*

UK

98,808 ACTIVE RESEARCHERS

Of whom women: 39.5%

FWCI: 2.27

1996 – 2015

Inflow TOTAL

Researchers: 5.8%

Of whom women: 37.2%

Relative Productivity: 1.27

Relative length of service: 1.24

FWCI: 2.58

Transitory TOTAL

Researchers: 42.8%

Of whom women: 38.3%

Relative Productivity: 1.25

Relative length of service: 1.02

FWCI: 2.46

Outflow TOTAL

Researchers: 7.7%

Of whom women: 31.8%

Relative Productivity: 1.02

Relative length of service: 1.26

FWCI: 2.13

Non-migratory

Researchers: 43.7%

Of whom women: 42.4%

Relative Productivity: 0.67

Relative length of service: 0.90

FWCI: 1.82

CHAPTER 4

Research Outputs

4.1 Highlights

UK ARTICLE SHARE

Article share	Decreased at	Ranks
6.3%	**-0.4%**	**3rd**
of the global total in 2014	per year in the period 2010-2014	amongst comparator countries in 2014

CITATION SHARE

Citation share	Decreased at	Ranks
10.7%	**-0.6%**	**3rd**
of the global total in 2014	per year in the period 2010-2014	amongst comparator countries in 2014

UK FIELD-WEIGHTED CITATION IMPACT

FWCI	Increased at	Ranks
1.57	**0.6%**	**1st**
in 2014	per year in the period 2010-2014	amongst comparator countries in 2014

UK HIGHLY-CITED ARTICLE SHARE

Share	Increased at	Ranks
15.2%	**0.4%**	**3rd**
of the global total in 2014	per year in the period 2010-2014	amongst comparator countries in 2014

The UK's global article and citation shares have been broadly maintained.

The UK's citation impact and its share of the most highly-cited articles are well above world averages, but the growth rates of both have slowed.

The quantity and excellence of the UK's research outputs keep it at the top of many of the rankings.

However, the UK's position may not be sustainable in the long term: the UK's limited levels of comparative growth in some areas may allow others to overtake it. China overtook the UK in global shares of highly-cited articles in 2013.

4.2 Introduction

The formal and systematic dissemination of original and innovative research leads to the furtherance of knowledge. Scholarly communication in the form of research outputs has long been a key academic measure of assessment and evaluation, and can be defined in many ways, including articles in journals, books and monographs, as well as non-textual media such as music and art. In this report, the focus is on the publication of research findings in journals, as the analysis of journal articles can provide useful insight into the comparative performance of a country's research base - though journal article and citation-based indicators capture the research performance better in some fields than in others. This chapter examines article quantity, article share, citation quantity, citation share, author leadership, and readership impact (the latter two are new in this report).

As discussed in Chapter 1, the global research landscape is constantly changing and this is especially noticeable when looking at research outputs, which are examined at a granular level in this chapter. The significant increase in output by emerging research nations such as China and India means that, based on current levels of performance, more established research countries such as the UK, the US, Germany and France will see their shares shrink as these others grow.

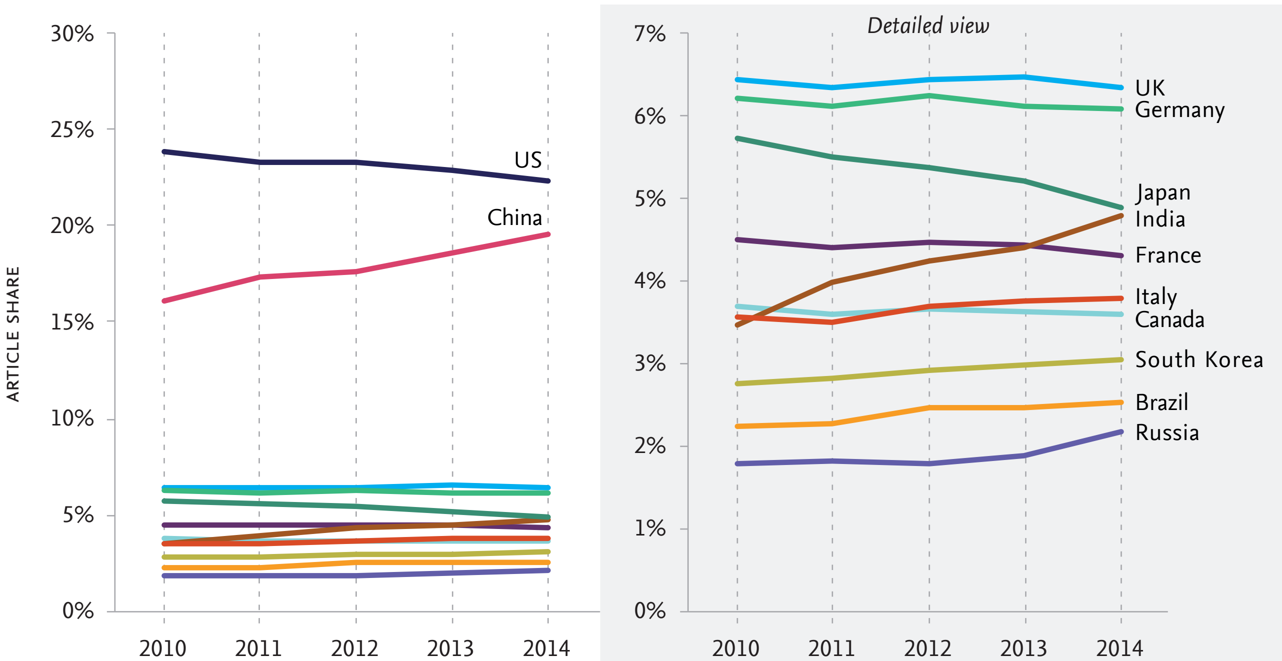
4.3 Key Findings

4.3.1 The UK maintained its worldwide ranking in the share of publications, despite the significant growth in research output of some comparator countries

UK researchers produced 745,274 publications between 2010 and 2014 as captured in Scopus, increasing their annual research output from 138,704 articles in 2010 to 154,653 in 2014. This yearly growth of less than 3% is slightly lower than the world average of 3.1% but greater than other research-intensive countries such as the US, France and Canada. The high annual growth in the number of publications of some emerging countries, for example India with nearly 12%, and China and Russia at around 8%, meant that the UK and other research-intensive nations saw a reduction in their proportional shares *(see Figure 4.1)*. The two largest countries by article shares, the US and China, continued to converge, and India's significant growth saw it overtake France in 2013. Japan continued to see a sharp year on year reduction in its share of publications, so much so that it is likely to be overtaken by India in 2015. While the UK retained its ranking of third globally, as well as its share rankings within the G8, EU28 and OECD41 groups, the indications are that, despite maintaining an increasing level of output, the UK is unlikely to sustain its current rankings as some of these comparator countries continue to gain greater shares.

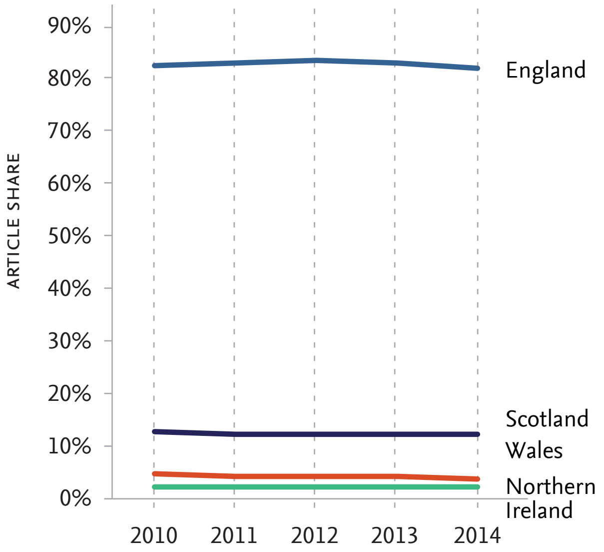
The UK's four constituent countries broadly maintained their relative shares over the reporting period, with some slight variations *(see Figure 4.2)*.

Figure 4.1 *— Share of world articles for the UK and comparators, 2010-2014 with right-hand panel excluding the US and China for clarity. Source: Scopus.*



	2010	2014	Change	CAGR	UK rank 2010	UK rank 2014
UK	6.4%	6.3%	-0.1p.p.	-0.4%	–	–
G8	49.8%	47.1%	-2.7p.p.	-1.4%	2	2
EU28	31.0%	30.6%	-0.4p.p.	-0.3%	1	1
OECD41	84.3%	84.5%	0.2p.p.	0.0%	2	2
World	100%	100%	–	–	3	3

Figure 4.2 — *Share of UK articles for constituent countries, 2010-2014. Shares may not add to 100% owing to co-authorship of some articles between constituent countries and not all UK articles containing sufficient publishing information to map to the constituents. Source: Scopus.*



ACTIVITY INDEX

The Activity Index[41] is defined as a country's share of its total article output across subject field(s) relative to the global share of articles in the same subject field(s). For example, in 2014 the UK published 41% of its articles in the Clinical Sciences, while globally this subject field represented 34% of all articles published. Thus the Activity Index for the UK in Clinical Sciences in 2014 was 41% / 34% = 1.2. A value of 1 therefore indicates that a country's research activity in a field corresponds exactly with the global activity in that field; higher than 1 implies a greater emphasis, while lower than 1 suggests a lesser focus.

4.3.2 The UK is a well-rounded research nation

The UK continues to be a well-rounded research nation *(see Figure 4.3 and box "Activity Index")*, with most subjects being above or close to the global Activity Index baseline. The Activity Index is a means of showing the relative focus on different subjects within a country. If a country has higher focus on some subjects, then relatively they must have lower focus on others. For the UK, Engineering, Physical Sciences and Mathematics are below the global baseline. Physical Sciences and Mathematics held closely to 2012 levels, but Engineering fell below its 2006 activity level, reflecting increased shares in these subjects for other nations rather than any reduction in focus in the UK. Business remained steady at 30-40% above the global Activity Index, while the continued focus on Social Sciences positioned it at 50% above the world average. There was a modest increase in Health & Medical Sciences, but correspondingly modest decreases in Clinical and Biological Sciences. Expenditure on R&D by field *(see Chapter 2)* is generally linked to the level of the activity index. The UK spent one third of its GERD on Social Sciences and on Humanities in 2012 and both demonstrated high activity levels.

Across the comparators, research-intensive countries tended to show a well-rounded Activity Index, with the US and Canada having profiles similar to that of the UK, while the emerging, fast-growing countries were still very focused on particular subjects; for example, China's increasing scientific output[42] saw high activity levels in Physical Sciences and Engineering. China and India were remarkably alike. Both demonstrated low emphasis on Humanities and Social Sciences, and high or increasing focus on Engineering and Physical Sciences. India also moved away from Environmental Sciences towards Engineering, whilst China's focus shifted from Business to Biological Sciences and Environmental Sciences. Russia reduced its emphasis on Physical Sciences and Mathematics and showed dramatic shifts closer to the world average in Business and Social Sciences. South Korea declined in Mathematics and Engineering between 2006 and 2014, but showed a more modest increase in Health & Medical Sciences and Environmental Sciences.

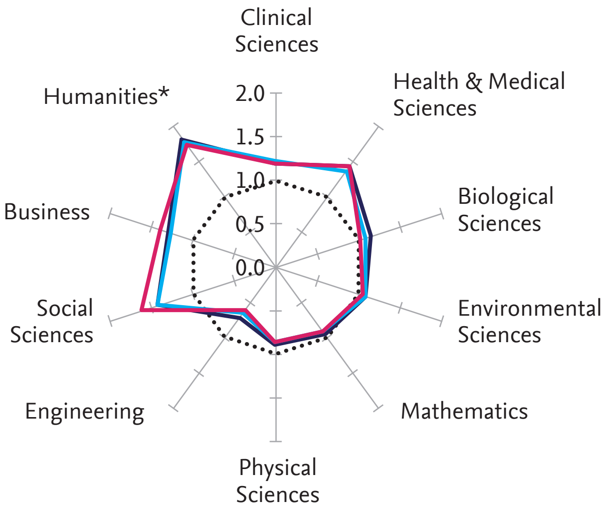
Figure 4.3 (see next pages) — *Activity Index for the UK and comparators (along with Brazil, India, Russia and South Korea) across ten research fields in 2006, 2010 and 2014. For all research fields, an Activity Index of 1.0 equals world average share in that particular research field. For Humanities(*), the baseline is defined with respect to OECD41 countries rather than to the world. Note that the axis maximum has been increased for Brazil (to 3.0). Source: Scopus.*

41 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.
42 http://www.nature.com/nature/journal/v528/n7582_supp_ni/full/528S170a.html

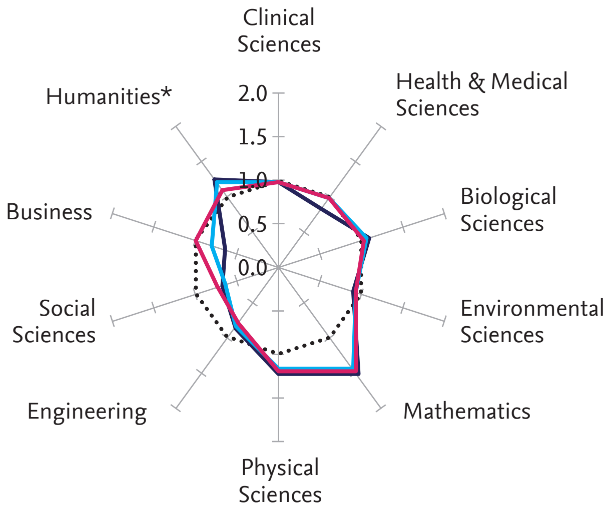
Figure 4.3 *(see caption on previous page)*

■ *2006* ■ *2010* ■ *2014* ■ *World average (= 1.0)*

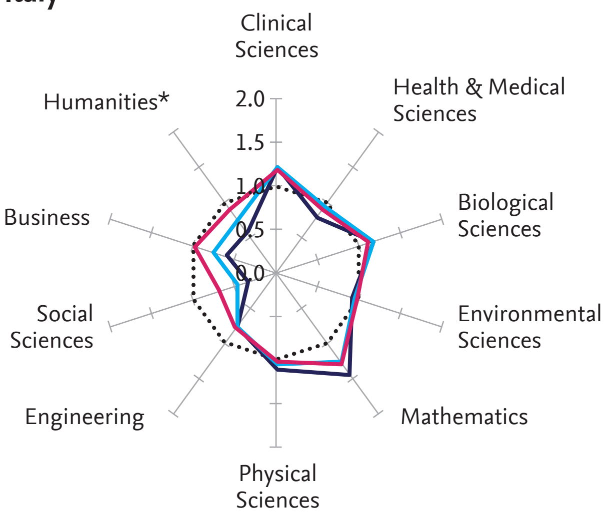
UK



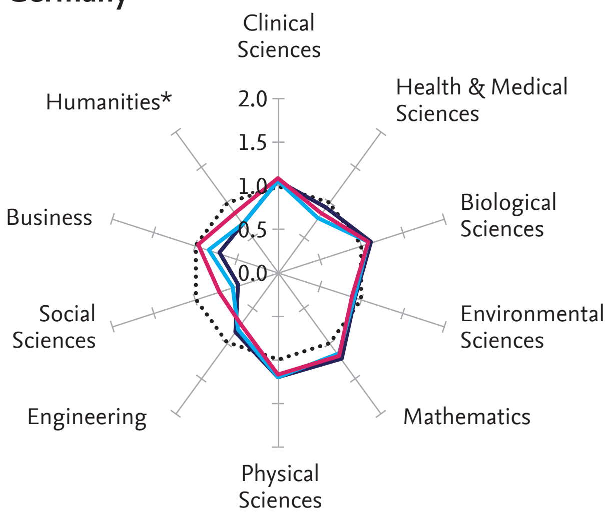
France



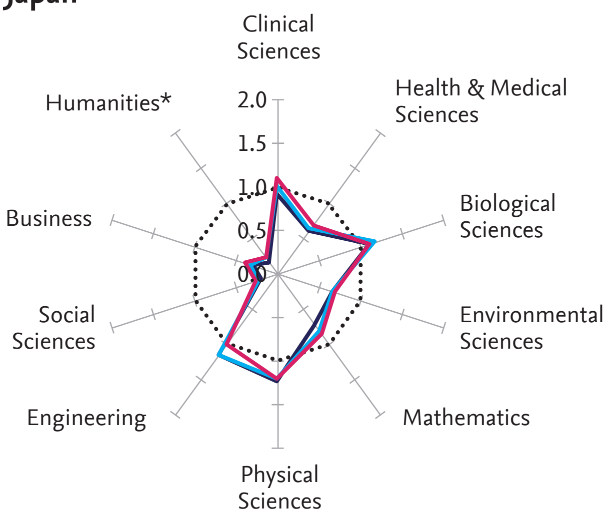
Italy



Germany



Japan



US

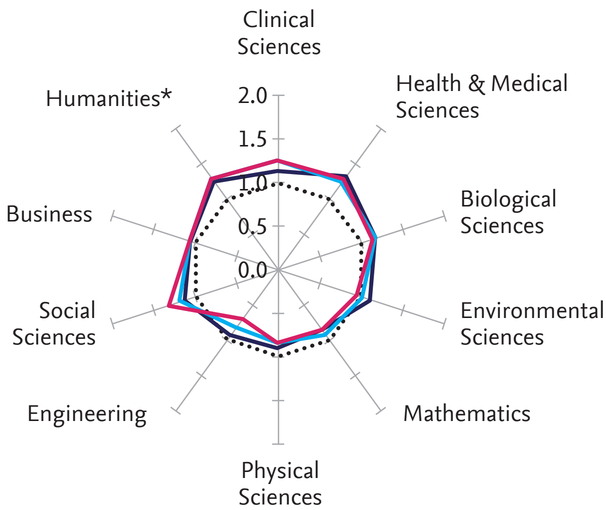
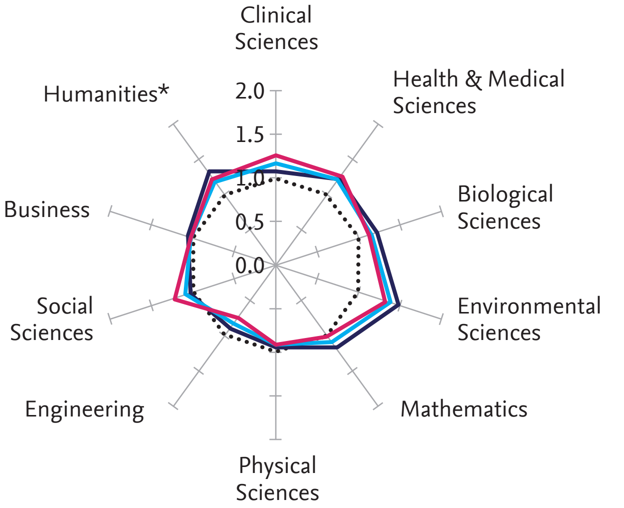


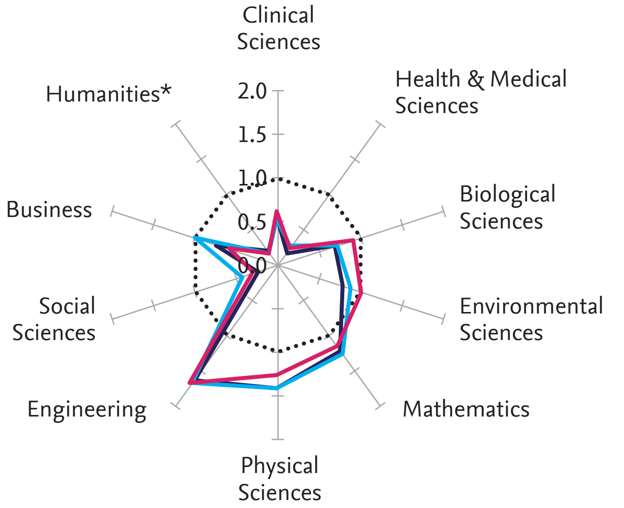
Figure 4.3 *(continued)*

■ *2006* ■ *2010* ■ *2014* ■ *World average (= 1.0)*

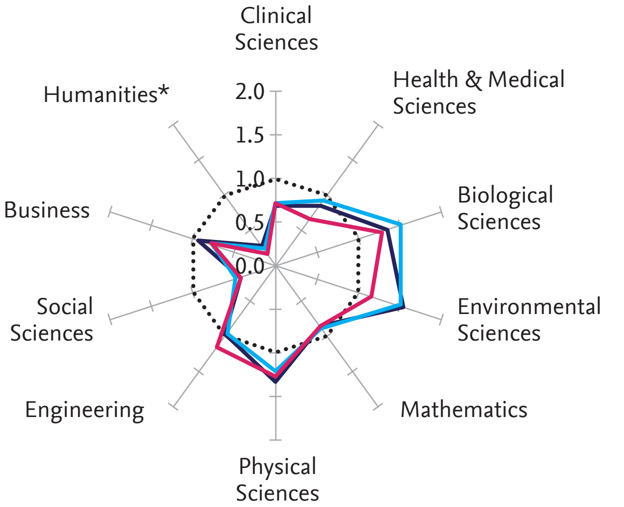
Canada



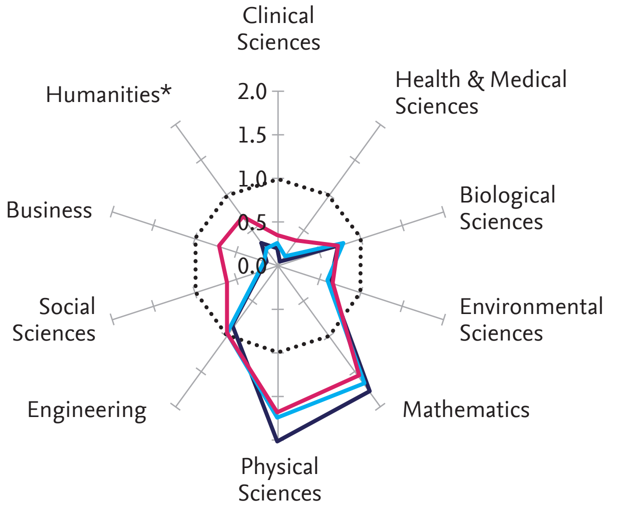
China



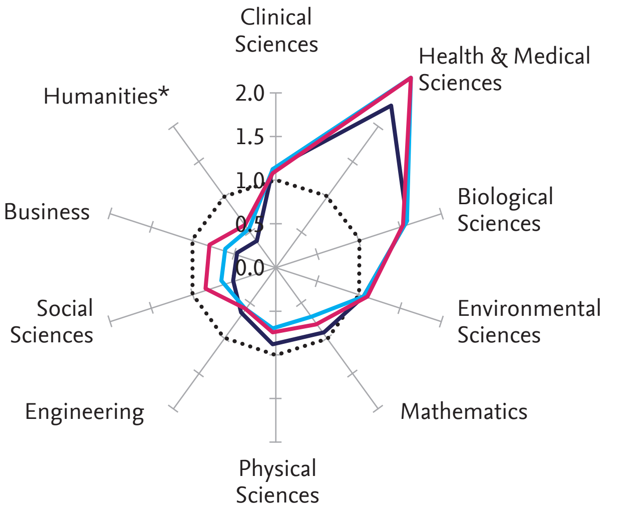
India



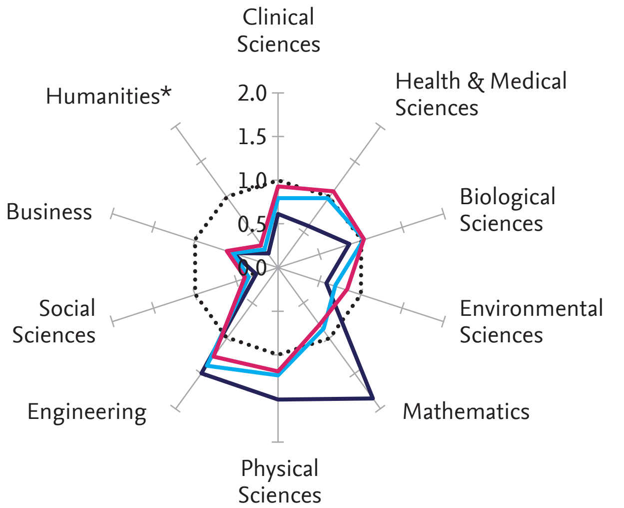
Russia



Brazil



South Korea

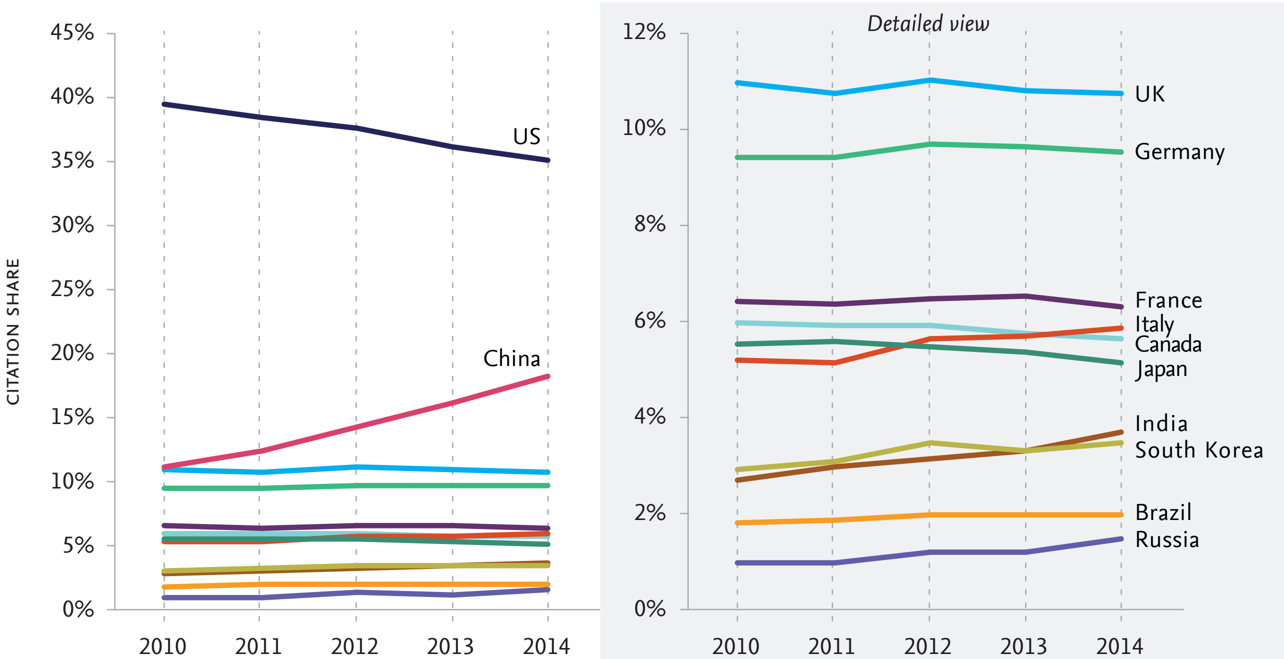


4.3.3 The UK's share of citations remains third highest globally, despite it being almost static

The number of citations received by an article from subsequently-published articles is an indicator of the quality or importance of the cited research[43]. UK articles continued to be cited frequently in the global research literature. It maintained its third place in the world share, with the UK's share fluctuating within a one percentage point band over the reporting period, ending in 2014 below 11% *(see Figure 4.4)*. The US preserved its hold on the highest share of citations, at 35%, despite its continued share decline, while China's share continued to grow sharply at an impressive annual rate of 13%. Due to the increasing shares of emerging and some smaller countries, the G8, as a whole, showed an overall decline in citation shares between 2010 and 2014, as did the EU28.

The UK's global performance was mirrored across its four constituent nations, with each country's shares fluctuating within a one percentage point band over the period 2010-14 *(see Figure 4.5)*. England and Scotland showed higher percentage shares of citations compared to shares of articles.

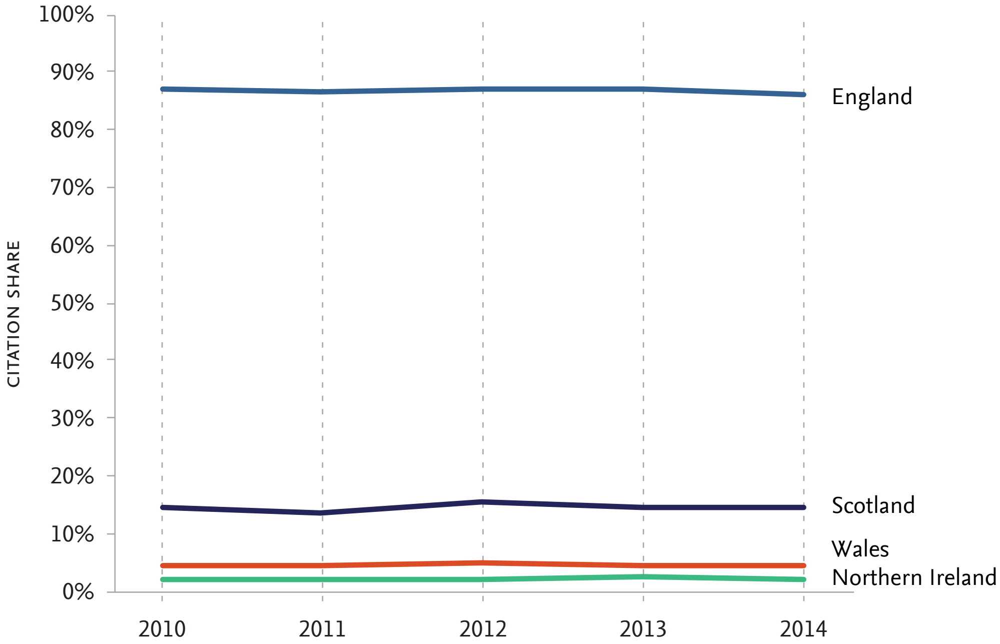
Figure 4.4 — *Share of world citations for the UK and comparators, 2010-2014 with right-hand panel excluding the US and China for clarity. Source: Scopus.*



	2010	2014	Change	UK rank 2010	UK rank 2014
UK	11.0%	10.7%	-0.3p.p.	–	–
G8	67.4%	61.5%	-5.8p.p.	2	2
EU28	39.2%	38.5%	-0.7p.p.	1	1
OECD41	93.5%	92.9%	-0.6p.p.	2	2
World	100%	100%	–	3	3

43 Davis, P.M. (2009) "Reward or persuasion? The battle to define the meaning of a citation" *Learned Publishing* 22 (1) pp. 5-11.

Figure 4.5 — *Share of UK citations by constituent country 2010-2014. Shares do not add up to 100% owing to co-authorship of some articles between constituent countries and not all UK articles containing sufficient publishing information to map to the constituents. Source: Scopus.*



4.3.4 The citation impact of UK articles continues to be high and rising and is first among the G8

Field-weighted citation impact is a bibliometric indicator that can be used to provide a meaningful analysis of research performance across countries of different sizes. It overcomes the challenges in data analysis created by the accumulation of citations over time and fields of study that use different citation practices *(see box "Measuring impact: Citation windows and field-weighting")*.

The UK has a high field-weighted citation impact. At 1.57 in 2014, it was well above the world average of 1.0 and ahead of all the comparator countries, allowing it to retain its top place in the G8. However, its year on year growth rate slowed, dropping from over 1% for the period 2008-12 to 0.6% in the period 2010-14 *(see Figure 4.6)*. The drops in the UK's rankings in the EU28 and OECD41 groups, as well as globally, again reflect the improved performance of other nations in this indicator. Italy, China and Russia each experienced considerable growth in this indicator over the period, with Italy rising to second place behind the UK in 2012 and, based on current trajectories, set to overtake the UK in the near future.

A look at the UK's field-weighted citation impact in the four constituent countries shows increasing values for all constituents except Scotland, which showed a decline after peaking in 2012 *(see Figure 4.7)*. The field-weighted citation impact for all the nations was consistently higher than the UK overall from 2012. This is due to two reasons, the first being that collaborations between constituent nations are of particularly high impact, and secondly, these high impact collaborations are included when calculating the international collaboration FWCI for the constituent nations. However, these collaborations are not included in the UK's international collaboration publication corpus as collaborations between constituent nations are not considered international collaborations, but rather national collaborations.

A recalculation of the UK's FWCI allowing an article to be counted for each of the constituent countries that contributed to it allows for a more direct comparison of the UK to its constituent countries. Even with multiple counting of articles, Scotland, Wales and Northern Ireland all outperformed the UK's FWCI, with England's performance consistently being lower. Northern Ireland's field-weighted citation impact increased the most between 2010 and 2014, ending the reporting period just below that of Wales.

MEASURING IMPACT: CITATION WINDOWS AND FIELD-WEIGHTING

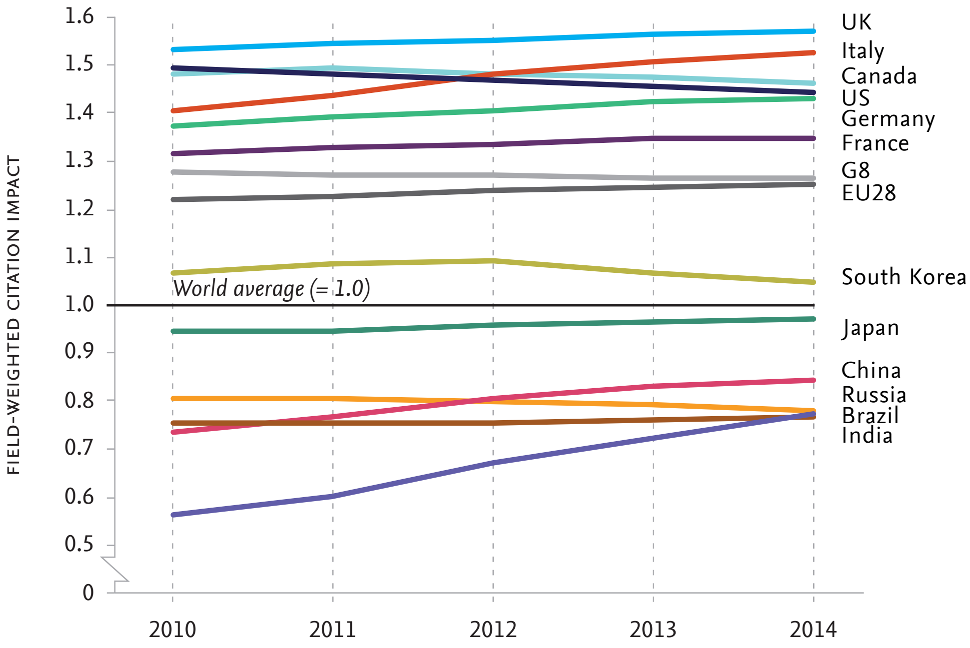
Citations accrue to published articles over time, as articles are first read and subsequently cited by other authors in their own published articles. Citation practices, such as the number, type and age of articles cited in the reference list, may differ by research field. As such, in comparative assessments of research outputs, citations must be counted over consistent time windows, and publication and field-specific differences in citation frequencies must be accounted for.

Field-weighted citation impact is an indicator of mean citation impact, and compares the actual number of citations received by an article with the expected number of citations for articles of the same document type (article, review or conference proceeding), publication year and subject field. Where the article is classified in two or more subject fields, the average (or harmonic mean) of the actual and expected citation rates is used. The indicator is therefore always defined with reference to a global baseline of 1.0 and intrinsically accounts for differences in citation accrual over time, differences in citation rates for different document types (reviews typically attract more citations than research articles, for example), as well as subject-specific differences in citation frequencies. It is one of the most sophisticated indicators in the modern bibliometric toolkit.

When field-weighted citation impact is used at a point of time (for example, in *Figure 4.13*), an unweighted variable window is applied. The field-weighted citation impact value for 2005, for example, is composed of articles published in 2005 and their field-weighted citation impact in the period 2005-09, while for 2014 it is composed of articles published in 2014 and their field-weighted citation impact in the period 2014-2015.

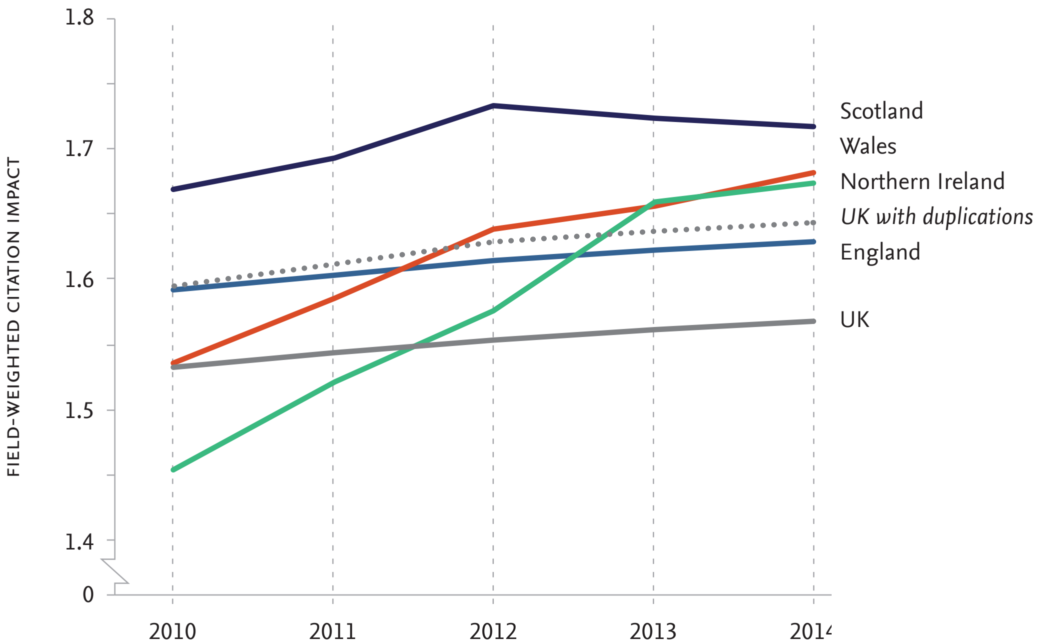
When field-weighted citation impact is used in trend analysis (for example, in *Figure 4.6*), a weighted moving window is applied. The field-weighted citation impact value for 2010, for example, is composed of the weighted average of the unweighted variable field-weighted citation impact values for 2008 and 2012 (weighted 13.3% each), 2009 and 2011 (weighted 20% each) and for 2010 (weighted 33.3%). The weighting applies in the same ratios for previous years also. However, for 2014 it is not possible to extend the weighted average by two years on either side, so weightings are re-adjusted across the remaining available values.

Figure 4.6 — Field-weighted citation impact for the UK and comparators, 2010-2014. UK ranking in the world is amongst 92 countries with at least 1,000 articles in 2014. Source: Scopus.



	2010	2014	Change	CAGR	UK rank 2010	UK rank 2014
UK	1.53	1.57	0.04	0.6%	–	–
G8	1.28	1.26	-0.01	-0.2%	1	1
EU28	1.22	1.25	0.04	0.8%	6	8
OECD41	1.09	1.09	0.00	-0.1%	9	11
World	1.00	1.00	–	–	10	13

Figure 4.7 — UK field-weighted citation impact, 2010-2014, per constituent country, with each contributor to inter-constituent co-authored articles receiving credit for those articles. The solid red line denotes the UK's FWCI over the period and is calculated by counting each publication once. The dashed grey line denotes the UK's FWCI over the period, but is based on multiple counting of articles, once for each of the constituent countries that contributed to it. Source: Scopus.



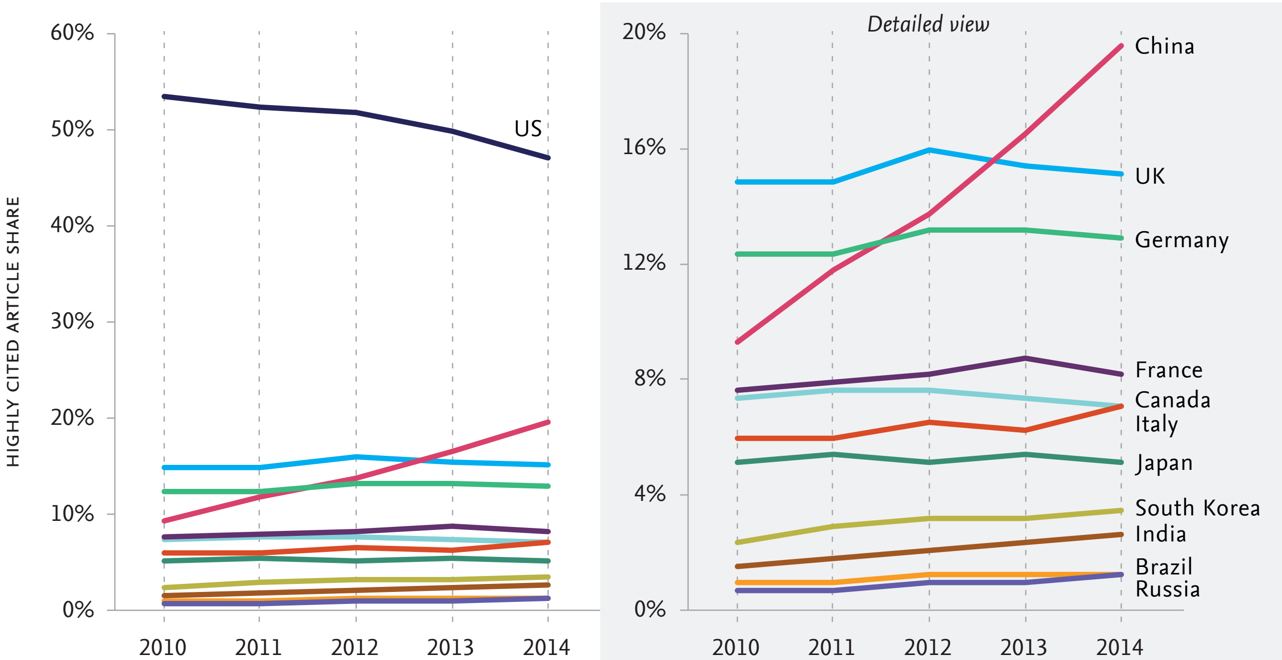
4.3.5 The UK's share of the most highly-cited articles is higher than would be expected from its overall article share, but its previously healthy growth has slowed and lags behind comparators in emerging nations

By its very nature, citation distribution across articles is strongly skewed: a small proportion of all published articles receive the majority of the citations, a larger proportion receive some citations, and a significant proportion of all articles never receive a single citation. One approach to research assessment is an examination of the small proportion of the most highly-cited articles. Research has suggested that this method may yield insights not possible from looking at aggregate measures that include the entirety of research outputs.[44] This principle has been applied here to look at each country's share of the articles comprising the top 1% of the most highly-cited articles.

Over the studied period, the UK saw a small increase in its share of the most highly-cited articles in the world *(see Figure 4.8)*, peaking at 16% in 2012, before falling back to just over 15% in 2014. Its 0.4% per year growth rate was higher than that of the EU28, which showed no growth at all, but was significantly lower than the UK had experienced between 2008 and 2012 (+1.5%). Nevertheless, the UK's share of highly-cited articles is still significantly greater than would be expected based on its overall article share; this suggests a focus on research excellence in the UK, although its share of highly-cited publications is decreasing. Of the comparator countries, the US showed the greatest decline, -3.1% CAGR, while the most significant gains were shown by China and Russia with 20% and 14%, respectively.

The UK had a static global share of articles over the reporting period, but experienced a slight increase in its share of highly-cited articles *(see Figure 4.9)*. When we contrast the UK's

Figure 4.8 — *Share of the world's highly-cited articles (top 1% of the most cited articles) for the UK and comparator countries, 2010-14 with right-hand panel excluding the US for clarity. The share for 2010 is composed of citations in the period 2010-14 attributed to articles that were published in 2010, while for 2014 it is composed of citations in the period 2014-2015 attributed to articles published in 2014. Source: Scopus*



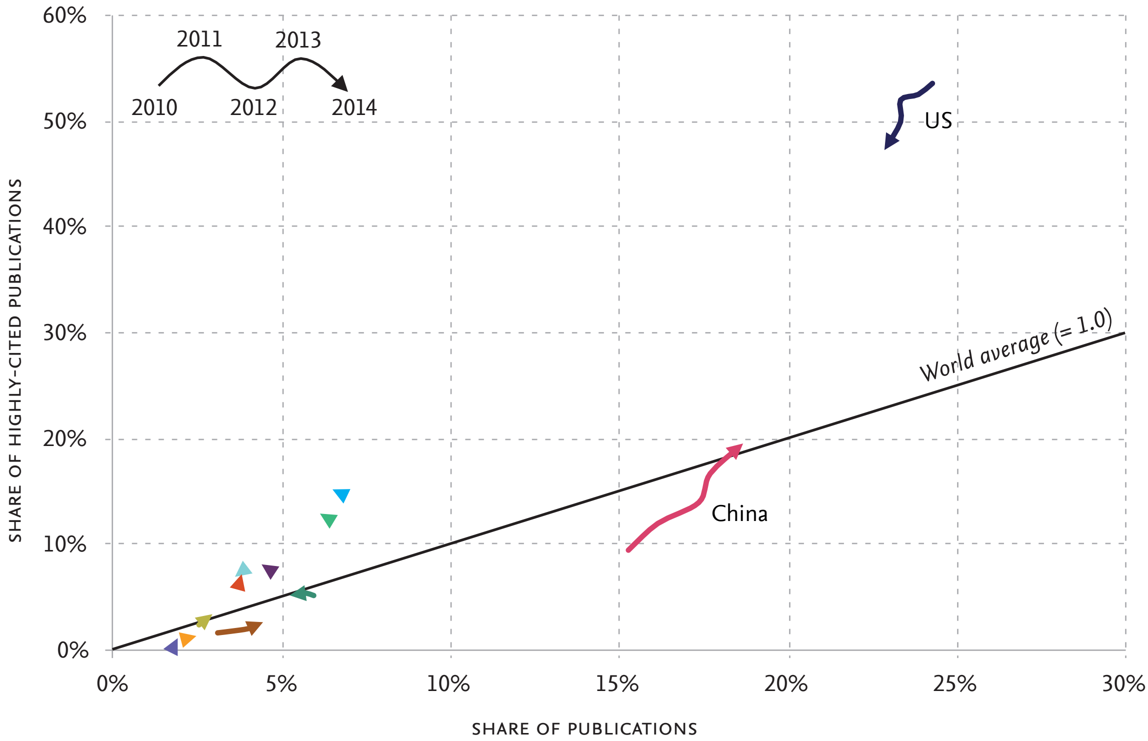
	2010	2014	Change	UK rank 2010	UK rank 2014
UK	14.9%	15.2%	0.3p.p.	–	–
G8	78.7%	71.2%	-7.5p.p.	2	2
EU28	41.7%	41.7%	0.0p.p.	1	1
OECD41	96.5%	96.6%	0.2p.p.	2	3
World	100%	100%	–	2	3

44 Bornmann, L., et al. (2011) "Mapping excellence in the geography of science: An approach based on Scopus data" *Journal of Informetrics* 5 (4) pp. 537-546; Bornmann, L. & Marx, W. (2013) "How good is research really? Measuring the citation impact of publications with percentiles increases correct assessments and fair comparisons" *EMBO Reports* 14 (3) pp. 226-230

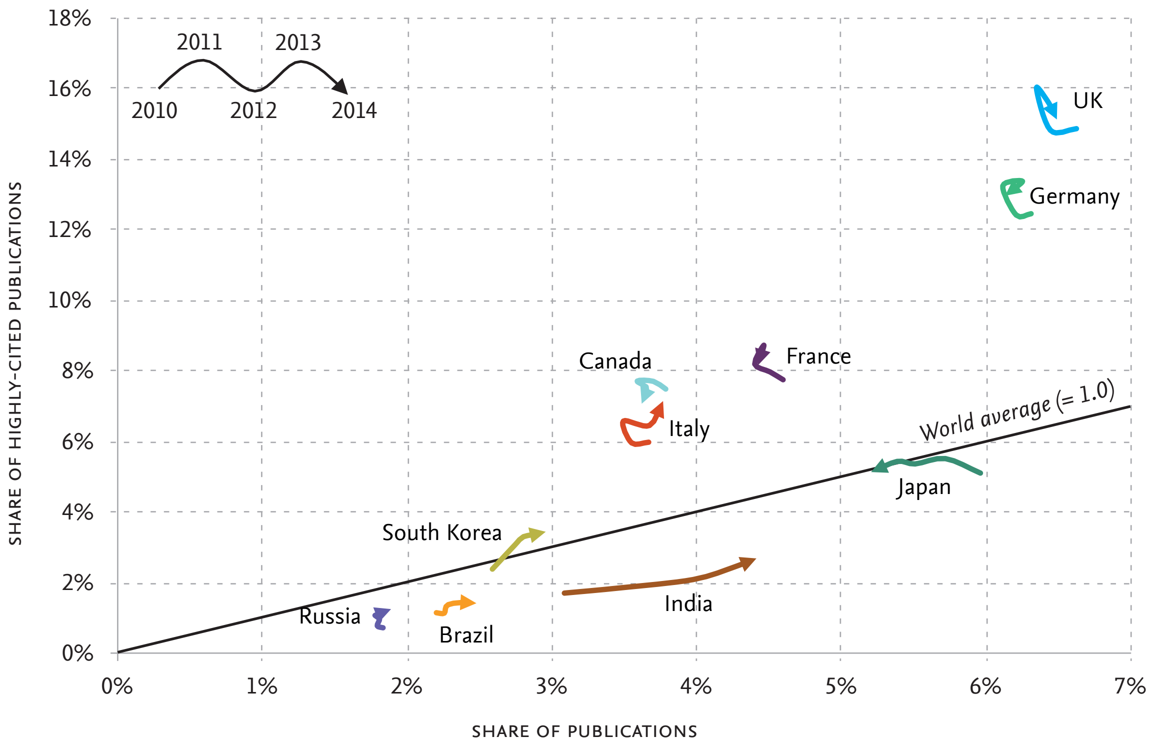
overall share of articles (6.3% in 2014) and its share of highly-cited articles (15.2%), it is evident the UK displays leadership in research excellence. Panel A demonstrates the US' high but decreasing share of global publications, as well as its declining share of highly-cited articles, while China saw most gains in both indicators. Where many of the comparator countries were fairly static in their respective shares, India's global share of articles increased at a faster rate than its share of highly-cited articles. Japan's share of highly-cited articles remained static. With its global article share decreasing over the period, this static highly-cited article share implies that Japan increased the proportion of its articles that were highly cited.

Figure 4.9 — *Share of the world's highly-cited articles (top 1% of the most cited articles) versus share of world articles for the UK and comparator countries, 2010-2014 with Panel B excluding the US and China for clarity. A country for which the share of global articles and the share of highly-cited articles were equal would be placed on the line of parity. Source: Scopus.*

Panel A

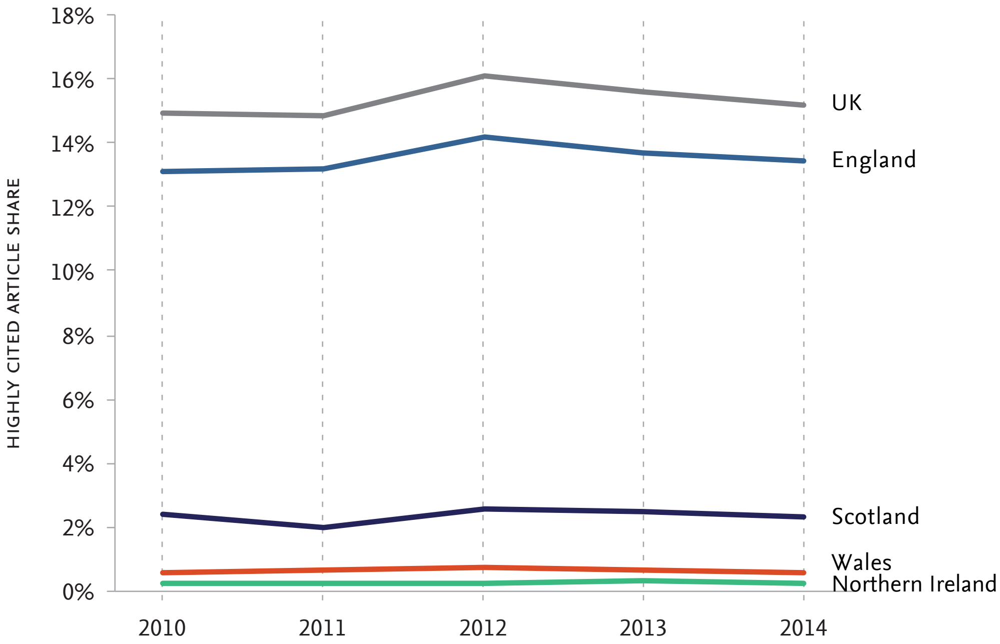


Panel B



Within the UK's constituent nations, only England's share of highly-cited articles rose in line with the UK overall *(see Figure 4.10)*. Wales and Northern Ireland's world shares remained static, while Scotland ended the period with a slightly lower share than it had in 2010.

Figure 4.10 — *Share of the world's highly-cited articles (top 1% of the most cited articles) for the UK and constituent countries, 2010-2014. The UK's share is smaller than the summation of the shares of the four constituent countries due to de-duplication of publications authored by researchers from more than one constituent country. Source: Scopus.*



4.3.6 The UK's field-weighted citation impact has dropped in the Humanities, Business, and Social Sciences, but increased in the Clinical, Health & Medical, Biological and Environmental Sciences

Not only is the UK active across all main research fields as was shown in Figure 4.3, but the field-weighted citation impact of the UK's articles in all of these fields is high and, in most of them, continues to rise *(see Figure 4.11)*.

In 2014, the UK's field-weighted citation impact was greater than the world average of 1.0 in all research fields, and increased from the 2010 value in all fields except Mathematics, Social Sciences, and Health & Medical Sciences. The greatest increases over the period were in Business, Environmental Sciences, and Biological Sciences, while the smallest was in Physical Sciences. The UK's field-weighted citation impact was especially high in fields where it had a lower Activity Index, particularly Engineering.

Italy, Germany, the US and Canada were the comparator countries that showed a field-weighted citation impact above 1.0 in all research fields in 2014; India and Brazil were the only countries almost consistently showing less than 1.0. Russian Humanities publications had a very high impact, almost quadrupling between 2010 and 2014, and Russia showed large gains also in Engineering, Business, and Social Sciences. The likely cause of Japan's high FWCI in Humanities in 2006 was its small number (293) of publications in this field (a few highly-cited articles among a small number of publications will increase the average significantly).

Figure 4.11 *(see next pages) — Field-weighted citation impact for the UK and comparators across ten research fields in 2006, 2010 and 2014. For all research fields, a field-weighted citation impact of 1.0 represents world average in that particular research field. Note that axis maximums have been decreased for China, India and Brazil (to 1.5) and increased for Russia (to 2.5). Source: Scopus.*

Figure 4.11 (see caption on previous page)

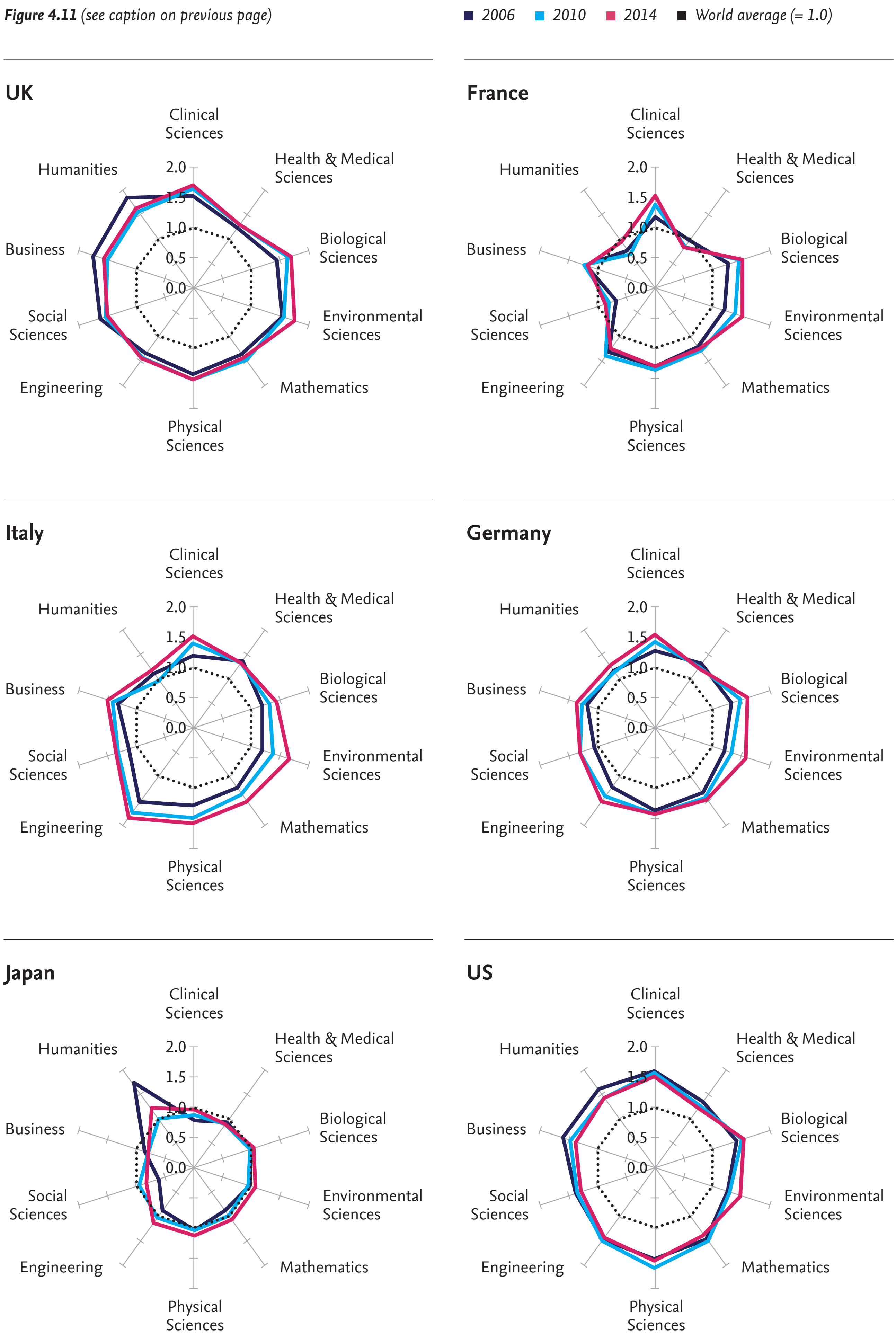
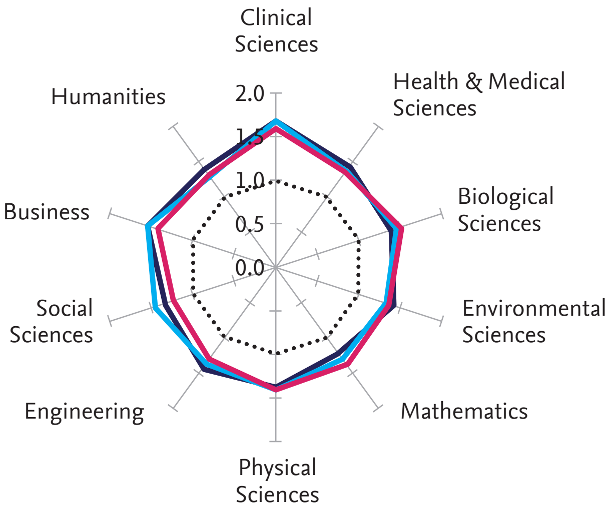


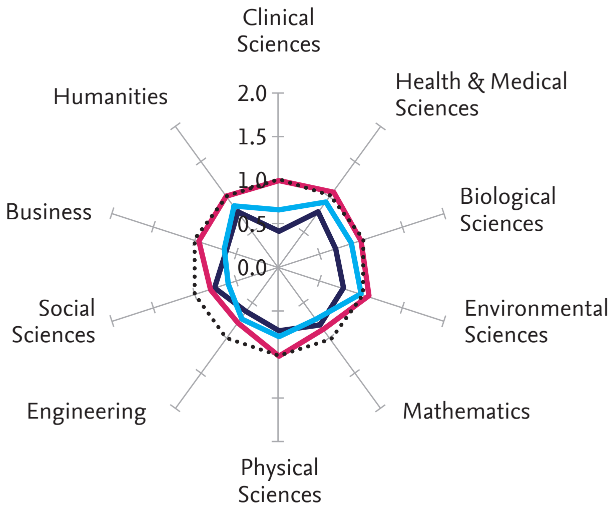
Figure 4.11 *(continued)*

2006 *2010* *2014* *World average (= 1.0)*

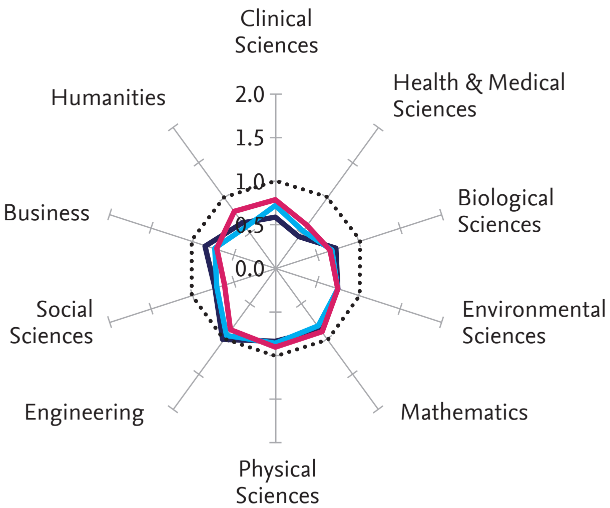
Canada



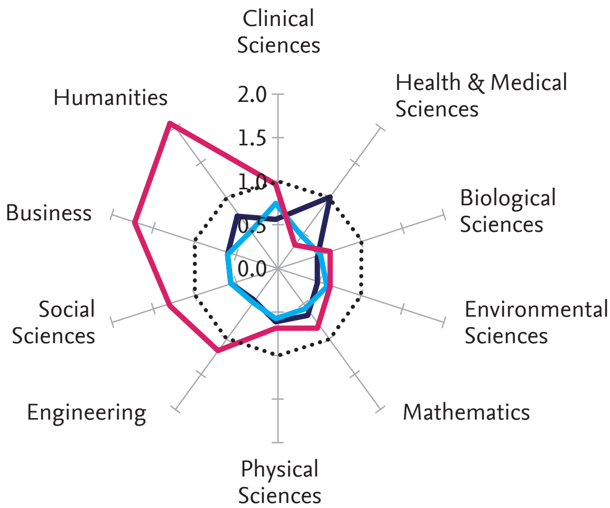
China



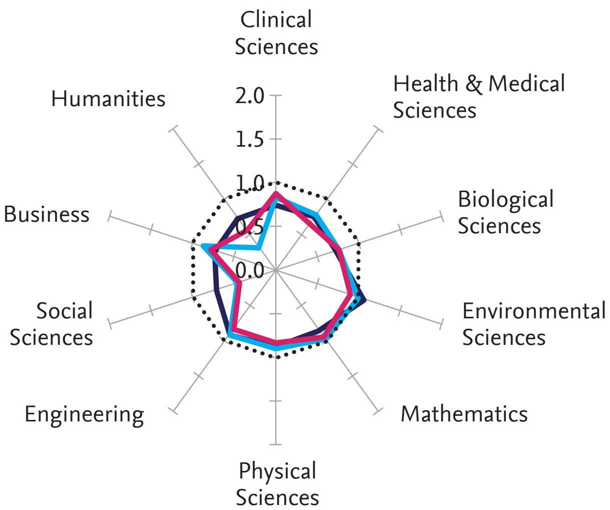
India



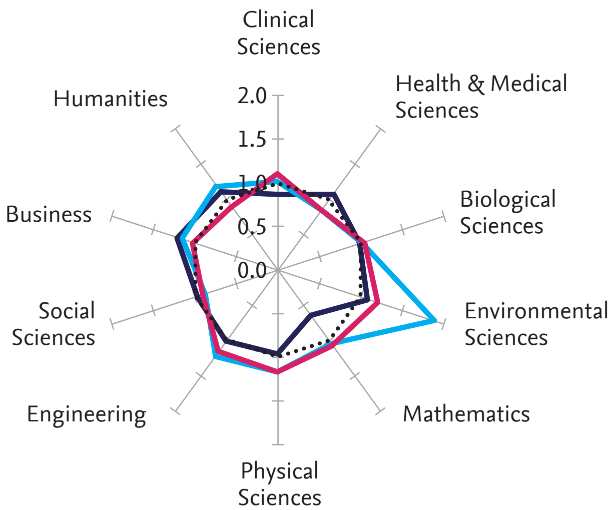
Russia



Brazil



South Korea



4.3.7 UK regions show diverse strengths in different research fields

Figure 4.12 summarises the number of publications, field-weighted citation impact, and share of UK publications by research fields for the UK and for each of its 12 regions. The angle of the pie slices denotes the number of publications (the wider the angle, the higher the number), the colour denotes the field-weighted citation impact (the darker the colour, the higher the FWCI), and the length of the pie slice denotes the share of UK publications in the research field (the longer the length, the greater the contribution to the UK output), which demonstrates the relative focus of a region in that research field. Taking South West England's chart as an example: the angle of the pie slices for Physical Sciences and Clinical Sciences are wider than the other fields, thus indicating that these two fields had the highest numbers of publications in 2014; the darkest slice, and therefore the field with the highest FWCI, is Environmental Sciences (at 2.21); Environmental Sciences also has the longest pie slice, meaning that it had the highest share of UK publications among all the fields in the region.

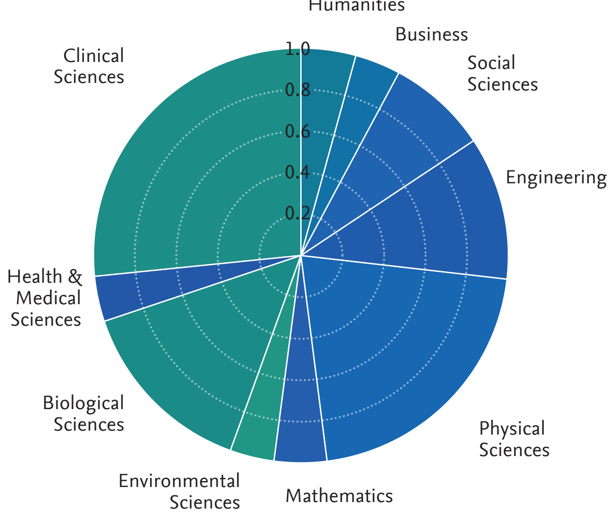
The research outputs of the UK's 12 regions vary in quantity and impact, although, since the UK had the largest number of publications in Clinical Sciences and Physical Sciences in 2014, it is to be expected that, in absolute terms, most of the UK regions would have the largest numbers of publications in these two research fields. Greater London and South East England had the highest shares of the total of all UK publications in most research fields. East England (which includes Cambridgeshire) had the highest FWCI in a number of research fields, but especially in Clinical Sciences, Biological Sciences, and Environmental Sciences. Regions showed diverse strengths in different research fields: North East England and South East England were strong in Physical Sciences, with relatively large numbers of publications compared to other research fields, along with high FWCI; North West England, and Yorkshire and the Humber were strong in Clinical Sciences with relatively large numbers of publications compared to other research fields, along with high FWCI; East England showed clear strength in Biological Sciences, and Greater London in Clinical Sciences; South West England, Scotland, and Wales each had a relatively high share of publications in Environmental Sciences along with high FWCI.

Figure 4.12 (continues next pages) — Publications, field-weighted citation impact and UK publication share per UK region, 2014.

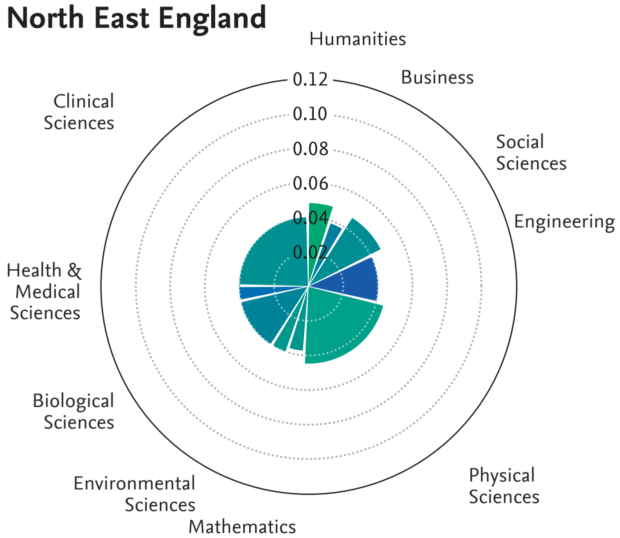
The angle of the pie slices denotes the number of publications (the wider the angle, the higher the number), the colour denotes field-weighted citation impact (the greener the colour, the higher the FWCI), and the radius denotes UK publication share for the region (the longer the radius, the larger the share). Note that axis maximums have been increased for South West England and East England (to 0.2), and for South East England and Greater London (to 0.4). Source: Scopus.

FWCI: 1.00 — 2.50

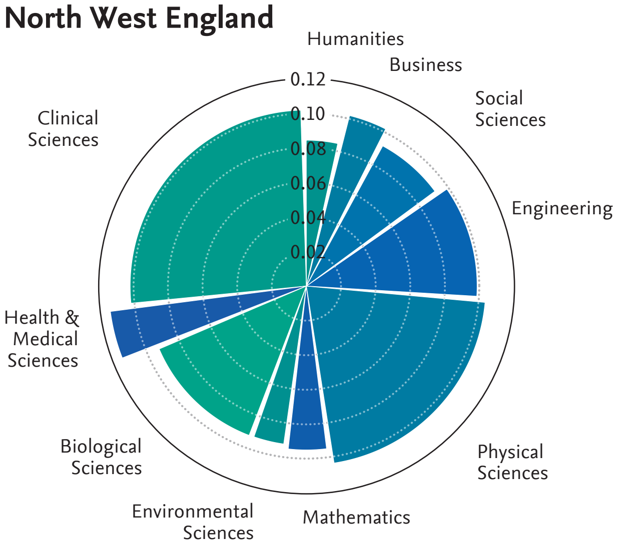
UK



North East England



North West England



Yorkshire & The Humber

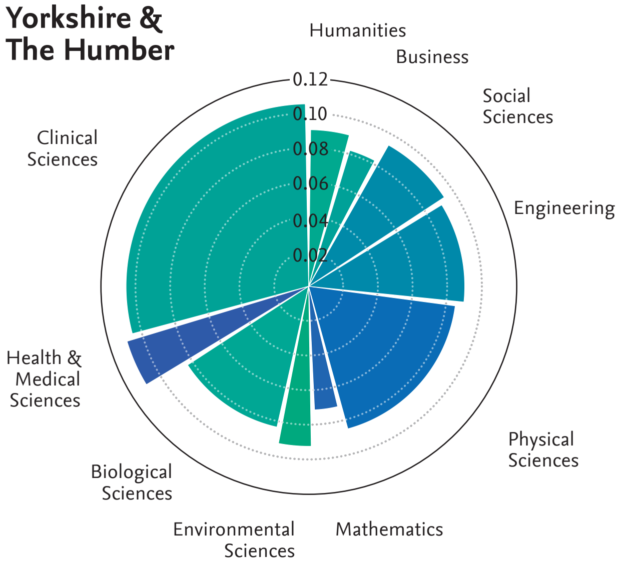


Figure 4.12 *(continued)*

FWCI: *1.00* *2.50*

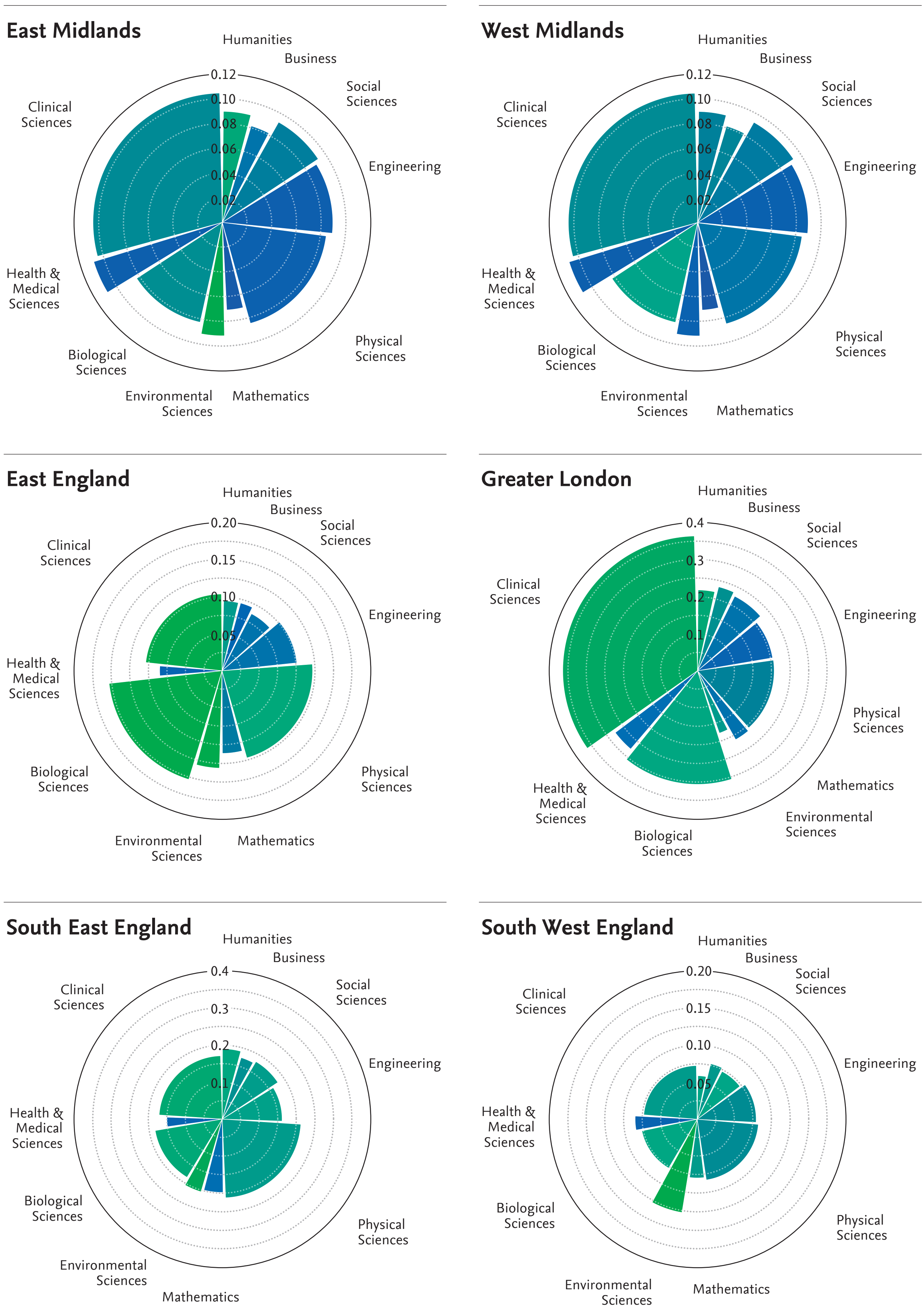


Figure 4.12 (continued)

FWCI: *1.00* *2.50*

4.3.8 UK articles are cited by diverse sources, reflecting changing shares of global article outputs

The continued diversification of the source of citations to UK articles *(see Table 4.1)* reflects not just the changing shares of global article outputs and citations (as was shown in *Figures 4.1* and *4.4*), but also the enduring global reach and impact of UK research outputs and collaborations.

Citation shares of the emerging research nations were mainly steady, although China's increased to over 6% in 2011-2015, a considerable growth from less than 4% in 2003-2007. The US, while still accounting for the largest share of citations to UK articles, continued to see a reduction in its share.

Table 4.1 *— Share of citations to UK articles from the UK and comparators, 2006-2010 and 2011-2015. All other sources of citations by country are grouped into the other category. Source: Scopus.*

Country	2006-2010	2011-2015
UK	19.0%	16.1%
US	20.9%	18.2%
Germany	6.7%	6.3%
France	4.6%	4.2%
China	4.2%	6.3%
Italy	3.9%	3.9%
Canada	3.7%	3.4%
Japan	2.8%	2.3%
India	1.1%	1.4%
Brazil	1.0%	1.3%
South Korea	1.0%	1.2%
Russia	0.7%	0.8%
Other	30.4%	34.5%

4.3.9 The download impact of UK research articles exceeds the global average

Downloads and digital readership counts are measures that complement traditional bibliometrics, such as citation counts, by showing an early indicator of the impact that a work may have. Although there is no consensus yet on the meaning of an article download[45], nor any central database of download statistics available for comparative analysis, article downloads from online platforms can be useful indicators of early interest in, or emerging importance of, research[46]. In this section download statistics are presented, and readership statistics can be found in *Appendix G*.

In 2014, the UK outperformed the global baseline in field-weighted citation impact (FWCI), and field-weighted download impact (FWDI) across all main research fields; the spread across subject fields was fairly uniform *(see Figure 4.13)*. Of particular note, the UK's publications in Clinical Sciences, Biological Sciences, and Environmental Sciences were more frequently cited in scientific publications and downloaded by users than the world average.

Most of the comparator countries showed a pattern of generally evenly-distributed field-weighted download impact in all research fields in 2014 (with the exceptions of India and Russia), compared to their less uniform patterns of field-weighted citation impact. For countries whose current field-weighted citation impact was well above the world average of 1, their field-weighted download impact was generally lower than field-weighted citation impact. Since downloads may be an early indication of citations, this raises the possibility that the field-weighted citation impact for these countries may decrease in the future. This prospect is reinforced by the fact that the field-weighted download impact for countries with relative low field-weighted citation impact (China, India, Japan, Russia and Brazil), is either close to or larger than their field-weighted citation impact, implying the possibility of field-weighted citation impact increasing in the future.

***Figure 4.13** (see next pages) — Field-weighted citation impact (FWCI) and field-weighted download impact (FWDI) for the UK and comparators across ten research fields in 2014. For all research fields, a field-weighted citation or download impact of 1.0 equals the world average in that particular research field. Source: Scopus, ScienceDirect.*

MEASURING ARTICLE DOWNLOADS

Citation impact is, by definition, a lagging indicator: newly-published articles need to be read, after which they might influence studies that will be carried out, which are then written up in manuscript form, peer-reviewed, published and finally included in a citation index such as Scopus. Only after these steps are completed can citations to the earlier article be systematically counted. For this reason, investigating downloads has become appealing alternatives, since it is possible to start counting downloads of full-text articles immediately upon online publication. What cannot be determined from looking at counts of article downloads is what use, if any, a researcher has made of them. Using as an analogy the "pay-per-click" internet advertising model, which directs traffic from first tier search engines to websites, and where "sale" equals "citation", researchers who download articles from online sites may be demonstrating an interest in the product on offer but that interest may not translate into a "sale". However, it can be assumed that those researchers who take the active step of downloading an article and subsequently saving it into some sort of electronic repository (into what is commonly referred to as reference manager software) are intending to use the article for future reference, such as a citation, thus ensuring a "sale".

In this report, a download is defined as the event where a user views the full-text HTML of an article or downloads the full-text PDF of an article from ScienceDirect, Elsevier's full-text journal article platform; views of an article abstract alone, and multiple full-text HTML views, or PDF downloads of the same article during the same user session, are not included in accordance with the COUNTER Code of Practice[47]. ScienceDirect provides download data for approximately 18% of the articles indexed in Scopus. The subject distribution of articles covered by ScienceDirect is similar to that in Scopus with slightly less proportion of articles in Mathematics, Engineering, Humanities and Social Sciences. It is assumed that user downloading behaviour across countries does not systematically differ between online platforms.

Field-weighted download impact is calculated from the ScienceDirect download data according to the same principles applied to the calculation of field-weighted citation impact *(see box "Measuring impact: Citation windows and field-weighting")*.

45 Cronin, B. (2005) "A hundred million acts of whimsy?" Current Science 89 (9) pp. 1505-1509; Bornmann, L., Daniel, H. (2008) "What do citation counts measure? A review of studies on citing behavior" *Journal of Documentation* 64 (1) pp. 45-80; Kurtz, M.J., & Bollen, J. (2010) "Usage Bibliometrics" *Annual Review of Information Science and Technology* 44 (1) pp. 3-64.

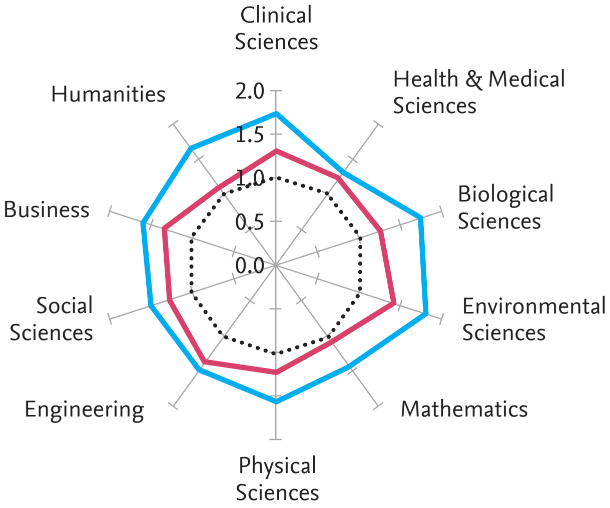
46 Moed, H.F. (2005) "Statistical relationships between downloads and citations at the level of individual documents within a single journal" *Journal of the American Society for Information Science and Technology* 56 (10) pp. 1088-1097; Schloegl, C. & Gorraiz, J. (2010) "Comparison of citation and usage indicators: The case of oncology journals" *Scientometrics* 82 (3) pp. 567-580; Schloegl, C. & Gorraiz, J. (2011) "Global usage versus global citation metrics: The case of pharmacology journals" *Journal of the American Society for Information Science and Technology* 62 (1) pp. 161-170.

47 See https://www.projectcounter.org/code-of-practice-sections/general-information/

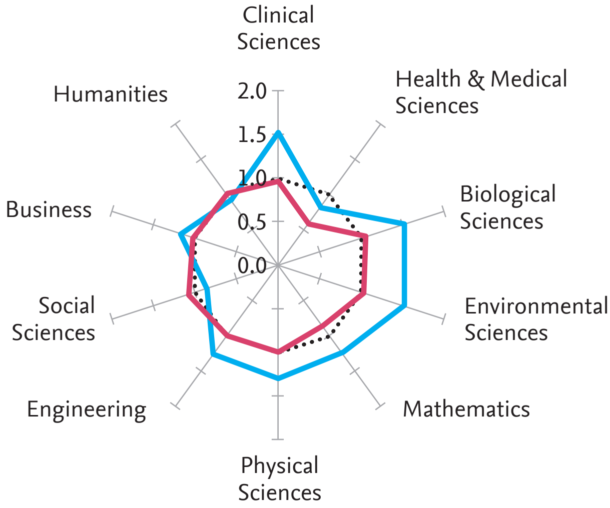
Figure 4.13 *(continued)*

FWCI *FWDI* *World average (= 1.0)*

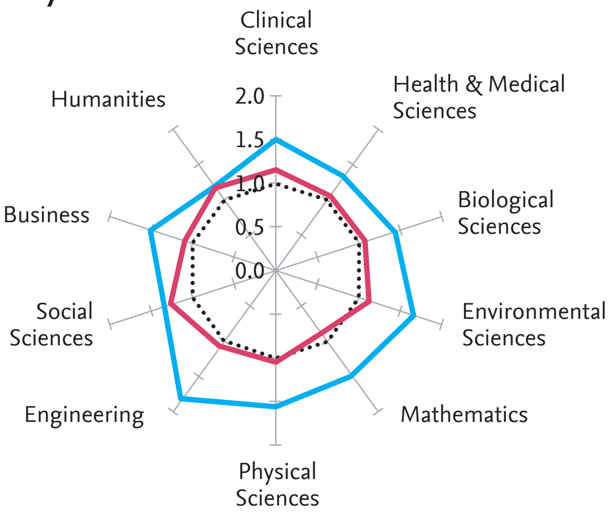
UK



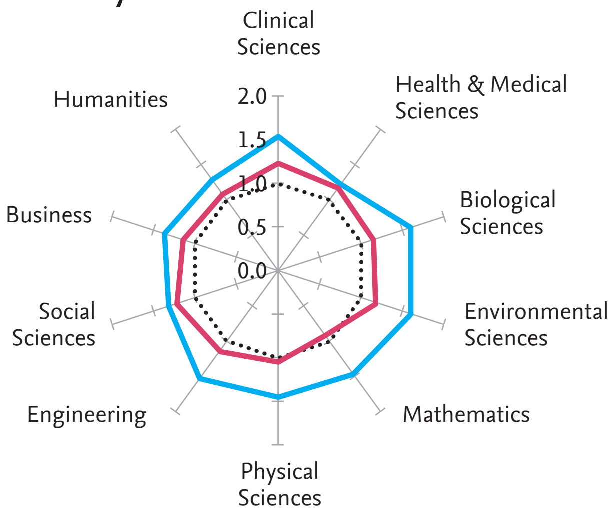
France



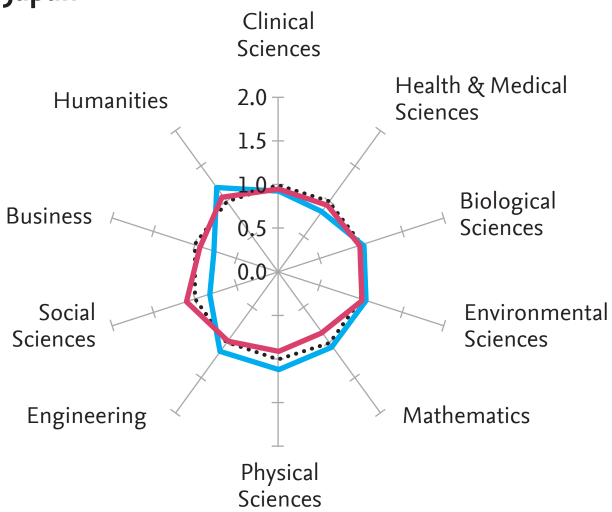
Italy



Germany



Japan



US

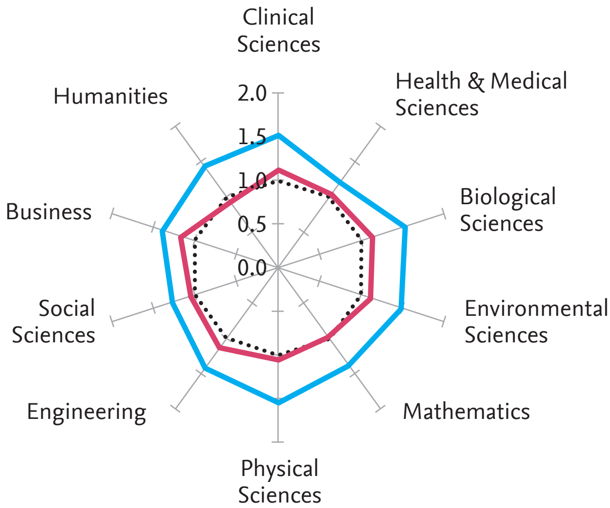
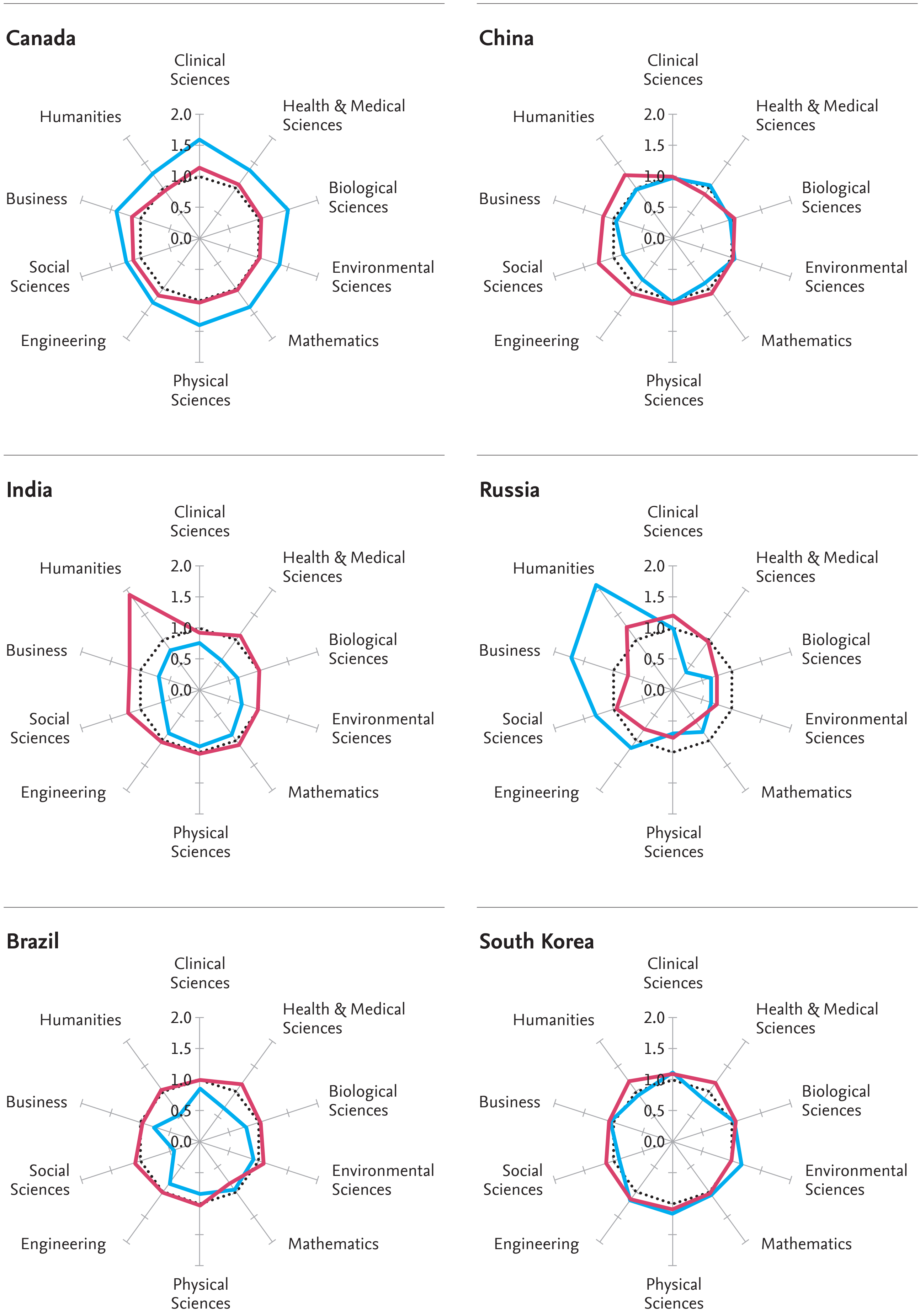


Figure 4.13 (continued)

■ *FWCI* ■ *FWDI* ■ *World average (= 1.0)*



CHAPTER 5

Research Collaboration

5.1 Highlights

UK INTERNATIONAL COLLABORATION

Share	Increased at	Ranks
51.3%	**6.7 p.p.**	**2nd**
of all UK articles in 2014 result from international collaboration	from 2010-2014	for share of international collaborations amongst comparator countries in 2014

In 2014, over half of all UK publications were co-authored with at least one non-UK researcher, indicating that UK researchers are highly collaborative internationally.

International collaboration is associated with increased field-weighted citation impact for the UK.

The UK occupies a central position in the international co-authorship network.

HYPERCOLLABORATION

The terms 'Hypercollaborative co-authorship' and 'hypercollaboration' have been coined to classify the growing phenomenon of articles that have hundreds or even thousands of co-authors. The rise of so-called 'Big Science' – a term used to describe research that requires major capital investment and is often, but not always, international in nature[51] – may be one of the causes of this phenomenon. The frequency of such articles is still relatively small: just 827 articles published between 2010 and 2015 had more than 1,000 authors. Most of these came from CERN's Large Hadron Collider in Switzerland, and include, in May 2015, the most multi-authored research paper published to date, with 5,154 authors[52].

While they may represent extreme outliers in co-authorship data and remain proportionally few, such hypercollaborative articles are included throughout the analyses in this chapter. Like other collaborative articles, they are counted as single internationally co-authored articles for each country represented in them, and for each country pairing.

5.2 Introduction

Over the past few decades, collaboration has become the cornerstone of innovation and excellence. It is an inherent and mutually beneficial part of the world of research, crossing borders, disciplines, and communities. The pervasiveness of low-cost travel, high-speed internet connectivity, mobile technology, social media, public engagement, and funding programmes all encourage scholars, communities and policy makers to expand their networks beyond their immediate working environments[48] and traditional spheres of influence.

The UK has a history of using research and innovation partnerships to promote economic development and social welfare in and across multiple countries. One such funding programme is the Newton Fund. Launched by the UK in 2014 as part of its official development assistance (ODA), it is managed by the UK Department of Business, Energy & Industrial Strategy. It is delivered through 15 UK partners to the 16 partnering countries: Brazil, Chile, China, Colombia, Egypt, India, Indonesia, Kazakhstan, Kenya, Malaysia, Mexico, the Philippines, South Africa, Thailand, Turkey, and Vietnam. Although it is too early to discern the fund's impact on the outcome of research collaborations, the Newton Fund countries are included in comparisons in this chapter about collaboration benefits and networks to provide baseline data for future analysis. As this chapter shows, this is just one example of how the UK occupies a central position in a hub of international collaborations that spans all sectors and all continents. Its researchers constantly strive to build collaborations that overcome challenges created by geographical, cultural and political differences in the pursuit of ground-breaking research that improves people's lives and builds strong, knowledge-based economies.

Research collaboration that is grown out of informal discussions and information sharing accounts for as much as half of all collaborations[49], and can usually be detected from the patterns of co-authorship of published articles or the acknowledgements within them. The single-author article is slowly becoming less common[50] in the face of the inexorable rise of international collaboration, the latter being measured by the proportion of articles with at least two different countries listed in the authorship byline – see box *"Hypercollaboration"* on page 72 for the most extreme case of collaboration. While co-authorship is not the only form of collaboration, particularly in fields such as the Social Sciences and Arts and Humanities, it can be quantified with reasonable robustness and is the basis for the indicators discussed in this chapter.

48 Pan et al. (2012) "World citation and collaboration networks: Uncovering the role of geography in science" *Scientific Reports 2* article 902.
49 Beaver, D. (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.
50 Greene, M. (2007) "The demise of the lone author" *Nature* 450 (7173) pg. 1165; Ossenblok, T. L.B., Verleysen, F. T. and Engels, T. C.E. (2014) "Coauthorship of journal articles and book chapters in the social sciences and humanities (2000–2010)." *Journal of the Association for Information Science and Technology* 65: 882–897.

5.3 Key Findings

5.3.1 The UK's rate of international co-authorship is high and rising and is associated with high field-weighted citation impact

In 2014, over 51% of all UK publications (i.e., articles with at least one author with a UK affiliation) were co-authored with at least one non-UK researcher *(see Figure 5.3 on page 76)*, highlighting that UK researchers are highly collaborative internationally. The only other comparator country to surpass 50% was France, ahead of the UK by just 0.3p.p. As might be expected, emerging countries, such as China, India and South Korea, generally had a smaller share of internationally collaborative articles.

The UK's share of international co-authorship increased annually from 2010 with corresponding reductions in the shares of the other types of authorship – single authored; collaborations within the same institution (institutional); and collaborations with different UK institutions (national).

Internationally co-authored articles are, generally, associated with a higher field-weighted citation impact than those co-authored institutionally or nationally *(see Table 5.1)*. The field-weighted citation impact of the UK's internationally co-authored articles was 47% higher than that of the UK's nationally co-authored articles, and 59% higher than the field-weighted citation impact of institutionally co-authored articles.

There is a clear relationship across the UK and comparator countries between the share of internationally co-authored articles and the field-weighted citation impact of those articles *(see Figure 5.1)*. As can be seen, the correlation is strongly positive, signifying a relationship between greater international collaboration and greater field-weighted citation impact. The positive correlation between international share and citation impact does not necessarily demonstrate a causal relationship, or direction, between the two.

The positive correlation between international collaboration and citation impact is further demonstrated by comparing the international co-authorship share of all publications with that of the top 1% most cited publications across all the comparator countries *(see Figure 5.2)*. This shows that the proportion of international collaboration is much higher in the highly-cited publication share.

Across the UK constituent countries, Wales had the highest international collaboration share in 2014, with nearly 70% of its publications involving co-authors outside of Wales *(see Table 5.2)*.

Table 5.1 *— Field-weighted citation impact of single-authored, institutionally, and nationally co-authored articles relative to internationally co-authored articles for the UK and comparators, 2014. Source: Scopus.*

Country	Single Author	Institutional	National	International
UK	47%	63%	68%	100%
Brazil	22%	39%	40%	100%
Canada	42%	59%	60%	100%
China	24%	41%	45%	100%
Germany	34%	60%	63%	100%
France	25%	54%	60%	100%
India	39%	46%	43%	100%
Italy	35%	65%	65%	100%
Japan	30%	49%	54%	100%
South Korea	33%	54%	57%	100%
Russia	33%	40%	39%	100%
US	43%	69%	80%	100%
G8	45%	70%	83%	100%
EU28	41%	63%	72%	100%
OECD41	52%	73%	97%	100%

51 Hand, E. (2010) "'Big science' spurs collaborative trend" *Nature* 463 (7279) pg. 282.
52 Aad, G. *et al.* (2015) "Combined Measurement of the Higgs Boson Mass in pp Collisions at √s = 7 and 8 TeV with the ATLAS and CMS Experiments" *Phys. Rev. Lett.* 114, article 191803.

Figure 5.1 — *Correlation between international co-authorship share and field-weighted citation impact of internationally co-authored articles, 2014. Source: Scopus.*

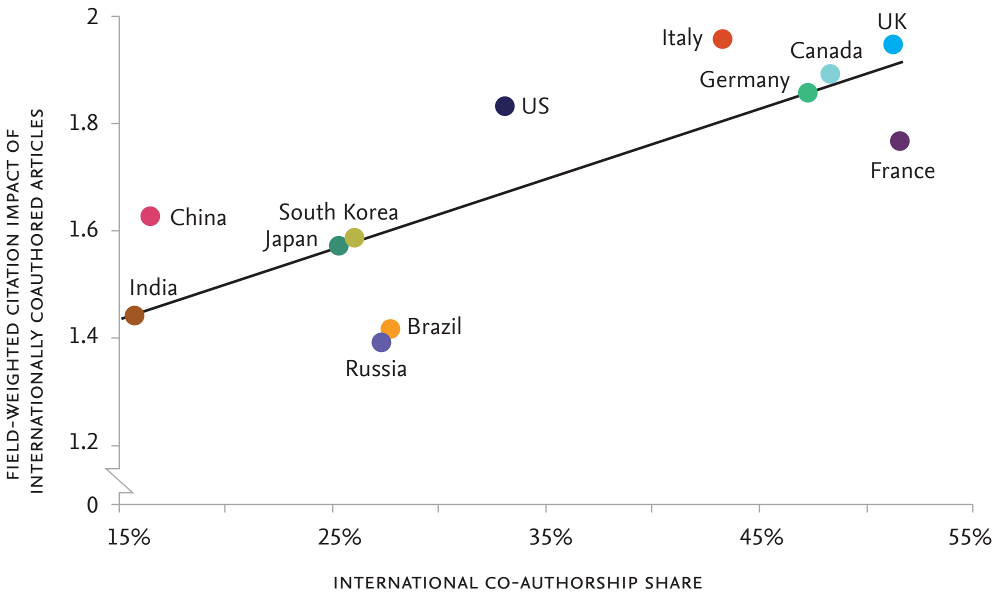


Figure 5.2 — *International co-authorship share in top 1% highly-cited articles and in all publications of the country. Source: Scopus.*

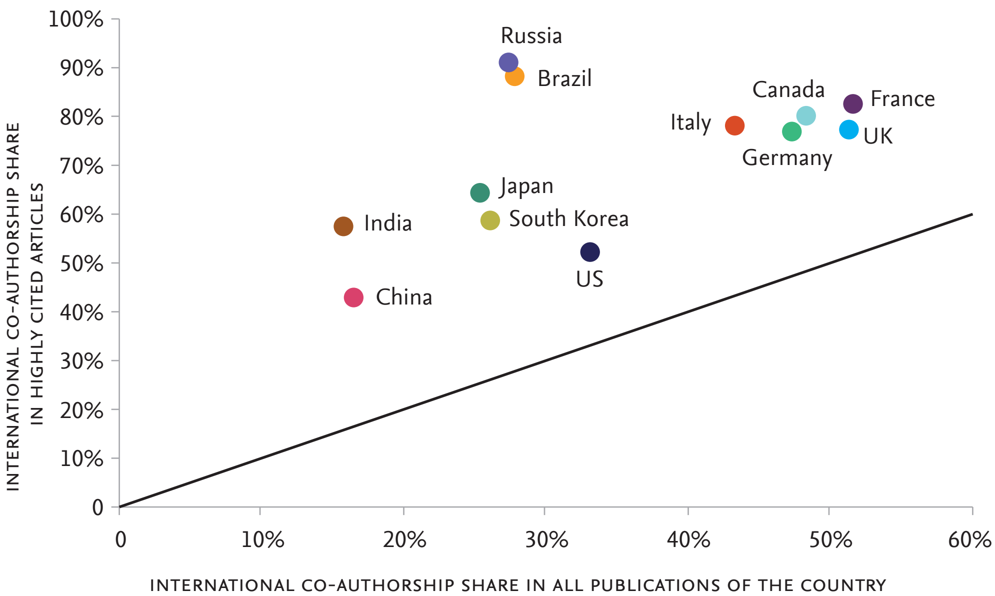


Table 5.2 — *International co-authorship share and field-weighted citation impact for UK constituent countries, 2014. Source: Scopus.*

UK constituent	International collaboration share	FWCI of international collaboration
England	54.8%	1.99
Scotland	67.3%	2.04
Wales	69.2%	2.03
Northern Ireland	67.1%	1.85

__Figure 5.3__ — Share of articles for the UK and comparators by co-authorship type, 2010-2014. The bubble's size is proportional to the field-weighted citation impact. Source: Scopus.

***Figure 5.3** (continued)*

5.3.2 International collaboration is associated with increased field-weighted citation impact for the UK and its partner countries

Although the relationship between international collaboration and citation impact is clear, as discussed in the last section, what cannot be determined from the data alone is whether countries that engage frequently in international collaboration achieve high-impact results because *(a)* the collaborations involve the best researchers in each country, *(b)* the countries systematically select the best partners to work with, or *(c)* countries that are likely to produce high-impact research outputs are actively solicited by other countries for collaborative partnerships.

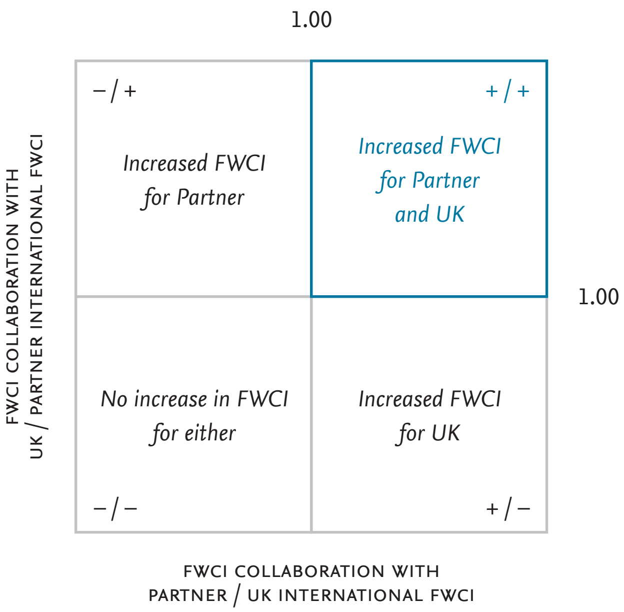
As to *(a)*, the H-index attempts to measure both the productivity and impact of the published work of a scholar. An author has an H-index of *n* if at least *n* of their publications have each received at least *n* citations. In 2014, the top 10% of UK authors with the highest H-index authored 67,206 publications, around 43% of all of the UK's publications in that year. 58% of these top authors' publications involved at least one international co-author, which is higher than the 51% share for the UK generally, and implies that these top authors are more likely to collaborate internationally. The FWCI of non-international publications for these top authors was 1.58, and that of their internationally collaborative publications was 2.44. This re-iterates the association between international collaboration and higher FWCI.

Although it is difficult to assess whether *(b)* countries systematically select the best partners to work with, or if *(c)* it is the best countries that collaborate with one another, it is possible to investigate which international partnerships are associated with higher citation impact.

Figure 5.4 demonstrates how collaborations between countries are associated with increased FWCI of both partners, or one, or none. The *horizontal* axis measures the impact of the collaboration, using FWCI, between the UK and a Partner ("Country A") compared to the collaboration between the UK and all of its international partners. If the FWCI of collaboration between the UK and Country A is larger than that of all the UK's international collaborations, collaborating with Country A is associated with higher FWCI for the UK, i.e., the collaboration is in the right two quadrants in Figure 5.4. If it were less, it would be in one of the two quadrants on the left.

The *vertical* axis measures the citation impact of the collaboration between the UK and Country A compared to the collaboration between Country A and all of its partners. In Figure 5.5, we provide two vertical lines. The yellow dashed line, is based on using the duplicated international collaboration FWCI of the UK in the denominator, and the black line is based on using the unduplicated international collaboration FWCI as denominator. Each line should be used to gauge the relative position of the UK's collaborators on either side of the line, following the guide to the collaboration quadrant provided in Figure 5.4. If the FWCI of collaboration between the UK and Country A is higher than that of all Country A's international collaboration, collaborating with the UK is associated with higher FWCI for Country A, i.e., the collaboration is in the upper two quadrants in Figure 5.4. If it were less, it would be in one of the two lower quadrants.[53]

Figure 5.4 — *Collaboration impact model.*



53 The average FWCI of collaborations between countries generally have higher FWCI values than the average international collaboration FWCI of each individual country. This has the effect of pushing collaborations into the upper right quadrant.

Publication ID	Countries	FWCI	Country & collaborations	Average FWCI
1	A-B	2.0	A	(2+3+9) / 3 = 4.7
2	A-C	3.0	A-B	(2+9) / 2 = 5.5
3	A-B-C	9.0	A-C	(3+9) / 2 = 6.0

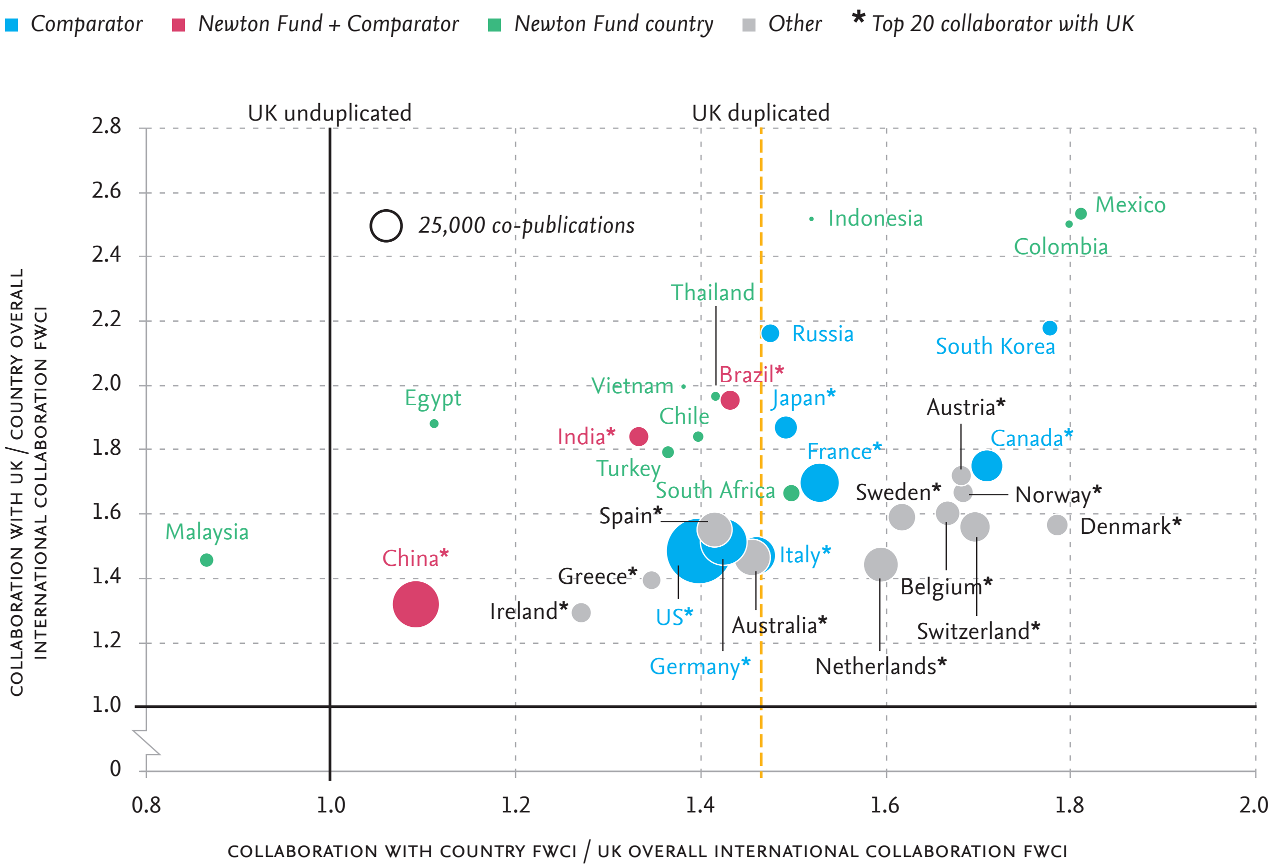
The FWCI of articles co-authored with the UK by the UK's most frequent international co-authorship partners was generally greater than that of all internationally co-authored articles of the partner country.

The UK's collaborations with those countries that have a higher overall field-weighted citation impact are usually associated with higher collaborative citation impact, although this is not always the case. For example, the UK's articles co-authored with France showed a higher citation impact than papers co-authored with the US, despite the US having a much greater overall field-weighted citation impact than France. Generally, collaborating countries saw a larger increase in FWCI for their collaborations with the UK compared to all their international collaborations than *vice versa*, reflecting the fact that the UK has a higher overall FWCI than most other countries.

The citation impact of the Newton Fund on the partner countries and the UK will not be known for several years due to the lag time between collaborations being established, the output of research publications, and the subsequent citing of those outputs. Therefore, the data provided in this report provides a baseline from which to measure changes in impact in the future.

In line with the comparator countries, the Newton Fund countries saw higher field-weighted citation impact for all articles co-authored with the UK. The largest increases in FWCI for both the UK and the partner countries were seen in collaborations with the Philippines (not shown on the chart), Mexico and Colombia.

Figure 5.5 — *Field-weighted citation impact of UK internationally co-authored articles by co-authoring countries that are either a top 20 collaborator by count, a Newton Fund country or listed comparator, 2011-2015. The Philippines (NF country, x: 2.43, y: 2.67) is excluded for ease of view. Bubble size is proportional to the number of co-authored articles, with the reference bubble showing 25,000 co-publications. The dashed yellow line denotes the relative fold position when using the UK's duplicated international collaboration FWCI as denominator, rather than the unduplicated international collaboration FWCI. Source: Scopus.*



5.3.3 The UK occupies a central position in the international co-authorship network

Every partner in a research collaboration influences the outcomes of that research, as each brings something different to the relationship, from basic needs such as access to resources, to more creative benefits like innovation sparked by the mixing of different approaches and methodologies in the search for answers to traditional questions. This is especially true of international collaborations. One tool to measure the strength of the collaborative ties between country pairs is Salton's Index *(see box "Salton's Index: An indicator of collaboration strength" on page 83)*, an indicator that takes into account the volume of international collaboration output of both partners.

Because of the sheer volume of research outputs produced by the largest research nations in the world, international collaborations between such countries are to be expected. However, collaborations involving less productive or emerging nations may be important for one or both partners.

Figure 5.6 provides a universal view of the relationships between all collaborative pairings globally, as revealed by a network map of these connections in the period 2011-2015. Each country (node) is connected by lines (edges) weighted by Salton's Index and coloured by the field-weighted citation impact of the collaborative research outputs. Countries that collaborate intensively with each other (measured by Salton's Index) are plotted close to each other. There is a clear core to the network map, composed mainly of the US, Canada, the UK and a number of other European countries, indicating the central position of these countries in the global co-authorship network. Even though geographic information is not used for the layout of the network, we see that sub-clusters of networks surround the main core, including Africa, South America, Scandinavia, Eastern Europe, Western Europe, Southeast Asia, and the Middle East. This suggests that countries that are geographically close and similar in culture and history are more likely also to collaborate in research. Between 2011 and 2015, the Newton Fund countries were well connected with the core, even though they tended to be on the outskirts (with the notable exception of Kazakhstan).

Table 5.3 illustrates further these tendencies in international collaborations. For example, between 2011 and 2015, the US, which dominates the left-hand side of the table, collaborated internationally most frequently with China, and more so than it did with the UK. While this is, at least in part, a product of the huge growth in the article output volume from China in recent years, it also reflects the growing attractiveness of China as a collaborative partner. The right-hand side of the Table presents a more nuanced view of global international collaboration on the basis of Salton's Index. It highlights some relatively small, but very close, collaborative ties, such as that between Egypt and Saudi Arabia, Austria and Germany, or Belgium and the Netherlands, each pairing reflecting a shared sociocultural history, as well as geographic proximity.

Table 5.4 demonstrates that, among the Newton Fund countries and as measured by Salton's Index, the UK was most closely connected to South Africa and China and least connected to Indonesia, the Philippines, and Kazakhstan.

Figure 5.6 — *Global co-authorship map, 2011-2015. Node size is proportional to overall international collaboration article output for each country.*

Edges are weighted by number of collaborative articles between each country pair. Data were visualised with Gephi using the ForceAtlas2 layout algorithm. Countries that collaborate with fewer than 10 other countries, and less than 100 publications per year in total are excluded. For ease of viewing, edges between countries with a Salton Index value of <0.01 are excluded. For a full list of countries and their three letter codes, see Appendix D: Countries included in Data Sources. Source: Scopus.

■ *UK* ■ *Comparator* ■ *Newton Fund + Comparator* ■ *Newton Fund country* ■ *Other* * *Top 20 collaborator with UK*

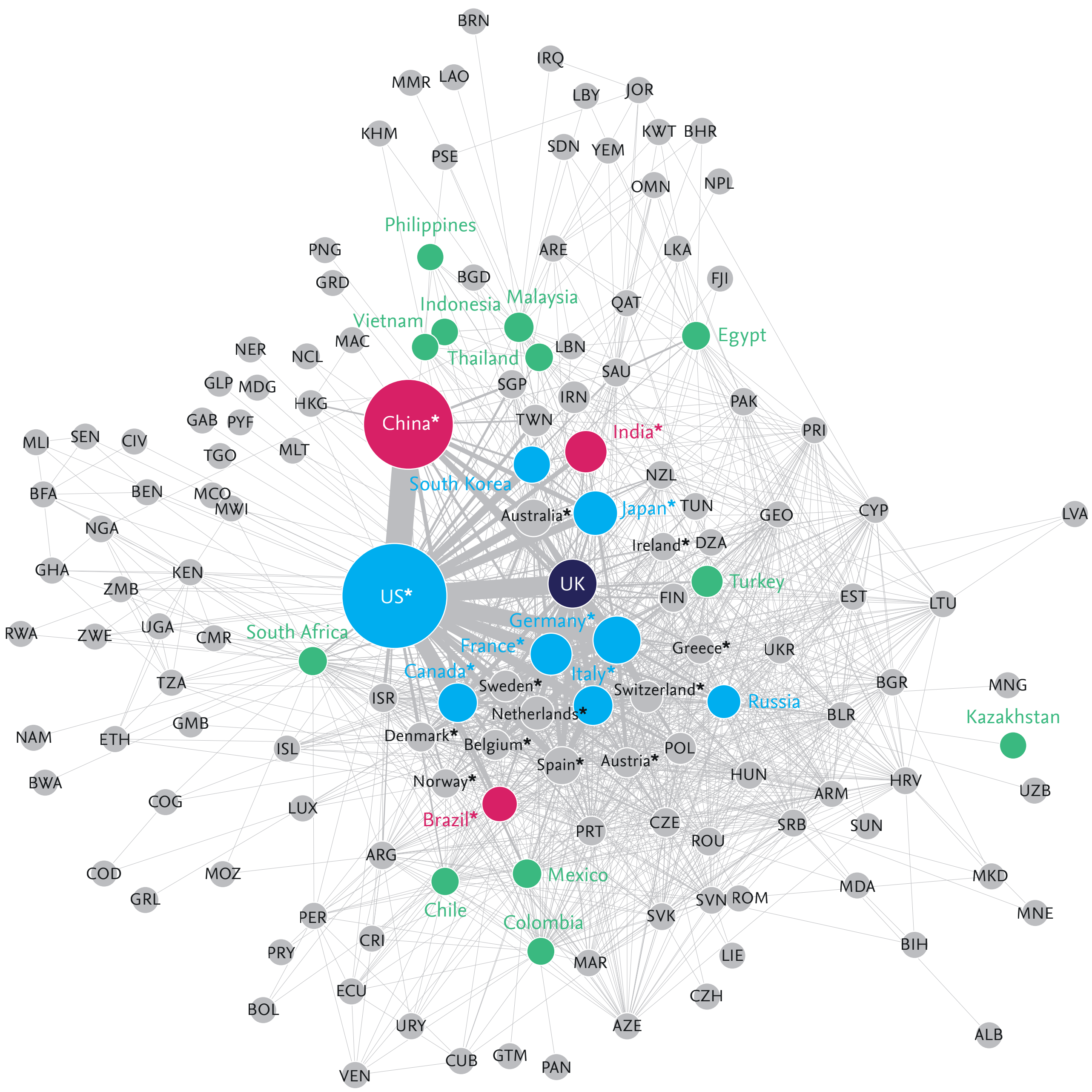


Table 5.3 — Major global co-authorship country partnerships, 2011-2015. Top 20 pairings as sorted by (above) count of co-authored articles, and (below) Salton's Index. The latter list excludes pairings for countries with fewer than 10,000 co-authored articles in this period. Source: Scopus

Top 20 co-authorship country pairings			Co-authored articles	FWCI of co-authored articles	Salton's Index
China	—	US	154,064 ▼	1.84	0.065
UK	—	**US**	**110,261**	**2.75**	**0.079**
Germany	—	US	97,386	2.62	0.071
Canada	—	US	89,422	2.47	0.085
France	—	US	65,207	2.77	0.057
UK	—	**Germany**	**57,951**	**2.80**	**0.080**
Italy	—	US	54,832	2.70	0.052
Australia	—	US	49,283	2.81	0.051
Japan	—	US	48,825	2.27	0.039
South Korea	—	US	46,362	1.91	0.049
Germany	—	France	42,981	2.83	0.072
UK	—	**France**	**42,097**	**3.01**	**0.069**
Spain	—	US	41,655	2.68	0.042
Netherlands	—	US	40,091	3.12	0.050
UK	—	**Italy**	**37,436**	**2.87**	**0.066**
Switzerland	—	US	37,076	3.00	0.053
Switzerland	—	Germany	35,492	2.55	0.099
Germany	—	Italy	34,914	2.92	0.063
UK	—	**China**	**34,324**	**2.15**	**0.027**
UK	—	**Australia**	**34,263**	**2.86**	**0.067**
Egypt	—	Saudi Arabia	12,047	0.95	0.182 ▼
Switzerland	—	Germany	35,492	2.55	0.099
Austria	—	Germany	23,217	2.32	0.088
Belgium	—	Netherlands	15,596	2.82	0.087
Canada	—	US	89,422	2.47	0.085
UK	—	**Germany**	**57,951**	**2.80**	**0.080**
UK	—	**US**	**110,261**	**2.75**	**0.079**
Germany	—	Netherlands	31,867	3.00	0.077
UK	—	**Netherlands**	**32,233**	**3.14**	**0.076**
France	—	Italy	33,450	2.80	0.072
Germany	—	France	42,981	2.83	0.072
Germany	—	US	97,386	2.62	0.071
Switzerland	—	France	21,462	2.95	0.071
Belgium	—	France	18,205	2.83	0.070
UK	—	**France**	**42,097**	**3.01**	**0.069**
UK	—	**Australia**	**34,263**	**2.86**	**0.067**
UK	—	**Italy**	**37,436**	**2.87**	**0.066**
China	—	US	154,064	1.84	0.065
Spain	—	Italy	25,675	2.79	0.065
Germany	—	Italy	34,914	2.92	0.063

Table 5.4 — *Number and field-weighted citation impact of co-authored publications and Salton's Index between the UK and Newton Fund countries. Source: Scopus.*

Newton Fund countries	Co-authored articles	FWCI of co-authored articles	Salton's Index
South Africa	7,927	2.95	0.034 ▼
China	34,324	2.15	0.027
Kenya	1,942	3.25	0.023
Chile	4,091	2.75	0.023
Brazil	10,005	2.82	0.022
Malaysia	5,273	1.70	0.018
India	9,425	2.62	0.015
Thailand	3,055	2.79	0.015
Mexico	3,751	3.56	0.015
Colombia	2,159	3.54	0.014
Turkey	4,917	2.68	0.014
Egypt	2,725	2.19	0.012
Vietnam	911	2.72	0.008
Indonesia	938	2.99	0.007
Philippines	521	4.79	0.007
Kazakhstan	258	1.20	0.004

SALTON'S INDEX: AN INDICATOR OF COLLABORATION STRENGTH

Salton's Index, also known as Salton's cosine or Salton's measure for a country pair, is calculated by dividing the number of co-authored articles by the geometric mean (square root of the product) of the outputs of the two partners[54]; hence, it is a size-independent indicator of collaboration strength. Salton's Index is the most desirable indicator of collaboration strength when the results are to be used for visualisation, as is the case here[55]. As a cosine measure, the values of Salton's Index vary between 0 (where there are no co-authored articles between a given country pairing) and 1 (where all articles from both countries represent co-authorship between them). In practice, the range typically seen at country level is in the range 0.01 to 0.20 for most country pairings of significant size. For example, the UK's most productive co-authorship country partnership in the period 2011-2015 is with the US, accounting for 110,261 co-authored articles in that period. Taking this value in the context of the total article output of both countries in the same period (741,581 for the UK, 2,634,502 for the US) using Salton's Index, the calculation (110,261 / √(741,581 x 2,634,502)) = 0.079.

54 Cunningham, S.W. & Kwakkel, J.H. (2011) "A complex network perspective on the world science system" *Proceedings of 2011 Atlanta Conference on Science and Innovation Policy: Building Capacity for Scientific Innovation and Outcomes*, article 6064467.

55 Glänzel, W. (2001) "National characteristics in international scientific co-authorship relations" *Scientometrics* 51 (1) pp. 69–115.

CHAPTER 6

Research Productivity

6.1 Highlights

UK PRODUCTIVITY PER MILLION USD R&D EXPENDITURE

Articles	Increased at	Ranks
3.7	**0.6%**	**1st**
per million USD GERD in 2014	per year in the period 2010-2014	amongst comparator countries in 2014

Citations	Increased at	Ranks
50.8	**6.7%**	**1st**
per million USD GERD in 2010-2014	between the periods 2006-2010 and 2010-2014	among comparator countries in 2014

UK HIGHER EDUCATION PRODUCTIVITY

Articles	Increased at	Ranks
11.5	**2.3%**	**3rd**
per million USD HERD in 2014	per year in the period 2010-2014	amongst comparator countries in 2014

Citations	Increased at	Ranks
156.7	**7.0%**	**1st**
per million USD HERD in 2010-2014	between the periods 2006-2010 and 2010-2014	among comparator countries in 2014

UK PRODUCTIVITY PER RESEARCHER

Articles	Increased at	Ranks
0.6	**1.1%**	**2nd**
per researcher in 2014	per year in the period 2010-2014	amongst comparator countries in 2014

Citations	Increased at	Ranks
7.6	**7.0%**	**2nd**
per researcher in 2010-2014	between the periods 2006-2010 and 2010-2014	among comparator countries in 2014

The UK remains a highly productive research nation in terms of articles and citation outputs per million USD of R&D expenditure.

Among comparators, the UK is the second most productive country in terms of articles and citations per researcher.

Across the board, the rate of growth in the UK's research productivity is higher than the averages of comparator groups.

There are signs that the UK may not be able to sustain its lead indefinitely. The time lag between inputs and outputs may see the UK losing more of its prime positions in the coming years as emerging countries gain greater shares of the indicators in this Chapter.

6.2 Introduction

A country's ability to convert its research inputs (R&D expenditure and human capital) into research outputs (particularly articles and received citations) is a commonly-accepted gauge of national research productivity[56]. Based on that premise, this chapter draws extensively on concepts and terminology introduced in Chapter 2 (input indicators such as Gross Domestic Expenditure on R&D (GERD)), Chapter 3 (human capital indicators such as number of researchers), and Chapter 4 (output indicators such as article and citation counts). Research has shown that, at least at the level of the individual researcher, the drivers of research productivity are many and various, and include at least these factors: persistence, resource adequacy, access to literature, initiative, intelligence, creativity, learning capability, stimulative leadership, concern for advancement, external orientation, and professional commitment[57]. By inference, a highly productive research base is one that creates an environment for researchers that satisfies some or all of these requirements to realise the greatest outcomes at the lowest cost.

As noted in Chapter 1, in the input-output model of R&D evaluation there is a time lag between inputs (such as R&D expenditure or human capital) and outputs (such as journal articles and citations). Owing to the complexities in determining and accounting for the time lags between inputs and outputs, this chapter does not address the time lags and focuses only on productivity indicators, such as articles and citations per unit R&D expenditure (adjusted for inflation) and per researcher. These indicators may capture a larger portion of research output in some research fields than in others, for example, in the Social Sciences and Arts and Humanities.

56 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.

57 Ramesh Babu, A. & Singh, Y.P. (1998) "Determinants of research productivity" *Scientometrics* 43 (3) pp. 309-329.

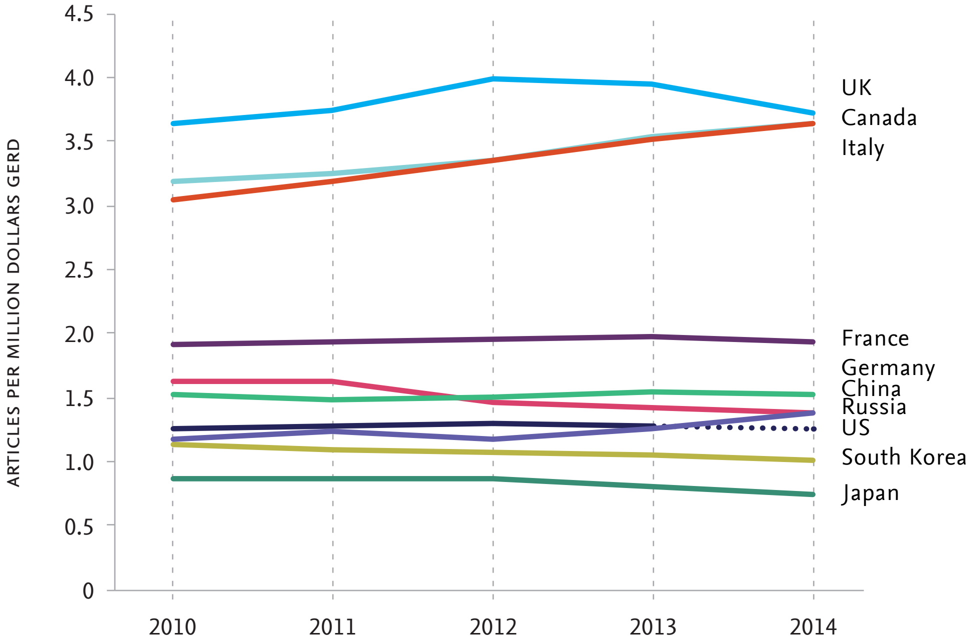
6.3 Key Findings

6.3.1 The UK is highly productive in terms of articles and citations per million USD spend on GERD

The UK's productivity, when its total article output is expressed per million USD GERD, was higher than that of any of the comparator countries from 2010 to 2014 *(see Figure 6.1)*, rising from 3.63 articles per million USD GERD in 2010 to 3.99 in 2012, before dropping to 3.72 in 2014. Canada and Italy had more steady growth patterns of performance over the period than the UK, and ranked second and third respectively among the comparators. Interestingly, these three countries had the highest proportion of R&D performed in the Higher Education Sector, as was shown in Figure 2.3. The remaining comparator countries, with the notable exception of Russia, generally had much lower and declining productivity. The UK was much more efficient in terms of articles per million USD GERD than the average of each of the G8, EU28 and OECD41 groups, and experienced a higher growth rate than the average of any of the G8 and OECD41 groups.[58]

When the total citation output for the UK is expressed per million USD of GERD, it outperformed all the comparator countries and the averages of the G8, EU28 and OECD41 groups, increasing nearly 7% per year in the period 2010-2014 *(see Figure 6.2)*. This growth rate was considerably greater than the average rates shown by each of the three comparator groups and was much higher than the 4% seen in the last report. Canada and Italy continued to track behind the UK's performance more closely than the remaining comparators, all of which generally showed lower levels of productivity, as well as growth.

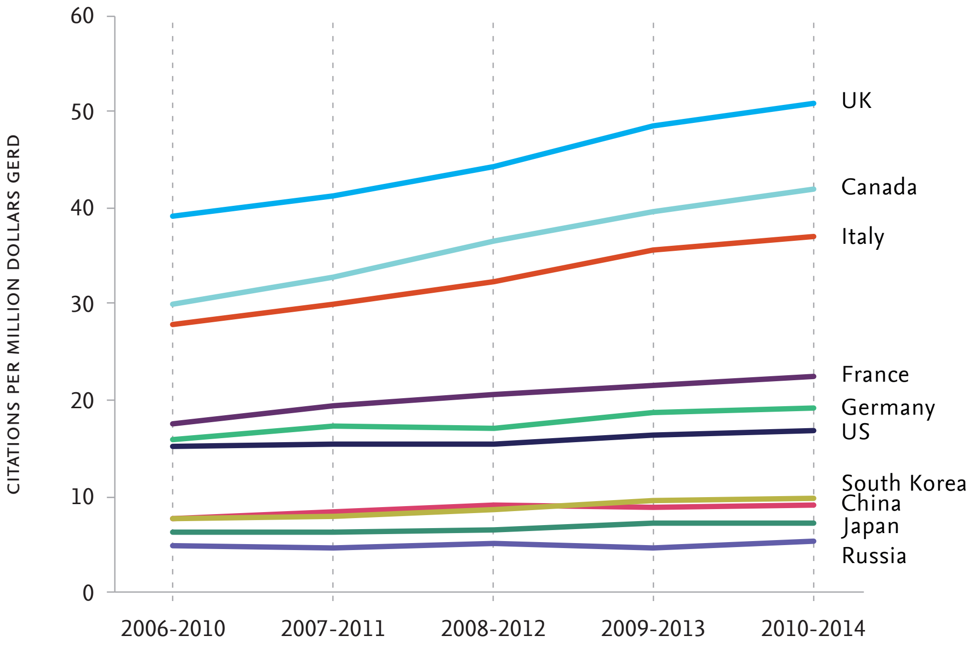
Figure 6.1 — *Articles per million USD GERD for UK and comparators, 2010-2014. GERD values are in 2010 prices. The 2014 GERD value for the US is extrapolated from the OECD data. UK ranking in EU28 is amongst 22 (of 28) countries with available data. Source: Scopus and OECD MSTI 2015/2.*



	2010	2014	Change	CAGR	UK rank 2010	UK rank 2014
UK	3.63	3.72	0.09	0.6%	–	–
G8	1.32	1.31	-0.01	-0.2%	1	1
EU28	2.14	2.22	0.08	0.9%	8	9
OECD41	1.41	1.34	-0.07	-1.2%	10	13

58 Caution should be applied when comparing analyses between reports in this series as OECD changed the base year of HERD and GERD from 2005 (used in the 2013 report) to 2010 (used in this report).

Figure 6.2 — *Citations per million USD GERD for UK and comparators, 2010-2014. GERD values are in 2010 prices. Each data point corresponds to articles published in the first year shown and citations to these articles over the subsequent five years, and GERD for the first year shown. That is, the data point for 2010-2014 corresponds to 2010 articles and citations to these in the period 2010-2014, divided by 2010 GERD. UK ranking in EU28 is amongst 22 (of 28) countries with available data. Source: Scopus and OECD MSTI 2015/2.*



	2006-2010	2010-2014	Change	CAGR	UK rank 2006-2010	UK rank 2010-2014
UK	39.15	50.84	11.69	6.7%	–	–
G8	12.70	14.67	1.97	3.7%	1	1
EU28	18.83	22.52	3.69	4.6%	3	4
OECD41	11.55	12.80	1.25	2.6%	5	7

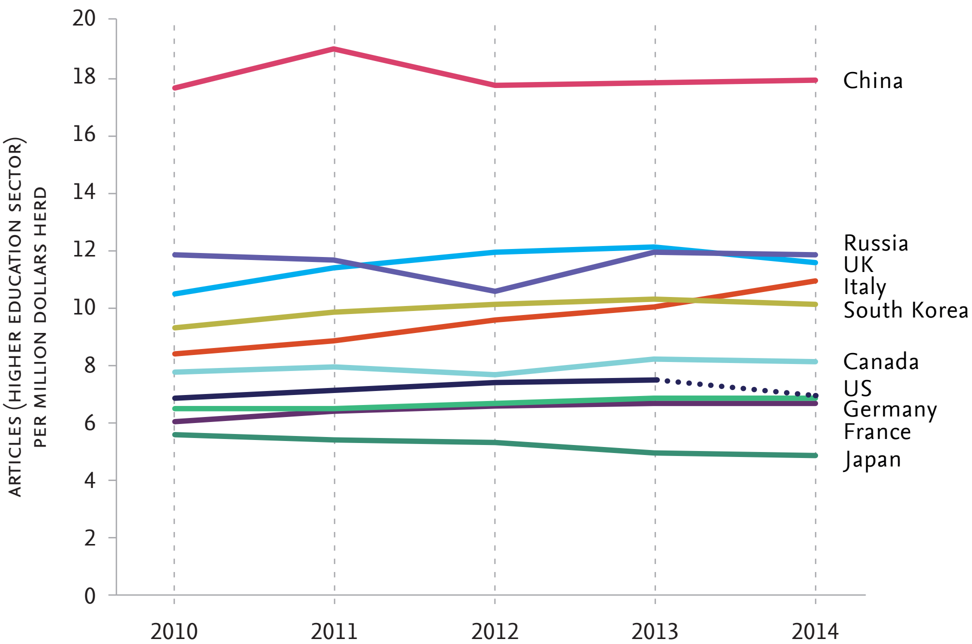
6.3.2 The UK is highly productive in terms of Higher Education articles and citations per million USD spend on HERD

The Higher Education sector globally produces the majority of article outputs, while the distribution of GERD by sector of performance varies by country but is generally greatest for the Business Enterprise sector *(refer to Figure 2.3)*. By definition, therefore, the article output of a country's Higher Education sector expressed per unit HERD offers a more direct comparison of national *academic* research productivity.

The UK was highly productive in terms of higher education articles, experiencing an annual growth of over 2% to generate nearly 12 articles per million USD spend in HERD *(see Figure 6.3)*. Over the period the UK maintained productivity above the averages of the G8, EU28 and OECD41 groups, and it also had a greater rate of growth than the G8 and OECD41 groups. Among the comparator countries, China demonstrated greatest productivity in this indicator at over 18 articles per million USD HERD. Russia had slightly greater productivity than the UK and Italy showed significant growth to rank fourth behind the UK.

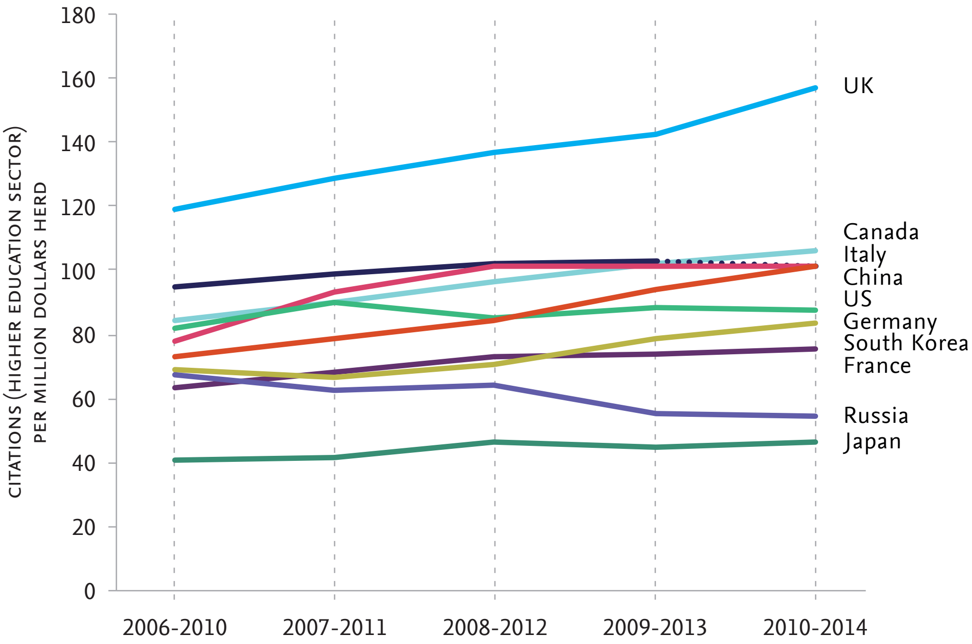
A robust 7% annual growth rate saw 157 citations per million USD spend on HERD over the 2010-2014 reporting period in the UK's Higher Education sector *(see Figure 6.4)*. This was considerably higher than any of the comparator countries and much higher than the growth and the averages of the G8, EU28 and OECD41 groups. China and Russia were well behind the UK in this indicator, even though they were above it in article productivity. Canada's and Italy's rates of growth saw them rise to second and third place respectively among the comparator countries, followed closely by the US and China, both of which experienced a slight decrease in growth in the last data point.

Figure 6.3 *— Articles (Higher Education sector) per million USD HERD for UK and comparators, 2010-2014. HERD values are in 2010 prices. The 2014 HERD value for the US is extrapolated from the OECD data. UK ranking in EU28 is amongst 22 (of 28) countries with available data. Higher Education sector articles are those in which at least one author is affiliated with a degree-granting institute that also engages in research. Source: Scopus and OECD MSTI 2015/2.*



	2010	2014	Change	CAGR	UK rank 2010	UK rank 2014
UK	10.52	11.53	1.02	2.3%	–	–
G8	6.50	6.64	0.14	0.5%	2	2
EU28	7.52	8.39	0.86	2.7%	10	11
OECD41	7.25	7.50	0.25	0.9%	17	16

Figure 6.4 — *Citations (Higher Education sector) per million USD HERD for UK and comparators, 2010-2014. HERD values are in 2010 prices. Each data point corresponds to articles published in the first year shown and citations to these articles over the subsequent five years, and HERD for the first year shown. That is, the data point for 2010-2014 corresponds to 2010 articles and citations to these in the period 2010-2014, divided by 2010 HERD. UK ranking in EU28 is amongst 22 (of 28) countries with available data. Source: Scopus and OECD MSTI 2015/2.*

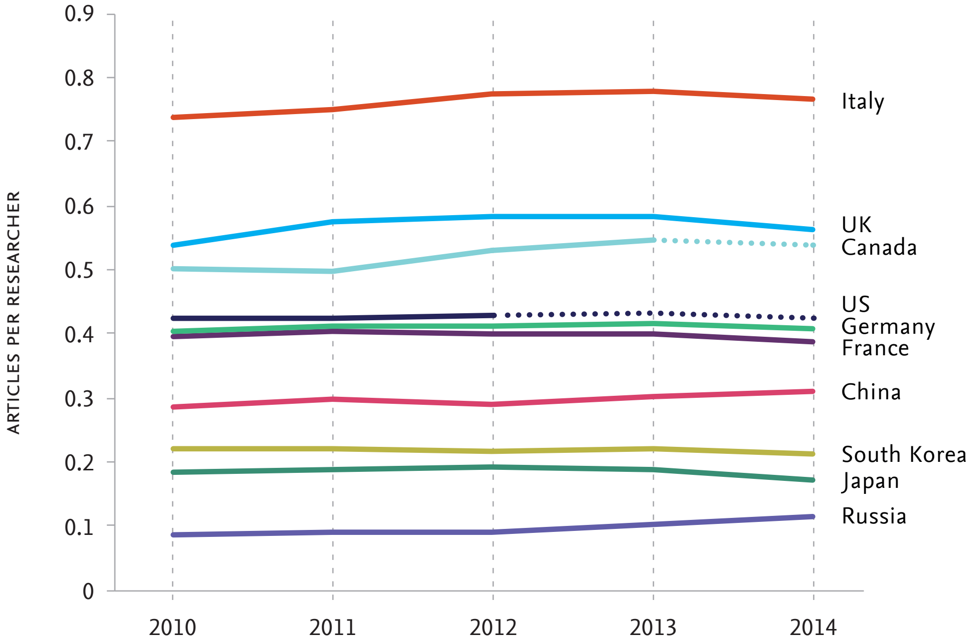


	2010	2014	Change	CAGR	UK rank 2010	UK rank 2014
UK	119.35	156.68	37.33	7.0%	–	–
G8	71.00	78.26	7.25	2.5%	1	1
EU28	76.55	85.79	9.25	2.9%	5	3
OECD41	64.29	70.35	6.06	2.3%	8	5

6.3.3 The UK is highly productive in terms of articles and citations per researcher

When the total article output for the UK is expressed per researcher[59], the UK, at 0.57 articles per researcher, per year, was second only to Italy[60] among the comparator countries by the end of the reporting period *(see Figure 6.5)*. The UK's annual rate of growth at just over 1% was higher than the averages of the G8, EU28 and OECD41 groups. China and Russia were the only comparator countries to demonstrate upward trends at the end of this period, the rest showing flat or, as is the case for the UK, declining productivity in this indicator. The UK's productivity with regards to citation output when expressed per researcher between 2010 and 2014 was 7.56 *(see Figure 6.6)*, an annual growth of over 7% and higher than the averages of the three comparator groups. This meant that the UK's position amongst comparator countries has remained unchanged in this series, it being the second highest, again behind Italy and ahead of Canada. Most other comparator countries experienced growth, the exceptions being Japan and Russia with largely static performance.

Figure 6.5 *— Articles per researcher for the UK and comparators, 2010-2014. The 2014 researcher values for the US and Canada and 2013 value for Canada are extrapolated from the OECD data. UK ranking in EU28 is amongst 22 (of 28) countries with available data, and in OECD41 is amongst 38 (of 41) countries with available data. Source: Scopus and OECD MSTI 2015/2.*

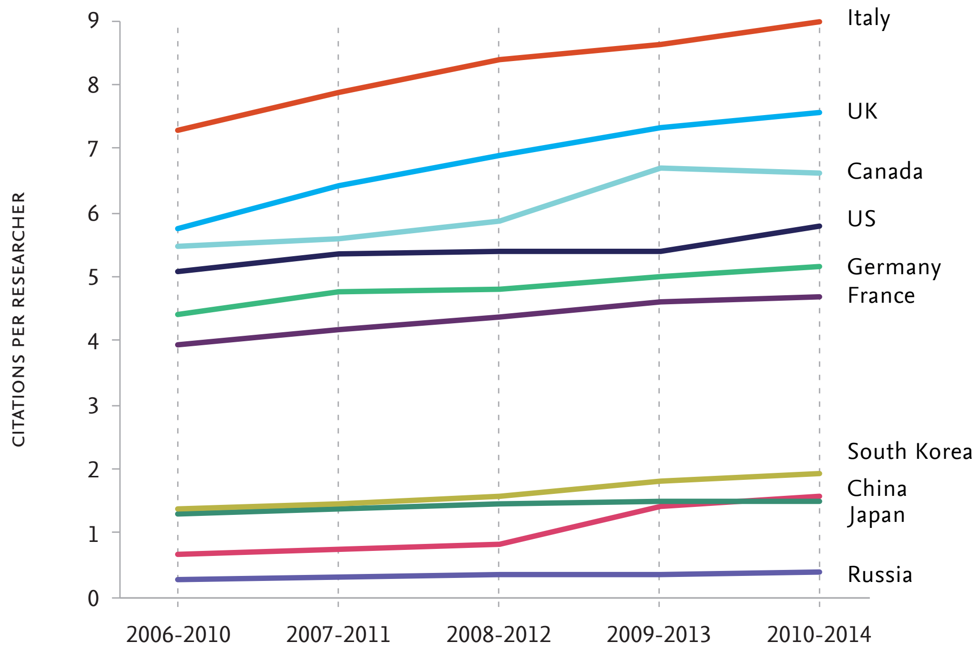


	2010	2014	Change	CAGR	UK rank 2010	UK rank 2014
UK	0.54	0.57	0.02	1.1%	–	–
G8	0.32	0.32	0.00	0.2%	2	2
EU28	0.42	0.43	0.01	0.4%	9	10
OECD41	0.30	0.30	0.00	0.1%	13	15

59 As explained in Chapter 3, researchers include not only staff working in universities and research institutes but also staff in civil and military research in government, hospitals and the business sector and also postgraduate students who conduct research.

60 Italy's position in this indicator may be overestimated due to underestimation of its researcher counts: International Comparative Performance of the UK Research Base – 2011, pp. 67. Available at www.bis.gov.uk/assets/BISCore/science/docs/I/11-p123-international-comparative-performance-uk-research-base-2011.pdf

Figure 6.6 *— Citations per researcher for UK and comparators, 2010-2014. Each data point corresponds to articles published in the first year shown and citations to these articles over the subsequent five years, and researchers for the last year shown. That is, the data point for 2010-2014 corresponds to 2010 articles and citations to these in the period 2010-2014, divided by 2010 researchers. UK ranking in EU28 is amongst 22 (of 28) countries with available data, and in OECD41 is amongst 40 (of 41) countries with available data. Source: Scopus and OECD MSTI 2015/2.*



	2006-2010	2010-2014	Change	CAGR	UK rank 2006-2010	UK rank 2010-2014
UK	5.76	7.56	1.80	7.02%	–	–
G8	2.98	3.51	0.53	4.17%	2	2
EU28	3.74	4.40	0.66	4.14%	6	6
OECD41	2.17	2.67	0.50	5.29%	9	9

CHAPTER 7

Knowledge Exchange

7.1 Highlights

UK PATENT APPLICATIONS

Applications	Increased at	Ranks	Represents
52,612	**0.8%**	**7th**	**2.0%**
in 2014	per year in the period 2010-2014	amongst comparator countries in 2014	of the global total

UK PATENT CITATION SHARE

Share	Decreased at	Ranks
9.1%	**0.6%**	**4th**
in 2014	per year in the period 2010-2014	amongst comparator countries in 2014

The UK increased its share of global patents in force and ranked third lowest amongst the comparator countries.

Although the UK accounts for a small proportion of global patenting activity, a high proportion of UK research is cited in patents.

Cross-sector knowledge exchange processes are strong in the UK, as indicated by article downloads and researcher moves, particularly between the corporate and academic sectors.

The UK excels in a number of technologies that are highly relevant to industry and have the potential to put the UK at the forefront of commercialisation.

7.2 Introduction

Knowledge exchange is the process by which any individual or organisation shares ideas and information and such exchange is integral to the progress and the success of any research initiative. Since knowledge generally resides with people and not in documents, much knowledge is tacit or difficult to articulate.

This chapter focuses on the academic-industry knowledge exchange that acts as a conduit between investment in research, from both public and private sectors, and its commercialisation, leading ultimately to economic growth. Consideration is primarily given here to explicit (codified and transferable) indicators and includes: licensing income, invention disclosures and start-up or spin-off company formation; patent applications and grants and patent citations; and cross-sector article downloads. Due to the availability of the data, the forms of the knowledge exchange we capture in this chapter are associated more with STEM (Science, Technology, Engineering and Mathematics) subjects than with the Social Sciences and Arts and Humanities. We report on the tacit indicator researcher moves, and acknowledge other tacit indicators such as teaching, joint student supervision, staff exchange and consulting. However, these indicators are not captured by the data used in this report.

7.3 Key Findings

7.3.1 UK commercialisation of intellectual property derived from academic research is comparable to the US

Despite systematically-collected data on knowledge exchange activities over time and across countries being limited, there are a growing number of sources that apply a rigorous survey-based approach to tracking key indicators of the commercialisation of academic research in the form of intellectual property (IP) that is created in higher education institutions (HEIs)[61]. IP describes intangible assets, such as discoveries and inventions, for which exclusive rights may be claimed. Common types of IP include those that may be formally recorded in copyright, trademarks, patents, and designs, although it must be acknowledged that not every discovery or invention can be codified in similar ways.

As with the time lags between publications and citations, the translation of research outcomes into products and services can be lengthy, with further time lags while the technology proves itself in the marketplace. After acquiring formal intellectual property rights – through patents, copyright, design registration or (more rarely) trademarks – it is common practice among HEIs either to license the innovation to an existing company, or to set up a new ('spin-off') company, which will likely take more time to generate significant financial returns. There is increasing interest in creating more and better indicators of commercialisation of research at a national level[62]. A small set of indicators has been proposed[63] for the commercial potential of research and its use by industry, including IP income, and new and on-going start-up and spin-off companies.

Licenses and the sale of spin-off companies are the main sources of IP income considered in this section *(see box "The definitions of research resource, IP income and spin-off companies")*.

Direct comparisons of IP income or numbers of spin-off companies may not be useful, as such comparisons do not take account of the different sizes of higher education sectors in the comparator countries. Therefore, some form of normalisation is required to allow a valid comparison.[64] The method employed in this section is to use research resource as an appropriate proxy for scale, as the information is available for HEIs, and is clearly linked to the value of available resources.

The UK's IP income amounted to £148 million in 2014, which was about 2.0% of the UK's total research resource in 2014, nearly one percentage point higher than in 2010. The US had a higher percentage *(see Figure 7.1)*, which implies that there is a higher level of research commercialization in the US than in the UK. The gap between the two countries closed in 2013 but widened slightly in 2014.

According to the Higher Education – Business and Community Interaction survey (HE-BCI), the UK had 268 spin-off companies in 2010, which reduced to 142 in 2014, while the US increased from 606 in 2010 to 840 in 2014. As a result of the reduction in the number of its spin-off companies (and, to a lesser extent, an increasing amount of research resources), the UK's research resource per spin-off increased and it overtook the US in this indicator in 2014 *(see Figure 7.2)*.

61 Association of University Technology Managers (AUTM; see http://www.autm.net/resources-surveys/research-reports-databases/), ProTon Europe (see http://www.astp-proton.eu/resource-center/publications/), the Higher Education – Business and Community Interaction survey in the UK (HE-BCI; see http://www.hefce.ac.uk/ke/hebci/) and Hughes, A., Lawson, C., Salter, A., Kitson, M. with Bullock, A. and Hughes, R.B. (2016) 'The Changing State of Knowledge Exchange: UK Academic Interactions with External Organisations 2005 -2015', NCUB, London.

62 Finne, H. *et al.* (2011) "A Composite Indicator for Knowledge Transfer" Report from the European Commission's Expert Group on Knowledge Transfer Indicators.

63 Arundel, A. & Bordoy, C. (2008) "Developing internationally comparable indicators for the commercialization of publicly-funded research" United Nations University MERIT Working Paper Series #2008-075.

64 Interpretation of conclusions from benchmarking should always take into consideration that definitions of indicators may vary between surveys.

Figure 7.1 — *IP income as percentage of total research resource. Source: Higher Education – Business and Community Interaction Survey reports 2010-11, 2011-12, 2012-13, 2013-14 and 2014-15*[65].

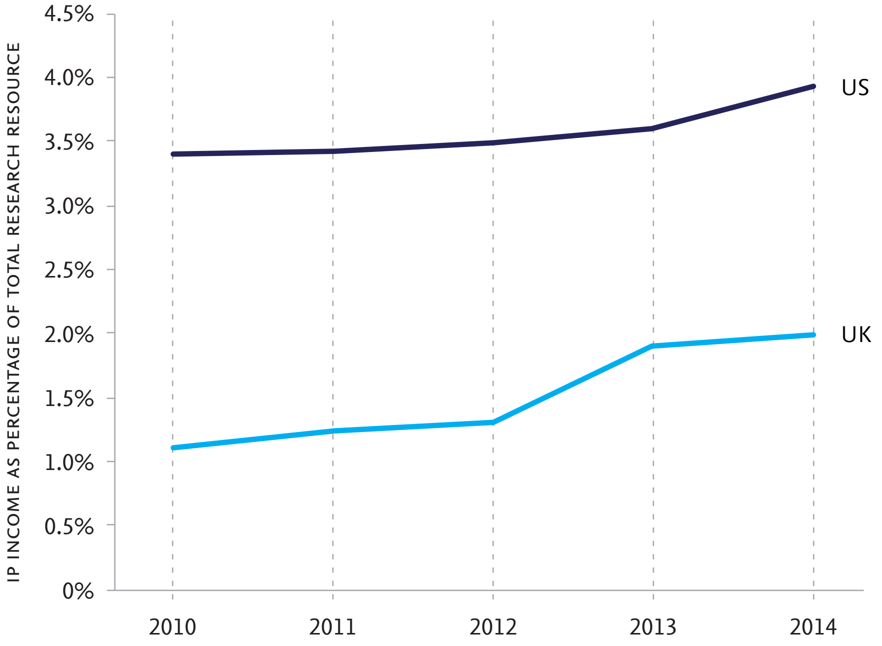
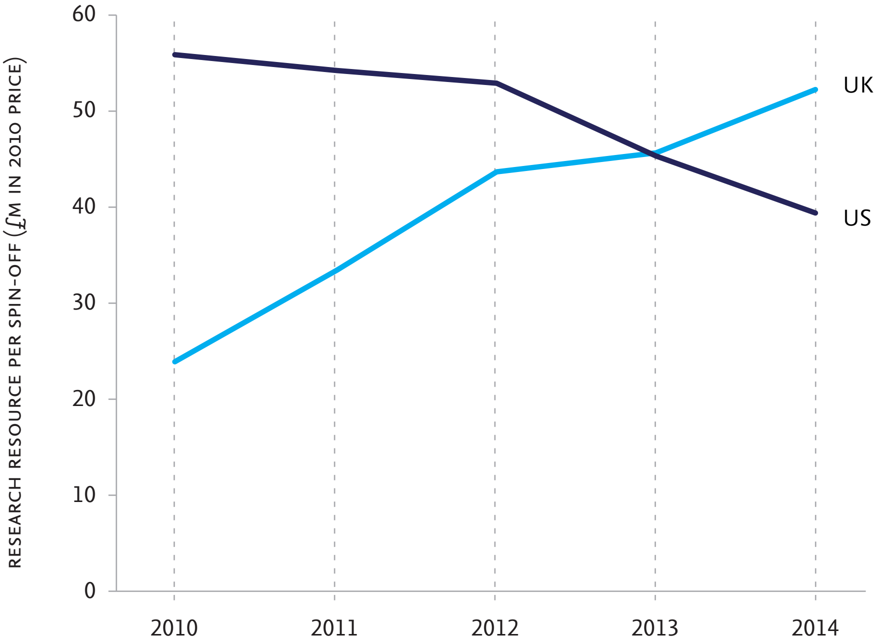


Figure 7.2 — *Research resource (million GBP in 2010 price) per spin-off. The original values in the Higher Education – Business and Community Interaction Survey reports are deflated using OECD PPP rates. Source: Higher Education – Business and Community Interaction Survey reports 2010-11, 2011-12, 2012-13, 2013-14 and 2014-15.*



65 http://www.hefce.ac.uk/ke/hebci/

THE DEFINITIONS OF RESEARCH RESOURCE, IP INCOME AND SPIN-OFF COMPANIES

Research resource
In HE-BCI, research resources are defined as income to higher education institutions (HEIs) reflecting the market value of the following types of knowledge exchange activity in the economy and society: collaborative research, contract research, consultancy, equipment and facilities, continuing professional development, regeneration and intellectual property. Research resources for the US are drawn from the Association of University Technology Managers (AUTM) data of "total research expenditures"; this includes expenditures (not new awards) made by the institution in the survey year in support of its research activities that are funded by all sources, including the federal government, local government, industry, foundations, voluntary health organizations, and other non-profit organizations.

IP income
HE-BCI identifies intellectual property (IP) income as income from licenses and the sale of spin-off companies. IP income for the US is taken from the AUTM data of "license income received", which includes license issue fees, payments under options, annual minimums, running royalties, termination payments, the amount of equity received when cashed-in, and software and biological material end-user license fees equal to $1,000 or more.

Spin-off companies
The total number of UK higher education institution spin-off companies is derived from the HE-BCI survey, and includes those companies with some Higher Education (HE) provider (roughly equivalent to a HEI) ownership and those that use HE-generated IP as a basis for their operation. The start-up companies defined in the AUTM survey are those dependent on institutions' technology for initiation, and so ca equivalent to those spin-off companies recorded in the UK's HE-BCI surveys.

7.3.2 The UK accounts for a small proportion of global patenting activity, but a high proportion of UK research is cited in patents

There is a direct correlation between the existence of IP and patenting activity – patenting activity can only happen if IP exists, but not all IP can be patented[66]. The same cannot be said of all knowledge exchange, but, although the act of exchanging knowledge may not lead directly to patenting activity, patenting activity may be used to indicate the existence of knowledge exchange processes[67]. National patenting activity can be measured at three key stages: application for a patent, the granting of a patent, and the on-going enforcement of a patent *(see box "Counting patent applications, patent grants and patents in force" on page 102)*. Among the comparator countries, the UK outperformed only Italy and Canada in each of the three stages.

The number of patent applications filed by UK residents increased by just under one percentage point over the period 2010-2014, with 52,612 applications made in 2014. Despite this increase in absolute terms, the UK's share of global patent applications decreased over the period to 2.0% in 2014, a drop of 0.5 percentage points since 2010 *(see Figure 7.3)*. China saw a dramatic increase in its global share over the period, overtaking the US and Japan in 2012, and ended the period with its residents filing over 31% of global patent applications in 2014. As a result of this growth, the US and Japan, and to a lesser degree Germany, experienced decreases in their global shares. South Korea held steady over the period with a share of nearly 9% in 2014.

With 21,222 patents granted in 2014, the UK's share of global patents granted remained stable at 1.8% over the entire period *(see Figure 7.4)*. Japan continued to have the largest share in this indicator but its continued decline and a corresponding increase by the US saw the two comparators moving closer together. China's significant growth in its global share of patent applications has not yet translated into patents granted but its global share of patents granted still grew quite sharply over the period.

The UK saw its best performance in patent activity in the number of patents in force – in 2014, there were 169,878 UK patents in force, a significant increase of 15% per year in the period 2010-2014. This led to an increase in the UK's share of global patents in force to nearly 2% *(see Figure 7.5)*, an increase of 0.3 percentage points over the reporting period and a reversal of the decline noted in the last report in this series. However, its share ranked third lowest amongst the comparator countries. Japan and the US together continued to have over half of the global share of patents in force; China was the only comparator country showing a clear upward trend in its share of this indicator.

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66 The UK government provides examples of inventions that cannot be patented including: "literary, dramatic, musical or artistic works; a method of medical treatment or diagnosis; a discovery, scientific theory or mathematical method; and 'essentially biological' processes, e.g., crossing-breeding plants, and plant or animal varieties" (www.gov.uk/patent-your-invention)

67 Jensen, M.B., Johnson, B., Lorenz, E., Lundvall, B. Å. (2007) "Forms of knowledge and modes of innovation", *Research Policy*, 36 (5) pp. 680-693.

Figure 7.3 — *Share of global patent applications for UK and comparators, 2010-2014.*
Source: WIPO Statistics Database (December 2015).

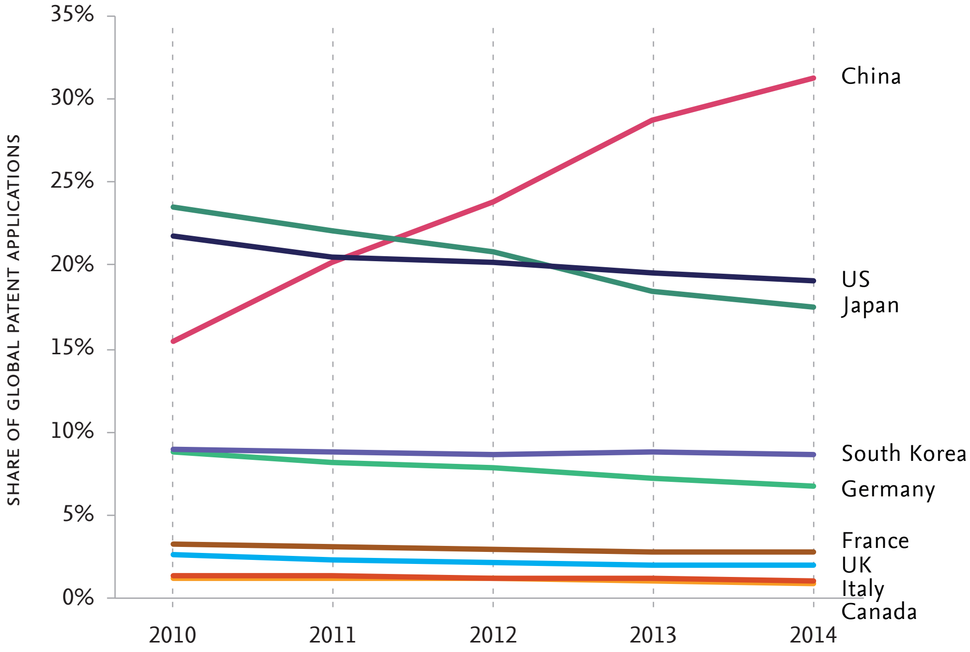


Figure 7.4 — *Share of global patent grants for UK and comparators, 2010-2014.*
Source: WIPO Statistics Database (December 2015).

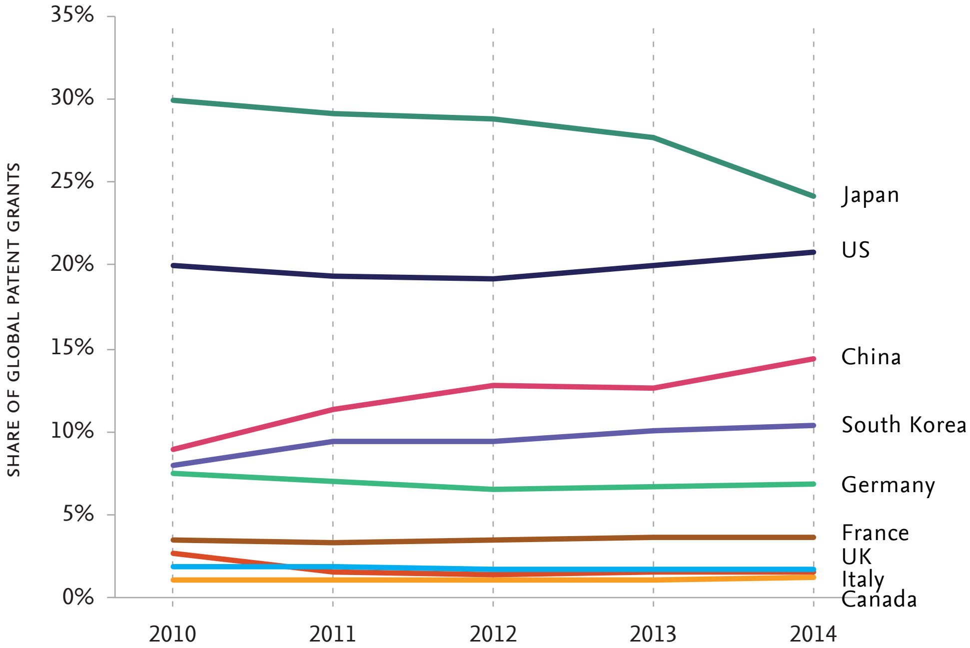
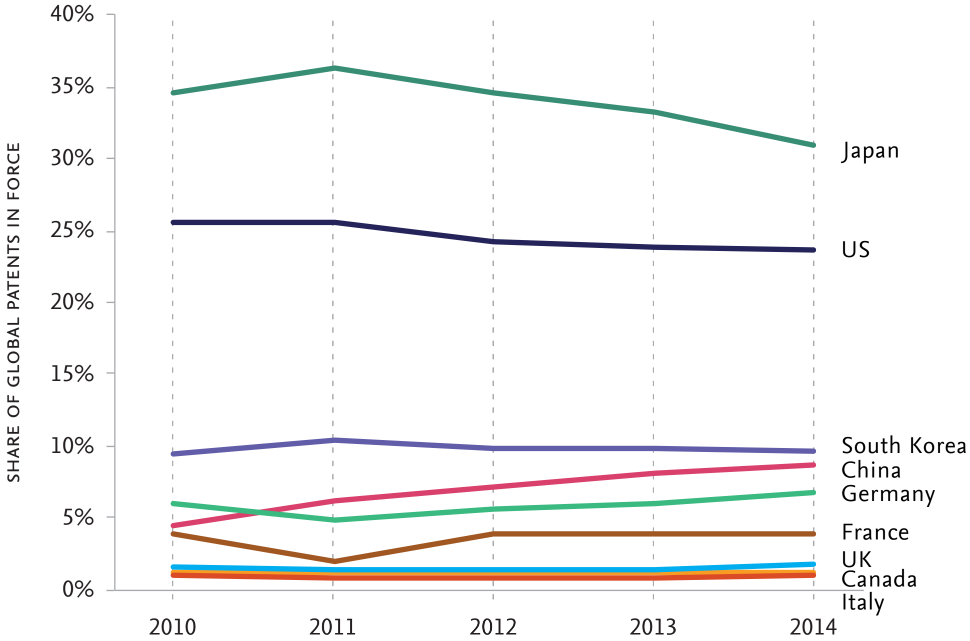


Figure 7.5 — *Share of global patents in force for UK and comparators, 2010-2014. Source: WIPO Statistics Database (December 2015).*



COUNTING PATENT APPLICATIONS, PATENTS GRANTED AND PATENTS IN FORCE

The patenting process can be divided into three distinct phases: (1) filing an application for a patent and its examination; (2) the registration of a decision (granted or not); and (3) the on-going payment of maintenance fees to keep the patent in force. Data indicating the volume of patenting activity in each of these phases are available: patent applications, patents granted, and patents in force. It is tempting to attempt to calculate the patenting "efficiency" of a given country by dividing the number of patents granted by the number of patent applications, for example. However, given the variable length of time taken for the examination of a patent application, phasing issues mean that any indicator derived in such a way could be somewhat misleading. It is important to note that these counts for patent applications, patents granted, and patents in force are totals, aggregated across all fields of research and all sectors of R&D performance. However, not all research fields, sectors or even countries have the same patenting norms, and so national patenting activities may reflect national research field specialisation, industry focus or cultural convention[68].

As a rule, a patent application must include one or more claims that define the invention, demonstrating its novelty and the "inventive step" that separates this invention from the prior art (i.e., from existing publicly-available documentary sources). To support such claims, many patent applications cite journal articles providing information that support or are related to the claims but do not constitute prior art. Therefore, the share of a country's articles cited in patent applications is an indicator of the success with which research findings published in journal literature are used to justify the patentability of an invention; this can be seen as a form of knowledge exchange that contributes to economic growth.

UK articles were cited steadily in global patents *(see Figure 7.6)* during the reporting period, with over 9% of global patent citations citing UK articles in 2014, three percentage points higher than the UK's global publication share for the same year *(refer to Figure 4.1)*. Of the comparator countries, the US had the highest global citation share at nearly 45%, well ahead of China with just over 12%, and of Germany, which was only marginally ahead of the UK. Although China and Canada both showed some growth between 2010 and 2014, there was general stability in this indicator across the comparator countries.

68 van Pottelsberghe de la Potterie, B. (2008) "Europe's R&D: Missing the wrong targets?" *Intereconomics* 43 (4) pp. 220-225.

The global share of a country's patent citations is influenced by the number of articles it publishes (and therefore are available to be cited in patents). The relative citation share corrects patent citation shares for differences in publication output shares. The UK's relative share of article output cited in global patents was much higher than the world average of 1.0 throughout the reporting period, ending at 1.44 *(see Figure 7.7)*. The US had the highest share at 2.00 in 2014, with Germany in second place at 1.55 and Canada rising to take third place at 1.50. The lowest relative patent citation shares were associated with emerging countries such as China, India, Brazil and Russia; although China's global patent citation share increased, its relative share remained stable because its rapid growth in published articles kept pace with its growth in patent citations. Among the other comparators, South Korea showed a sharp decrease in its relative share from 2012 onwards, and Japan showed a drop in 2013 but improved its position in 2014.

Figure 7.6 — *Share of patent citations to articles published for the UK and comparators with the right panel excluding US for clarity, 2010-2014. Each data point corresponds to articles published in the year shown and citations to these articles from patent applications and granted patents thereafter. Source: LexisNexis Univentio and Scopus.*

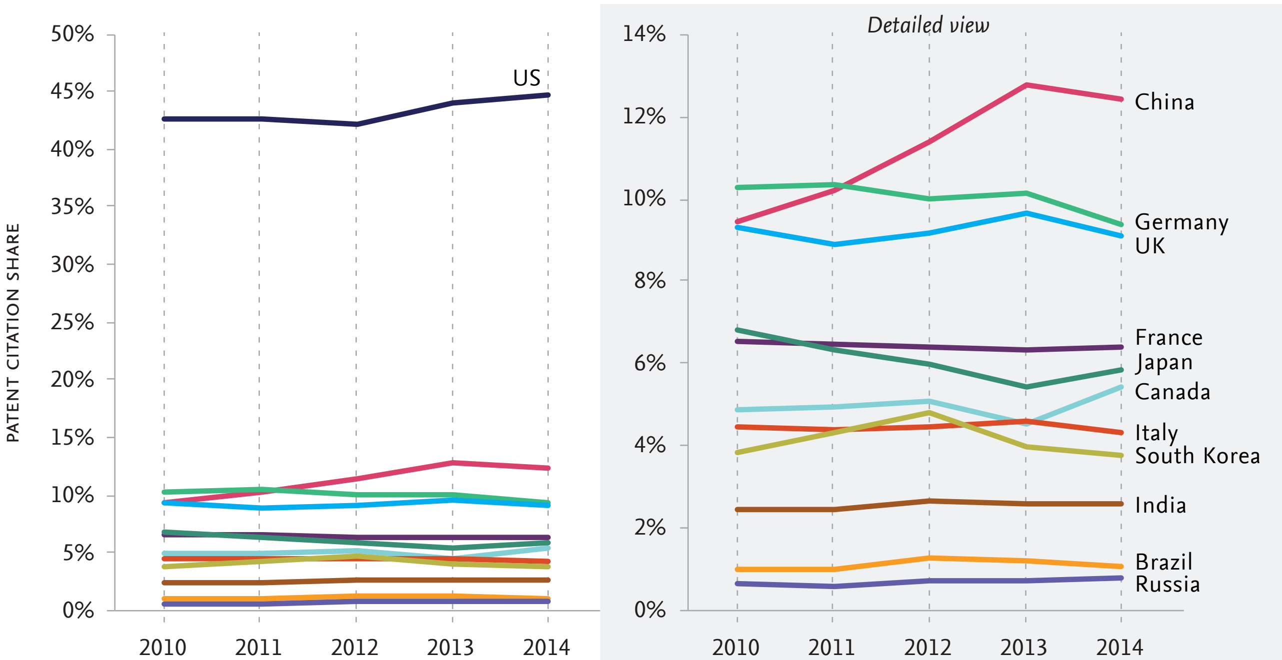
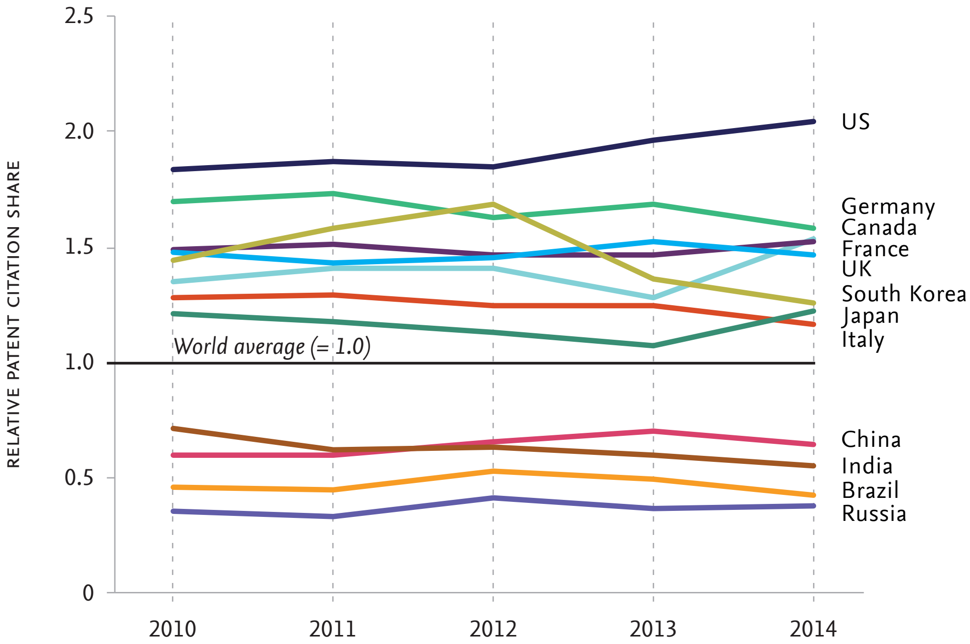


Figure 7.7 — *Relative share of patent citations to articles published for the UK and comparators, 2010-2014. Each data point corresponds to each country's share of patent citations (as in Figure 7.6), divided by the country's share of global publication output to give a global baseline defined at 1.0. Source: LexisNexis Univentio and Scopus.*



7.3.3 UK academia and UK industry increase their cross-sector usage of UK authored articles

While the majority of the UK research output is produced by the academic sector, 3.1% of all publications in the reporting period were generated by the corporate sector. The high proportion of downloads of UK articles that have one or more authors with a corporate or academic sector affiliation by other UK sector users is an indication that there are strong cross-sector knowledge flows within the country. Between 2011 and 2015 nearly 64% of downloads of corporate-authored articles came from UK academia and almost 33% came from users in the corporate sector itself *(see Figure 7.8)*. There was an increase of one percentage point in such downloads by academia and a corresponding decrease in the corporate user downloads between 2006-2010 and 2011-2015, continuing an upward trend in the usage of corporate-authored research by the academic sector.

Nearly half of all the articles downloaded by users in the UK corporate sector had at least one academic affiliation and a further 32% were articles with one or more corporate authors *(see Figure 7.9)*. Downloads of academic-authored articles by corporate users between 2006-2010 and 2011-2015 increased by almost two percentage points, which indicates a growing usage of academia-authored research in the corporate sector.

***Figure 7.8** — Downloading sector distribution of downloads by UK users of articles with at least one UK corporate author, 2006-2010 and 2011-2015. Source: Scopus and ScienceDirect.*

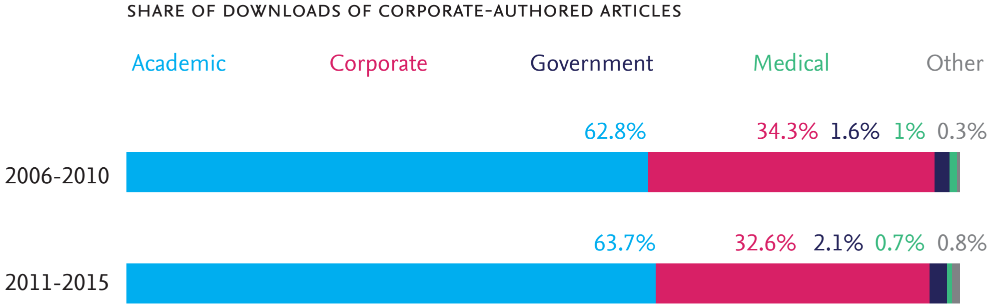
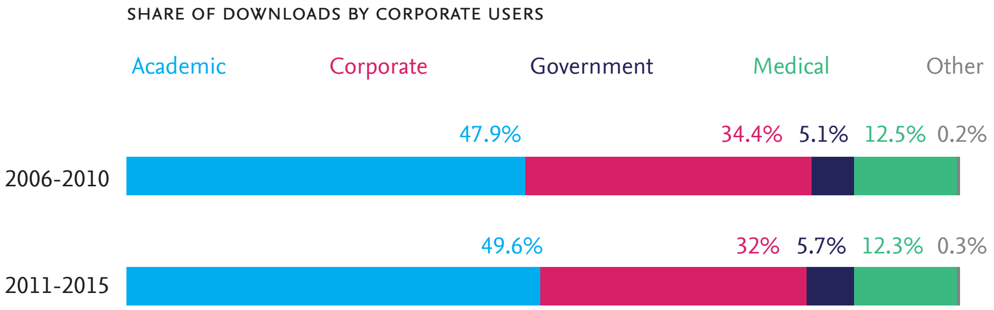


***Figure 7.9** — Publishing sector distribution of downloads of UK articles by UK corporate users, 2006-2010 and 2011-2015. Since some articles are co-authored between sectors, shares have been normalised to add to 100%. Source: Scopus and ScienceDirect.*



7.3.4 The UK shows more cross-sector movements internationally than within the country

The cross-sector mobility of researchers between academia and industry, both within a country and internationally, is a key indicator of the existence of knowledge exchange[69]. Within the UK, and as seen by the Scopus data, there were more moves by researchers from academia to industry than *vice versa*, with a net domestic inflow to industry of 1,870 (i.e., 11,762 moves from academia to industry and 9,892 from industry to academia) between 1996 and 2015 *(see Figure 7.10)*. Similarly, the UK corporate sector saw a net gain of 1,714 in researcher moves from international industry (i.e., 13,649 - 11,935), while the UK academic sector experienced a net loss of 2,187 moves (i.e., 14,851 - 12,664) to international industry.

Comparator countries showed quite different cross-sector patterns to the UK. Whereas the UK's overall pattern showed more movement between academic and corporate affiliations internationally than domestically, as did Italy's and Canada's, the majority of comparators (France, Germany, Japan, the US, China, India, Russia, Brazil and South Korea) had more domestic than international moves. This is likely to relate to the way that the R&D effort is structured, such that Italy and Canada, along with the UK, have the highest proportion of R&D performed in the Higher Education sector. Interestingly South Korea had a large number of cross-sector moves, particularly domestic moves, for such a relatively small country, with the actual count of domestic moves being relatively similar to that of China.

The balance of international inflow and outflow varied across the comparator countries. The UK had a more or less balanced pattern, as did Germany and Brazil, but others showed a greater disparity. For example, the US and France had considerably greater movement from international academic to domestic corporate affiliations than from international corporate to domestic academic affiliations. The US and France also showed considerably greater movement from domestic corporate to international academic affiliations than from domestic academic to international corporate affiliations. Canada and China demonstrated the opposite patterns.

Figure 7.10 *(see next page) — Cross-sector moves of researchers between academia and industry, either domestically or internationally for UK and comparators (also Brazil, India and Russia), 1996-2015. This analysis is based on Scopus author data and reflects the number of observed moves, not the number of researchers moving, and so may reflect some researchers moving more than once in this period. Note that the axis maximum/minimum has been increased for Japan (to ±60,000) and for the US (to ±160,000). Source: Scopus.*

69 Herrera, L. *et al.* (2010) "Mobility of public researchers, scientific knowledge transfer, and the firm's innovation process" *Journal of Business Research* 63 (5) pp. 510-518.

Figure 7.10 (see caption on previous page)

7.3.5 UK excels in many technologies that are highly relevant to industry

The UK has identified a number of key technologies where the UK has world leading research, where the technologies have a range of applications across a spectrum of industries, and where these technologies have the potential for the UK to be at the forefront of commercialisation. This section examines how the UK compares in research output and field-weighted citation impact for a number of emerging technologies: Advanced Materials and Nanotechnology; Agri-Science; Big Data and Energy-efficient Computing; Energy and its Storage; Genomics and Synthetic Biology; Regenerative Medicine; Robotics and Autonomous Systems; and Satellites and Commercial Applications of Space; it also looks at its performance in Quantum Technology.[70]

In 2014, the FWCI of the UK's publications was high in all nine technologies, demonstrating that the UK produces world-leading research in technologies that have great potential for commercialisation *(see Figure 7.11)*. It ranked first among the comparator countries in four out of the nine technologies: Genomics and Synthetic Biology, Regenerative Medicine, Robotics and Autonomous Systems, and Satellites and Commercial Applications of Space. Among the comparators, the UK ranked third in the number of publications in Big Data and Robotics and it ranked fourth in Genomics and Synthetic Biology.

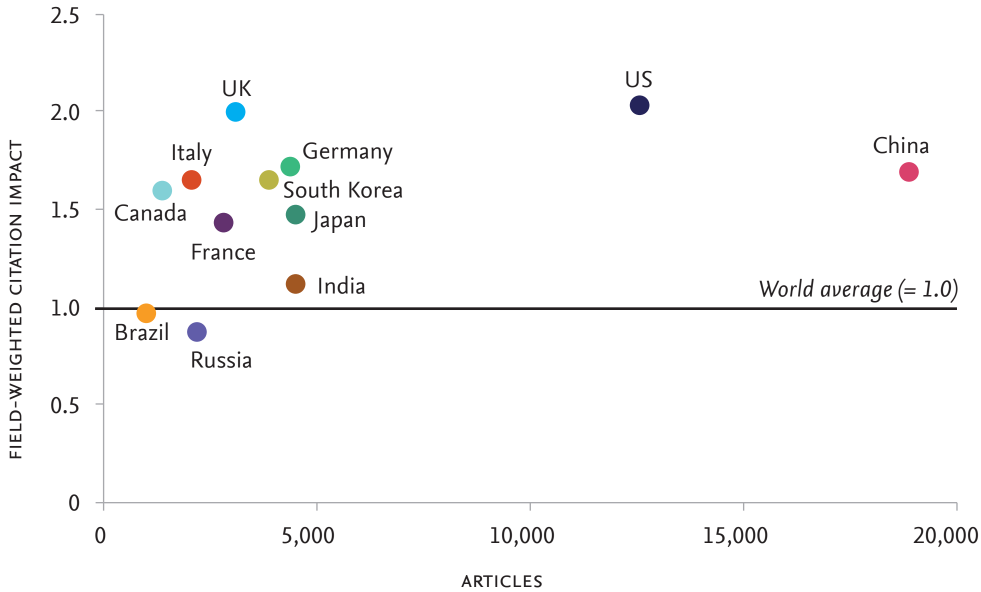
The US and China had the highest numbers of publications in all nine technologies. China led in technologies related to materials, energy and agriculture, while the US led in those related to information technology and medicine. Germany had a leading position in Quantum Technology, with the highest FWCI and third highest number of publications in this technology; it also performed well in Robotics, with the second highest FWCI (after the UK) and fourth highest number of publications.

Figure 7.11 *(see next pages) — The number of publications and field-weighted citation impact for the UK and comparators, 2014. Source: Scopus.*

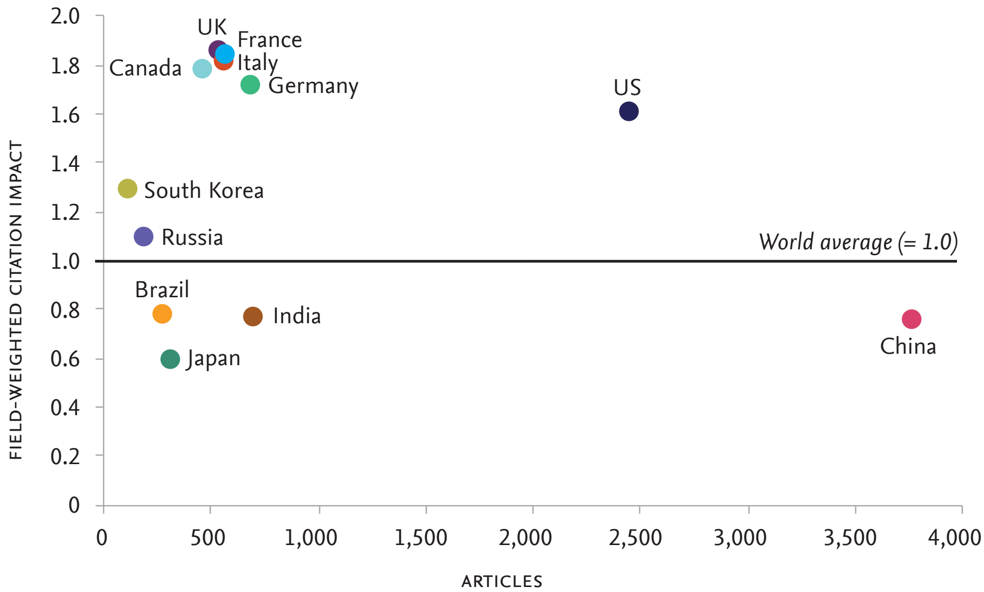
70 The first eight of these have been identified as the "Eight Great Technologies" in 2012, being a core part of the former UK government's Industrial Strategy (see www.gov.uk/government/publications/eight-great-technologies-infographics). The Industrial Strategy Challenge Fund (ISCF), announced to be created in November 2016 by the current UK government, appears to incorporate stimulating these technological sectors into its strategy (see https://beisgovuk.citizenspace.com/strategy/industrial-strategy/supporting_documents/buildingourindustrialstrategygreenpaper.pdf)

Figure 7.11 *(see caption on previous page)*

a) **Advanced Materials and Nanotechnology**



b) **Agri-Science**



c) **Big data**

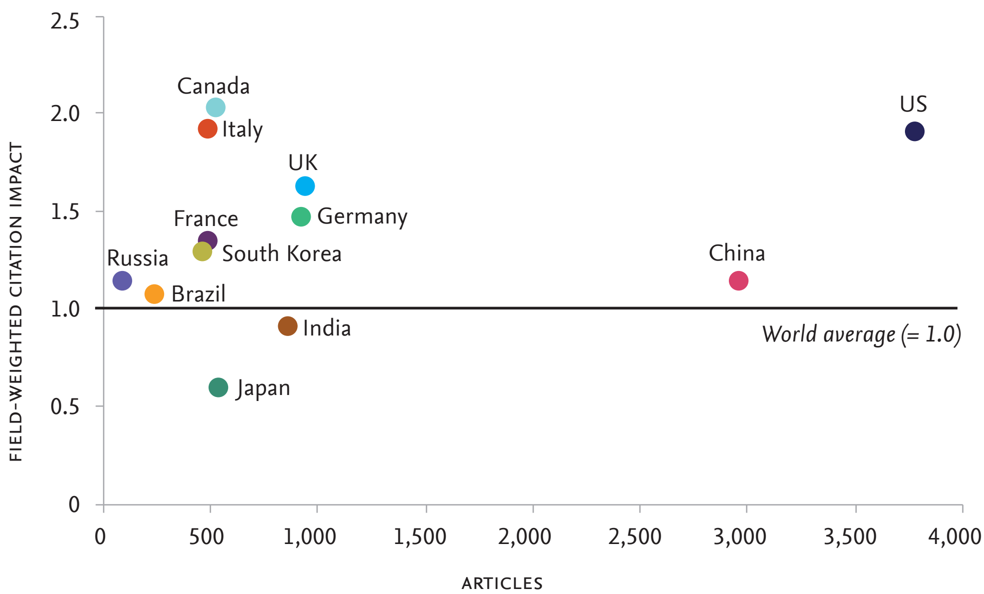
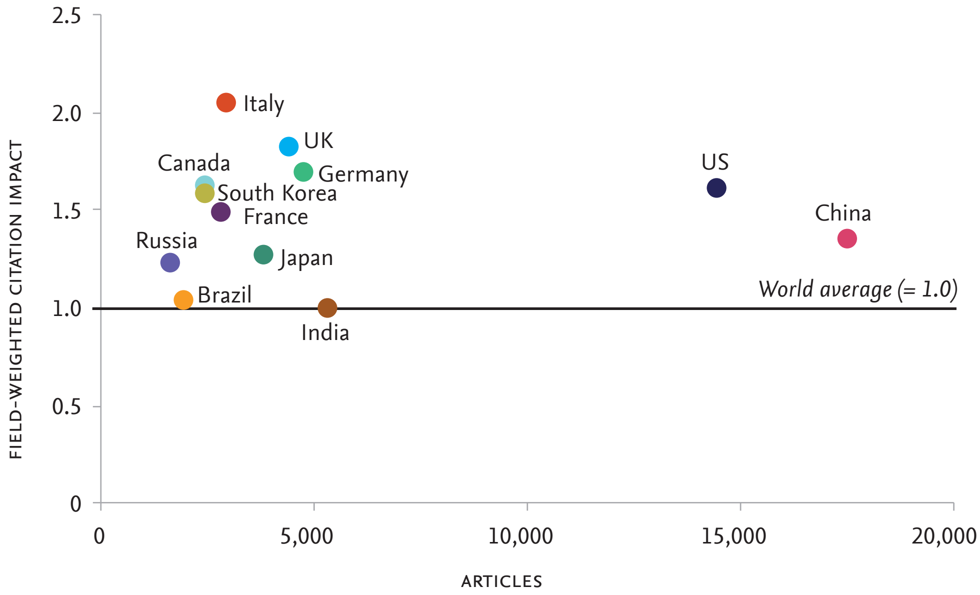
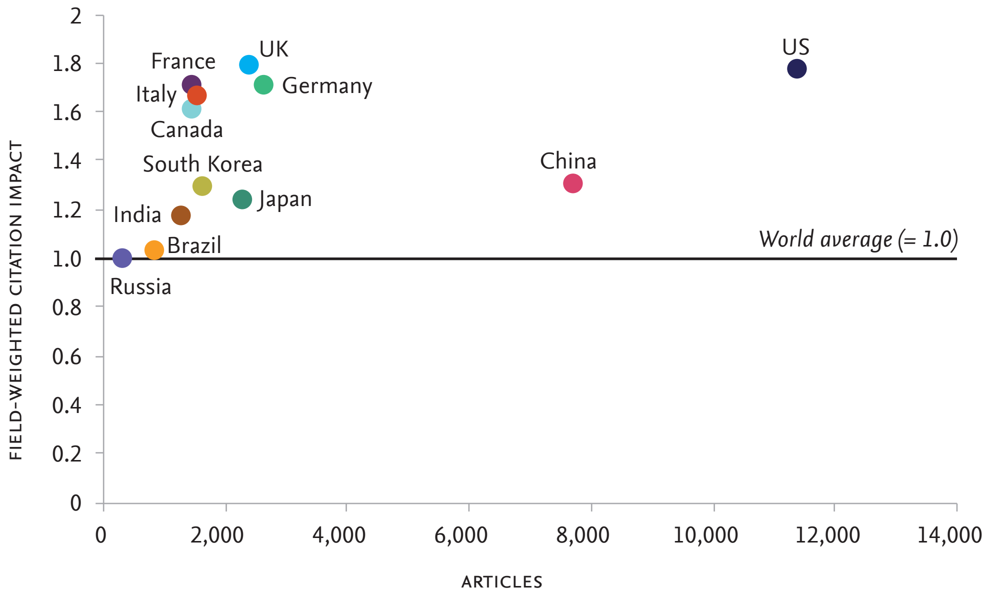


Figure 7.11 (continued)

d) **Energy and its Storage**



e) **Genomics and Synthetic Biology**



f) **Quantum Technology**

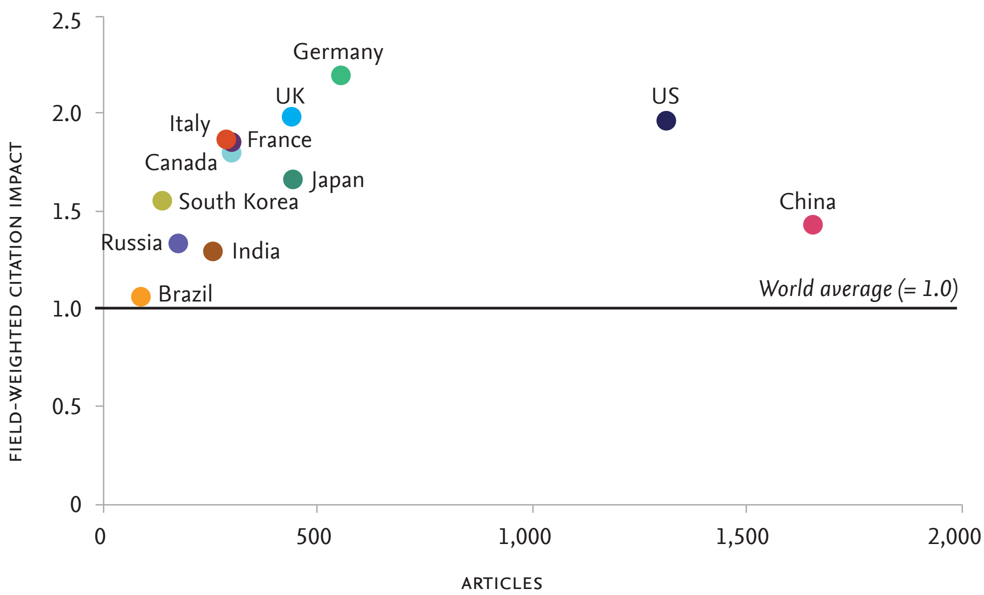
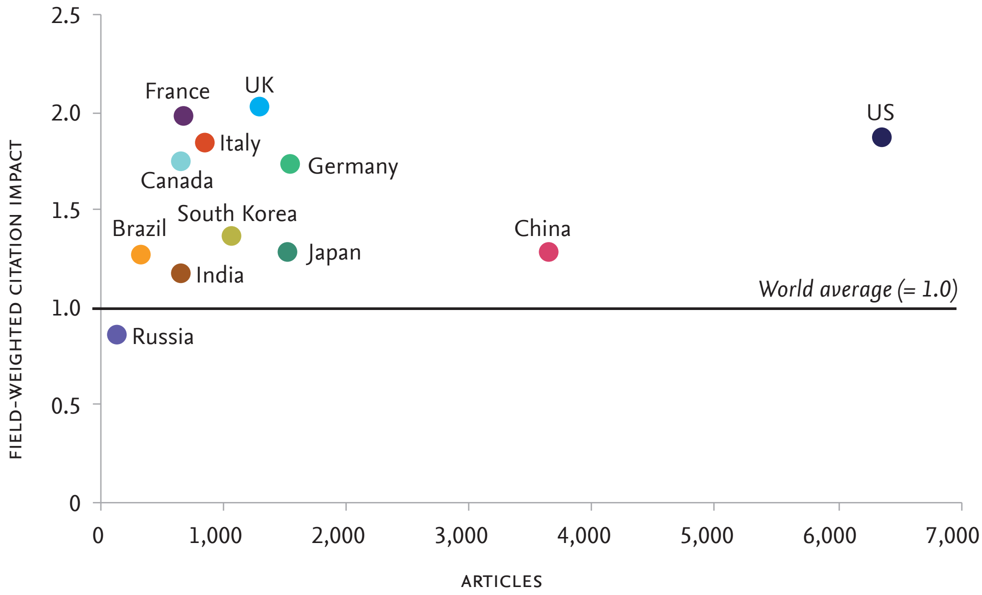
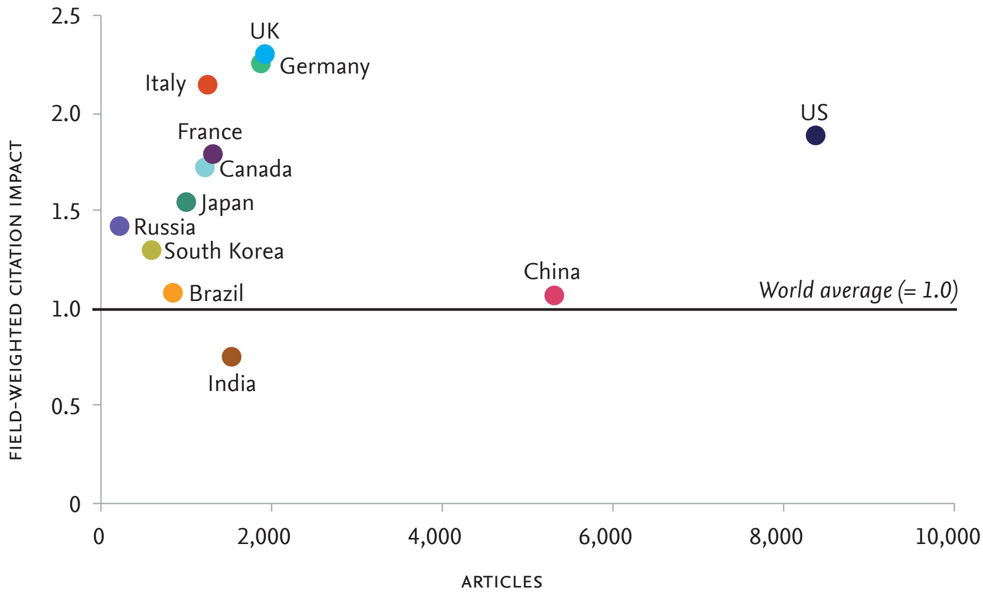


Figure 7.11 (continued)

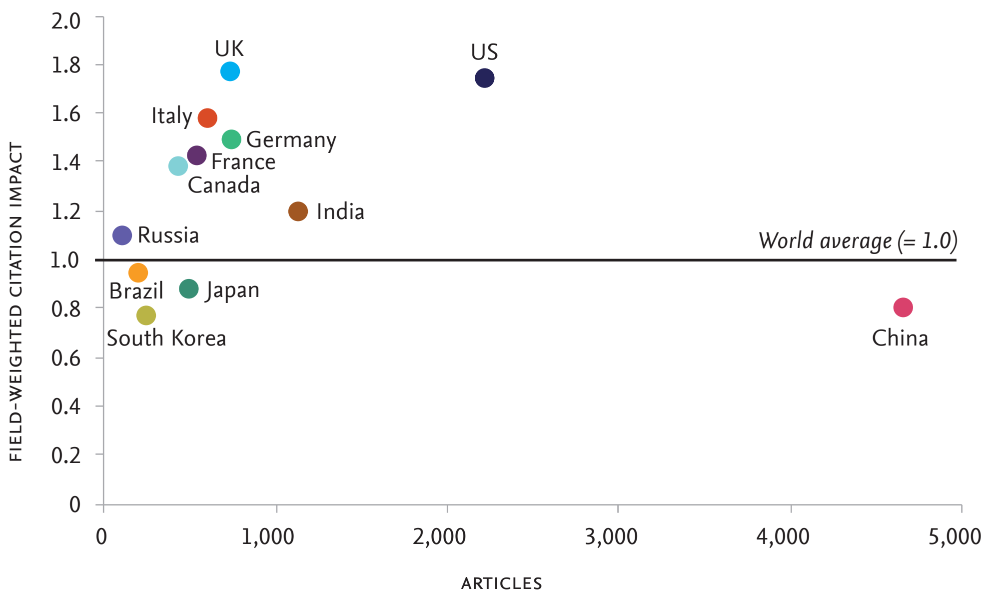
g) **Regenerative Medicine**



h) **Robotics and Autonomous Systems**



i) **Satellites and Commercial Applications of Space**



7.3.6 Collaborations between the academic sector in UK regions and the corporate sector are many and varied

Collaborations between the academic sector in UK regions and companies in the corporate sector are many and varied. A region's research strengths may influence or be influenced by the opportunities offered by geographical proximity of industry and academia. The academic sector in the UK's regions share numerous corporate collaborators (*see Figure 7.12*, noting that, due to the discipline coverage limitations of the dataset, the chart does not reflect all the research strengths that have a strong interface with the corporate sector). Almost every region collaborates with large pharmaceutical companies such as GlaxoSmithKline, Merck, Pfizer, and AstraZeneca, software giants like Microsoft, or diverse engineering companies like Rolls Royce, to one degree or another, which is why these companies appear in the centre of the chart.

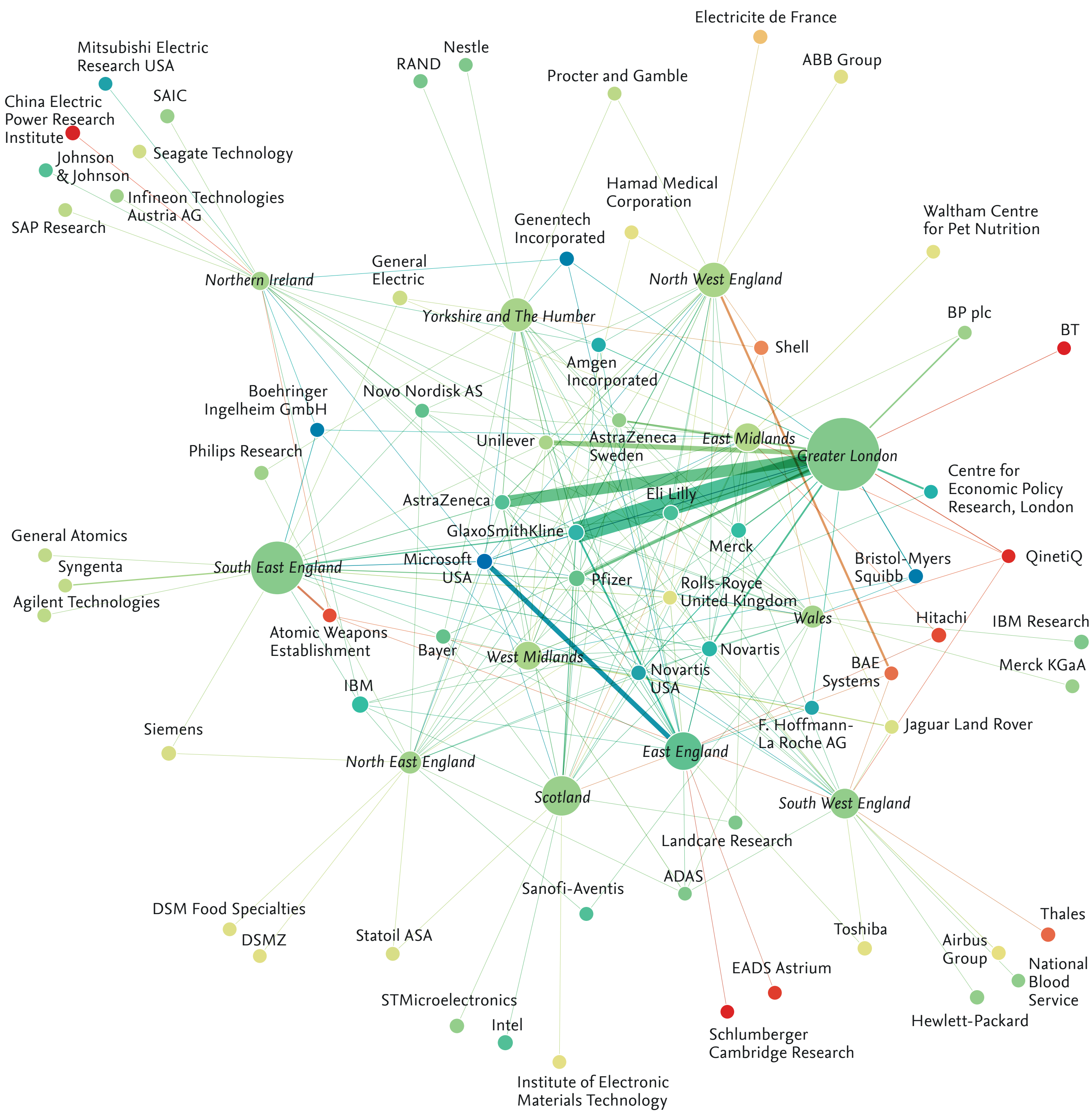
Universities and research institutions play a key role in generating innovation and defining future job growth in cities and regions – businesses position themselves close by in order to benefit from these outputs. For example, AstraZeneca decided to establish a new Global R&D Centre and corporate headquarters on the Cambridge Biomedical Campus in East England because of its proximity to world-leading scientific expertise and collaborative opportunities with academic research institutions, hospitals and biotech companies[71].

Regions also have their specific collaborators. Northern Ireland has a group of collaborators that do not appear among the top collaborators of other regions. Of particular note, China Electronic Power Research Institute, one of its top collaborators, is the only Chinese company that appears in the chart.

71 http://www.astrazeneca.co.uk/astrazeneca-in-uk/our-uk-sites/cambridge

Figure 7.12 *— Collaboration network map between the academic sector by UK regions and their top 20 corporate collaborators, 2011-2015.*

Node size is proportional to overall article output for each entity. Node colour is the field-weighted citation impact of the article output of the entity (on a scale from red (below 1.0) to blue (above 1.0), with yellow at the world average (1.0)). Edges are weighted by the number of collaborative articles between each pair of entities and edge colour is the field-weighted citation impact of the co-authored articles between each entity pair (on a scale from red (below 1.0) to blue (above 1.0), with yellow at the world average (1.0)). Data are visualised with Gephi. UK regions are placed according to their geographical location, and other nodes were placed using the ForceAtlas2 layout algorithm based on the number of collaborative articles between the node and the regions. The more collaborative articles a company has with a region, the closer they are plotted to each other. Source: Scopus.



Appendices

Appendix A
Author Credits, Advisory Groups, and Acknowledgements

This study was commissioned and funded by the UK's Department for Business, Energy & Industrial Strategy (BEIS). It was delivered by M'hamed El Aisati (Project Governor), Dr Judith Kamalski (Project Director), Dr Nick Fowler (Supplier Quality Assurance Chair), Dr Sophia Katrenko (Technical Work Stream Lead), Dr Lei Pan (Analytical Work Stream Lead), Dr Andrew Plume and Susan Lacey (Editorial Work Stream Lead), Dr Lesley Thompson (Communications Work Stream Lead), and Lisette van Kessel (Project Manager) at Elsevier. Other contributors include (in alphabetical order): Jeroen Baas, Thomas Gurney, Anton Jumelet, Eleonora Palmaro, and Steven Scheerooren.

Where applicable, missing OECD data values were estimated using established statistical methods by Statisticor (www.statisticor.nl). Statistical quality control and internal data quality was assessed by the Quality Assurance Group (consisting of Dr Nick Fowler and Mayur Amin, at Elsevier) and by Dr John T. Green at Queens' College, University of Cambridge.

The Advisory group at the BEIS was responsible for oversight, review and final sign-off of the report. Special thanks to Aloke Siddique and Lauretta Gable, and colleagues at BEIS for their collaboration and valuable reviews of draft versions of the report.

Preliminary findings were reviewed in three workshops with 15 participants representing organisations including Academy of Medical Sciences, BP plc, Campaign for Science and Engineering, Cardiff University, the Economic and Social Research Council, the Higher Education Funding Council for England, Imperial College London, Innovate UK, King's College London, Lancaster University, Research Councils UK, the Royal Society, the University of Aberdeen, and the University of Nottingham. We are indebted to the participants in the report review workshops for their advice and perspectives.

The report was designed for online and print by CLEVER°FRANKE (www.cleverfranke.com).

The report is available online via the UK's Department for Business, Energy & Industrial Strategy (www.beis.gov.uk).

Appendix B
Glossary of Terms

Activity Index
The Activity Index is defined as a country's share of its total article output across subject field(s) relative to the global share of articles in the same subject field(s).

Article
The term 'article' and 'publication' are used interchangeably in this report to denote the main types of peer-reviewed documents: articles, reviews and conference proceedings.

Article output
The article output for a country is the count of articles with at least one author from that country (according to the affiliation listed in the authorship byline). Unless specified, analyses make use of 'whole' rather than 'fractional' counting: an article representing international collaboration (with at least two different countries listed in the authorship byline) is counted once each for every country listed.

Compound annual growth rate (CAGR)
Compound annual growth rate (CAGR) is defined as the year-over-year constant growth rate over a specified period of time. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series. Throughout the term CAGR is also referred to as '(yearly) growth rate'.

Citation
Formal references to earlier work made in an article or patent, frequently to other journal articles. A citation is used to credit the originator of an idea or finding and is usually used to indicate that the earlier work supports the claims of the work citing it. The number of citations received by an article from subsequently-published articles is a proxy of the quality or importance of the reported research.

Collaboration
Research collaboration in this report is categorised by three different types of co-authored publications: articles with at least two different countries listed in the authorship byline *(international)*, articles with at least two different institutions from the same country listed in the authorship byline *(national)*, and articles with at least two authors from the same institution as authors *(institutional)*.

Digital readership
The number of Mendeley users who have added a particular article to their personal library. Mendeley readership complements traditional bibliometrics such as citation counts by showing an early indicator of the impact a work has, both on other authors as well as non-authors such as clinicians, policymakers, funders, and students. Additionally, some early research into the relationship of Mendeley readership with traditional citations has found evidence supporting that Mendeley readership counts correlate moderately with future citations.[72]

Download
A download in this report is the event where a user views the full-text HTML of an article or downloads the full-text PDF of an article from ScienceDirect, Elsevier's full-text journal article platform.

72 Costas, R., Zahedi, Z., & Wouters, P. (2015). Do "altmetrics" correlate with citations? Extensive comparison of altmetric indicators with citations from a multidisciplinary perspective. *Journal of the Association for Information Science and Technology*, 66(10), pp. 2003-2019. doi:10.1002/asi.23309; Thelwall, M., Haustein, S., Larivière, V., & Sugimoto, C. R. (2013). Do altmetrics work? Twitter and ten other social web services. *PloS One*, 8(5), e64841. doi:10.1371/journal.pone.0064841

Field-weighted citation impact (FWCI)	Field-weighted citation impact is an indicator of mean citation impact; it compares the actual number of citations received by an article with the expected number of citations for articles of the same document type (article, review, or conference proceeding), publication year, and subject field. Where the paper is classified in two or more subject fields, the harmonic mean of the actual and expected citation rates is used. The indicator is therefore always defined with reference to a global baseline of 1.0 and intrinsically accounts for differences in citation accrual over time, differences in citation rates for different document types (e.g., reviews typically attract more citations than research articles), as well as subject-specific differences in citation frequencies overall and over time and document types.
Field-weighted download impact (FWDI)	Field-weighted download impact is an indicator similar to FWCI that uses downloads instead of citations.
Field-weighted readership impact (FWRI)	Field-weighted readership impact is an indicator similar to FWCI that uses digital readership instead of citations.
Full-time equivalent (FTE)	A unit that indicates the workload of a person (based on number of hours worked per week) in a way that makes workloads comparable across various contexts. An FTE of 1.0 means that the person is equivalent to a full-time worker, while an FTE of 0.5 signals that the worker is only half-time.
Gross domestic product (GDP)	The market value of all officially recognised final goods and services produced within a country in a given period of time.
Gross domestic expenditure on R&D (GERD)	Total intramural expenditure on research and development performed on the national territory during a given period.
Highly-cited article	Highly-cited articles in this report are those in the top-cited 1% of all articles published and cited in a given period.
H-index	An author has an H-index of *n* if at least *n* of their publications have each received at least *n* citations.
Hypercollaboration	Article with hundreds or thousands of co-authors.
Intellectual property (IP)	Intangible assets such as discoveries and inventions for which exclusive rights may be claimed, including that which is codified in copyright, trademarks, patents, and designs.
Journal	A peer-reviewed periodical in which scholarship relating to a particular research field is published. It is the primary mode of dissemination of knowledge in many fields. Research findings may also be published in conference proceedings, reports, monographs and books and the significance of these as an output channel varies between fields.
Media mentions	The number of times an article has been mentioned in various media sources as captured by Newsflo. This is indicative of media interest in a researcher's or institution's work, and as such, a potential indicator for societal impact.
Purchasing power parity (PPP)	Rates of currency conversion that equalise the purchasing power of different currencies by eliminating the differences in price levels between countries.
Research and development (R&D)	Any creative systematic activity undertaken in order to increase the stock of knowledge, including knowledge of humanity, culture and society, and the use of this knowledge to devise new applications. R&D includes fundamental research, applied research in such fields as agriculture, medicine, industrial chemistry, and experimental development work leading to new devices, products or processes.

Research field Research fields in this report are aggregations of a more granular scheme of more than 300 subjects for classifying journals by research topic or focus in Scopus.

Researcher Professionals engaged in the conception or creation of new knowledge. They conduct research and improve or develop concepts, theories, models, techniques, instrumentation, software or operational methods.

R&D intensity R&D intensity (GERD as a percentage of GDP) is an indicator of an economy's relative degree of investment in generating new knowledge.

Salton's Index Salton's Index is an indicator of research collaboration strength. It is calculated by dividing the number of co-authored articles by the geometric mean (square root of the product) of the outputs of the collaboration partners.

Sector Sectors are used to delimit the different parts of the national research base. Mainly, the research base is split into *Business Enterprise*, *Higher Education*, and *Government* sectors. This is not necessarily a comprehensive list of sectors. In Chapter 7, we use the division of *Academic*, *Corporate*, *Medical*, and *Government* sectors.

Appendix C
Data Sources

Higher Education - Business and Community Interaction (HE-BCI) Survey

www.hefce.ac.uk/ke/hebci/

The annual HE-BCI survey examines the exchange of knowledge between universities and the wider world, and informs the strategic direction of 'knowledge exchange' activity that funding bodies and higher education institutions in the UK undertake.

Higher Education Statistics Agency (HESA)

www.hesa.ac.uk

Higher Education Statistics Agency (HESA) collects a range of data every year UK-wide from universities, higher education colleges and other differently funded providers of higher education. The data on the number of PhD graduates in the UK is available in the Students, Qualifiers and Staff data tables (www.hesa.ac.uk/data-and-analysis).

LexisNexis Univentio

www.lexisnexis.com

LexisNexis Univentio from LexisNexis (a business of Reed Elsevier, Elsevier's parent company) is a full-text patent database with coverage of over 65 million patent publications from over 100 patent authorities in bibliographic form, 20 authorities in full-text, and 20 authorities with machine translations that allow English-language searching across the entire full-text database. For this report, a static version of the LexisNexis Univentio database covering the period 2010-2014 inclusive was analysed for citations to the journal literature indexed in Scopus.

Mendeley

www.mendeley.com

Mendeley is a reference manager and academic social network that allows its users to discover the latest research, read and annotate articles, automatically generate bibliographies, and collaborate with others researchers online. It has over three million users, including not only students, post-doctoral researchers, professors/lecturers, and other academic researchers but also commercial R&D professionals, government/NGO researchers, and other professionals. The distribution of the registered Mendeley users is 32% from Europe, 20% from Asia, 19% from North America, 14% from South America, 4% from Africa, 2% from the Middle East and 2% from Oceania.

Newsflo

www.elsevier.com/solutions/newsflo

Founded in 2012 by Imperial College London physicists, Newsflo monitors and analyses the media impact of individual research papers, researchers and institutions. Developed with leading UK universities, the technology caters to the needs of both researchers and institutions looking to track the media reach of their work. Currently Newsflo tracks over 55,000 English-speaking global media sources and has the technology and network to expand to non-English language media.

Office for National Statistics (ONS)

www.ons.gov.uk

The Office for National Statistics (ONS) is the national statistical institute for the UK. It is responsible for collecting and publishing statistics related to the economy, population and society at national, regional and local levels, and conducts the census in England and Wales every ten years. The Office for National Statistics collects data on UK GERD and related indicators and the data are available in the Datasets and Reference Tables database (www.ons.gov.uk/ons/datasets-and-tables/index.html).

Organisation for Economic Co-operation and Development (OECD)

www.oecd.org

The OECD is an international economic organisation founded in 1961 and represents 34 member countries in this report. Latvia, which became the 35th OECD member state on 1 July 2016, has not been included. In this report the OECD data do typically include the non-member countries Argentina, China, Romania, Russia, Singapore, South Africa, and Taiwan.

The OECD collects internationally comparable data on research and development and the data are available in the Main Science and Technology Indicators database (MSTI 2015/2; www.oecd.org/sti/msti). A useful history of the development of the OECD's R&D statistics is available[73]. Data are presented for the most recent five years for which data are available, though some countries may lack data for certain years. Where applicable, missing values were estimated using established statistical methods by Statisticor (www.statisticor.nl). Financial data are given in constant USD at 2010 prices and corrected for purchasing power parity (PPP), allowing comparability over time and between countries. Full-time equivalent (FTE) counts are used for all human capital data in this report.

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73 Godin, B. (2008) "The Culture of Numbers: Origins and Development of Statistics on Science, Technology and Innovation" Project on the History and Sociology of S&T Statistics, Working Paper No. 40, Canadian Science and Innovation Indicators Consortium.

ScienceDirect

www.sciencedirect.com

ScienceDirect is Elsevier's full-text journal article platform with coverage of over 3,800 journals and more than 35,000 book titles across a wide range of research fields. ScienceDirect has a large customer base, including some 17,000 institutions worldwide, with more than 15 million active users and over 850 million full-text article downloads in 2014. For this report, a static version of the ScienceDirect usage analytics database covering the period 2010-2014 was aggregated by country, region, and subject. The usage statistics from ScienceDirect are compliant with the COUNTER Code of Practice.[74]

Scopus

www.scopus.com

Scopus is Elsevier's abstract and citation database of peer-reviewed literature, covering 62 million documents published in over 22,500 journals, book series and conference proceedings by some 6,000 publishers.

Scopus coverage is multi-lingual and global: the database contains titles from more than 120 different countries and over 50 languages in all geographic regions. Scopus covers approximately 11,800 active titles from Europe (18,000 total), 6,400 from North-America (10,500 total), 2,500 from Asia-Pacific (3,600 total), 700 from Central and South America (900 total), and 800 titles from the Middle East and Africa (1,050 total). Approximately 15% of titles in Scopus are published in languages other than English (or published in both English and another language).

Scopus coverage is also inclusive across all major research fields, with 11,700 titles in the Physical Sciences (7,500 active), 12,900 in the Health Sciences (6,800 active), 6,300 in the Life Sciences (4,500 active), and 9,800 in the Social Sciences (8,100 active) (the latter including some 3,200 Arts & Humanities related titles [2,800 active]).

Titles which are covered are predominantly serial publications (journals, trade journals, book series and conference material), but considerable numbers of conference papers are also covered from stand-alone proceedings volumes (a major dissemination mechanism, particularly in the computer sciences). Acknowledging that a great deal of important literature in all fields (but especially in the Social Sciences and Arts & Humanities) is published in books, Scopus began to increase book coverage in 2013, and currently covers more than 121,000 books.

For this report, a static version of the Scopus database covering the period 1996-2015 inclusive was aggregated by country, region, and subject. Subjects were defined by BEIS for comparative purposes as follows: clinical sciences; health & medical sciences; biological sciences; environmental sciences; mathematics; physical sciences; engineering; social sciences; business; humanities. When aggregating article and citation counts, an integer counting method was employed where, for example, a paper with two authors from a UK address and one from a French address would be counted as one article for each country (i.e. 1 UK and 1 France). This method was favoured over fractional counting, in which the above paper would count as 0.67 for the UK and 0.33 for France.

World Intellectual Property Organization (WIPO)

www.wipo.int

The World Intellectual Property Organization (WIPO) is an agency of the United Nations created in 1967 to promote the protection of intellectual property globally.

WIPO collects internationally comparable data on patenting activity and the data are available in the WIPO IP Statistics Data Center (http://ipstatsdb.wipo.org). Methodological notes on the collection and usage of these data are available[75]. Data are presented for the most recent five years for which data are available.

74 See www.projectcounter.org/code_practice.html
75 See www.wipo.int/export/sites/www/ipstats/en/statistics/patents/pdf/patent_stats_methodology.pdf

Appendix D
Countries Included in Data Sources

Country	*ISO country code*	*Comparator group*	*G8 member*	*EU28 member*	*OECD member*	*OECD non-member*
Aruba	ABW					
Afghanistan	AFG					
Angola	AGO					
Anguilla	AIA					
Albania	ALB					
Andorra	AND					
Netherlands Antilles	ANT					
United Arab Emirates	ARE					
Argentina	ARG					●
Armenia	ARM					
American Samoa	ASM					
Antarctica	ATA					
French Southern Territories	ATF					
Antigua and Barbuda	ATG					
Australia	AUS				●	
Austria	AUT			●	●	
Azerbaijan	AZE					
Burundi	BDI					
Belgium	BEL			●	●	
Benin	BEN					
Burkina Faso	BFA					
Bangladesh	BGD					
Bulgaria	BGR			●		
Bahrain	BHR					
Bahamas	BHS					
Bosnia and Herzegovina	BIH					
Belarus	BLR					
Belize	BLZ					
Bermuda	BMU					
Bolivia, Plurinational State of	BOL					
Brazil	BRA					
Barbados	BRB					
Brunei Darussalam	BRN					
Bhutan	BTN					
Bouvet Island	BVT					
Botswana	BWA					
Central African Republic	CAF					
Canada	CAN	●	●		●	
Cocos (Keeling) Islands	CCK					
Switzerland	CHE				●	
Chile	CHL				●	
China	CHN	●				●
Côte d'Ivoire	CIV					
Cameroon	CMR					
Congo, the Democratic Republic of the	COD					
Congo	COG					

Country	ISO country code	Comparator group	G8 member	EU28 member	OECD member	OECD non-member
Cook Islands	COK					
Colombia	COL					
Comoros	COM					
Cape Verde	CPV					
Costa Rica	CRI					
Cuba	CUB					
Cayman Islands	CYM					
Cyprus	CYP			●		
Czech Republic	CZE			●	●	
Germany	DEU	●	●	●	●	
Djibouti	DJI					
Dominica	DMA					
Denmark	DNK			●	●	
Dominican Republic	DOM					
Algeria	DZA					
Ecuador	ECU					
Egypt	EGY					
Eritrea	ERI					
Spain	ESP			●	●	
Estonia	EST			●	●	
Ethiopia	ETH					
Finland	FIN			●	●	
Fiji	FJI					
Falkland Islands (Malvinas)	FLK					
France	FRA	●	●	●	●	
Faroe Islands	FRO					
Micronesia, Federated States of	FSM					
Gabon	GAB					
United Kingdom	GBR [A]	●	●	●	●	
Georgia	GEO					
Ghana	GHA					
Gibraltar	GIB					
Guinea	GIN					
Guadeloupe	GLP					
Gambia	GMB					
Guinea-Bissau	GNB					
Equatorial Guinea	GNQ					
Greece	GRC			●	●	
Grenada	GRD					
Greenland	GRL					
Guatemala	GTM					
French Guiana	GUF					
Guam	GUM					
Guyana	GUY					
Hong Kong	HKG					
Heard Island and McDonald Islands	HMD					
Honduras	HND					
Croatia	HRV			●		
Haiti	HTI					
Hungary	HUN			●	●	
Indonesia	IDN					
India	IND					
British Indian Ocean Territory	IOT					
Ireland	IRL			●	●	

Country	ISO country code	Comparator group	G8 member	EU28 member	OECD member	OECD non-member
Iran, Islamic Republic of	IRN					
Iraq	IRQ					
Iceland	ISL				●	
Israel	ISR				●	
Italy	ITA	●	●	●	●	
Jamaica	JAM					
Jordan	JOR					
Japan	JPN	●	●		●	
Kazakhstan	KAZ					
Kenya	KEN					
Kyrgyzstan	KGZ					
Cambodia	KHM					
Kiribati	KIR					
Saint Kitts and Nevis	KNA					
Korea, Republic of [B]	KOR				●	
Kuwait	KWT					
Lao People's Democratic Republic	LAO					
Lebanon	LBN					
Liberia	LBR					
Libya	LBY					
Saint Lucia	LCA					
Liechtenstein	LIE					
Sri Lanka	LKA					
Lesotho	LSO					
Lithuania	LTU			●		
Luxembourg	LUX			●	●	
Latvia	LVA			●	● [C]	
Macao	MAC					
Morocco	MAR					
Monaco	MCO					
Moldova, Republic of	MDA					
Madagascar	MDG					
Maldives	MDV					
Mexico	MEX				●	
Marshall Islands	MHL					
Macedonia, the former Yugoslav Republic of	MKD					
Mali	MLI					
Malta	MLT			●		
Myanmar	MMR					
Montenegro	MNE					
Mongolia	MNG					
Northern Mariana Islands	MNP					
Mozambique	MOZ					
Mauritania	MRT					
Montserrat	MSR					
Martinique	MTQ					
Mauritius	MUS					
Malawi	MWI					
Malaysia	MYS					
Mayotte	MYT					
Namibia	NAM					
New Caledonia	NCL					
Niger	NER					
Norfolk Island	NFK					

Country	ISO country code	Comparator group	G8 member	EU28 member	OECD member	OECD non-member
Nigeria	NGA					
Nicaragua	NIC					
Netherlands	NLD			●	●	
Norway	NOR				●	
Nepal	NPL					
Nauru	NRU					
New Zealand	NZL				●	
Oman	OMN					
Pakistan	PAK					
Panama	PAN					
Peru	PER					
Philippines	PHL					
Palau	PLW					
Papua New Guinea	PNG					
Poland	POL			●	●	
Puerto Rico	PRI					
Korea, Democratic People's Republic of	PRK					
Portugal	PRT			●	●	
Paraguay	PRY					
Palestine, State of	PSE					
French Polynesia	PYF					
Qatar	QAT					
Réunion	REU					
Romania	ROU			●		●
Russian Federation [D]	RUS		●			●
Rwanda	RWA					
Saudi Arabia	SAU					
Sudan	SDN					
Senegal	SEN					
Singapore	SGP					●
South Georgia and the South Sandwich Islands	SGS					
Saint Helena, Ascension and Tristan da Cunha	SHN					
Svalbard and Jan Mayen	SJM					
Solomon Islands	SLB					
Sierra Leone	SLE					
El Salvador	SLV					
San Marino	SMR					
Somalia	SOM					
Serbia	SRB					
Sao Tome and Principe	STP					
Suriname	SUR					
Slovakia	SVK			●	●	
Slovenia	SVN			●	●	
Sweden	SWE			●	●	
Swaziland	SWZ					
Seychelles	SYC					
Syrian Arab Republic	SYR					
Turks and Caicos Islands	TCA					
Chad	TCD					
Togo	TGO					
Thailand	THA					
Tajikistan	TJK					
Turkmenistan	TKM					
Timor-Leste	TLS					

Country	ISO country code	Comparator group	G8 member	EU28 member	OECD member	OECD non-member
Tonga	TON					
Trinidad and Tobago	TTO					
Tunisia	TUN					
Turkey	TUR				●	
Tuvalu	TUV					
Taiwan, Province of China	TWN					●
Tanzania, United Republic of	TZA					
Uganda	UGA					
Ukraine	UKR					
United States Minor Outlying Islands	UMI					
Uruguay	URY					
United States	USA [E]	●	●		●	
Uzbekistan	UZB					
Holy See (Vatican City State)	VAT					
Saint Vincent and the Grenadines	VCT					
Venezuela, Bolivarian Republic of	VEN					
Virgin Islands, British	VGB					
Virgin Islands, U.S.	VIR					
Vietnam	VNM					
Vanuatu	VUT					
Wallis and Futuna	WLF					
Samoa	WSM					
Yemen	YEM					
South Africa	ZAF					●
Zaire	ZAR					
Zambia	ZMB					
Zimbabwe	ZWE					

[A] *UK* used throughout this report.

[B] *South Korea* used throughout this report.

[C] Latvia has been an OECD member since 1 July 2016 and has not been included in the OECD data for this report.

[D] *Russia* used throughout this report.

[E] *US* used throughout this report.

Appendix E
Methodology

Rationale

The methodology used in the construction of the indicators presented in this report is based on the theoretical principles and best practices developed in the field of quantitative science and technology studies, particularly in science and technology indicators research[76].

The analyses of article and citation data in this report are based upon recognised, advanced indicators (such as the concept of field-weighted citation impact). Our base assumption is that such indicators are useful and valid, though imperfect and partial measures, in the sense that their numerical values are determined by research performance and related concepts, but also by other influencing factors that may cause systematic biases. In recent years there have been increasing efforts by the research community active in the development and use of these indicators to ensure that they are based on a solid theoretical understanding and are used according to best practice in the field.

A body of literature is available on the limitations and caveats in the use of such 'bibliometric' data, such as the accumulation of citations over time, the skewed distribution of citations across articles, and differences in publication and citation practices between fields of research, different languages, and applicability to social sciences and humanities research. In social sciences and humanities, the bibliometric indicators presented in this report and conclusions drawn from analysing these indicators for these fields must be interpreted with caution because a reasonable proportion of research outputs in such fields take the form of books, monographs and non-textual media. As such, analyses of journal articles, their usage and citation, provides a less comprehensive view than in other fields, where journal articles comprise the vast majority of research outputs.

Detailed methodology

In addition to the details in the section *"Data sources and methodology"* in Chapter 1, the following boxes accompanying the figures and text they relate to address methodological issues:

- *"What is a 'researcher'?"*
  in Chapter 3
- *"Measuring international researcher mobility"*
  in Chapter 3
- *"Activity Index"*
  in Chapter 4
- *"Measuring impact: Citation windows and field-weighting"*
  in Chapter 4
- *"Measuring article downloads"*
  in Chapter 4
- *"Journal publishing models by source of financial support"*
  in Chapter 4
- *"Hypercollaboration"*
  in Chapter 5
- *"Salton's Index: An indicator of collaboration strength"*
  in Chapter 5
- *"The definitions of research resource, IP income and spin-off companies"*
  in Chapter 7
- *"Counting patent applications, patent grants and patents in force"*
  in Chapter 7

Extrapolation

Data are presented for the most recent five years for which data are generally available, though individual countries may lack data for certain years. Where values were missing between supplied data points, these were estimated using interpolation to find the intermediate point or points between supplied data. The interpolation assumes that the change between two values is linear. If the most recent values were missing, the linear growth rate of the data available for earlier years was extrapolated to estimate a forecast.

Ranking

The OECD's Main Science and Technology Indicators database is used for data on GERD, HERD, and researchers. Six of the EU member states are not included in the OECD data: Bulgaria, Cyprus, Croatia, Latvia, Lithuania and Malta. Consequently, when the UK's ranking among EU countries was calculated, these countries were excluded. For indicators that were derived using the Scopus database, the UK's ranking is among all 28 EU member states.

76 See Moed, F. *et al.* (2004) *Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems* (Dordrecht: Kluwer) and references cited therein.

Appendix F Detailed Analysis on Researcher Mobility[77]

The Inflow and Outflow groups of UK migratory researchers are senior and associated with high field-weighted citation impact

Between 1996 and 2015, a higher percentage of researchers left the UK and did not return within two years (classified as the *Outflow* group) than the percentage of those who moved in and stayed for at least two years (classified as the *Inflow* group) *(see Figure F.1)*. The Outflow researchers were more productive but their publications had a lower field-weighted citation impact than their Inflow peers. The seniority of the population of the all-researcher set in the Outflow group was slightly higher than the Inflow group. A higher percentage of women researchers were attracted into the UK than the percentage of those that left. The articles published by the Outflow and Inflow groups had higher than average field-weighted citation impact.

The Returnees Inflow group of UK migratory researchers are productive, senior and are associated with high field-weighted citation impact

The UK experienced a greater percentage of researchers who moved into the UK and subsequently left after more than two years in the country (the *Returnees Outflow* group) than those who relocated from the UK and repatriated at least two years later (the *Returnees Inflow* group). The two Returnees groups were the most senior researchers, but the Returnees Inflow group had the highest level of productivity and the highest field-weighted citation impact across all the mobility classes. This appears to confirm further the findings in the 2013 study of Argentinean life scientists[78] that showed that returnees are more likely to publish in high-quality journals, and concluded that, "Return migration leads to the formation of scientific ties between home and host system and capacity building in the home system" .

The Transitory (mainly non-UK) group of UK transitory researchers outperforms the Transitory (mainly UK) group in all three indicators

More than two and a half times the number of researchers primarily based outside the UK showed transitory mobility into the UK (36%) *(Transitory (mainly non-UK))* than UK-based researchers transited to non-UK countries (14%) *(Transitory (mainly UK))*. Interestingly, there was a slightly higher percentage of women in the Transitory (mainly UK) group than in the mainly non-UK group. The Transitory (mainly non-UK) researchers tended to be more productive and senior, and have a higher field-weighted citation impact, than the UK-based researchers.

The UK is attractive to highly productive short publication history researchers

Migratory patterns among the short publication history researchers were similar in some ways to that of the all-researcher set, but there were also significant differences *(see Figure F.2)*. There was a higher percentage of short publication history researchers who left the UK and did not return within two years (Outflow group) than those who moved in and stayed for more than two years (Inflow group), and there was a higher percentage of women researchers in the Inflow group. However, although the Outflow group was more productive, it was slightly less senior and had a lower field-weighted citation impact than its Inflow peers.

With the Returnees groups, a greater percentage moved into the UK and subsequently left after more than two years (Returnees Outflow) than those who left the UK and returned at least two years later (Returnees Inflow); again, there was a higher percentage of women in this latter group. Like the all-researcher set, the two short publication history researcher Returnees groups were the most senior amongst their peers. However, those in the Returnees Inflow group were nearly two and a half times more productive than the Returnees Outflow group and had the highest field-weighted citation impact across all mobility classes in this set.

Transitory mobility among the short publication history researchers was nearly twice as high in the Transitory (mainly non-UK) group (i.e., those who came to the UK and stayed for less than two years) than in the Transitory (mainly UK) group. The former group was more senior, more productive and had a higher field-weighted citation impact than the 'mainly-UK' group. There was a higher percentage of short publication history women researchers in the Transitory (mainly non-UK) group.

77 The classification of UK researchers into the mobility categories is based the affiliation data in publications, the same methodology as in Chapter 3.

78 Jonkers, K. & Cruz-Castro, L. (2013) "Research upon return: The effect of international mobility on scientific ties, production and impact" *Research Policy* 42 (8) pp. 1366-1377.

MOBILITY CLASSES & INDICATORS

How are mobility classes defined?

Migratory — researchers who stay abroad or in the UK for two years or more (Total Outflow and Total Inflow), further subdivided into those where the researcher remained abroad (Outflow and Inflow) or where they subsequently returned to their original country (Returnees Outflow and Returnees Inflow).

- *Outflow:* active UK researchers whose Scopus author data for the period 1996–2015 indicate that they have migrated from the UK to another country (or countries) for at least two years without returning to the UK.
- *Returnees Outflow:* active UK researchers whose Scopus author profile data for the period 1996–2015 indicate that they have migrated to the UK from another country (or countries) for at least two years, and then subsequently migrated to another country (or countries) for at least two years.
- *Total Outflow:* the sum of Outflow and Returnees Outflow groups.
- *Inflow:* active UK researchers whose Scopus author data for the period 1996–2015 indicate that they have migrated to the UK from another country (or countries) for at least two years without leaving the UK.
- *Returnees Inflow:* active UK researchers whose Scopus author data for the period 1996–2015 indicate that they have migrated from the UK to another country (or countries) for at least two years, and then subsequently migrated back to the UK for at least two years.
- *Total Inflow:* the sum of Inflow and Returnees Inflow groups.

Transitory — researchers who stay abroad or in the UK for less than two years (Total Transitory), further subdivided into those who mostly published under a UK (Transitory (mainly UK)) or a non-UK (Transitory (mainly non-UK)) affiliation.

- *Transitory (mainly UK):* active UK researchers whose Scopus author data for the period 1996–2015 indicate that they are based in another country (or countries) for less than two years at a time but are predominantly based in the UK.
- *Transitory (mainly non-UK):* active UK researchers whose Scopus author data for the period 1996–2015 indicate that they are based in the UK for less than two years at a time but are predominantly based in another country (or countries).
- *Total Transitory:* the sum of Transitory (mainly UK) and Transitory (mainly non-UK) groups.

Non-migratory — researchers with only UK affiliations in Scopus during the period 1996–2015.

- *Non-migratory:* active UK researchers whose Scopus author data for the period 1996–2015 indicate that they have not published under an affiliation outside the UK.

What indicators are used to characterise each mobility group?
To better understand the composition of each group defined above, three aggregate indicators were calculated for each to represent the productivity and seniority of the researchers they contain, and the field-weighted citation impact of their articles.

Relative Productivity — represents a measure of the articles per year since the first appearance of each researcher as an author during the period 1996–2015, relative to all UK researchers in the same period.

Relative length of service — represents years since the first appearance of each researcher as an author during the period 1996–2015, relative to all UK researchers in the same period.

Field-weighted citation impact — is calculated for all articles in each mobility class.

All three indicators are calculated for each author's entire output in the period (i.e., not just those articles listing a UK address for that author). For further detail on the approach used, see box "*Measuring international researcher mobility*" in Chapter 3.

Figure F.1 / Detailed view of Figure 3.4 in Chapter 3 — International mobility of UK active researchers, 1996–2015 ("UK all-researcher set"). This analysis is based on Scopus author data and a set of 334,437 active UK researchers.

Relative Productivity, Relative length of service, and FWCI:
< 0.50 · 0.50–0.75 · 0.75–1.25 · 1.25–1.75 · > 1.75

UK

334,437 ACTIVE RESEARCHERS
Of whom women: 30.7%
FWCI: 1.97

1996–2015

Inflow TOTAL

Researchers: 9.6%
Of whom women: 28.2%
Relative Productivity: 1.03
Relative length of service: 1.11
FWCI: 2.22

Inflow
Researchers: 6.5%
Of whom women: 31.1%
Relative Productivity: 0.79
Relative length of service: 1.06
FWCI: 2.10

Returnees Inflow
Researchers: 3.1%
Of whom women: 22.4%
Relative Productivity: 1.48
Relative length of service: 1.20
FWCI: 2.33

Transitory TOTAL

Researchers: 49.3%
Of whom women: 28.6%
Relative Productivity: 1.24
Relative length of service: 1.05
FWCI: 2.01

Transitory (mainly UK)
Researchers: 13.5%
Of whom women: 29.9%
Relative Productivity: 0.79
Relative length of service: 0.97
FWCI: 1.91

Transitory (mainly non-UK)
Researchers: 35.8%
Of whom women: 28.2%
Relative Productivity: 1.39
Relative length of service: 1.08
FWCI: 2.03

Outflow TOTAL

Researchers: 13.3%
Of whom women: 26.6%
Relative Productivity: 0.92
Relative length of service: 1.11
FWCI: 1.87

Outflow
Researchers: 7.3%
Of whom women: 26.8%
Relative Productivity: 0.81
Relative length of service: 1.07
FWCI: 1.89

Returnees Outflow
Researchers: 6.0%
Of whom women: 26.3%
Relative Productivity: 1.05
Relative length of service: 1.15
FWCI: 1.86

Non-migratory

Researchers: 27.8%
Of whom women: 37.2%
Relative Productivity: 0.49
Relative length of service: 0.82
FWCI: 1.67

Figure F.2 / Detailed view of Figure 3.5 in Chapter 3 — *International mobility of UK active short publication history researchers, 1996–2015. This analysis is based on Scopus author data and a set of 98,808 active UK researchers with less than 10 years since the first appearance of each researcher as an author during the period 1996–2015.*

Relative Productivity, Relative length of service, and FWCI:
■ *< 0.50* ■ *0.50–0.75* ■ *0.75–1.25* ■ *1.25–1.75* ■ *> 1.75*

UK

98,808 ACTIVE RESEARCHERS
Of whom women: 39.5%
FWCI: 2.27 ■

1996–2015

Inflow TOTAL

Researchers: 5.8%
Of whom women: 37.2%
Relative Productivity: 1.27 ■
Relative length of service: 1.24 ■
FWCI: 2.58 ■

Inflow
Researchers: 4.7%
Of whom women: 37.9%
Relative Productivity: 0.97 ■
Relative length of service: 1.24 ■
FWCI: 2.28 ■

Returnees Inflow
Researchers: 1.1%
Of whom women: 34.4%
Relative Productivity: 2.48 ■
Relative length of service: 1.26 ■
FWCI: 3.05 ■

Transitory TOTAL

Researchers: 42.8%
Of whom women: 38.3%
Relative Productivity: 1.25 ■
Relative length of service: 1.02 ■
FWCI: 2.46 ■

Transitory (mainly UK)
Researchers: 15.0%
Of whom women: 38.9%
Relative Productivity: 0.88 ■
Relative length of service: 0.93 ■
FWCI: 2.26 ■

Transitory (mainly non-UK)
Researchers: 27.8%
Of whom women: 37.9%
Relative Productivity: 1.42 ■
Relative length of service: 1.06 ■
FWCI: 2.52 ■

Outflow TOTAL

Researchers: 7.7%
Of whom women: 31.8%
Relative Productivity: 1.02 ■
Relative length of service: 1.26 ■
FWCI: 2.13 ■

Outflow
Researchers: 5.3%
Of whom women: 31.7%
Relative Productivity: 1.04 ■
Relative length of service: 1.23 ■
FWCI: 2.05 ■

Returnees Outflow
Researchers: 2.4%
Of whom women: 31.9%
Relative Productivity: 0.99 ■
Relative length of service: 1.32 ■
FWCI: 2.31 ■

Non-migratory

Researchers: 43.7%
Of whom women: 42.4%
Relative Productivity: 0.67 ■
Relative length of service: 0.90 ■
FWCI: 1.82 ■

Appendix G
Digital Readership Analysis

Downloads and digital readership counts are measures that complement traditional bibliometrics, such as citation counts, by showing an early indicator of the impact that a work may have.

Statistics for digital readership in this report are drawn from the Mendeley database. Mendeley[79] is a reference manager and academic social network that allows its users to discover the latest research, read and annotate articles, automatically generate bibliographies, and collaborate with others researchers online *(see box "Measuring digital readership" for more details)*.

In 2014, the UK outperformed the global baseline in field-weighted readership impact (FWRI) across all main research fields; the spread across subject fields was fairly uniform. Of particular note, the UK's publications in Clinical Sciences, Biological Sciences, and Environmental Sciences were much more read by digital users than the world average.

For research-intensive countries (the UK, France, Italy, Germany, Japan, the US and Canada), field-weighted readership impact showed very similar patterns. This is perhaps to be expected since many users employ Mendeley as a tool for references, but it goes some way to supporting the hypothesis that Mendeley readership is an indication of usage of research and an early predictor of citations. In contrast, China, India and Russia had low field-weighted readership impact, partly due to relatively low levels of Mendeley penetration in these countries.

MEASURING DIGITAL READERSHIP

Citation impact is, by definition, a lagging indicator: newly-published articles need to be read, after which they might influence studies that will be carried out, which are then written up in manuscript form, peer-reviewed, published and finally included in a citation index such as Scopus. Only after these steps are completed can citations to the earlier article be systematically counted. For this reason, investigating downloads and digital readership have become appealing alternatives, since it is possible to start counting downloads and digital reads of full-text articles immediately upon online publication. Some early research into the relationship of digital readership (i.e., Mendeley users who have downloaded articles and saved them in their Mendeley library) with traditional citations has also found evidence supporting the premise that digital readership counts correlate moderately with future citations.[80]

A digital read is defined as a Mendeley user having saved the article held in Scopus in his/her Mendeley library. Among the UK's 154,653 publications globally in 2014, 75,624 (49%) were saved in Mendeley since publication, and of all 2014 publications worldwide (2,439,249) 41% (1,006,387) were saved.

Field-weighted readership impact is calculated from Mendeley digital readership data according to the same principles applied to the calculation of field-weighted citation impact *(see box "Measuring impact: Citation windows and field-weighting")*.

Table G.1 — *Field-weighted readership impact (FWRI) for the UK and comparators across ten research fields in 2014. For all research fields, a field-weighted readership impact of 1.0 equals the world average in that particular research field. Source: Mendeley.*

Research field	Brazil	Canada	China	Germany	France	UK	India	Italy	Japan	South Korea	Russia	US	World
Clinical sciences	1.07	1.57	0.69	1.47	1.46	1.77	0.79	1.31	0.88	0.95	0.67	1.48	1.00
Health & Medical Sciences	0.85	1.49	0.94	1.34	0.93	1.59	0.61	1.41	0.90	0.74	0.29	1.33	1.00
Biological Sciences	1.05	1.62	0.69	1.70	1.71	1.94	0.65	1.39	1.01	0.88	0.45	1.62	1.00
Environmental Sciences	1.37	1.65	0.76	1.81	1.88	2.21	0.70	1.77	0.99	1.01	0.51	1.58	1.00
Mathematics	0.95	1.37	0.60	1.41	1.18	1.59	0.63	0.99	0.86	0.83	0.33	1.43	1.00
Physical Sciences	1.12	1.51	0.69	1.54	1.41	1.68	0.78	1.47	1.07	1.13	0.42	1.63	1.00
Engineering	1.17	1.63	0.51	1.90	1.64	1.86	0.85	1.92	1.11	1.14	0.39	1.60	1.00
Social Sciences	0.77	1.51	0.96	1.56	1.08	1.52	0.80	1.40	1.12	1.39	0.36	1.28	1.00
Business	0.94	1.69	0.88	1.86	1.56	1.86	0.56	1.73	1.13	1.31	0.32	1.70	1.00
Humanities	0.79	1.28	1.07	1.41	1.03	1.46	1.10	1.19	1.55	1.70	0.53	1.34	1.00

Appendix H
Media Mentions Analysis

Many institutions and companies monitor media coverage to measure how and where research has been mentioned, discussed or applied in non-scholarly materials. This report draws on statistics of online media mentions of researchers and institutions from the database of the media monitoring service Newsflo[81].

In 2014 and 2015, around 74% of all mentions, captured by Newsflo, were generated from online news outlets in the US, 7% from Australia, and 6% from the UK. During this period, Newsflo data captured 19,102,874 mentions of researchers or institutions from online news outlets, of which around 70% mentioned US researchers or institutions and 8% the UK. This signifies that UK researchers and institutions were 21% (i.e., 7.6% divided by 6.3%) more frequently mentioned in news outlets than the world average at 1.0 (assuming that research is reported more or less equally by all countries). Of the top five countries that generated the largest number of mentions, the US was mentioned 5% less frequently than the world average, while Canada led with 63% higher than the world average.

Table H.1 *— Mentions from the country (1) and to researchers and institutions in the country (2) for the top five countries that generated most mentions. Source: Newsflo.*

Country	Given mentions (1)	Received mentions (2)	Ratio of (2) relative to (1)
US	73.6%	69.6%	0.95
Australia	7.1%	6.2%	0.88
UK	6.3%	7.6%	1.21
India	2.8%	1.0%	0.36
Canada	2.2%	3.6%	1.63

79 A free reference manager and academic social network with over three million users broadly distributed across the globe. The distribution of the registered Mendeley users is 32% from Europe, 20% from Asia, 19% from North America, 14% from South America, 4% from Africa, 2% from the Middle East and 2% from Oceania. More details of Mendeley can be found in *Appendix C*.

80 Mohammadi, E. & Thelwall, M. (2014) "Mendeley readership altmetrics for the social sciences and humanities: Research evaluation and knowledge flows" *Journal of the Association for Information Science and Technology* 65 (8) pp. 1627–1638;
Thelwall, M. & Wilson, P. (2016) "Mendeley readership altmetrics for medical articles: An analysis of 45 fields" *Journal of the Association for Information Science and Technology* 67 (8), pp. 1962-1972;
Thelwall, M. & Sud, P. (2016) "Mendeley readership counts: An investigation of temporal and disciplinary differences" *Journal of the Association for Information Science and Technology* 67 (12), pp. 3036-3050.

81 Newsflo monitors over 55,000 online news outlets in more than 20 countries, including the US, India, China, Brazil and all major European countries, but with a bias towards English-language news outlets.

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