International **Comparative Performance** of the **UK** Research Base – **2013**

A report prepared by Elsevier for the UK's Department of Business, Innovation and Skills (BIS)

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Executive Summary International **Comparative Performance** of the **UK** Research Base – **2013**

This report has been commissioned by the UK's Department of Business, Innovation and Skills (BIS) to assess the performance of the United Kingdom's (UK) research base compared with seven other research-intensive countries (Canada, China, France, Germany, Italy, Japan, and the US), three fast growing nations (Brazil, India and Russia), and other international benchmarks. It tracks investment in, and performance of, the national research system in an international setting, combining a variety of indicators to present a multifaceted view of the UK's comparative performance in research as well as the trends that may affect its future position.

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

The locus of global research continues to shift, with rising research nations such as China and Brazil competing on a global stage with long-standing research powerhouses such as the UK, Germany, France and the US. Within this context, this report examines how the UK research base compares internationally, and what trends may affect the UK's future standing as a world-leading research economy.

The UK punches above its weight as a research nation
While the UK represents just 0.9% of global population, 3.2% of R&D expenditure, and 4.1% of researchers, it accounts for 9.5% of downloads, 11.6% of citations and 15.9% of the world's most highly-cited articles. Amongst its comparator countries, the UK has overtaken the US to rank 1st by field-weighted citation impact (an indicator of research quality). Moreover, with just 2.4% of global patent applications, the UK's share of citations from patents (both applications and granted) to journal articles is 10.9%. The UK is a highly productive research nation in terms of articles and citation outputs per researcher or per unit of R&D expenditure, resulting from a trend towards increasing outputs from broadly stable or decreasing inputs. It is likely that recent increases in UK research productivity have, at least to some extent, been driven by the increase in UK international research collaboration, which is also associated with greater citation impact. Taken together, the observation that the UK punches above its weight reflects the underlying well-roundedness and high impact of UK research across most disciplines.

The UK research base is well-rounded and impactful across most major research fields
The UK is a well-rounded research nation, with activity (as indicated by article outputs) and multidisciplinary competencies across all major research fields. The UK's field-weighted citation impact continues to rise (and now ranks 1st amongst the comparator countries) despite a decreasing share of global articles, and this trend is broadly reflected across most of research fields (with the exception of Social Sciences, Business and Humanities) and across the UK's constituent countries. With high field-weighted citation impact and in most cases high field-weighted download impact across these fields, the UK also demonstrates excellence in diverse research domains. UK research is increasingly cited internationally, and the UK is also leading the world in making its articles available under a variety of different access models. Taken together, these factors may serve to reinforce the UK's central position in the global collaboration network and also make the UK an attractive destination for researchers from other countries.

The UK is a focal point for global research collaboration and researcher mobility
International research collaboration and international researcher mobility can be considered as two sides of the same coin, representing collaborative interactions with or without physical co-location. It should therefore be expected that countries exhibiting high levels of research collaboration typically also have high levels of researcher mobility, and this is certainly true of the UK. Indeed, the UK

occupies a central position in the global network of collaborative partnerships and the resulting articles from these partnerships are associated with higher field-weighted citation impact than that observed for all internationally collaborative articles published by either the UK or its major partner countries. Moreover, despite a broadly stable researcher population, the UK's research base is continually refreshed through the increasing numbers of new PhD graduates gaining their qualification within the UK, coupled with a high degree of international mobility amongst active UK researchers. In interviews with key individuals in the academic sector from across the UK and abroad, international collaboration and researcher mobility were acknowledged as being core to the maintenance and further development of the UK's world-leading position as a research nation, especially in light of the relatively limited inputs to the UK research base in terms of R&D expenditure and the number of researchers. Since UK researchers are clearly highly collaborative and mobile across international borders, it should come as no surprise that they are also highly cooperative and mobile between academic and corporate sectors within and beyond the UK.

The UK exhibits strong cross-sector knowledge exchange

The UK demonstrates strong cross-sector knowledge exchange processes, indicated by the high and rising propensity for UK academic users to download UK corporate-authored articles and the similar pattern for UK corporate users to download UK academic-authored articles. Moreover, it is clear that the UK is successful at commercialising the Intellectual Property (IP) derived from academic research when compared with other countries for which comparable indicators are available, despite relatively low patenting activity. A high and rising proportion of UK journal articles are cited in patents globally, pointing to both the quality and usefulness of UK research. In interviews with key individuals in the UK academic and corporate sectors, the mutual benefits of cross-sector partnerships were widely recognised, but so too were the barriers and risks associated with them.

The UK research base shows areas of potential vulnerability

While the UK punches above its weight to deliver increasingly high-quality research outputs on broadly stable or decreasing R&D expenditure or human capital inputs, it may not be possible to sustain its position as a world-leading research nation on this basis indefinitely. While the US remains the world's largest research base, recent trends indicate that the relative standing of it and the other traditional research powerhouses like the UK may be starting to be eroded by pressure from the emerging nations of the East: most notably China, in terms of sheer volume of research inputs and outputs, if not (yet) in terms of overall research quality. However, with China's slowly increasing rate of international collaboration and a net Total Inflow of researchers, it seems likely that quality (in terms of field-weighted citation impact) will follow.

While the mechanisms of research funding and researcher training - as well as the economic context of national research bases - make direct comparisons difficult, it is clear that the global research ecosystem has become increasingly complex in recent years, characterised by the opposing forces of collaboration and competition. In this context, while the UK is well-positioned to remain a research leader in the future, continued investment in the research base is essential to this aim.

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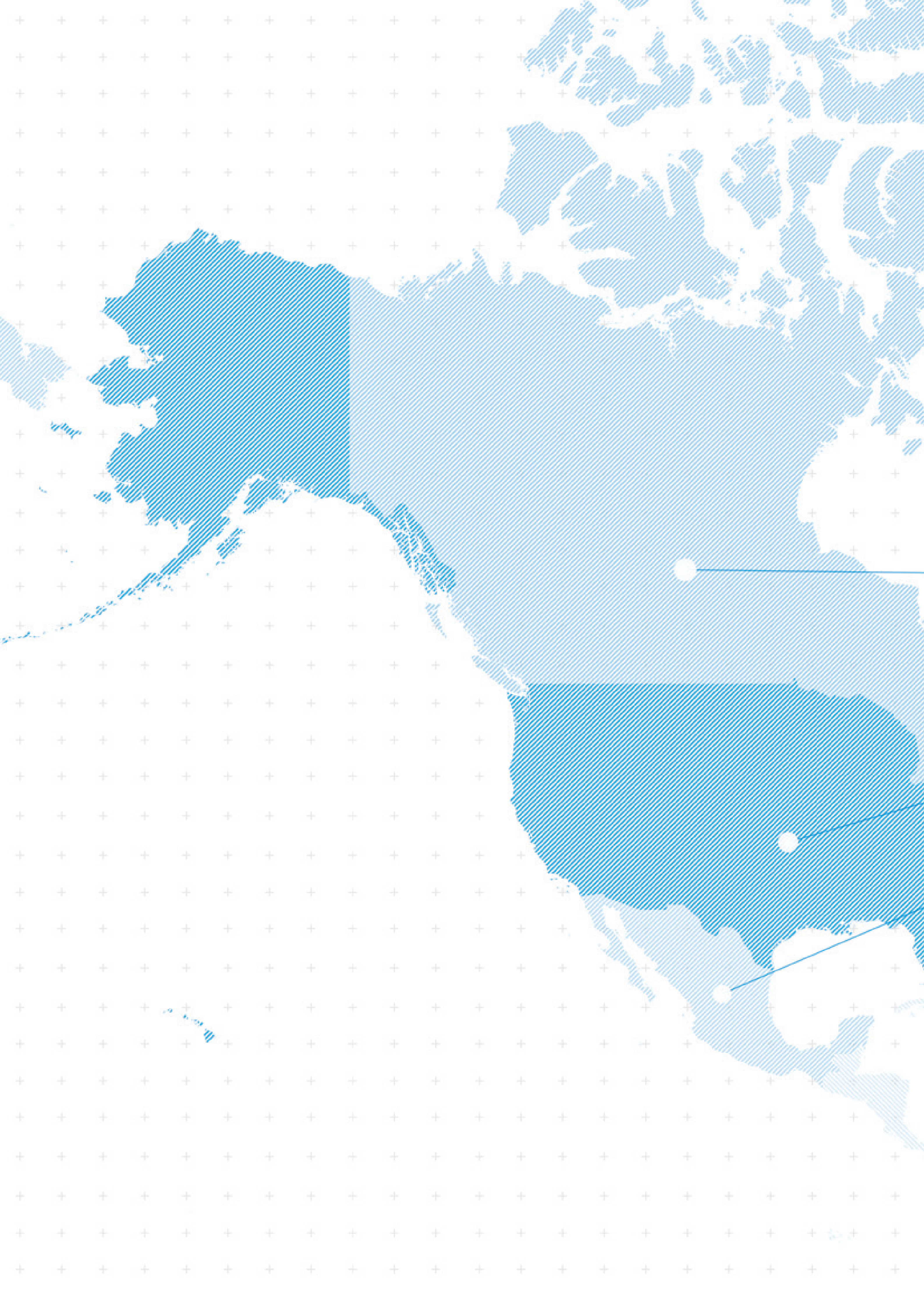
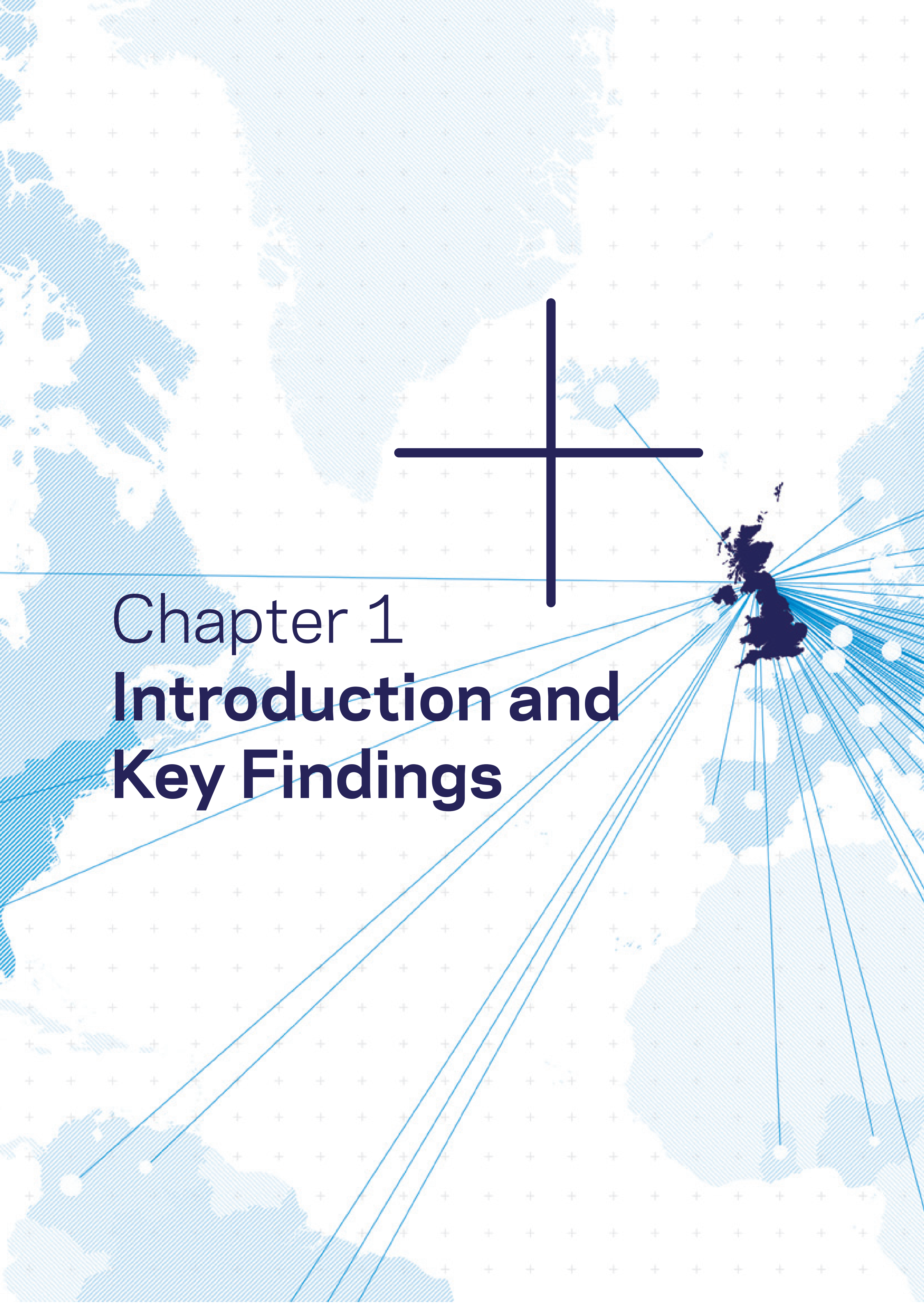




Chapter 1
Introduction and Key Findings

1.1 Introduction

This report has been commissioned by the UK's Department of Business, Innovation and Skills (BIS) to assess the performance of the United Kingdom's (UK) research base compared with seven other research-intensive countries (Canada, China, France, Germany, Italy, Japan, and the US), three other fast growing nations (Brazil, India and Russia), and international benchmarks. It tracks investment in, and performance of, the national research system in an international setting, combining a variety of indicators to present a multifaceted view of the UK's comparative performance in research as well as the trends that may affect its future position. This is the second consecutive report in this series to be delivered by Elsevier, the first having been published in October 2011[1]. Details on those involved in the production of this report and further acknowledgements are given in Appendix A: Author Credits, Advisory Groups, and Acknowledgements.

The main themes were explored through data analyses, literature reviews and in-depth interviews with key stakeholders. Themes pertain to research inputs such as R&D expenditure and human capital (including number of researchers, mobility and collaboration), research outputs such as published journal articles and the citation and usage of those articles, and research commercialisation and knowledge exchange. The efficiency of research, such as output per unit spend on research or per researcher, is also a key theme.

For two of these themes, research collaboration and knowledge exchange, more than 60 in-depth interviews were held with key individuals with a close involvement in the topic. In each case, stakeholders were interviewed to gain insights about the drivers and benefits of international or cross-sector collaboration, the process of finding partners, and barriers and possibilities for improvement. A narrative summary of these interviews appears at the end of the relevant chapters in this report, and these are intended to complement the quantitative analyses with more qualitative perspectives.

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

The locus of global research continues to shift, with rising research nations such as China and Brazil competing on a global stage with long-standing research powerhouses such as the UK, Germany, France and the US. Within this context, this report examines how the UK research base compares internationally, and what trends may affect the UK's future standing as a world-leading research economy.

Data sources and methodology

The majority of data presented in this report are derived from the OECD[2] (R&D expenditure and human capital), Scopus[3] (articles and citations), and WIPO[4] (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 also been gathered to add to the expanded view 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.

Measuring change

Throughout this report, a standard method of measuring change over time is used: 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. The formula for determining CAGR is given in Appendix B: Glossary of Terms.

Changing measures

The main data sources used in this report (OECD, Scopus, and WIPO; see Appendix C: Data Sources) represent dynamic databases with regular updates throughout the year. The indicators presented here are therefore a snapshot taken from 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.

Defining a comparator country group

Comparator countries are defined consistently across all data sources: unless otherwise indicated, a grouping of G7 plus China is used for charting, and aggregates representing the G8, EU27 and OECD member countries 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.

In most analyses presented in this report that do not reflect sheer volumes but instead are based on size-normalised indicators (such as field-weighted citation impact or articles per researcher), 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 in this report (but are included, where appropriate, when indicating the UK's rank for a given indicator).

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 has been used.

Time lags between inputs and outputs
In the input-output model of R&D evaluation[5], 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 2013 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[6]. Such lags will vary by indicator, country and subject field, and may even shift in magnitude over time. Owing to these complexities in determining and accounting for the time lags between input and output, this has not been attempted in this report. As such, productivity indicators (such as articles and citations per unit R&D expenditure and per researcher) are more meaningful in a comparative rather than in an absolute sense.

Table 1.1 *— Countries in this report, their ISO 3-character code and key for charting in this report.*

Country	ISO 3-character code	Key	Comparator group
Brazil	BRA	— (orange)	
Canada	CAN	— (light blue)	✓
China	CHN	— (dark green)	✓
France	FRA	— (blue)	✓
Germany	DEU	— (indigo)	✓
India	IND	— (green)	
Italy	ITA	— (steel blue)	✓
Japan	JPN	— (lime)	✓
Russia	RUS	— (purple)	
United Kingdom	GBR *(UK used throughout this report)*	— (red)	✓
United States	USA	— (navy)	✓

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

[2] 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, Russian Federation, Singapore, South Africa, and Chinese Taipei.

[3] Scopus is the largest abstract and citation database of peer-reviewed literature, covering 50 million documents published in over 21,000 journals, book series and conference proceedings by some 5,000 publishers.

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

[5] Godin, B. (2007) "Science, accounting and statistics: The input-output framework" *Research Policy* 36 (9) pp. 1388-1403.

[6] 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

While the UK represents 0.9% of global population, 3.2% of R&D expenditure, and 4.1% of researchers, it accounts for 9.5% of downloads, 11.6% of citations and 15.9% of the world's most highly-cited articles (see Figure 1.1A). Amongst its comparator countries, the UK has overtaken the US to rank 1st by field-weighted citation impact (an indicator of research quality). Moreover, with just 2.4% of global patent applications, the UK's share of citations from patents (both applications and granted) to journal articles is 10.9%. The UK is a highly productive research nation in terms of articles and citation outputs per researcher or per unit of R&D expenditure (see Figures 1.1B and 1.1C, respectively), resulting from a trend towards increasing outputs from broadly stable or decreasing inputs. It is likely that recent increases in UK research productivity have, at least to some extent, been driven by the increase in UK international research collaboration, which is also associated with greater citation impact (see Figure 5.1 and Table 5.1). Taken together, the observation that the UK punches above its weight reflects the underlying well-roundedness and high impact of UK research across most fields of research.

1.2.2 The UK research base is well-rounded and impactful across most major research fields

The UK is a well-rounded research nation, with activity (as indicated by article outputs; see Figure 4.3) and multidisciplinary competencies (see Figure 4.14) across all major research fields. The UK's field-weighted citation impact continues to rise, and now ranks 1st amongst the comparator countries, despite a decreasing share of global articles (see Figure 1.2A), and this trend is broadly reflected across most research fields (with the exception of Social Sciences, Business and Humanities; see Figure 1.2B) and across the UK's constituent countries (see Figure 1.2C). With high field-weighted citation impact and, in most cases high field-weighted download impact across these fields, the UK also demonstrates excellence in diverse research domains (see Figure 4.13). UK research is increasingly cited internationally, and the UK is also leading the world in making its articles available under a variety of different access models. Taken together, these factors 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.

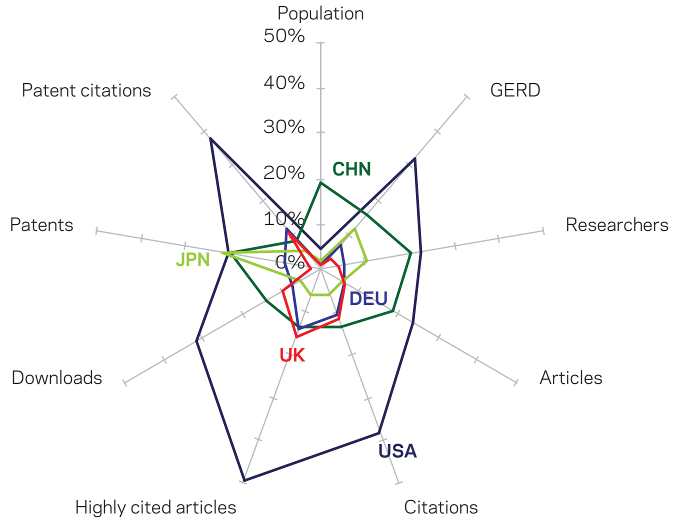
1.2.3 The UK is a focal point for global research collaboration and researcher mobility

International research collaboration and international researcher mobility can be considered as two sides of the same coin, representing collaborative interactions with or without physical co-location. It should therefore be expected that countries exhibiting high levels of research collaboration typically also have high levels of researcher mobility, and this is certainly true of the UK (see Figures 5.1 and 3.4 respectively). Indeed, the UK occupies a central position in the global network of collaborative partnerships (see Figure 5.4) and the resulting articles from these partnerships are associated with greater field-weighted citation impact than that observed for all internationally collaborative articles published by either the UK or its major partner countries (see Figure 5.3). Moreover, despite a broadly stable researcher population, the UK's research base is continually refreshed through the increasing numbers of new PhD graduates gaining their qualifications within the UK, coupled with a high degree of international mobility amongst active UK researchers. In interviews with key individuals in the academic sector from across the UK and abroad, international collaboration and researcher mobility were acknowledged as being core to the maintenance and further development of the UK's world-leading position as a research nation, especially in light of the relatively limited inputs to the UK research base in terms of R&D expenditure and the number of researchers (see Case Study in Chapter 5). Since UK researchers are clearly highly collaborative and mobile across international borders, it should come as no surprise that they are also highly cooperative and mobile between academic and corporate sectors within and beyond the UK.

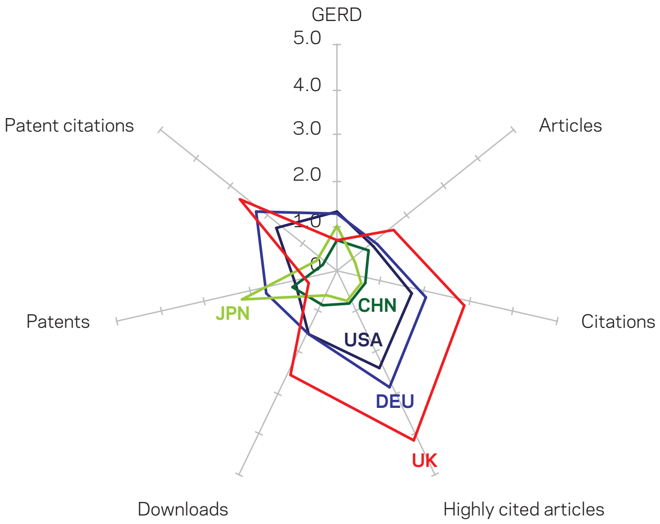
1.2.4 The UK exhibits strong cross-sector knowledge exchange

The UK demonstrates strong cross-sector knowledge exchange, indicated by the high and rising propensity for UK academic users to download UK corporate-authored articles (see Figure 7.9) and the similar pattern for UK corporate users to download UK academic-authored articles (see Figure 7.10). Moreover, it is clear that the UK is successful at commercialising the IP derived from academic research when compared with other countries for which comparable indicators are available, despite relatively low patenting activity. A high and rising proportion of UK journal articles are cited in patents globally, pointing to both the quality and usefulness of UK research. In interviews with key individuals in the UK

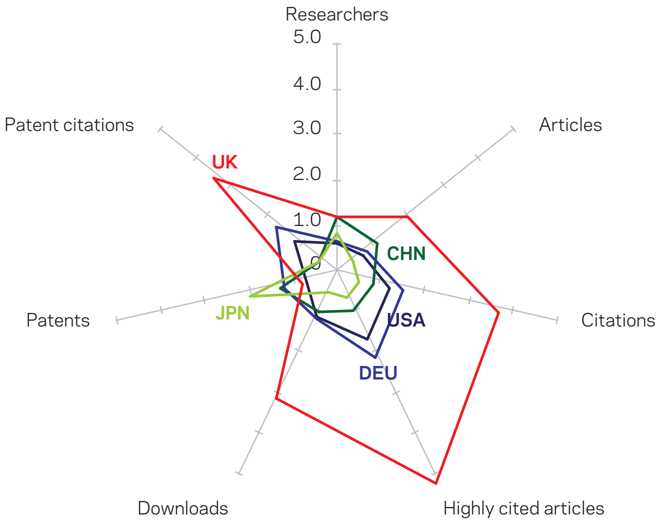
Figure 1.1 *— Key input and output indicators for the UK and four key comparator countries (China, Germany, Japan and the US). Sources: OECD MSTI for Population 2012, Researchers 2010 (Germany and Japan) or 2011 (UK, China and US; extrapolated for the latter), GERD 2011 (except 2010 Japan); world totals are the sum of data for all countries with available data. Scopus for Articles 2012, Citations 2008-12, Highly-cited articles 2008-12. ScienceDirect for Downloads 2008-12. WIPO Statistics Database for patents 2011. LexisNexis Univentio and Scopus for Patent citations 2007-11.*



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

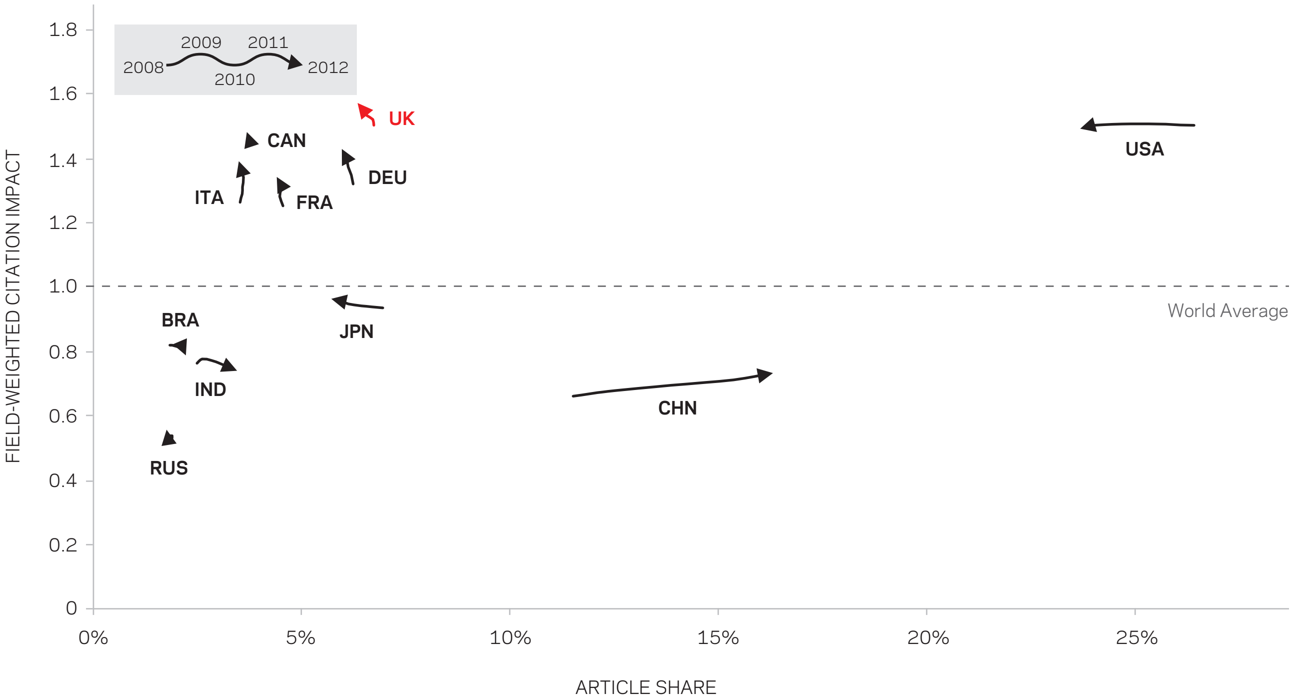


Panel B: Relative share of key input and output indicators per researcher.
All data are expressed as world share divided by world share of researchers, giving a relative index where a value of 1.0 implies that, per researcher, the indicator is equal to the world average.

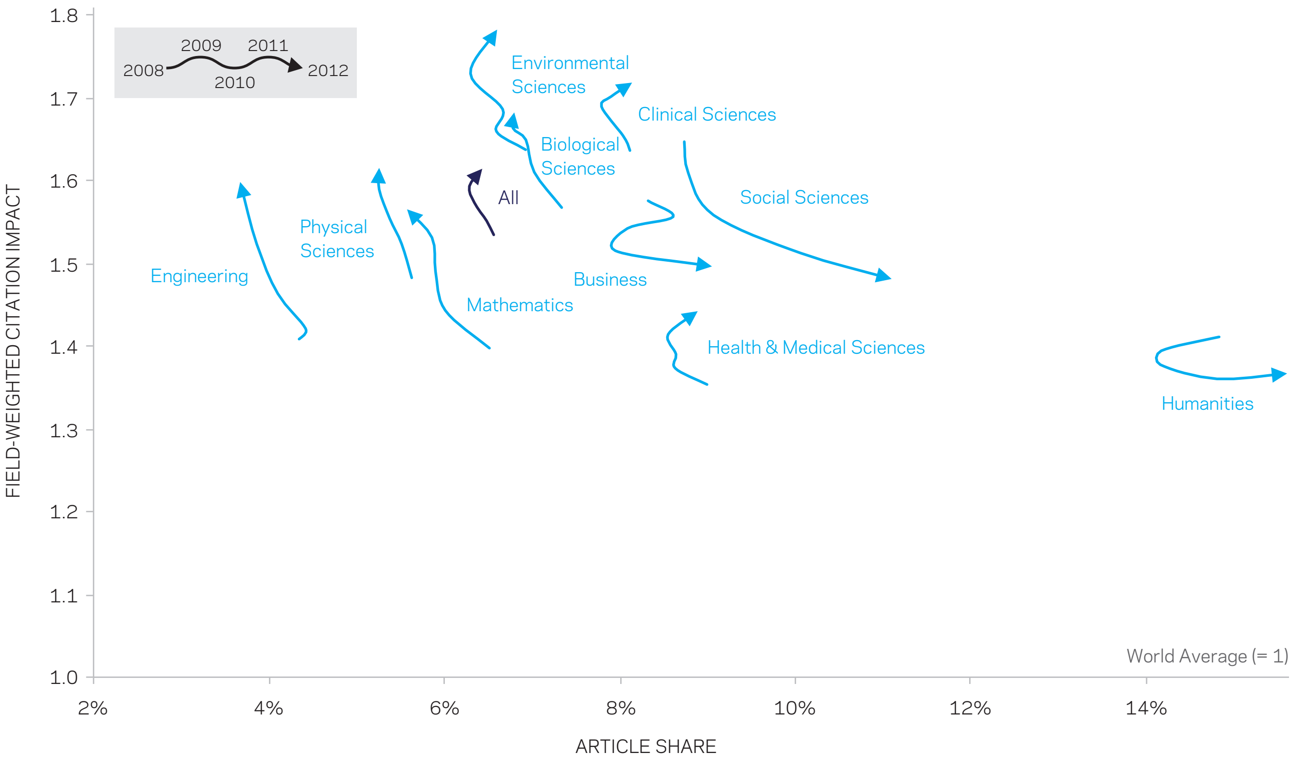


Panel C: Relative share of key input and output indicators per unit GERD.
All data are expressed as world share divided by world share of Gross Expenditure on Research and Development (GERD), giving a relative index where a value of 1.0 implies that, per unit GERD, the indicator is equal to the world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

***Figure 1.2** — Article share and field-weighted citation impact, 2008-12. Source: Scopus.*

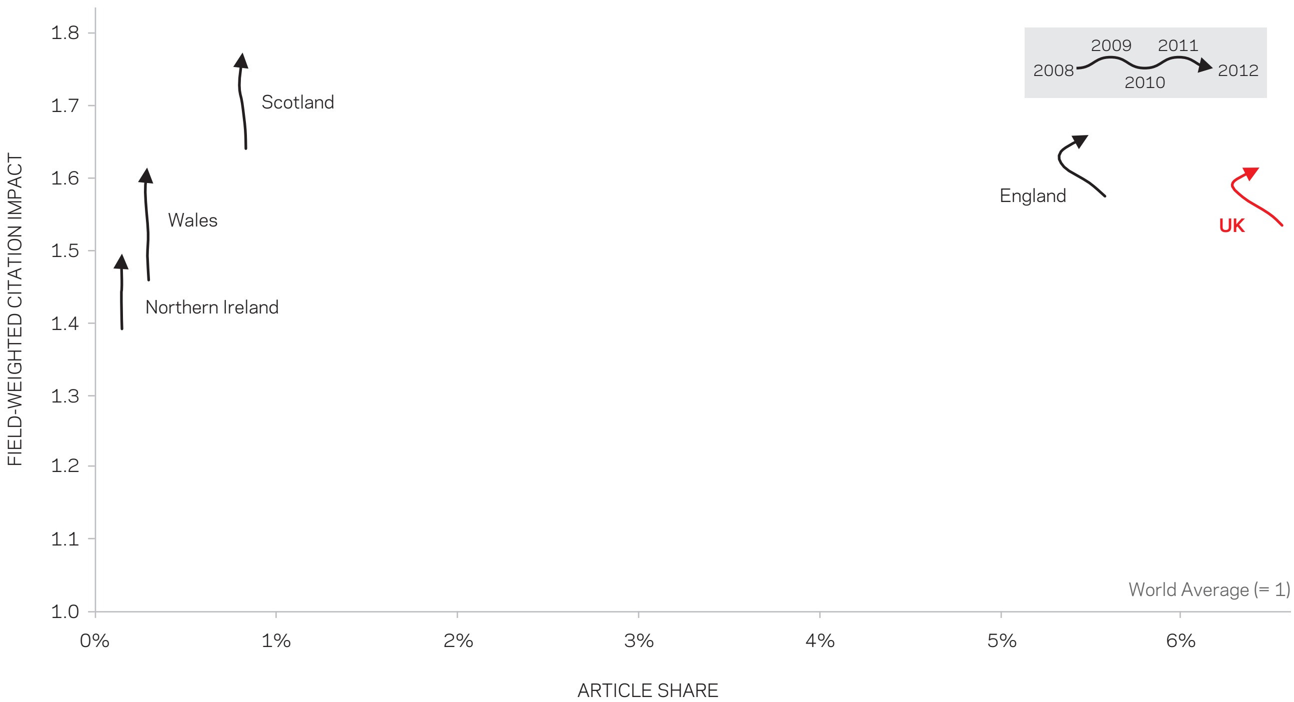


***Panel A**: The UK and comparator countries.*



***Panel B**: Research fields within the UK.*

Figure 1.2 continued from previous page.



Panel C*: The UK's constituent countries.*

academic and corporate sectors, the mutual benefits of cross-sector partnerships were widely recognised, but so too were the barriers and risks associated with them (see Case Study in Chapter 7).

1.2.5 The UK research base shows areas of potential vulnerability

While the UK punches above its weight to deliver increasingly high-quality research outputs on broadly stable or decreasing R&D expenditure or human capital inputs, it may not be possible to sustain its position as a world-leading research nation on this basis indefinitely. While the US remains the world's largest research base, recent trends indicate that its relative standing, and that of other traditional powerhouses like the UK, may be starting to be eroded by pressure from the emerging nations of the East: most notably China, in terms of sheer volume of research inputs (see Figures 3.1 and 3.3) and outputs (see Figure 4.1), if not (yet) in terms of overall research quality (see Figure 4.6). However, with China's slowly increasing rate of international collaboration (see Figure 5.1) and a net Total Inflow of researchers (see Table 3.1), it seems likely that quality (in terms of field-weighted citation impact) will follow.

While the mechanisms of research funding and researcher training - as well as the economic context of national research bases - make direct comparisons difficult, it is clear that the global research ecosystem has become increasingly complex in recent years, characterised by the opposing forces of collaboration and competition. In this context, while the UK is well-positioned to remain a research leader in the future, continued investment in the research base is essential to this aim.

Chapter 2
Research Inputs

UK R&D EXPENDITURE

£27.4b ($36.5b) in 2011

Decreased at **-0.8%** per year in the period 2007-11

Ranks **6th** amongst comparator countries in 2011

Represents **3.2%** of the global total in 2011

UK R&D INTENSITY

1.75% in 2012

Decreased at **-0.5%** per year in the period 2008-12

Ranks **6th** amongst comparator countries in 2012

UK R&D EXPENDITURE BY SECTOR

64% in the Business Enterprise sector in 2011

26% in the Higher Education sector in 2011

9% in the Government sector in 2011

2% in Other sectors in 2011

UK R&D EXPENDITURE BY SOURCE OF FUNDS

46% from the Business Enterprise sector in 2011

1% from the Higher Education sector in 2011

30% from the Government sector in 2011

23% from Other sectors in 2011

2.1 Highlights

- Amongst its comparator countries, the UK has the third-lowest R&D intensity, and this indicator shows that investment in the research base is declining.
- While the UK's R&D expenditure is predominantly funded by the Business Enterprise sector, the proportion of GERD accounted for by Business Enterprise as either the sector of performance or the source of funding is lower than for most comparator countries.
- Conversely, UK R&D expenditure is proportionally greater in the Higher Education sector, but proportionally lower in this sector as the source of funding, than for most comparator countries.
- Taken together, this pattern of GERD expenditure distribution may - at least in part - explain the UK's relative strength in university-derived research outputs such as publications and citations (see Chapter 4 and 6) and its relative weakness in terms of technology outputs such as patents (see Chapter 7).

2.2 Introduction

Expenditure on Research & Development (R&D) is the key enabler of the development and maintenance of national research capabilities, as it creates both the market for skilled researchers and the infrastructure required to support them. Since the global financial crisis which began in 2008, most countries have recognised the need to maintain or increase R&D spending, as the level of R&D expenditure has been associated with underlying economic growth[7].

2.3 Key Findings

2.3.1 UK R&D expenditure is predominantly funded by the Business Enterprise sector

Gross Domestic Expenditure on R&D (GERD) represents the total expenditure on R&D within a country, regardless of the sector of performance or source of funding; it includes domestically-conducted R&D financed from overseas, but excludes R&D funding paid for abroad (for example, to international agencies). R&D expenditure can be viewed from two complementary perspectives: by sector of performance (i.e. the sector in which the money was spent) or by source of funding (i.e. the sector from which the money came). The sum of expenditure from either perspective totals the overall level of expenditure on R&D, GERD (see Figure 2.1). A comparison of the distribution of GERD by sector within a country offers a perspective on the emphasis placed on different types of R&D, and so can help to explain the relative distribution of outputs from the national research base as a whole.

According to the UK's Office for National Statistics, UK GERD amounted to £27.4b in 2011 (see Figure 2.1). The predominant source of funding and sector of research-performance for UK R&D expenditure is the Business Enterprise sector, which accounts for 46% and 64% of GERD, respectively. While 30% of UK GERD is derived from Government funding, relatively little (just 9%) is spent in the Government sector; conversely, Higher Education accounts for 26% of GERD by R&D performance but contributes just 1% as a funding source. The 'Other' category, which includes investment from overseas and from the non-profit sector, represents a significant proportion of the source of funding in the UK (23%), but accounts for little R&D performance expenditure (at just 2%). In the UK, the non-profit sector includes medical research charities such as the Wellcome Trust, the British Heart Foundation, and Cancer Research UK. According to the Association of Medical Research Charities, "Medical research charities have consistently spent more than £1b on research in each of the past five years."[8]

2.3.2 The UK's level of R&D spending has decreased in real terms and as a proportion of GDP

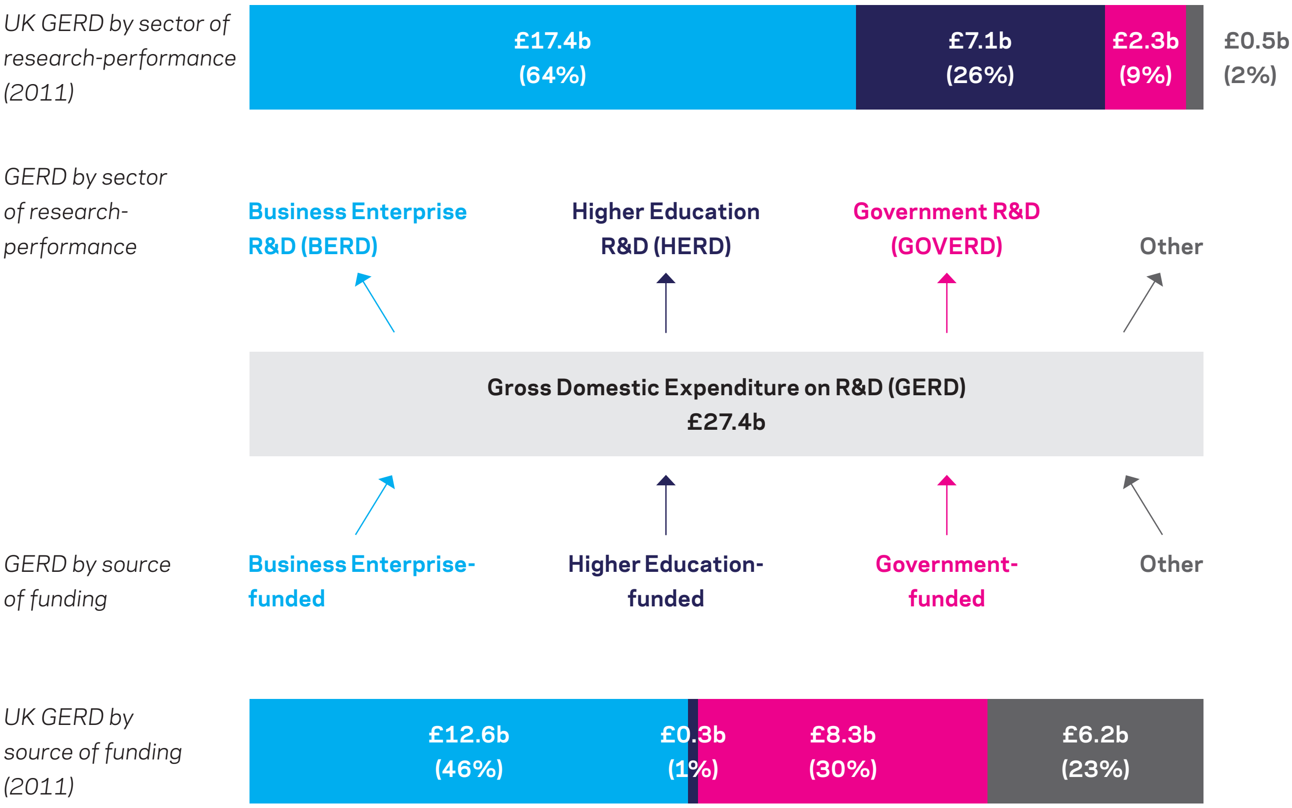
To allow for comparison between countries and over time, GERD and related indicators are sourced from the OECD and are typically expressed in US dollars, adjusted for constant prices and purchasing power parity[9]. UK GERD decreased from $37.2b in 2008 to $36.5b in 2011, and extrapolation to 2012 (for which official OECD figures are not yet available) suggests that it decreased to $36.1b in 2012. By contrast, in 2011 Germany spent more than twice as much (at $80.4b) on GERD than the UK, China five times as much (at $183.2b), and the US ten times as much ($366.3b). UK GERD represents just 3.2% of the global total GERD expenditure of over $1.14 trillion in 2011.

[7] 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.

[8] Retrieved from *www.amrc.org.uk/our-members/sector-data/research-spend*.

[9] The Office for National Statistics reports the UK's GERD and related indicators to the OECD, where the appropriate currency and price conversions are made.

Figure 2.1 — The distinction between research-performing and -funding sector in establishing the composition of GERD, and UK GERD by sector of performance and by source of funding, 2011. In this figure only, monetary values are shown in billions of pounds sterling. Sector of research-performance and by source of funding are shown per OECD categorisation for comparability with other countries. Source: Office for National Statistics.



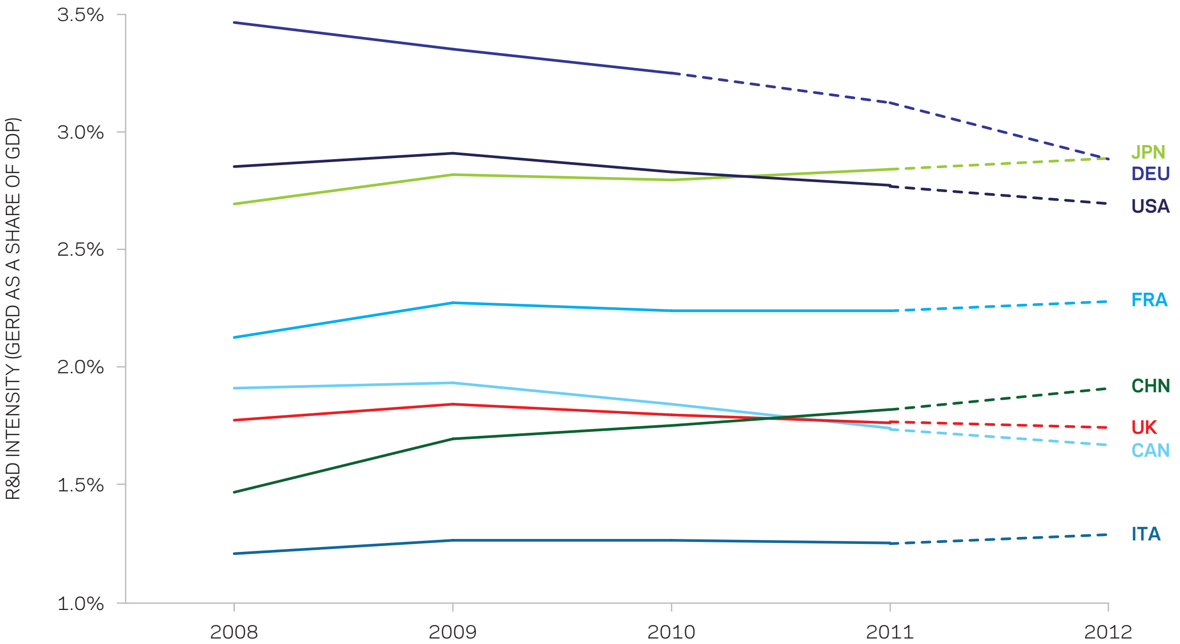
R&D intensity is a relative indicator of national investment in the research base and is defined as GERD as a share of Gross Domestic Product (GDP; the key national indicator of economic production). The UK's R&D intensity decreased slightly from 1.78% in 2008 to 1.77% in 2011 (see Figure 2.2), and extrapolation to 2012 (for which official OECD figures are not yet available) suggests that it has decreased to 1.75% in 2012. This is driven by decreases in both GERD and GDP over this period, but with GERD falling more steeply than GDP.

The UK's R&D intensity in 2012 is lower than all but two comparator countries (Canada and Italy), having surpassed Canada in 2011 but being surpassed by China in the same year; it is also below that of the aggregate R&D intensity for the G8, EU27 and OECD country groups. The R&D intensity of the US, Canada and, most notably, Japan all decreased between 2008 and 2012, while Germany, France, Italy and, most notably, China saw increases.

2.3.3 UK R&D expenditure by sector of research-performance is proportionally greater in the Higher Education sector and lower in the Business Enterprise sector than for most comparator countries

The composition of GERD by sector of research-performance for the UK differs from that of comparator countries in that it is relatively high in the Higher Education sector at 27% and relatively low in the Business Enterprise sector at 61%, despite the latter still being proportionally greater than the former within the UK; only Italy and Canada have a lower proportion of Business Enterprise and a higher proportion of Higher Education expenditure than the UK. R&D performance in the Business Enterprise sector is considered a driver of short-term economic growth[10]. The UK's strong emphasis on R&D performance by the UK's Higher Education sector, which is also significantly greater than that of the aggregate figure for the G8 and, to a lesser extent, the EU27 country groups, reflects the UK's longstanding emphasis on university-centred research[11].

Figure 2.2 — *R&D intensity (GERD as a share of GDP) for UK and comparators, 2008-12. All 2012 values (and also 2011 for Japan) are extrapolated from OECD data. UK ranking in EU27 is amongst 20 (of 27) countries with available data and in OECD is amongst 38 (of 41) countries with available data. Source: OECD MSTI 2013/1.*



	2008	2012	Change 2008-12	CAGR 2008-12	UK Rank 2008	UK Rank 2012
UK	1.78%	1.75%	-0.03%	-0.5%	-	-
G8	2.53%	2.41%	-0.12%	-1.2%	6	5
EU27	1.89%	2.05%	0.16%	2.0%	8	13
OECD	2.00%	1.98%	-0.02%	-0.3%	16	21

2.3.4 UK R&D expenditure by source of funding is proportionally lower in the Higher Education and Business Enterprise sectors than for most comparator countries

A comparison of the UK's GERD by source of funding with that of comparator countries reveals a markedly different composition. While Business Enterprise remains the largest source of funding for R&D in the UK (at 44.0%), the proportion is significantly lower than the aggregate figure for the G8 and EU27 country groups and for most comparator countries (except Italy and Canada, which show a similar proportion to the UK), and the proportion of funding from the Higher Education sector in the UK (at 1%) is lower only in France and Italy. The UK's proportion of GERD sourced from Government is similar to that of the aggregate figure for the G8 and EU27 country groups. Most strikingly, a significantly greater proportion (at 22%) of the UK's GERD is sourced from the 'Other' category (representing foreign investment and the non-profit sector) than for any other comparator country of the G8 and EU27 country groups, highlighting the UK's strong support from foreign and research charity funding[12].

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

[11] 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 (2010) "The allocation of science and research funding, 2011/12 to 2014/15: Investing in world-class science and research".

[12] Leevers, H. & Dusic, N. (2009) "The Magic Number? Reaching 2.5% of GDP on R&D" CaSE News 62.

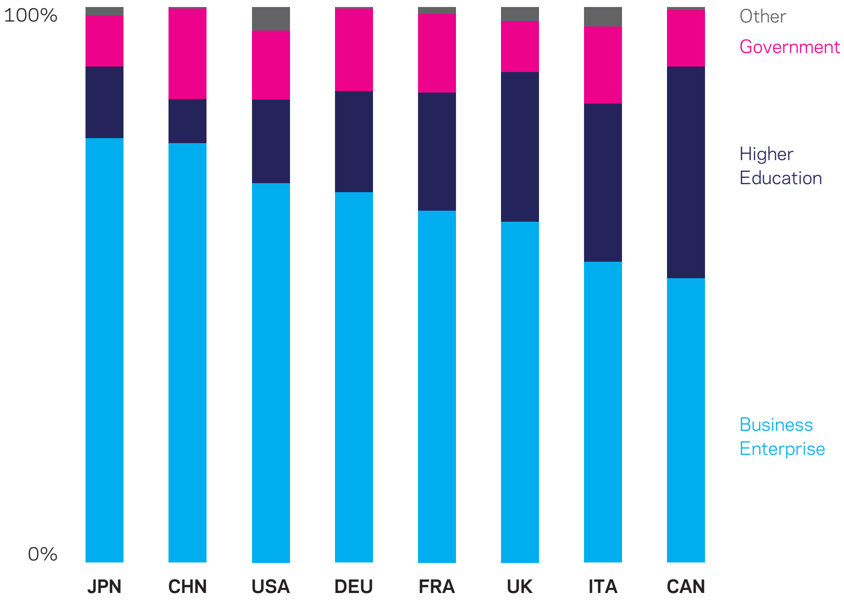


Figure 2.3 — R&D expenditure by sector of research-performance for the UK and comparators, 2011. Data are shown for 2011 as this is the most recent year for which data are available for the majority of countries. For Japan, no 2011 values were available so 2010 data were used. For all countries, 'Other' was estimated by (subtraction) from the total. Countries are shown left to right by descending proportion of Business Enterprise as the sector of research-performance. Source: OECD MSTI 2013/1.

	HERD	BERD	GOVERD	Other
UK	26.9%	61.5%	9.3%	2.4%
G8	17.1%	68.0%	12.6%	2.4%
EU27	24.1%	61.7%	13.1%	1.1%

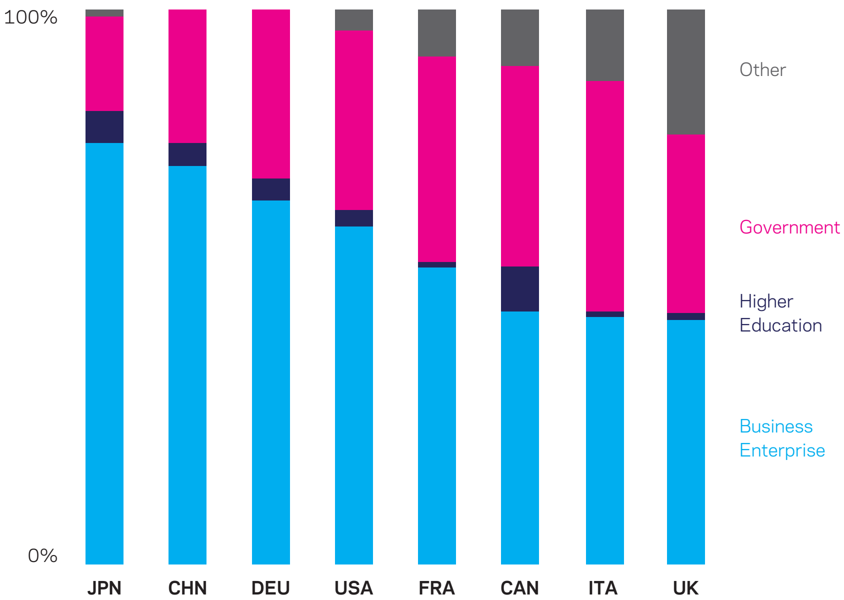


Figure 2.4 — R&D expenditure by source of funds for the UK and comparators, 2010. Data are shown for 2010 as this is the most recent year for which data are available for all countries. For all countries, 'Other' was estimated by (subtraction) from the total except for China and Germany, for which no recent Higher Education data were available and so 'Other' was assumed to equal zero in order to instead estimate Higher Education. Countries are shown left to right by descending proportion of Business Enterprise as the source of funding. Source: OECD MSTI 2013/1.

	Higher Education-funded	Business Enterprise-funded	Government-funded	Other
UK	1.2%	44.0%	32.3%	22.4%
G8	2.9%	60.7%	31.4%	5.0%
EU27	0.9%	53.2%	34.8%	11.0%

Chapter 3
Human Capital

UK RESEARCHERS

262,303 in 2011

Increased at **0.9%** per year in the period 2007-11

Ranks **5th** amongst comparator countries in 2011

Represents **3.9%** of the global total in 2011

UK HIGHER EDUCATION RESEARCHERS

163,505 in 2011

Increased at **2.1%** per year in the period 2008-12

Represents **62.3%** of the UK researchers total in 2011

UK PHD GRADUATES

20,076 in 2011

Increased at **3.4%** per year in the period 2007-11

Ranks **4th** amongst comparator countries in 2011

Represents **6.3%** of the OECD total in 2011

UK RESEARCHER MOBILITY

71.6% of active researchers were internationally mobile in the period 1996-2012

Ranks **2nd** amongst comparator countries

3.3% net Total Outflow of active UK researchers

3.1 Highlights

- The UK's apparently stable researcher count in recent years masks the underlying increases in Higher Education researcher numbers, the influx of increasing numbers of new PhD graduates gaining their qualification within the UK, and a high degree of international mobility amongst active UK researchers.
- This dynamic flux of talent from within and beyond the UK means that the human capital element of the UK research base is constantly refreshing.
- Analysis of the UK's research mobility suggests that the Returnee Inflow group is a small but important group of researchers that contribute strongly to the UK research base, and that there is a net Total Outflow of active UK researchers.

3.2 Introduction

Researchers are the engine that drives the progress of research, and so a country's research base is critically dependent on the individual contributions of the researchers affiliated with its research institutions. The prestige of individual researchers and laboratories, historic centres of research and top-ranking universities, serves not only to develop the next generation of researchers but also to attract excellent researchers from overseas.

International research collaboration and international researcher mobility can be considered as two sides of the same coin, representing collaborative interactions in which the participants may be located in the same country or different countries at different points in the research cycle that leads to published articles. Given this close association, further insights on the drivers for, and barriers to, international researcher mobility emerged from extensive interviews with key individuals in the academic sector from across the UK and abroad (as highlighted in the Case Study in Chapter 5).

3.3 Key Findings

3.3.1 The UK researcher population is growing more slowly than comparator countries, and growth is driven by the Higher Education sector

A key determinant of a country's research capacity is the total number of researchers working in higher education, business, government, charity or other private non-profit contexts (see box "What is a 'researcher'?"). In the UK there were 262,303 researchers in 2011 (expressed as full-time equivalents rather than as a simple headcount), representing 3.9% of the global total and increasing at just 0.9% per year over the period 2007-11 (see Figure 3.1). This growth rate is well below the 2.88% for the G8 countries in the same period, but is higher than for the EU27 and OECD countries, and is similar to the growth of the global researcher total. Of the comparator countries, only Canada and Japan saw lower researcher growth rates in the same period, at -0.8% and -1.0% per year, respectively. Indeed, when expressed per thousand population, UK growth is even more modest at 0.3% per year over the period 2007-11, and when expressed per thousand labour force growth is negative at -0.2% per year in the same period.

A breakdown of the UK's researchers by sector of employment shows that researcher numbers have changed in different ways in the four main R&D sectors in recent years (see Figure 3.2). Researcher numbers in the Government and Private non-profit sectors have grown at a rate commensurate with that of the overall modest growth in UK researcher numbers in the period 2007-11 (at 0.9% per year), but these two sectors represent just 3.4% and 1.5% of the UK researcher population in 2011, respectively. Meanwhile, researcher counts in the Business Enterprise sector, accounting for some 32.8% of UK researchers in 2011, have fallen at a rate of 1.0% per year in the same period. However, the number of researchers working in a Higher Education context, which accounts for the largest share of UK researchers at 62.3% in 2011, has grown at 2.1% per year in the period 2007-11. The distribution of researchers across sectors is in clear contrast to the distribution of UK GERD funding by sector of performance (see Figure 2.2), where Higher Education accounts for just 27% of total GERD, while Business Enterprise accounts for 61% of GERD by sector of performance.

WHAT IS A 'RESEARCHER'?

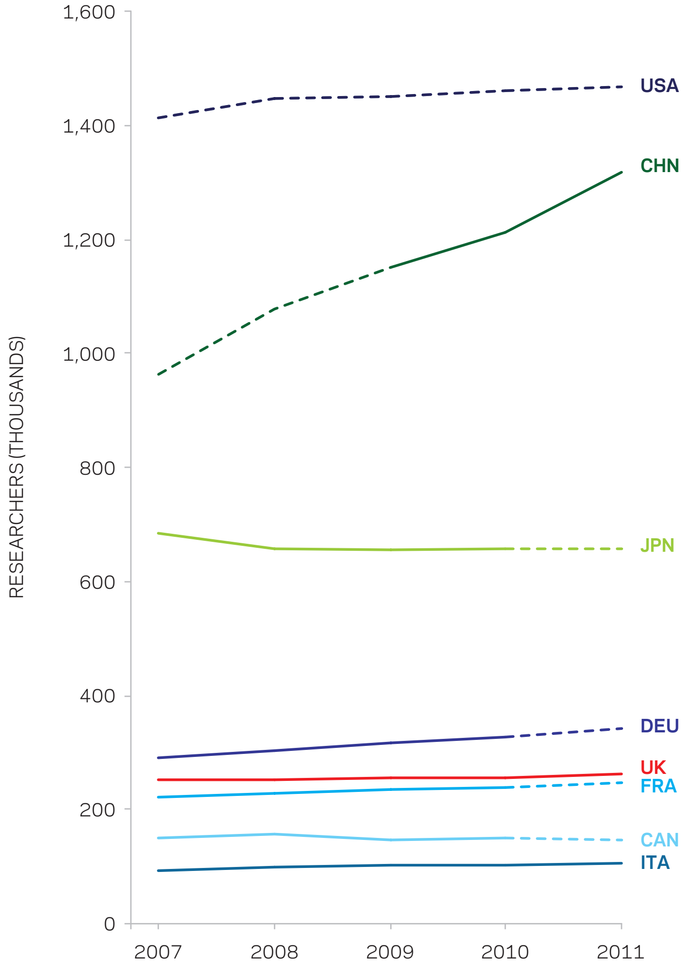
The OECD data on research inputs used in this report are compiled from data supplied by national statistical agencies, such as The Office for National Statistics (ONS) and various government bodies in the UK. Agencies collect data according to definitions provided in the Frascati Manual, first published in the early 1960s and updated periodically ever since. According to the latest (2002) edition[13]:

> *"Researchers are professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems and also in the management of the projects concerned."*

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.

[13] Frascati Manual (2002) "Proposed Standard Practice for Surveys on Research and Experimental Development." OECD Publishing. pg. 93.

Figure 3.1 *— Researchers for the UK and comparators, 2007-11. All 2011 values (except Italy, UK and China) are extrapolated from OECD data; for the US, all values except 2007 are extrapolated from OECD data. Note that data for China were rebased in 2009 according to the Frascati Manual definition of "researcher"; prior to this, much of the data for China were collected according to the United Nations Educational, Scientific and Cultural Organization (UNESCO) concept of "scientist and engineer"; the researcher count for 2008 was estimated from the 2009 value by applying the average percentage increase from the 2009-11 data, and then the 2008 count was estimated by the percentage increase from the original 2008-09 data. World totals are based on the 40 countries with available data, and represent the majority of research-intensive countries globally. UK ranking in the EU27 is amongst 22 (of 27) countries with available data, in the OECD is amongst 37 (of 41) countries with available data, and for the World is amongst 40 countries with available data. Source: OECD MSTI 2013/1.*



	2007	2011	Change 2007-11	CAGR 2008-12	UK Rank 2007	UK Rank 2011
UK	252,651	262,303	9,652	0.9%	-	-
G8	3,575,711	3,676,886	171,389	2.9%	5	4
EU27	1,426,665	1,598,054	101,175	0.7%	2	2
OECD	6,078,149	6,282,519	204,370	0.8%	6	6
World	6,480,364	6,734,433	254,069	1.0%	6	6

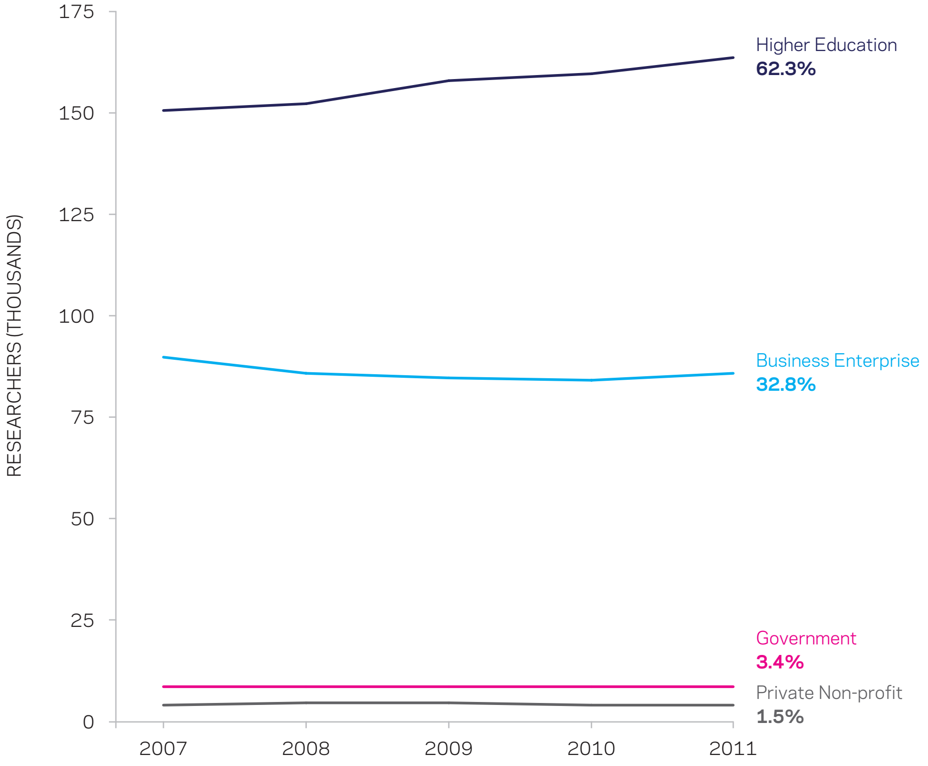


***Figure 3.2** — UK researchers by sector of employment, 2007-11. Source: OECD MSTI 2013/1.*

Sector	2007	2011	Change 2007-11	CAGR 2007-11
Higher Education	150,623	163,505	12,882	2.1%
Business Enterprise	89,599	85,947	-3,652	-1.0%
Government	8,504	8,812	308	0.9%
Private non-profit	3,924	4,038	114	0.7%

3.3.2 The UK is the fourth largest producer of PhD graduates globally

The flow of people through higher education and into a research career can be characterised as a 'pipeline' of talent, but one that narrows as individuals pass through it and are 'siphoned off' into careers outside research[14]. The final stage in this pipeline before becoming considered a full member of the researcher community is typically a higher research degree: in most research fields, a PhD. As such, the number of PhD graduates produced from a national research system each year is an indicator of the volume of new talent generated within that country, irrespective of the national origin or destination of those graduates.

In 2011, 20,076 PhD students graduated in the UK, reflecting 6.3% of the aggregate across OECD countries and increasing at 3.4% per year in the period 2007-11 (see Figure 3.3). Of the comparator countries, the US, China and Germany each produced more PhD graduates than the UK in 2011. The growth in PhD graduates for the UK is within the range of those seen across most comparator countries (except for Japan, which saw negative growth in this period at -1.4% per year), is slightly lower than that seen in the G8 and OECD country groups, but is significantly greater than for the EU27 country group.

Although there is not a linear relationship between graduating with a PhD and going on to become a researcher in the same country, a comparison of PhD graduates (see Figure 3.3) and researchers (see Figure 3.1) data shows that the relative ranking of the UK and most comparator countries in both is comparable, with the exception of Japan, which ranks far above Germany and the UK by researchers but somewhat below both of these countries by PhD graduates. Note also that the relative rankings of Italy and Canada are inverted on these two key indicators of human capital.

[14] 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.

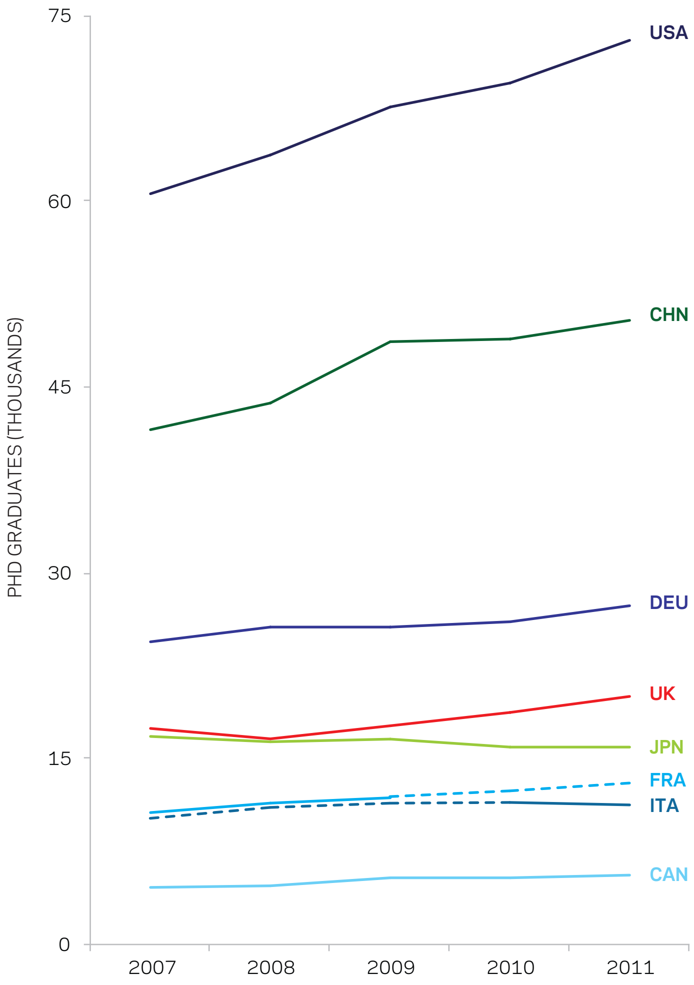


Figure 3.3 *— PhD graduates for the UK and comparators, 2007-2011. Values for 2010 and 2011 for France and 2008, 2009 and 2010 for Italy are extrapolated from OECD data. Note that comparable figures for China are not available in OECD data; these values are from China's Ministry of Education*[15]*. Source: OECD MSTI 2013/1 and China Ministry of Education.*

	2007	2011	Change 2007-11	CAGR 2007-11	UK Rank 2007	UK Rank 2011
UK	17,545	20,076	2,531	3.43%	-	-
G8	144,856	176,308	31,452	5.03%	3	3
EU27	104,647	110,079	5,432	1.27%	2	2
OECD	267,022	318,598	51,576	4.5%	4	4

3.3.3 **The UK researcher population is internationally mobile**

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[16], surveys of researchers[17], CV analysis[18], or a combination of methods[19]. 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.

[15] Retrieved from *www.moe.gov.cn/publicfiles/business/htmlfiles/moe/s7382/list.html*.

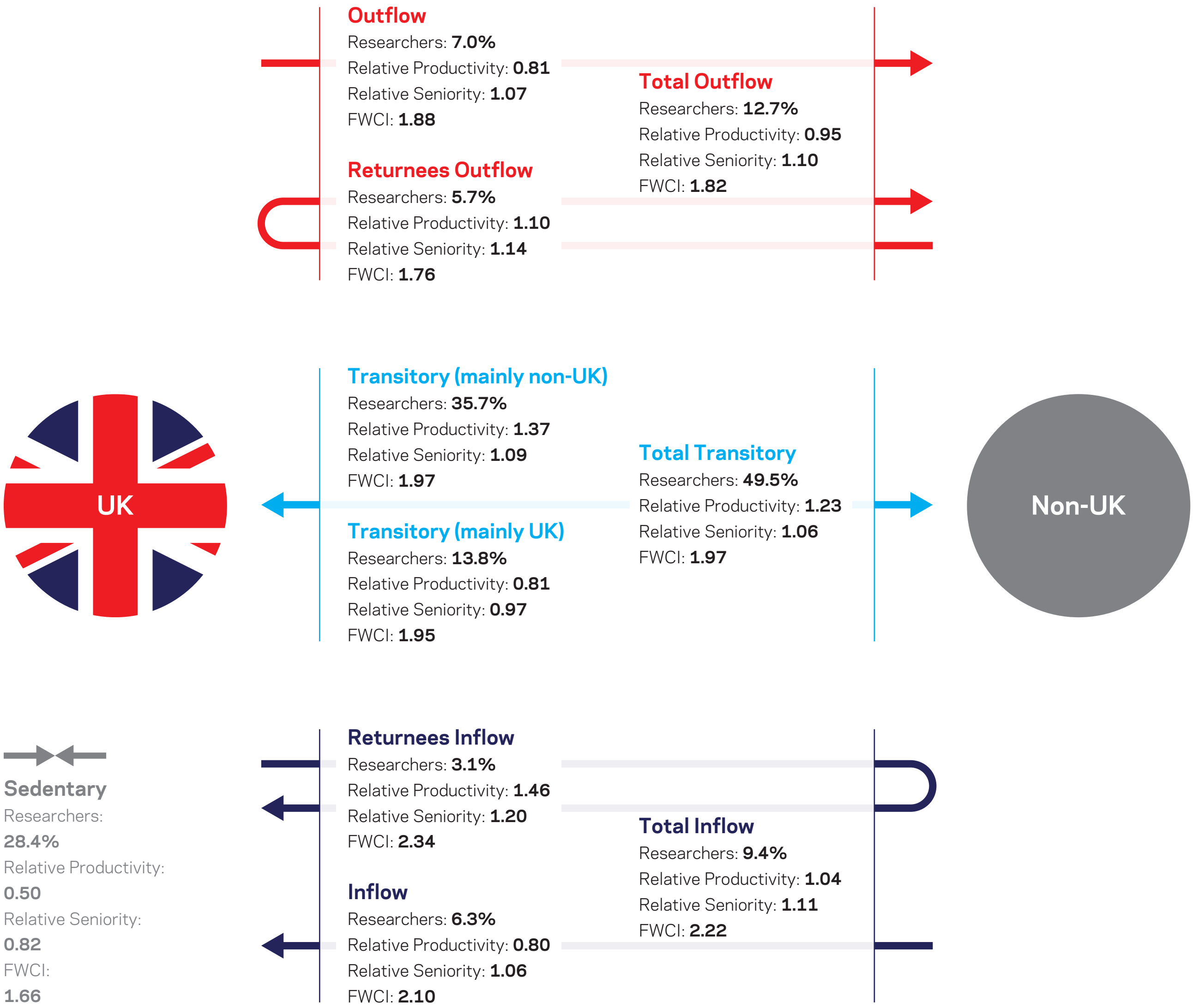


Figure 3.4 *— International mobility of UK researchers, 1996-2012. This analysis is based on Scopus author data and is restricted to a set of 265,579 active UK researchers. UK researchers are defined as authors that have listed a UK affiliation on at least one publication in Scopus during the period 1996–2012, and active researchers are defined as those authors with at least 1 article in the latest 5-year period (2008–2012) and at least 10 articles in the entire 17-year period (1996–2012), or those with fewer than 10 articles in 1996–2012, but at least 4 articles in 2008–2012.*

Mobility classes *are defined as follows: stays overseas of 2 years or more were considered migratory (Total Outflow and Total Inflow) and were 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). Stays abroad of less than 2 years were deemed transitory (total Transitory), and were also further subdivided into those who mostly published under a UK (Transitory (mainly UK)) or a non-UK (Transitory (mainly non-UK)) affiliation. Researchers with only UK affiliations in Scopus during the period 1996–2012 were classified as Sedentary.*

Indicators *are defined as follows: Relative Productivity is a measure of the articles per year since the first appearance of each researcher as an author during the period 1996–2012, relative to all UK researchers in the same period. Relative Seniority represents years since the first appearance of each researcher as an author during the period 1996–2012, relative to all UK researchers in the same period. Field-weighted citation impact (FWCI) is calculated for all researchers in each mobility class; since this analysis is restricted to active UK researchers, the aggregate of these FWCI values will not equal that of the UK overall in the period 1996-2012. 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.*

Comparator	Sedentary	Total Transitory	Total Outflow	Total Inflow	Net Total Outflow (Total Outflow less Total Inflow)
UK	28.4%	49.5%	12.7%	9.4%	3.3%
France	36.7%	46.8%	8.6%	7.9%	0.7%
Italy	51.9%	36.7%	5.9%	5.5%	0.4%
Germany	36.3%	44.8%	10.7%	8.2%	2.6%
Japan	60.0%	29.4%	5.5%	5.1%	0.4%
US	46.8%	35.6%	9.7%	7.9%	1.8%
Canada	27.0%	50.0%	12.5%	10.5%	2.0%
China	71.1%	17.8%	4.1%	7.0%	-2.9%

Table 3.1 *— Summary of international mobility of researchers for the UK and comparator countries, 1996-2012. Source: Scopus.*

The approach presented here is a refinement of that reported in the previous report in this series, and represents researcher mobility patterns as a snapshot based on available data at author level and aggregates this into mobility groups at a country level (see box "Measuring international researcher mobility"). The same approach has recently been used to compare patterns of European and US researcher mobility[20]. However, it is not possible to draw direct comparisons between the results presented here and those shown in the previous report in this series because:

- the present analysis includes two additional years of publication data compared with the previous 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;
- 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.

[16] 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.

[17] 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.

[18] 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.

[19] 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*.

MEASURING INTERNATIONAL RESEARCHER MOBILITY

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.

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[21]). Gender is not captured in Scopus author profiles.

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 papers) published across the sources included in Scopus during the period 1996–2012.

What is an 'active researcher'?
The 1.5 million UK authors identified includes a large proportion with relatively few articles over the entire 17-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 5-year period 2008–2012 and at least 10 articles in the entire 17-year period 1996–2012, or those with fewer than 10 articles in 1996–2012, and at least 4 articles in 2008–2012. After applying the productivity filter, a set of 265,579 active UK researchers was defined and formed the basis of the study.

How are mobility classes defined?
The measurement of international researcher mobility by co-authorship 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, stays overseas of 2 years or more were considered migratory[22] and were further subdivided into those where the researcher remained abroad or where they subsequently returned to their original country. Stays overseas of 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 may be 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 sedentary.

Migratory

- *Outflow*: active UK researchers whose Scopus author data for the period 1996-2012 indicates that they have migrated from the UK to another country (or countries) for at least 2 years without returning to the UK.

- *Returnees Outflow*: active UK researchers whose Scopus author profile data for the period 1996-2012 indicates that they have migrated to the UK from another country (or countries) for at least 2 years, and then subsequently migrated to another country (or countries) for at least 2 years.

- *Total Outflow*: the sum of Outflow and Returnee Outflow groups.

- *Inflow*: active UK researchers whose Scopus author data for the period 1996-2012 indicates that they have migrated to the UK from another country (or countries) for at least 2 years without leaving the UK.

- *Returnees Inflow*: active UK researchers whose Scopus author data for the period 1996-2012 indicates that they have migrated from the UK to another country (or countries) for at least 2 years, and then subsequently migrated back to the UK for at least 2 years.

- *Total Inflow*: the sum of Inflow and Returnee Inflow groups.

Transitory

- *Transitory (mainly non-UK)*: active UK researchers whose Scopus author data for the period 1996-2012 indicates that they are based in the UK for less than 2 years at a time but are predominantly based in another country (or countries).

- *Transitory (mainly UK)*: active UK researchers whose Scopus author data for the period 1996-2012 indicates that they are based in another country (or countries) for less than 2 years at a time but are predominantly based in the UK.

- *Total Transitory*: the sum of Transitory (mainly non-UK) and Transitory (mainly UK) groups.

Sedentary

- *Sedentary*: active UK researchers whose Scopus author data for the period 1996-2012 indicates that they have not published outside the UK.

What indicators are used to characterise each mobility group?
To better understand the composition of each group defined on the map, 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 1996–2012, relative to all UK researchers in the same period. Relative Seniority represents years since the first appearance of each researcher as an author during the period 1996–2012, 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).

[21] See *www.orcid.org*.

[22] 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).

3.3.3.1 UK researchers are highly internationally mobile

The UK has a highly mobile researcher population, with almost 72% of active UK researchers in the period 1996-2012 having published articles while affiliated with non-UK institutions in the same period. The remaining 28% of UK researchers have not published with a non-UK institution during this period. It is of course possible that many of these Sedentary researchers did travel and collaborate internationally in this period, but such activities did not lead to peer-reviewed publication(s) in which they listed their address as being outside the UK. As a group, these Sedentary researchers have a low relative productivity (articles published per year since first appearance as an author), of just 0.50 (compared to an average score of 1.0 for all active UK researchers over this period). They are also at an earlier stage in their publishing career, with a relative seniority (number of years since their first appearance as an author) of just 0.82 (relative to 1.0 for all active UK researchers over this period).

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

In the period 1996-2012, 7.0% of UK researchers moved out of the UK and have not returned to the UK as indicated by the countries listed in their published articles (the Outflow group), while 6.3% of UK researchers moved into the UK and showed no indication of having left the UK since (the Inflow group). Both the Outflow and Inflow groups have lower relative productivity than average (at 0.81 and 0.80, respectively) but are more senior than average, with relative seniority values of 1.07 and 1.06, respectively. However, the articles published by both groups have high field-weighted citation impact at 1.88 and 2.10 for the Outflow and Inflow groups, respectively. The most common destination countries for researchers in the Outflow group were the US, Australia, Canada, Germany and Ireland, while the most common source nations for the Inflow group were the US, Germany, Australia, France and Italy.

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

Across the 17-year period analysed, 5.7% of active UK researchers moved into the UK and subsequently left after more than two years in the country (the Returnees Outflow group), while 3.1% of UK researchers moved out of the UK and subsequently returned after more than two years abroad (the Returnees Inflow group). Though the

Returnees Outflow group are relatively productive and senior (at 1.10 and 1.14, respectively), the field-weighted citation impact of their articles at 1.76 is the lowest amongst all the mobility groups aside from the Sedentary researchers. In contrast, the Returnees Inflow group are relatively senior (at 1.20), highly productive (at 1.46) and have the highest field-weighted citation impact of any of the mobility groups (at 2.34). Indeed, a recent study of Argentinean life scientists showed that returnees are more likely to publish in high-quality journals and also concludes that, "Return migration leads to the formation of scientific ties between home and host system and capacity building in the home system"[23]. The most common destination countries amongst the Returnees Outflow group were the US, Germany, Australia, France and China, while the most common source nations in the Returnees Inflow group were the US, Germany, Australia, Canada and France.

3.3.3.4 The UK has a net Total Outflow of researchers

Taking together the Total Outflow (i.e. Outflow and Returnees Outflow groups) and Total Inflow (i.e. Inflow and Returnees Inflow groups), there is a net outflow of researchers from the UK of 3.3%. Both the Total Outflow and Total Inflow groups have similar seniority (at 1.11 and 1.10, respectively); the Total Inflow group is more productive and has a greater field-weighted citation impact (at 1.04 and 2.22, respectively) than the Total Outflow groups (at 0.95 and 1.82, respectively). This outflow is in apparent contrast to the overall growth of UK researchers seen in Figure 3.1, but since these mobility figures are derived from the author profiles of active researchers over a period of 17 years (rather than a count of FTE researchers in a single year), some discrepancy is to be expected.

3.3.3.5 The Transitory (mainly non-UK) group of UK transitory researchers are more productive and senior than the Transitory (mainly UK) group

The most prominent groups identified in this analysis are the large numbers of researchers displaying patterns of transitory mobility (with stays either in or outside of the UK of less than two years, as indicated by the countries listed in their published articles). In the period 1996-2012, 13.8% of researchers primarily based in the UK showed transitory mobility to non-UK countries (as indicated by their country listed in their published articles), while a large proportion (35.7%) of UK researchers were based mainly outside the UK and showed transitory mobility into the UK. While the former group is less senior than the average (at 0.97) and considerably less productive (at 0.81), the latter group is relatively senior (at 1.09) and highly productive (at 1.37). Despite these differences, the articles published by both groups have similarly high field-weighted citation impact (at 1.95 and 1.97, respectively). The most common destination countries for the mainly UK-based group were the US, Australia, Germany, Canada and France, while the most common source nations for the mainly non-UK-based group were the US, Germany, France, Canada and Italy.

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

The UK has a very internationally-mobile researcher population, with a correspondingly low proportion of Sedentary researchers (see Table 3.1). Indeed, at 28.4%, the UK's Sedentary rate is higher only than that of Canada (at 27.0%), and less than half that of Japan (at 60.0%) or China (at 71.1%). Japan's very high proportion of Sedentary researchers appears to confirm the view that Japan runs an "intellectual closed shop", with low migration rates and high return rates from abroad[24].

The UK also has the second-highest proportion of transitory researchers amongst these comparator countries at 49.5%, just 0.5% behind Canada (at 50.0%). However, the UK has the greatest net Total Outflow (the difference between the Total Outflow and Total Inflow) of any of these comparator countries, with the next greatest being Germany (at 2.6%); only China shows a negative net Outflow (i.e. a net Inflow) of active researchers in this period (at -2.9%).

[23] 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.

[24] 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.

Chapter 4
Research Outputs

UK ARTICLE SHARE

6.4% of the global total in 2012

Decreased at **-0.5%** per year in the period 2008-12

Ranks **3rd** amongst comparator countries in 2012

UK CITATION SHARE

11.6% of the global total in 2012

Increased at **1.5%** per year in the period 2008-12

Ranks **3rd** amongst comparator countries in 2012

UK FIELD-WEIGHTED CITATION IMPACT

1.61 in 2012

Increased at **1.3%** per year in the period 2008-12

Ranks **1st** amongst comparator countries in 2012

UK HIGHLY-CITED ARTICLE SHARE

15.9% of the global total in 2012

Increased at **0.9%** per year in the period 2008-12

Ranks **2nd** amongst comparator countries in 2012

4.1 Highlights

- Amongst its comparator countries, the UK has only the 3rd-highest share of global articles and citations, and yet is ranked 1st by field-weighted citation impact and has a much greater share of the world's most highly-cited articles than would be expected from the UK's overall article share.
- The UK is a well-rounded research nation, with article output and multidisciplinary competencies across all major research fields and high field-weighted citation impact and download impact across most of them.
- The UK is increasingly cited internationally, and UK articles are made available through a variety of different access models more frequently than the global baseline.

4.2 Introduction

The publication of research findings in journals serves four main functions: to register the research findings with a third party which is date-stamped, to have them certified through review by expert peers, disseminated (by print and/or electronic means) and archived via preservation in physical or virtual repositories. Journal publication also serves a crucial function in the assignment of credit for research results to individual authors, institutions and countries. Of course, in research fields in which journal articles are not the predominant form of output, such as the Humanities, such indicators may be an imperfect reflection of the totality of research activity. Nonetheless, analysing journal articles as one of the myriad possible outputs of research can provide useful insight into the comparative performance of a country's research base.

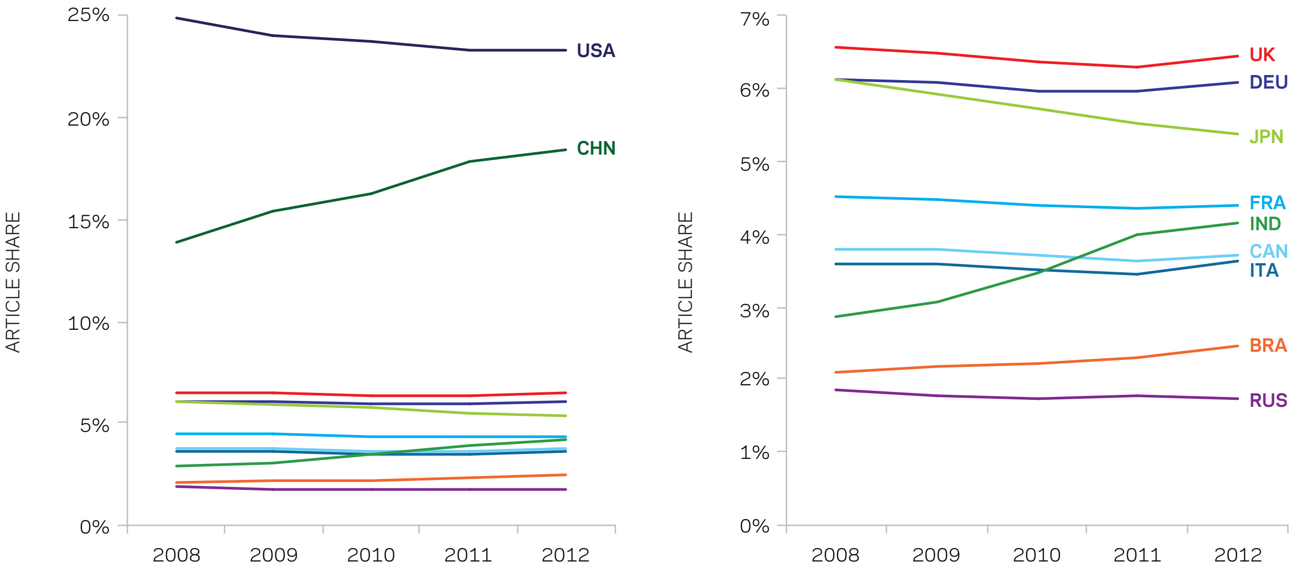
4.3 Key Findings

4.3.1 The UK's share of global articles has increased in 2012 after a period of recent decreases

UK researchers published 139,701 articles in 2012, up from 124,811 in 2008 and representing an increase of 2.35% per year over this period; article growth globally has been slightly higher at 2.87% per year in the same period. As such, the UK's share of global article output has decreased overall in the period 2008-12 (by 0.50% per year), despite showing a slight increase in 2012 (to 6.43%, ranking 3rd largest globally) after a period of downward trending (see Figure 4.1). A similar increase in the 2012 article share after a period of decreasing share is seen for Canada, Germany, France and Italy, while Russia and, markedly, Japan continue to decrease in article share each year. Conversely, China and India exhibit remarkable year-on-year growth in article share, with India exceeding the article shares of Canada and Italy since 2011. The apparent deceleration in the impressive growth of China's article share in 2012, coupled with the very slight increase in the US article share in 2012, means that previous estimates[25] of the overtake of the US by China in global article share by as early as 2015 may need to be revised outwards.

An examination of the UK's article output in its four constituent countries reveals that England constitutes the largest share (at 85.3% in 2012), followed by Scotland (12.6%), Wales (4.4%) and Northern Ireland (2.3%; see Figure 4.2). These shares have remained broadly stable over the period 2008-12.

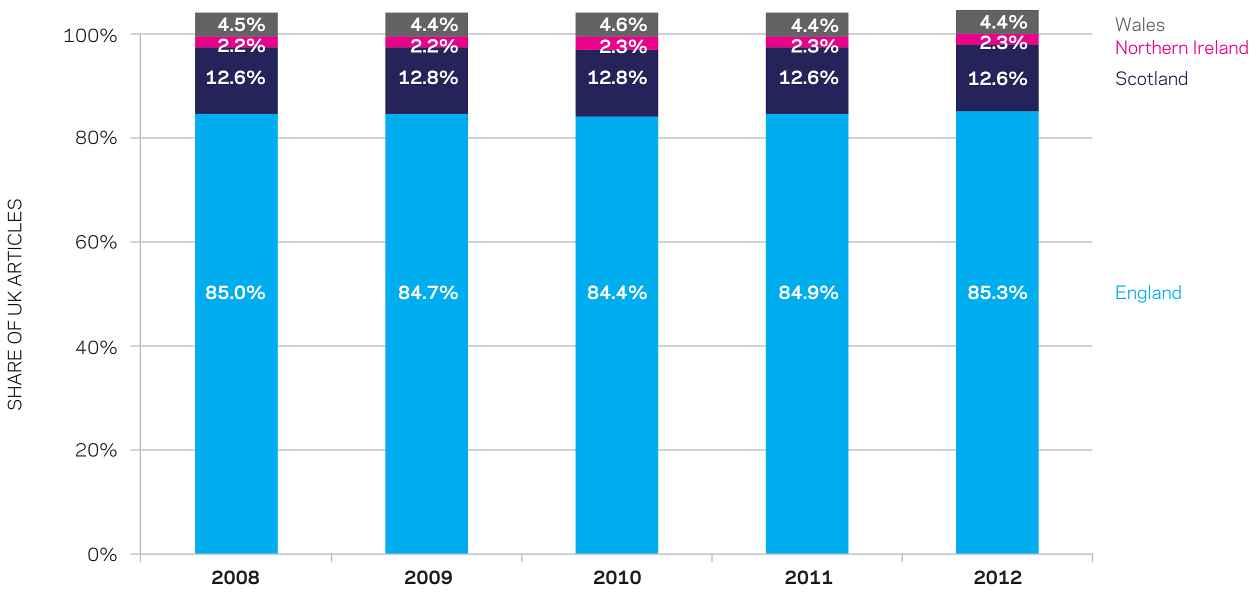
***Figure 4.1** — Share of world articles for the UK and comparators (also Brazil, India and Russia), 2008-2012 with right-hand panel excluding the US and China for clarity. Source: Scopus.*



	2008	2012	Change	CAGR	UK Rank 2008	UK Rank 2012
UK	6.56%	6.43%	-0.13%	-0.50%	-	-
G8	51.48%	48.38%	-3.10%	-1.54%	2	2
EU27	30.56%	30.47%	-0.09%	-0.07%	1	1
OECD	85.20%	88.40%	3.20%	0.93%	3	3
World	100%	100%			3	3

25 The Royal Society (2011) "Knowledge, Networks and Nations: Global Scientific Collaboration in the 21st Century". Available at www.royalsociety.org/policy/projects/knowledge-networks-nations/report/; Leydesdorff, L. (2011) "When can the cross-over between China and the USA be expected using Scopus data?" *Research Trends* 25.

Figure 4.2 *— Share of UK articles for constituent countries, 2008-2012. Shares do not add to 100% owing to co-authorship of some articles between constituent countries. Source: Scopus.*



4.3.2 The UK is a well-rounded research nation, but with increased emphasis on Social Sciences and Business

The UK is a well-rounded research nation, as shown by the broadly similar Activity Index values across the major research fields (see Figure 4.3 and box "Activity Index"). In 2012, the UK's Activity Index is greater than 1.0 in all research fields except for Mathematics, Physical Sciences, and Engineering. Indeed, compared with 2002 there has been a shift in focus away from Biological Sciences, Environmental Sciences, Mathematics, Physical Sciences and Engineering and a very clear emphasis on Social Sciences and Business article outputs. More modest increases in Activity Index are seen for Clinical Sciences, Health & Medical Sciences and Humanities between 2002 and 2012.

Several of the comparator countries are similarly well-rounded, such as the US and Canada, while others, such as Japan, China and Russia are more strongly focussed on those fields in which the UK has the lowest Activity Index: Mathematics, Physical Sciences, and Engineering. Of particular note is Brazil, which shows a significant reorientation of the Activity Index across these main subject fields between 2002 and 2012, shifting away from Mathematics and Physical Sciences and into Health & Medical Sciences, Social Sciences and Business.

ACTIVITY INDEX

The Activity Index[26] 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 2012 the UK published 37.1% of its articles in the Clinical Sciences, while globally this subject field represents just 29.3% of all articles published. The Activity Index for the UK in Clinical Sciences in 2012 is therefore 37.1% / 29.3% = 1.27. A value of 1.0 therefore indicates that a country's research activity in a field corresponds exactly with the global activity in that field; higher than 1.0 implies a greater emphasis while lower than 1.0 suggests a lesser focus.

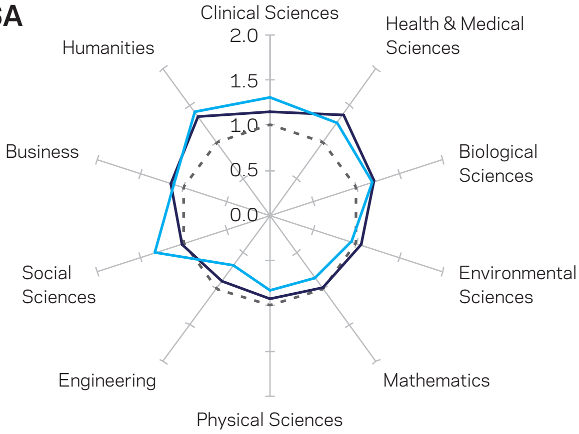
[26] Hu, X., & Rousseau, R. (2009) "A comparative study of the difference in research performance in biomedical fields among selected Western and Asian countries" *Scientometrics*, 81 (2) pp. 475-491.

***Figure 4.3** — Activity Index for the UK and comparators (also Brazil, India and Russia) across ten research fields in 2002 and 2012. 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 OECD countries rather than to the world[27]. Note that the axis maximum has been increased for Italy and Russia (to 2.5) and for Brazil (to 3.0). Source: Scopus.*

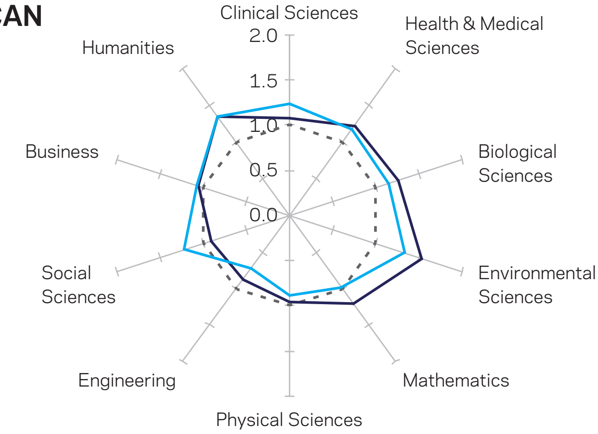
[27] Scopus has increased its coverage in Humanities considerably in recent years, and this expansion has come largely from OECD countries. As such, benchmarking for the Humanities is shown against OECD countries only and not the World, as these countries are similarly affected by the coverage issue and account for over 88% of global articles published in 2012.

Figure 4.3 continued from previous page.

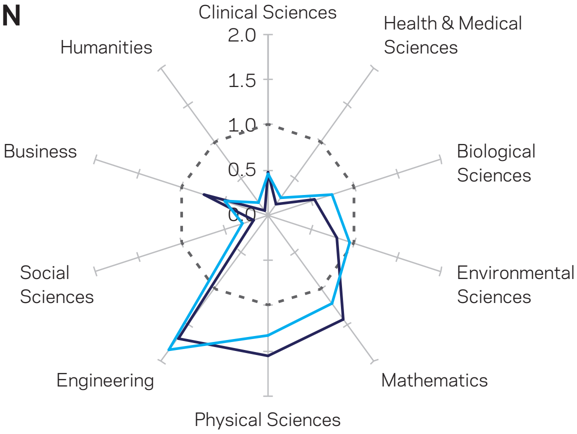
USA



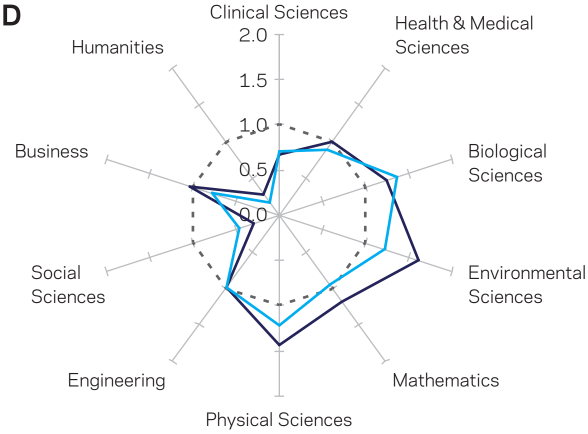
CAN



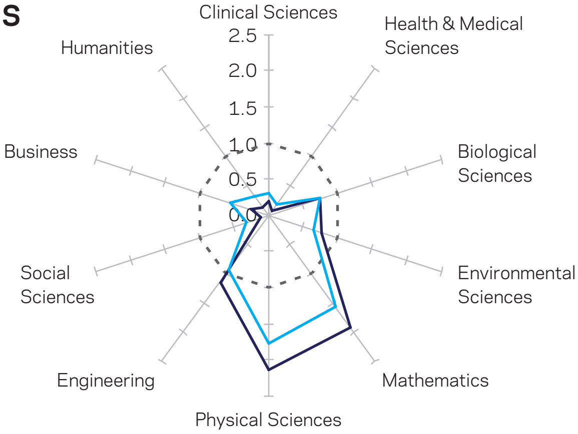
CHN



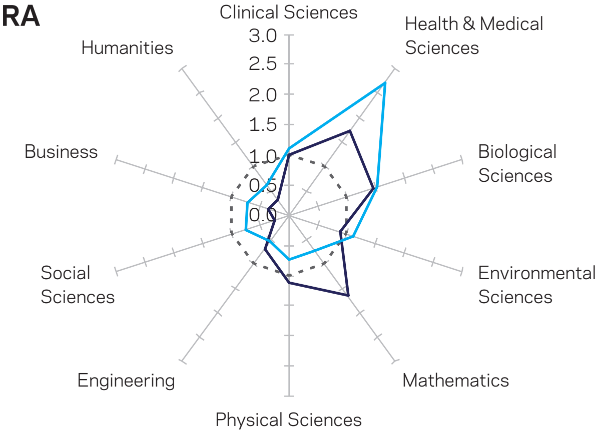
IND



RUS



BRA



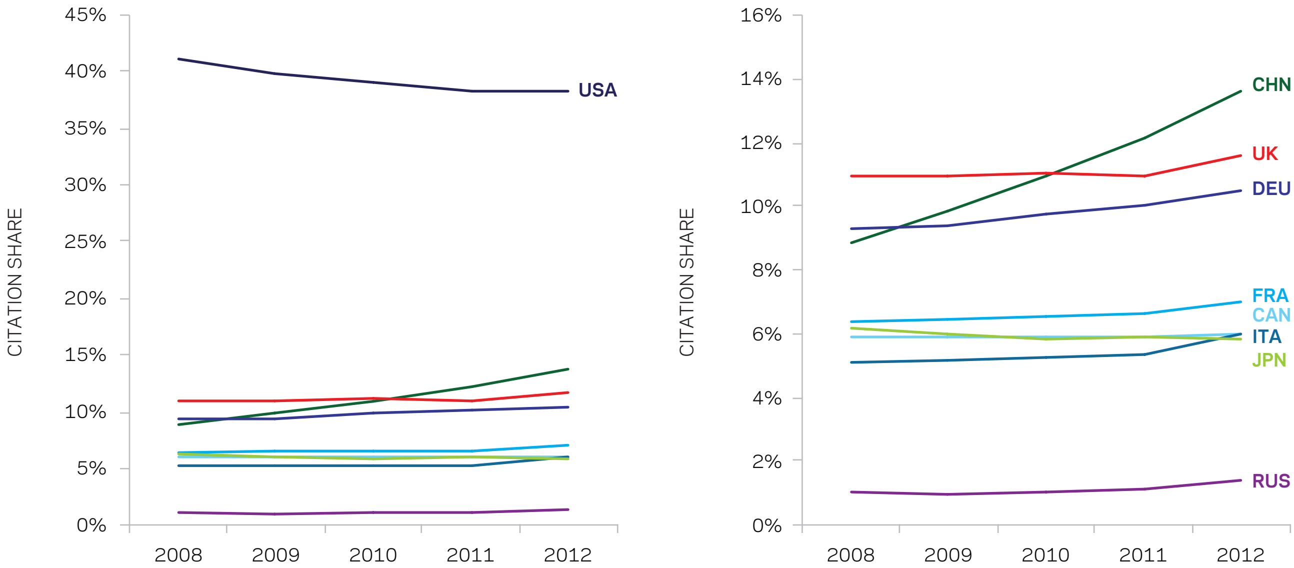
4.3.3 The UK's share of global citations has increased in 2012 after a period of relative stability

The number of citations received by an article from subsequently-published articles is a proxy of the quality or importance of the reported research[28]. UK articles are cited frequently in the global research literature. While the UK produced 6.4% of global articles in 2012, its share of global citations rose to 11.6% in 2012 after a period of holding steady at 11.0% (see Figure 4.4). The UK's citation share increased at 1.5% per year in the period 2008-2012, a rate significantly greater than that of the G8 or especially the EU27 country group. In comparison, the US citation share has continually decreased in this period, compensated by the rise of China and to a lesser extent Germany, France and Italy.

Like the UK, the citation shares for Canada and Russia are relatively stable over the period 2008-12, while Japan's decrease has levelled off in the last 3 years. The UK has the highest citation share amongst EU27 countries and in 2008 ranked 2nd amongst OECD countries as well as globally (after the US), but by 2012 China has overtaken the UK and ranks second in the OECD and globally, with the UK now ranking 3rd.

An examination of the UK's citations across its four constituent countries reveals that England constitutes the largest share (at 88.3% in 2012), followed by Scotland (15.5%), Wales (4.3%) and Northern Ireland (2.0%; see Figure 4.5). These shares have remained broadly stable over the period 2008-12.

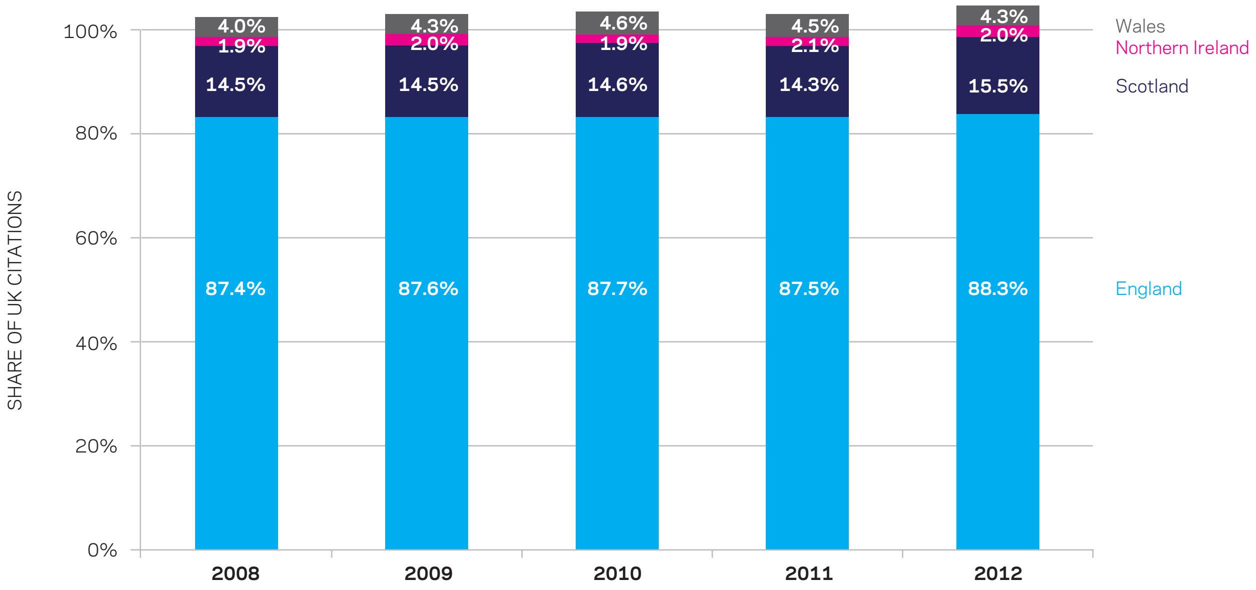
Figure 4.4 *— Share of world citations for the UK and comparators, 2008-2012 with right-hand panel excluding the US for clarity. The share for '2008' is comprised of citations in the period 2008-12 to articles published in 2008, while for '2012' it is comprised of citations in the period 2012 to articles published in 2012. Source: Scopus.*



	2008	2012	Change 2008-12	CAGR 2008-12	UK Rank 2008	UK Rank 2012
UK	10.95%	11.63%	0.68%	1.51%	-	-
EU27	39.08%	40.88%	1.80%	1.13%	1	1
OECD	95.46%	95.5%	0.03%	0.01%	2	3
World	100%	100%	-	-	2	3

[28] 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. Shares do not add up to 100% owing to co-authorship of some articles between constituent countries. The share for '2008' is comprised of citations in the period 2008-12 to articles published in 2008, while for '2012' it is comprised of citations in the period 2012 to articles published in 2012. Source: Scopus.*



4.3.4 The citation impact of UK articles is high and rising and is greater than that of any of the comparator countries

Since citations accumulate over time and citation practices vary by research field, citations must be counted in consistent time windows and field-specific differences in citation rates accounted for. One of the most sophisticated indicators currently available that does intrinsically account for these factors is called field-weighted citation impact (see box "Measuring impact: citation windows and field-weighting").

The UK's field-weighted citation impact is high – at 1.61 in 2012 it is well above the world average (which is by definition 1.0) – and rising, increasing at 1.28% per year in the period 2008-12 from the 2008 value of 1.53 (see Figure 4.6). In 2012, the UK ranks 1st in the G8 on this indicator and 6th in the EU27 country group after the smaller research nations of Denmark, the Netherlands, Belgium, Sweden, and Austria; Austria moved above the UK in the EU27 ranking between 2008 and 2012. In the 2012 ranking amongst OECD countries, the UK's rank of 8th reflects the higher ranking of Iceland and Switzerland.

An examination of the UK's field-weighted citation impact in its four constituent countries shows increasing trends for all constituent countries (see Figure 4.7). In addition, the field-weighted citation impact for England and Scotland is consistently higher than the UK overall, whereas Northern Ireland's field-weighted citation impact remains consistently below. In 2012, the field-weighted citation impact for Wales reached the same level as that for the UK overall.

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 also 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 paper), publication year and subject field. Where the article 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 (reviews typically attract more citations than research articles, for example) as well as subject-specific differences in citation frequencies overall and over time and document types. It is one of the most sophisticated indicators in the modern bibliometric toolkit.

When field-weighted citation impact is used as a snapshot (for example, in Figure 4.11), an *unweighted variable* window is applied. The field-weighted citation impact value for '2008', for example, is comprised of articles published in 2008 and their field-weighted citation impact in the period 2008-12, while for '2012' it is comprised of articles published in 2012 and their field-weighted citation impact in 2012 alone.

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 comprised 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 2011 and 2012 it is not possible to extend the weighted average by 2 years on either side, so weightings are readjusted across the remaining available values.

In the previous report in this series, an *unweighted fixed* window was applied in both snapshot and trend analysis. The field-weighted citation impact value for '2004-08', for example, was comprised of articles published in 2004-08 and their field-weighted citation impact in the same period 2004-08. This method has the disadvantage that citations to recent articles in this 5-year window are relatively underweighted since they have has less time to accrue, and so recent underlying changes may be dampened by this indicator.

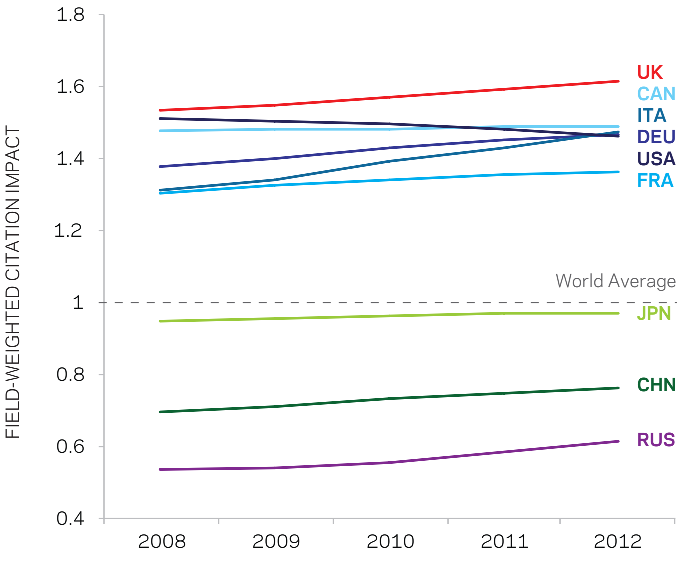
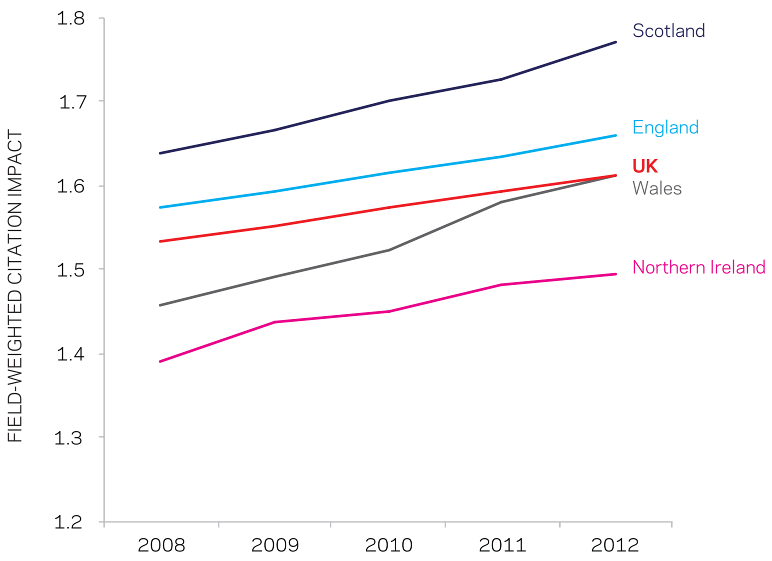


Figure 4.6 — *Field-weighted citation impact for the UK and comparators, 2008-2012. UK ranking in the World is amongst 76 countries with at least 1,000 articles in 2012, which includes all 41 OECD countries and accounts for 98.8% of the global article output. Source: Scopus.*

	2008	2012	Change 2008-12	CAGR 2008-12	UK Rank 2008	UK Rank 2012
UK	1.53	1.61	0.08	1.28%	-	-
G8	1.28	1.28	0.00	-0.04%	1	1
EU27	1.23	1.28	0.05	1.04%	5	6
OECD	1.09	1.07	0.02	-0.58%	7	8
World	1.00	1.00	-	-	8	9

Figure 4.7 — *UK field-weighted citation impact, 2008-2012, per constituent country. Source: Scopus.*



4.3.5 The UK's share of the most highly-cited articles is high and rising and is greater than expected from the UK's overall article share

Citations are not evenly distributed across articles: there is instead a strongly skewed distribution, with a small proportion of all published articles receiving the majority of the citations, with a 'long tail' of articles receiving the remainder and a significant proportion of all articles never receiving a single citation (see box "The Pareto Principle"). Recent research has suggested that not only is an examination of the small proportion of the most highly-cited articles a robust approach to research assessment[29], it may yield insights not possible from looking at aggregate measures which include the entirety of research outputs.

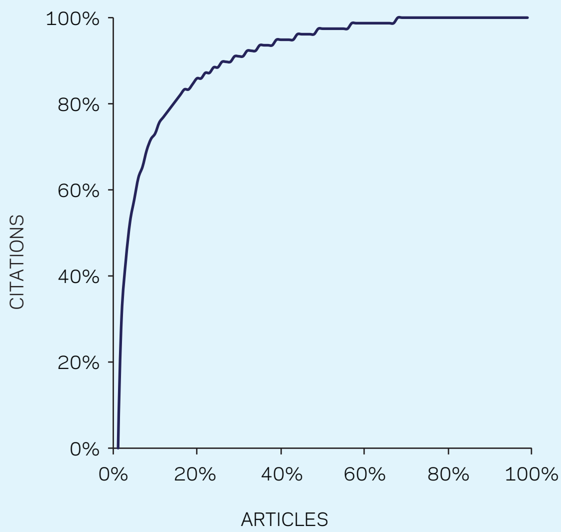
This principle has been applied here to look at each nation's share of the articles comprising the top 1% most highly-cited articles. The UK has a high and rising share of the most highly-cited articles in the world, rising to 15.9% in 2012 (see Figure 4.8). This rate of growth, at 1.52% per year over the period 2008-12, is lower than that for the EU27 country group but contrasts with the decline in highly-cited article share seen for the OECD country group and, even more markedly, for the G8 country group. All comparator countries also show a trend to slightly increase in share over the period 2008-12 except for China, which increased by 7.3% to reach 13.4% in 2012, and the US, which showed a 7.4% decrease to 49.4% in 2012.

The UK's share of highly-cited articles is significantly greater than would be expected based on the UK overall article share (at 15.9% versus 6.4% in 2012; see Figure 4.9). This suggests a focus on research excellence in the UK and other countries positioned above the line of parity, irrespective of the sheer size of the research base or output volumes. Some evidence exists to suggest that highly-cited articles are mostly research articles, are typically multi-authored and often involve international collaboration, and may be more likely to be interdisciplinary or, at least, relevant to more different research fields[31].

An examination of the UK's highly-cited article share for its four constituent countries shows increasing trends for all four (see Figure 4.10), with England representing the largest share (at 14.3% in 2012), followed by Scotland (2.6%), Wales (0.7%) and Northern Ireland (0.3%; see Figure 4.2). These shares have remained broadly stable over the period 2008-12.

THE PARETO PRINCIPLE

The Pareto Principle, or '80/20 rule', states that in any system roughly 80% of the effects come from 20% of the causes. A form of power law probability distribution, this applies to citation distributions: a large proportion of publications are never or rarely cited, and a select few publications account for the majority of all citations[30]. This is illustrated here from Scopus data for all articles published in 2008 versus citations received in the period 2008-2012. Note that while approximately 80% of the citations come from just 20% of the articles, about 32% of these articles remain uncited in this period; the citation threshold for articles in the top 1% is 78 citations. The Pareto Principle also applies to other indicators used in research assessment, including the distribution of articles and citations across authors, institutions and countries.

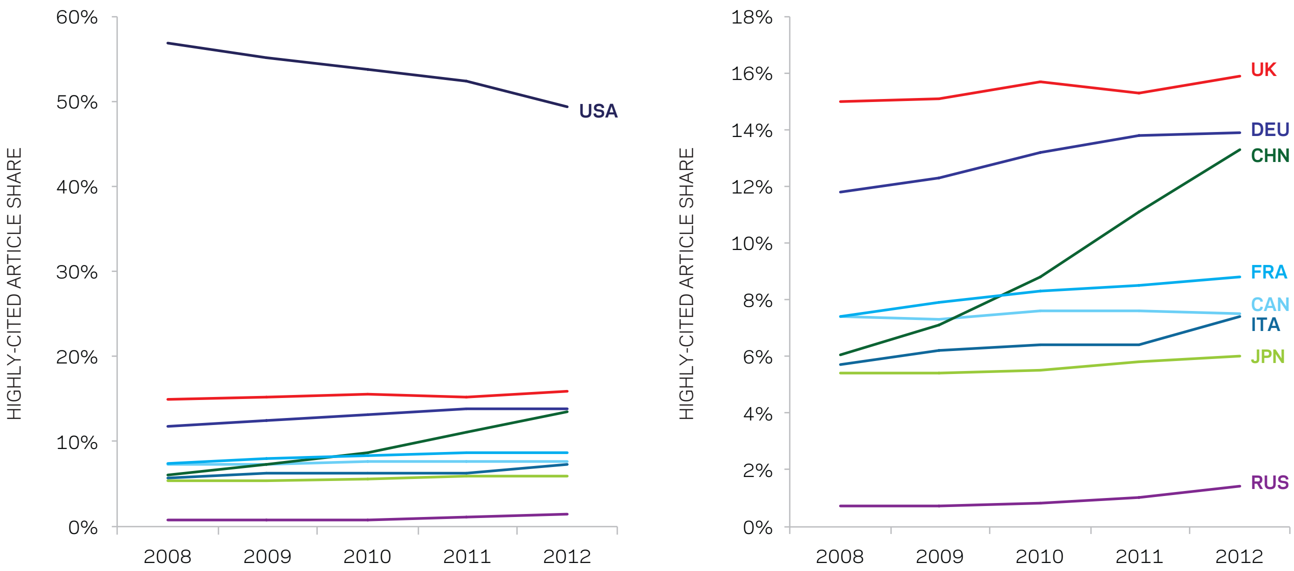


[29] Bornmann, L., *et al.* (2011) "Mapping excellence in the geography of science: An approach based on Scopus data" *Journal of Informetrics* 5 (4) pp. 537-546; Bornmann, L. & Marx, W. (2013) "How good is research really? Measuring the citation impact of publications with percentiles increases correct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

[30] De Solla Price, D.J. (1965) "Networks of Scientific Papers" *Science* 149 (3683) pp. 510-515.

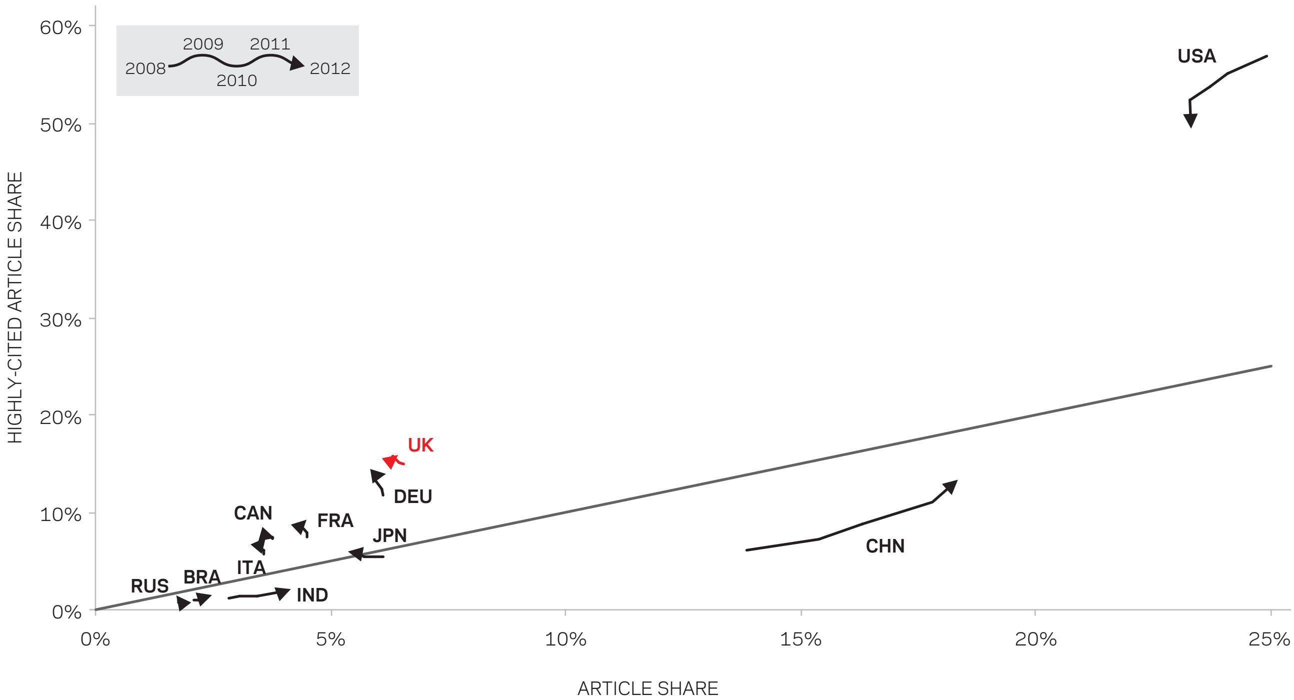
[31] Aksnes, D.W. (2003) "Characteristics of highly cited papers" *Research Evaluation* 12 (3) pp. 159-170.

***Figure 4.8** — Share of the world's highly-cited articles (top 1% of the most cited articles) for the UK and comparator countries, 2008-12 with right-hand panel excluding the US for clarity. The share for '2008' is comprised of citations in the period 2008-12 to articles published in 2008, while for '2012' it is comprised of citations in the period 2012 to articles published in 2012. Source: Scopus.*



	2008	2012	Change 2008-12	CAGR 2008-12
UK	14.97%	15.90%	0.93%	1.52%
G8	82.75%	75.95%	-6.80%	-2.12%
EU27	41.34%	45.29%	3.94%	2.30%
OECD	97.76%	97.27%	-0.49%	-0.13%

***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, 2008-12. 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.*



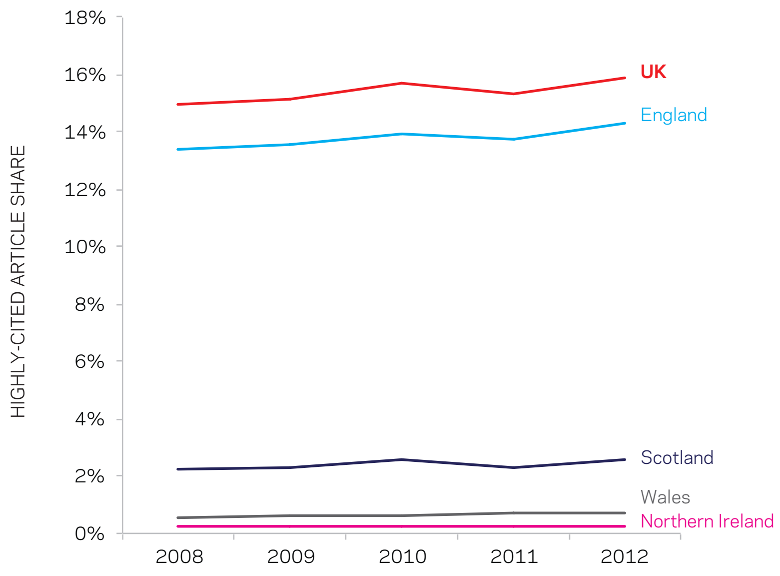


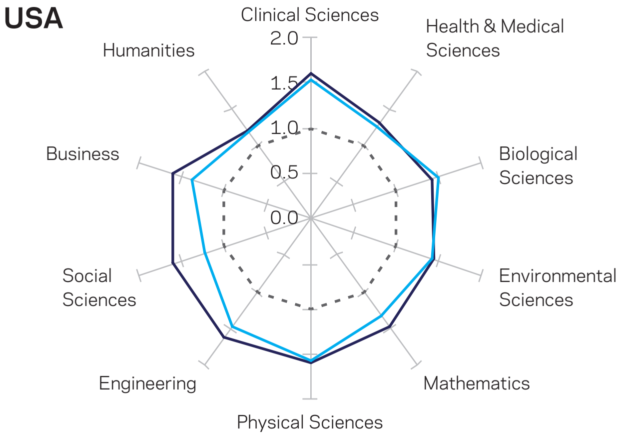
Figure 4.10 *— Share of the world's highly-cited articles (top 1% of the most cited articles) for the UK and constituent countries, 2008-2012. The share for '2008' is comprised of citations in the period 2008-12 to articles published in 2008, while for '2012' it is comprised of citations in the period 2012 to articles published in 2012. Note that, owing to refinement of the methodology used to calculate citation indicators, these shares differ slightly from those presented in the previous report in this series. Source: Scopus.*

4.3.6 **The citation impact of UK articles is high in all major research fields and is rising in the majority of them**

Not only is the UK active across all main research fields (see 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, is rising (see Figure 4.11). In 2012, the UK's field-weighted citation impact is greater than 1.0 in all research fields, and has increased from the 2002 value in all fields except for Social Sciences, Business and Humanities. The greatest increases in this period were in Biological Sciences, Environmental Sciences and Mathematics, and the smallest was in Health & Medical Sciences. The UK's field-weighted citation impact is especially high in fields where it has lower Activity Index, especially Mathematics, Physical Sciences and Engineering (c.f. Figure 4.3).

The only comparator countries also showing a similar pattern, of all field-weighted citation impact above 1.0 in all research fields in 2012, are Italy, Germany, the US and Canada. France shows mixed performance across the 10 fields, while Japan is close to 1.0 across the board. China, India, Russia and Brazil typically have a field-weighted citation impact below 1.0 across all or most fields in 2012. Of particular note is China, which shows very high field-weighted citation impact in Humanities and Social Sciences in 2002 but significantly lower than 1.0 in these same fields in 2012; given the relatively low Activity Index for China in these fields, this is likely to be due to the small number of articles this represented for China in 2002 (c.f. Figure 4.3).

Figure 4.11 *— Field-weighted citation impact for the UK and comparators (including Brazil, India and Russia) across ten research fields in 2002 and 2012. For all research fields, a field-weighted citation impact of 1.0 represents world average in that particular research field. Note that the axis maximum has been increased for Italy (to 2.5) and for China (to 3.0). Source: Scopus.*


USA
Clinical Sciences
Health & Medical Sciences
Biological Sciences
Environmental Sciences
Mathematics
Physical Sciences
Engineering
Social Sciences
Business
Humanities
2.0
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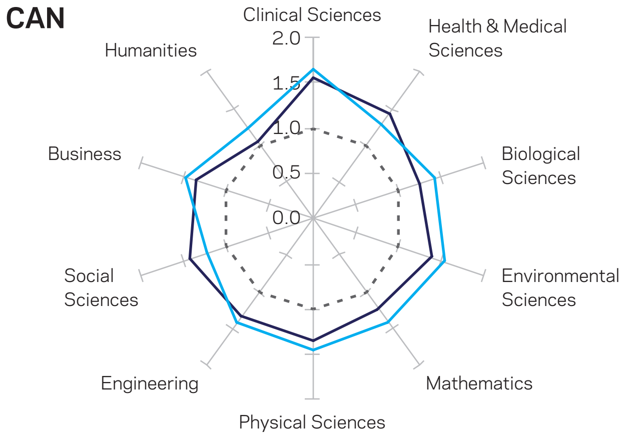
CAN
Clinical Sciences
Health & Medical Sciences
Biological Sciences
Environmental Sciences
Mathematics
Physical Sciences
Engineering
Social Sciences
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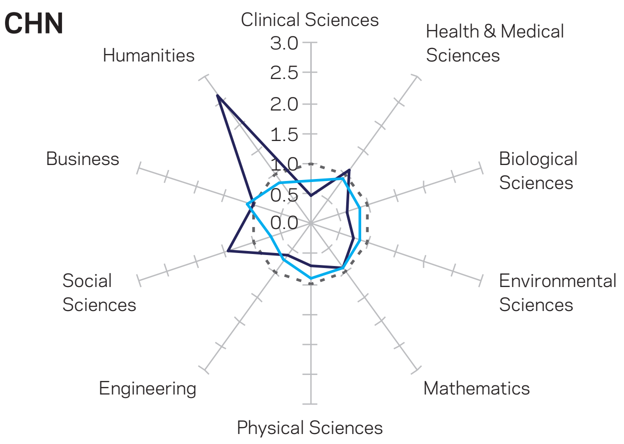
CHN
Clinical Sciences
Health & Medical Sciences
Biological Sciences
Environmental Sciences
Mathematics
Physical Sciences
Engineering
Social Sciences
Business
Humanities
3.0
2.5
2.0
1.5
1.0
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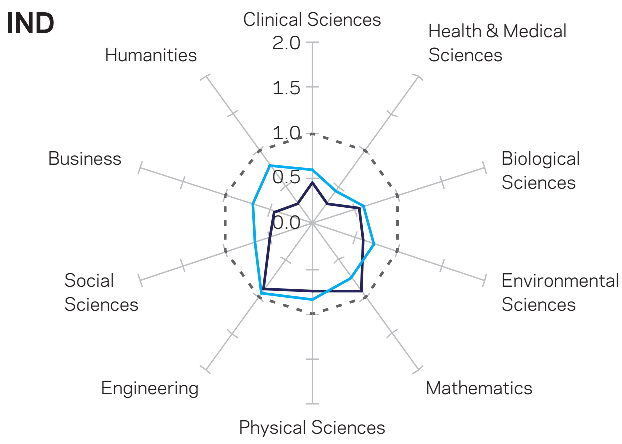
IND
Clinical Sciences
Health & Medical Sciences
Biological Sciences
Environmental Sciences
Mathematics
Physical Sciences
Engineering
Social Sciences
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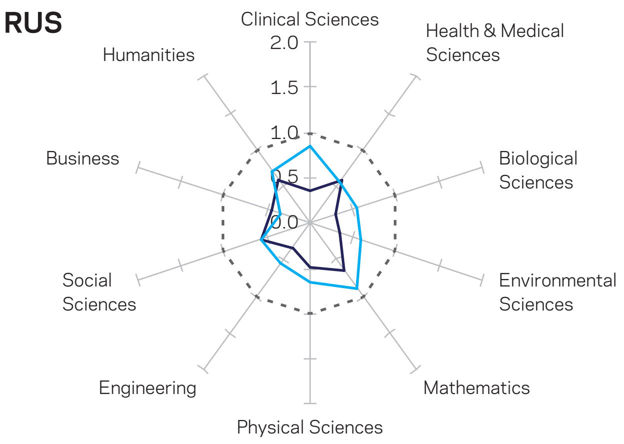
RUS
Clinical Sciences
Health & Medical Sciences
Biological Sciences
Environmental Sciences
Mathematics
Physical Sciences
Engineering
Social Sciences
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Humanities
2.0
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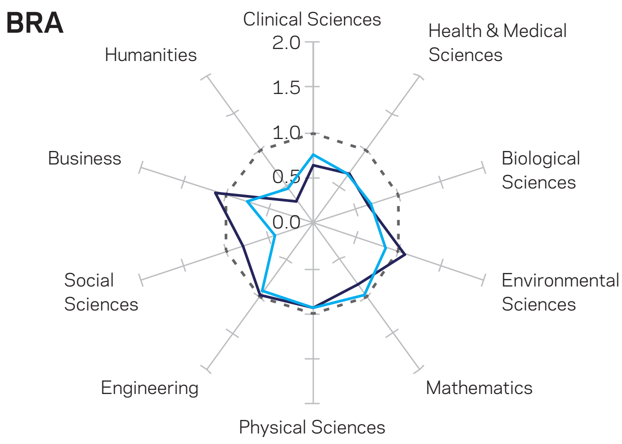
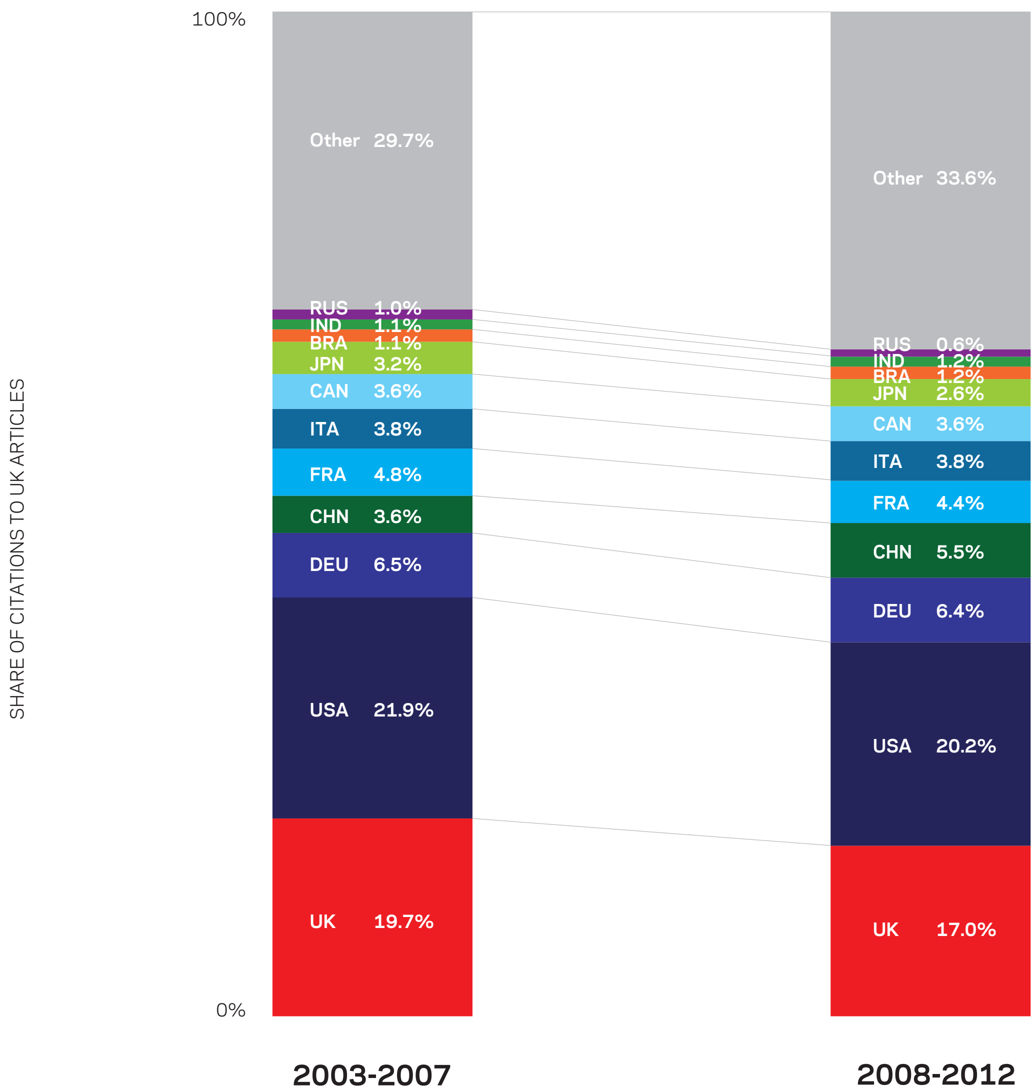

BRA
Clinical Sciences
Health & Medical Sciences
Biological Sciences
Environmental Sciences
Mathematics
Physical Sciences
Engineering
Social Sciences
Business
Humanities
2.0
1.5
1.0
0.5
0.0

4.3.7 UK articles are increasingly cited internationally, especially by smaller research nations

The source of citations to UK articles is diversifying over time, with a decreasing share coming from traditional sources such as the US (which still accounts for the largest share of citations to UK articles, at 20.2% in 2008-12), Germany (6.4%) and France (4.4%; see Figure 4.12). The share of UK citations coming from UK-authored articles is also decreasing over time, from 19.7% in 2003-07 to just 17.0% in 2008-12. Instead, a growing share of citations to UK articles comes from emerging research nations such as China (increasing from 3.6% in 2003-07 to 5.5% in 2008-12), Brazil and India (both increasing from 1.1% in 2003-07 to 1.2% in 2008-12) and from the rest of the world (other increasing from 29.7% in 2003-07 to 33.6% in 2008-12). While these changes are a reflection of changing shares of global article outputs and citations over time (c.f. Figure 4.1 and 4.4), they also indicate the growing awareness and impact of UK research globally.

Figure 4.12 *— Share of citations to UK articles from the UK and comparators (also Brazil, India and Russia), 2003-2007 and 2008-2012. All other sources of citations by country are grouped into the other category. The share for '2003-07' is comprised of citations in the period 2003-07 to articles published in the same period, and for '2008-12' it is comprised of citations in the period 2008-12 to articles published in the same period. Source: Scopus.*



4.3.8 The usage of UK articles is high in the majority of subject fields

Article downloads from online platforms are an emerging alternative metric used as a proxy for research impact. Since full-text journal articles reside on a variety of publisher and aggregator websites, there is no central database of download statistics available for comparative analysis. Despite this, and the fact that no consensus yet exists on the meaning of an article download, downloads are nonetheless a useful indicator of early interest in, or emerging importance of, research (see box "Measuring article downloads").

While the UK's field-weighted citation impact in 2012 is higher than the global baseline of 1.0 across all main research fields, field-weighted download impact is lower for all of them and is less than 1.0 for Mathematics (at 0.953) and Humanities (at 0.962; see Figure 4.13). The greatest differences between the citation and download metrics are in Biological Sciences, Environmental Sciences and Mathematics, and the smallest was in Health & Medical Sciences.

Most of the comparator countries also show a pattern of generally evenly-distributed field-weighted download impact in all research fields in 2012, in contrast with the less uniform patterns of field-weighted citation impact across research fields for many of these countries. This suggests that users download (and by implication, read) widely across the literature but cite more selectively, and may reflect differences in the ease (and meaning) of downloading versus citing. Of particular note are China, India, Russia and Brazil, for which field-weighted citation impact is typically lower across all research fields than field-weighted download impact, suggesting that for these countries the article readership is not converted at a very high rate to citations.

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 an appealing alternative, since it is possible to start counting downloads of full-text articles immediately upon online publication and to derive robust indicators over windows of months rather than years.

While there is a considerable body of literature on the meaning of citations and indicators derived from them[32], the relatively recent advent of download-derived indicators means that there is no clear consensus on the nature of the phenomenon that is measured by download counts[33]. A small body of research has concluded however that download counts may be a weak predictor of subsequent citation counts at the article level[34].

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[35]. ScienceDirect provides download data for approximately 16% of the articles indexed in Scopus; it is assumed that user downloading behaviour across countries does not systematically differ between online platforms. Field-weighted download impact is calculated from these data according to the same principles applied to the calculation of field-weighted citation impact (see box "Measuring impact: citation windows and field-weighting").

[32] 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.

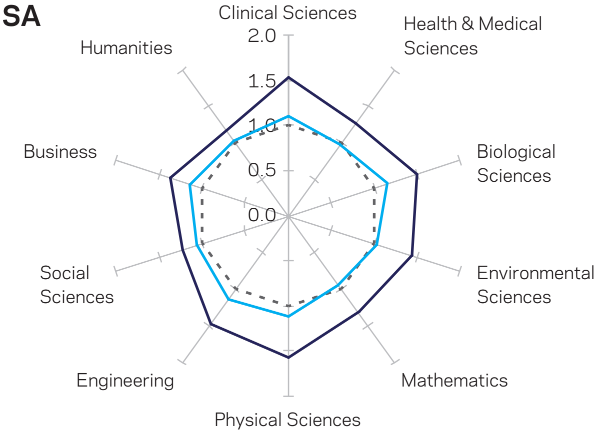
[33] Kurtz, M.J., & Bollen, J. (2010) "Usage Bibliometrics" *Annual Review of Information Science and Technology* 44 (1) pp. 3-64.

[34] 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.

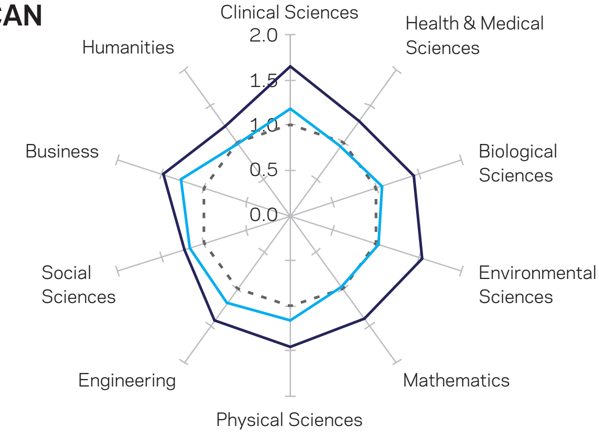
[35] See *www.projectcounter.org/code_practice.html*.

Figure 4.13 *— Field-weighted citation impact (FWCI) and field-weighted download impact (FWDI) for the UK and comparators (also Brazil, India and Russia) across ten research fields in 2012. For all research fields, a field-weighted citation or download impact of 1.0 equals world average in that particular research field. Note that the axis maximum is increased for Italy (to 2.5). Source: Scopus and ScienceDirect.*

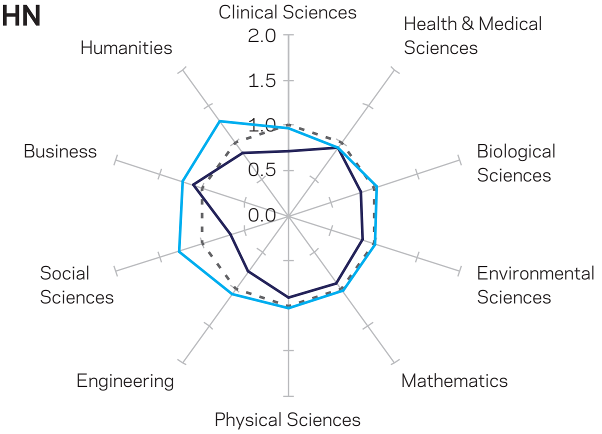
USA



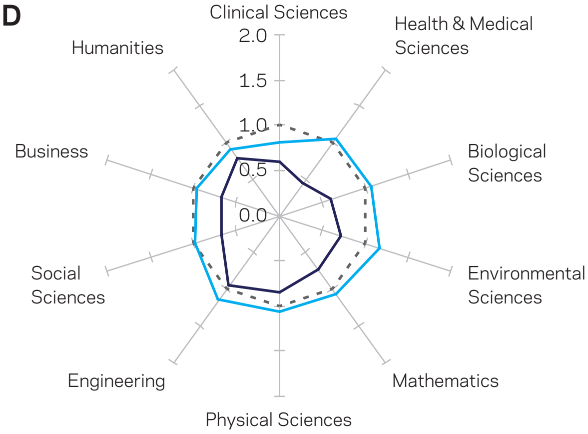
CAN



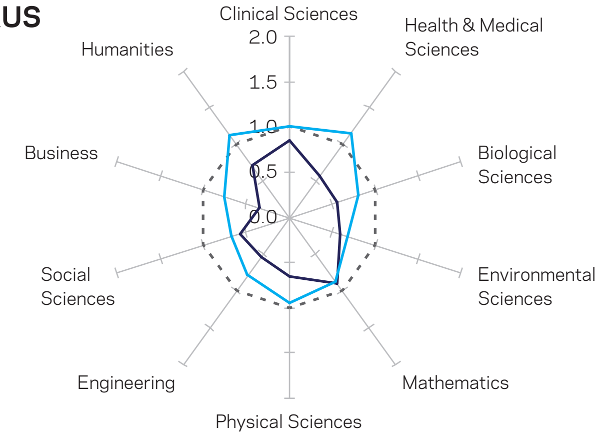
CHN



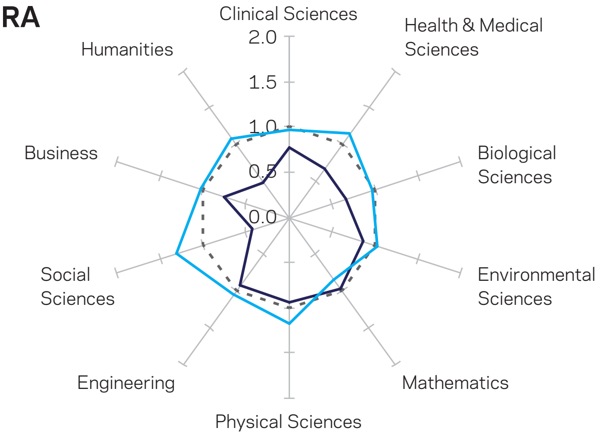
IND



RUS



BRA



4.3.9 The UK has multidisciplinary competencies spanning all major research disciplines, especially in the biomedical and social sciences

The SciVal competency map of the UK's global research strengths for 2012 shows 480 competencies for the UK in this period (see box "SciVal competency map and co-citation analysis"), an increase from the 430 competencies shown in the map for 2010 (see Figure 4.14). It shows that the UK has competencies touching in all of the major disciplinary groups around the circle, but these are not evenly distributed. As shown in Table 4.1, the UK has a higher concentration of competencies in Medical Specialties, Health Sciences, and Social Sciences, and fewer in Earth Sciences, Biotechnology and Humanities.

The UK competency map for 2012 contrasts strikingly with those of the key comparator countries. The UK's map differs in being focused towards the biomedical and social sciences (see Figure 4.14), while Germany, Japan and China are clearly focused towards the physical sciences. The US map is characterised by its density of competencies spread around the entirety of the circle, but, like the UK, it is focused towards the biomedical and social sciences. The UK has proportionally more competencies in Health Sciences, Humanities and Social Sciences than any of these countries, but the least in Chemistry and Biotechnology (see Table 4.1).

For each competency, keywords are extracted from article abstracts using a combination of thesauri spanning all major subject areas and natural language processing techniques, and those keywords co-occurring most frequently are used to represent the competency. The most frequently-occurring keywords amongst the UK's 480 competencies are shown in Figure 4.15, and point to the predominance of competencies in specific research topics related to Health, Medicine and Social Sciences.

[36] Small, H. (1973) "Co-citation in the scientific literature: A new measure of the relationship between two documents" *Journal of the American Society for Information Science* 24 (4) pp. 265-269.

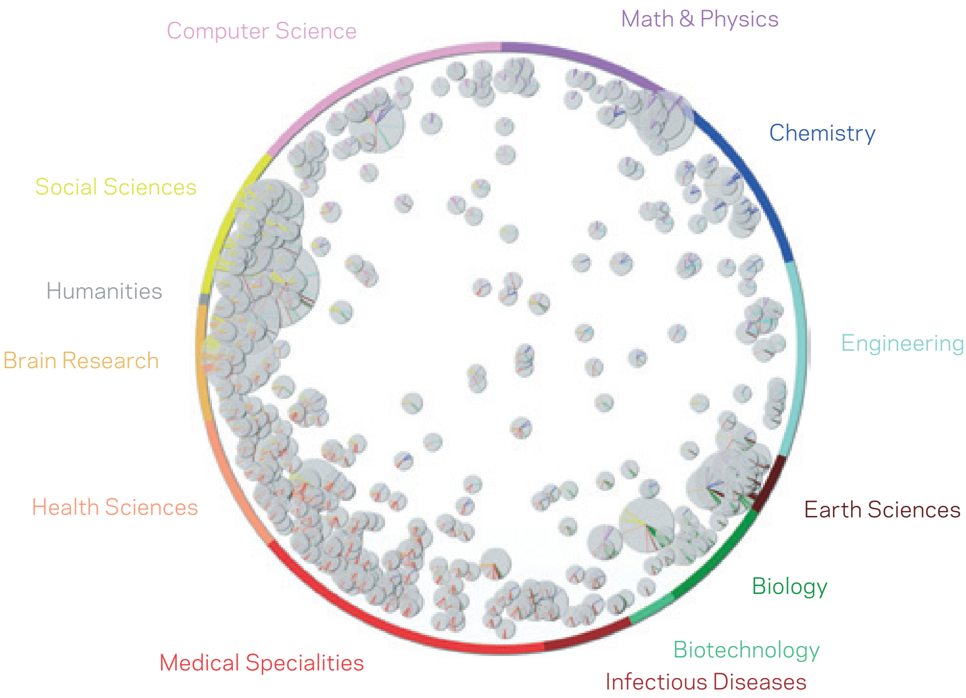
SCIVAL COMPETENCY MAP AND CO-CITATION ANALYSIS

The SciVal competency map is built on Scopus data and represents a novel approach to assessing the global research strengths of a country or institution. The competency map offers a complementary view to traditional article- and citation-based indicators. Rather than analysing article outputs within a pre-defined subject classification, the competency analyses the global article output in the current year (in this case, 2012) and uses co-citation analysis (see below) to create clusters of articles representing areas of research. To create a country-specific view, those clusters in which a significant proportion of the articles include at least one author from the selected country are grouped if they share one or more articles from that country; these groups of clusters are called competencies. Competencies are typically multidisciplinary in nature and are visualised within a circle to give an indication of the disciplinary composition of each competency; competencies at the edge of the circle consist of articles in topics that fit well into traditional subject categories, while competencies that are closer to the centre consist of more articles across disparate topics and have a more multidisciplinary character.

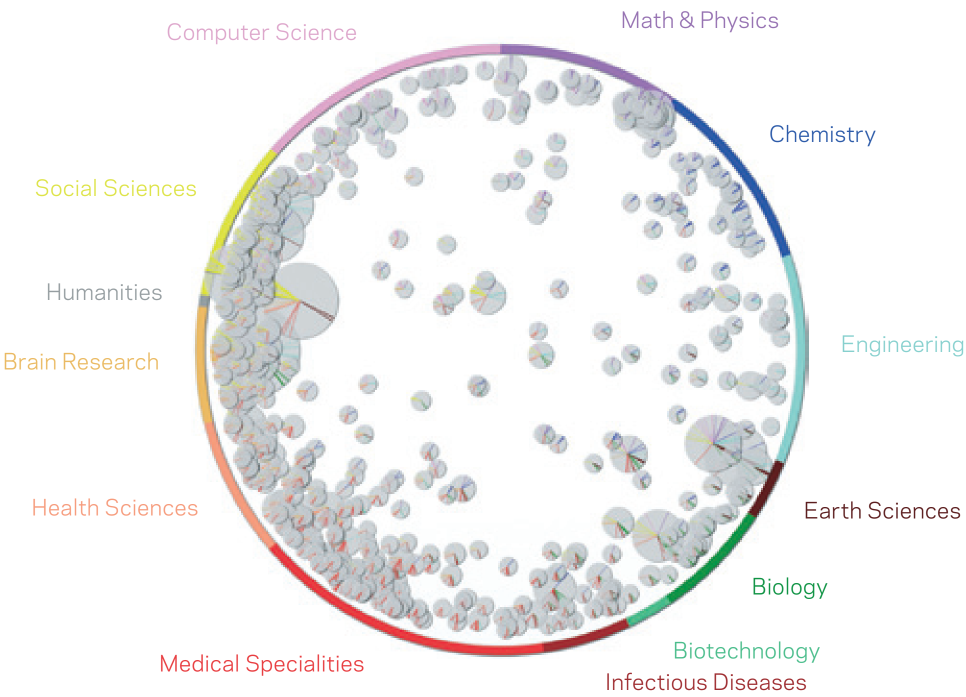
The SciVal competency map uses co-citation analysis to create clusters of articles representing areas of research, which are then used to build competency map at the country or institution level. Co-citation analysis was first proposed in 1973[36], and has been developed extensively since then. Co-citation is defined as the frequency at which two articles are cited together by the authors of other articles; in the simplest case, two articles that are cited by a single other document are said to be co-cited. The greater the number of co-citations a pair of articles has, the higher their co-citation strength, and the more likely they represent related research topics. In the SciVal competency map, co-citation analysis is applied to the articles published in a single year (in this case, 2012) before all articles published in the most recent 5 years (in this case, 2008-12) are assigned to the resulting clusters on the basis of their cited references. A single article may be assigned to more than one cluster.

Figure 4.14 *— SciVal competency maps for the UK and key comparator countries (2012) and also for the UK (2010). Source: SciVal competency map.*

United Kingdom
2010

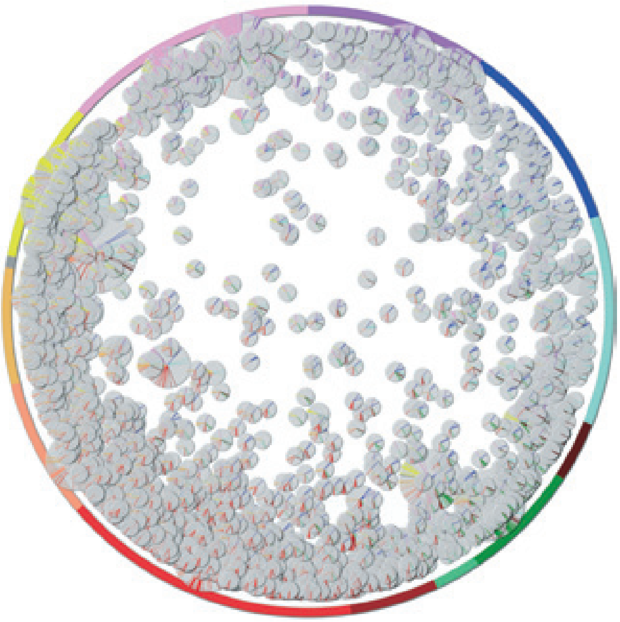


United Kingdom
2012

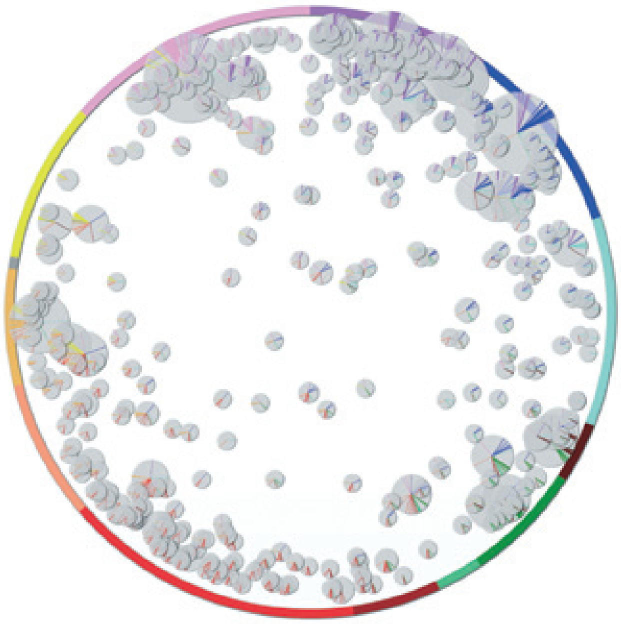


Math & Physics
Chemistry
Engineering
Earth Sciences
Biology
Biotechnology
Infectious Diseases
Medical Specialities
Health Sciences
Brain Research
Humanities
Social Sciences
Computer Science

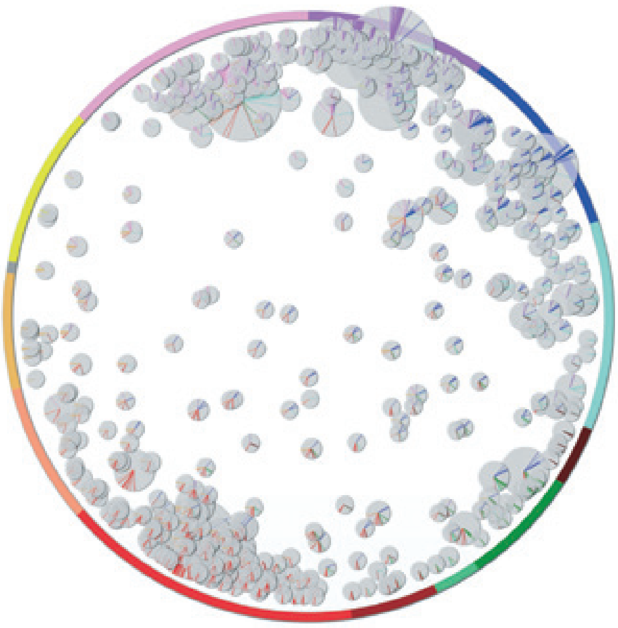
United States
2012



Germany
2012



Japan
2012



China
2012

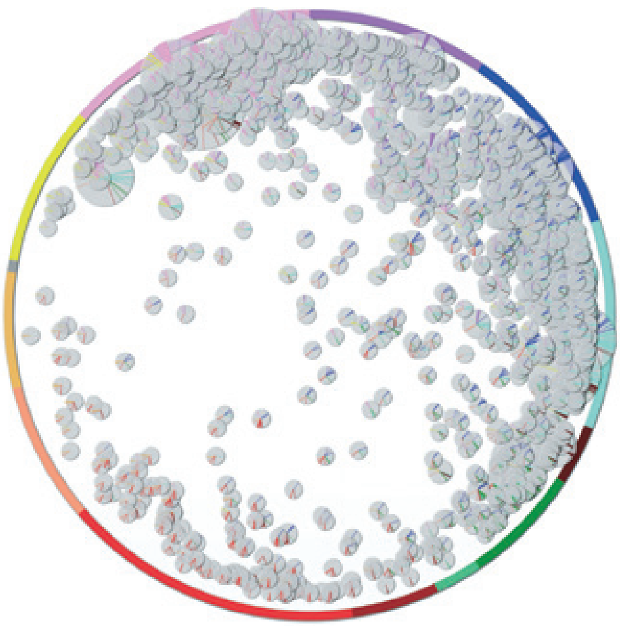


Table 4.1 *— Table 4.1 — Share of SciVal competencies for the UK and key comparators across 13 major disciplinary groups (2012). Competencies are assigned to disciplinary groups on the basis of the subject classification of the articles included in the competency. Source: SciVal competency maps.*

	UK	USA	DEU	JPN	CHN	Average
Competencies	480	1960	401	442	1096	876
Mathematics & Physics	5.9%	5.3%	13.5%	14.4%	13.0%	10.4%
Chemistry	5.9%	7.5%	10.6%	13.0%	14.1%	10.2%
Engineering	7.2%	6.1%	9.6%	10.5%	20.0%	10.7%
Earth Sciences	3.0%	2.6%	3.4%	1.9%	4.1%	3.0%
Biology	4.9%	4.8%	3.5%	4.2%	5.1%	4.5%
Biotechnology	3.4%	5.0%	5.9%	4.2%	4.7%	4.7%
Infectious Diseases	6.7%	9.0%	7.3%	7.1%	3.6%	6.7%
Medical Specialties	17.1%	20.2%	14.4%	16.7%	6.6%	15.0%
Health Sciences	13.6%	12.6%	7.9%	8.2%	4.6%	9.4%
Brain Research	8.8%	11.4%	8.3%	9.6%	3.2%	8.3%
Humanities	2.1%	0.9%	0.3%	0.0%	0.0%	0.7%
Social Sciences	11.7%	7.1%	3.7%	0.9%	4.6%	5.6%
Computer Science	9.7%	7.4%	11.5%	9.2%	16.3%	10.8%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Figure 4.15 *— Word cloud of the most frequently-occurring keywords amongst the UK's 480 competencies (2012). Created using Wordle. Source: SciVal competency maps.*

4.3.10 UK articles are made available under a wider variety of access models than the global baseline

A topic of growing interest in the global research community, not least in the UK, is that of access to research outputs. Recent policy initiatives in the UK and overseas, including in the US, Australia and the EU, have highlighted the need to understand the proportion of articles currently made available under different publishing models, such as Open Access. In the UK, The Working Group on Expanding Access to Published Research Findings, an independent group chaired by Dame Janet Finch, reported its findings on 16th June 2012[37]. Referred to colloquially as the Finch report, the document sets forth a comprehensive view of the current and historical issues relating to journal access and business models in the UK and beyond, and has led to intense discussion and debate amongst the various stakeholders in the UK research base. In 2013, both the House of Lords Science and Technology Select Committee and the House of Commons Business, Innovation and Skills Committee investigated the evidence supporting these recommendations and the potential impact of their implementation on the competitiveness of the UK research base, and their final reports were published in February 2013[38] and September 2013[39] respectively.

Publishing models are primarily defined by the source of financial support of the journal in which its articles are published. Financial support can come from Article Publishing Charges[40] (Gold Open Access), subscriptions (Subscription), a mixture of the two (Hybrid), or neither (Subsidised; see Figure 4.16). The Open Archives model is a subset of the Subscription model in which the publisher makes some or all final published versions of articles available after a journal-specific delay. Green Open Access is an Open Access mechanism that originated as a derivative of the Subscription publishing model, but is independent of journal financial models; it does not require payment of Article Publishing Charges as in the Gold Open Access or Hybrid models. Green Open Access is normally delivered by authors posting the pre-print or accepted author manuscript versions of their article on a website, in an institutional repository, or in a subject-area repository such as Europe PubMed Central or arXiv; some journals deposit copies of manuscripts to repositories on behalf of authors. In the case of accepted author manuscripts, these are then typically made openly accessible after a journal-specific embargo period. A small number of journals permit authors to post the final published journal article rather than the pre-print or author manuscript version. Since current discussions in the UK are centred around the Gold Open Access, Hybrid and Green Open Access models, the analysis presented in Table 4.2 focusses on these models from both a global and a UK perspective; uptake of the Subsidised and Open Archives models are also included for

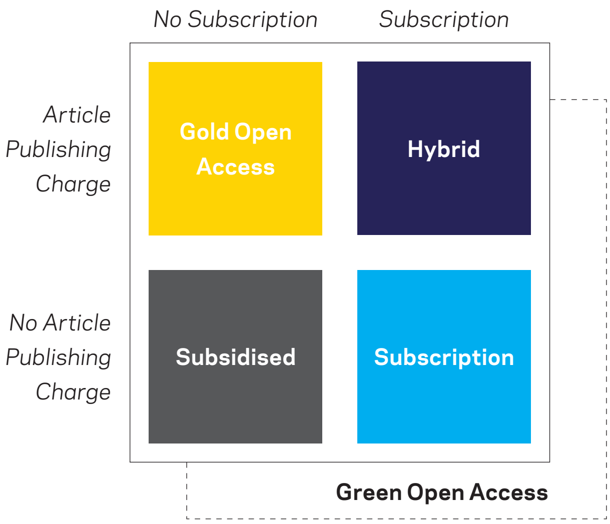


***Figure 4.16** — Publishing models by source of journal financial support, from Article Publishing Charges[40] (Gold Open Access), subscriptions (Subscription), a mixture of the two (Hybrid), or neither (Subsidised). Also shown is the Green Open Access model (dashed outline), which relates to manuscript versions of published journal articles and is independent of the source of journal financial support but may operate in conjunction with any of these other models. Not shown in this schematic is the Open Archives model, a subset of the Subscription model in which the publisher makes some or all final published versions of articles available after a journal-specific delay.*

[37] Working Group on Expanding Access to Published Research Findings (2012) "Accessibility, sustainability, excellence: how to expand access to research publications".

[38] House of Lords Science and Technology Committee (2013) "3rd Report of Session 2012-13. The implementation of open access".

[39] House of Commons Business, Innovation and Skills Committee (2013) "Open Access: Fifth Report of Session 2013-14".

[40] Article Publishing Charges may be paid by the author(s) or a sponsor (often research funding body) on behalf of the author(s).

Table 4.2 *— Publishing model uptake globally and for the UK. Importantly, these uptake rates cannot be meaningfully summed across these models, because of different measurement methods and periods (Gold Open Access and Subsidised are direct counts of articles published in 2012, while Hybrid, Open Archives and Green Open Access are estimates extrapolated from manually-verified samples of articles published in the 24 months prior to July-August 2013) and also because the Green Open Access model can duplicate access to articles already available under the Gold Open Access, Hybrid or Subsidised models.*

Publishing model	Description	Global uptake	UK uptake
Gold Open Access [41]	Articles published in journals in which *all* articles are accessible without a subscription immediately upon publication, after payment of an Article Publishing Charge.	5.5% [42]	5.9% [43]
Hybrid [41] [44]	Articles published in journals in which *all* articles are accessible to subscribers immediately upon publication, but which also offer an *option* for articles to be made accessible without a subscription immediately upon publication after payment of an Article Publishing Charge.	0.5% [45]	2.7% [46]
Subsidised [41]	Articles published in journals in which *all* articles are accessible without a subscription immediately upon publication; journals are typically financially supported by a sponsor(s).	4.2% [42]	1.9% [43]
Open Archives [44]	Articles published in predominantly subscription journals in which *some or all* articles are accessible without subscription after a journal-specific delay, typically via the publisher's website.	1.0% [45]	4.2% [46]
Green Open Access: Pre-print versions [44]	Pre-print versions of articles (i.e. prior to submission to a journal for peer review) which are accessible online, typically at personal or institutional webpages, or institutional or subject repositories.	6.4% [45]	7.4% [46]
Green Open Access: Accepted Author Manuscript versions [44]	Accepted Author Manuscript versions of articles (i.e. after undergoing peer review and incorporating any revisions required for acceptance by a journal) which are accessible online, typically at personal or institutional webpages or institutional or subject repositories, and typically after a journal-specific embargo.	5.0% [45]	11.6% [46]

[41] Gold Open Access, Hybrid and Subsidised publishing models were assigned to all journals indexed in Scopus in 2012 using the Directory of Open Access Journals (see *www.doaj.org*) supplemented with desk research for the major journal publishers using each of these models.

[42] Direct count of articles published in 2012 in journals indexed in Scopus.

[43] Direct count of articles with at least one UK author published in 2012 in journals indexed in Scopus.

[44] Uptake of the Hybrid, Open Archives and Green Open Access models was determined by using automated Google queries to replicate the search behaviour of a human seeking a full-text copy of a known published journal article, using up to the first 10 words of the article title and restricting to common full-text file formats (.pdf, .doc/docx, .ps). All documents identified were manually verified as representing a full-text version of the articles in question. Those representing final published versions at the publisher website of Hybrid journals were counted as Hybrid uptake, while those representing final published versions at the publisher website of Subscription journals were counted as Open Archives uptake. Those representing manuscript versions (i.e. Green Open Access) were manually classified as a pre-print or an accepted author manuscript.

[45] Extrapolated from a sample of 833 articles published 1, 6, 12 or 24 months prior to measurement of uptake in July-August 2013, a total of 3,332 articles.

[46] Extrapolated from a sample of 833 articles with at least one UK author published 1, 6, 12 or 24 months prior to measurement of uptake in July-August 2013, a total of 3,332 articles.

reference.
The uptake of the two Article Publishing Charge-supported publishing models in the UK (at 5.9% for Gold Open Access and 2.7% for Hybrid) is higher than the uptake level globally (at 5.5% for Gold Open Access and 0.5% for Hybrid). This may reflect the impact of UK research funding bodies that have directly provided funding to grantees for the payment of Article Publishing Charges in Gold Open Access and Hybrid journals in recent years, such as the Wellcome Trust since 2006. The uptake of the Subsidised model in the UK (at 1.9%) is less than half of that of the global uptake rate (at 4.2%), likely reflecting the fact that many Subsidised journals are focused on regional research outside the typical remit of UK researchers. Conversely, the uptake of Open Archives model in the UK (at 4.2%) is considerably greater than that of the global uptake rate (at 1.0%), which is likely to reflect the high-quality nature of many journals making articles available under this model[47] and the prevalence of UK-authored articles in high-quality journals (as suggested by the UK's high field-weighted citation impact and large share of the world's most highly-cited articles; see Figures 4.6 and 4.10, respectively). Finally, the uptake level of Green Open Access for Pre-print versions in the UK (7.4%) is slightly above the global level (6.4%), while the uptake level of Green Open Access for Accepted Author Manuscript versions in the UK (at 11.6%) is more than double the uptake level globally (at 5.0%), likely driven by the implementation of policies on mandatory posting of accepted author manuscript versions of published journal articles by various UK funding bodies and universities in recent years.

Critically, it is important to note that these uptake rates cannot be meaningfully summed across these models, because of different measurement methods and periods (Gold Open Access and Subsidised are direct counts of articles published in 2012, while Hybrid, Open Archives and Green Open Access are estimates extrapolated from manually-verified samples of articles published in the 24 months prior to July-August 2013) and also because the Green Open Access model can duplicate access to articles already available under the Gold Open Access, Hybrid or Subsidised models.

Various estimates on the global uptake of Gold Open Access, Hybrid, Open Archives, Subsidised and Green Open Access models have been published in recent years, all with differing methodologies and approaches. Amongst the most recent is a study[48] that found that 9% of articles published in 2011 and indexed in Scopus were published in 'full immediate OA journals' (Gold Open Access and Subsidised models in Table 4.2; these two models can be directly summed and add to 9.7%) and 0.7% for Hybrid uptake (0.5% in Table 4.2). This high degree of agreement between independently-derived estimates suggests that the estimates for these models in Table 4.2 are robust. However, published estimates of Green Open Access are subject to greater variation, owing to the dynamic nature of the internet, changes in search engine algorithms and the time-sensitivity of detection of manuscript versions of published journal articles. The most recent published estimate of Green Open Access uses a robot-based approach to search selected websites and repositories for manuscript copies of published journal articles indexed in Scopus, but the results are manually verified for just 500 articles[49]; in the present study, results were manually verified across more than 3,300 articles and a high proportion of false positives were found and discarded.

[47] Laakso, M. & Björk, B.-C. (2013) "Delayed open access: An overlooked high-impact category of openly available scientific literature" *Journal of the American Society for Information Science and Technology* 64 (7) pp. 1323-1329.

[48] Laakso, M. & Björk, B.-C. (2012) "Anatomy of open access publishing: a study of longitudinal development and internal structure" *BMC Medicine* 10 article 124.

[49] Archambault, E. *et al.* (2013) "Proportion of Open Access Peer-Reviewed Papers at the European and World Levels—2004-2011", Report for European Commission DG Research & Innovation.

Chapter 5
Research Collaboration

UK INTERNATIONAL COLLABORATION

47.6% of all UK articles in 2012 result from international collaboration

Increased at **2.9%** per year in the period 2008-12

Ranks **2nd** amongst comparator countries in 2012

UK COLLABORATION PARTNERS

UK international co-authorship is typically associated with **high field-weighted citation impact** for both partners

UK COLLABORATION NETWORK

The UK occupies a **central position** in the global collaboration network

Western European collaboration partners are of high importance

5.1 Highlights

- Amongst its comparator countries, the UK has the second-highest rate of international co-authorship, and this rate continues to rise.
- The resulting articles are associated with high field-weighted citation impact, and this is typically greater than that observed for all internationally- collaborative articles published by either the UK or its major partner countries.
- The UK occupies a central position in the international co-authorship network, acting as a 'collaboration hub' alongside other research-intensive nations.

5.2 Introduction

Research collaboration is a complex and multi-dimensional phenomenon, typically built from the myriad social interactions engaged in by researchers in the course of their day-to-day work. This may take the form of informal discussions and information sharing, which account for as much as half of all collaborations[50], or may be detected in patterns of co-authorship of published articles or the acknowledgements within them. The rise in international collaboration, as measured by the proportion of articles with at least two different countries listed in the authorship byline, continues unabated as low-cost travel, high-speed internet connectivity and funding programs that encourage cross-border partnerships continue to spread[51]. While the single-author article is becoming less and less common[52], the number of articles representing 'hypercollaboration' is on the rise (see box "Hypercollaboration").

Research collaboration is a complex and multi-dimensional phenomenon, the essence of which cannot be wholly captured with indicator-based approaches. As such, the findings above have been supplemented with extensive interviews with key individuals in the academic sector from across the UK and overseas in the Case Study in this chapter.

HYPERCOLLABORATION

While no definition exists on the number of co-authors required to constitute 'hypercollaborative' co-authorship, numbers in the hundreds or thousands seem worthy of the term. The most multi-authored research paper of all time was published in April 2010 and has 3,222 authors from 37 countries[53]. As an indication of the frequency of such hypercollaborative articles, 74 articles published in 2012 had more than 3,000 authors; like the record-holder, all of them reported results from the ATLAS experiment at CERN's Large Hadron Collider in Switzerland. Indeed, hypercollaborative co-authorship may be a consequence of 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[54].

While such hypercollaborative articles may represent extreme outliers in co-authorship data, they are included in all the analyses in this chapter since they remain proportionally few and because they are counted only as a single internationally co-authored article for each country represented in the article, and for each country pairing.

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

UK researchers are highly collaborative; in 2012, 47.6% of UK-authored published articles were co-authored with at least one non-UK researcher (see Figure 5.1). 36.6% of UK-authored articles published in 2012 were co-authored between UK authors only; 14.8% with affiliations at different UK institutions (national co-authorship) and 21.8% with all authors with the same affiliation (institutional co-authorship). 14.5% of UK articles published in 2012 had only a single author. The UK's rate of international co-authorship is rising over time, at the expense of decreases in national and institutional co-authorship.

The UK's rate of international co-authorship is second only to France (at 50.0%) in the comparator group. Comparator countries show different co-authorship patterns based upon their emphasis on collaboration as measured by co-authorship, and these patterns fall into three main categories: (a) high and rising rates of international co-authorship with moderate and falling institutional co-authorship rates (UK, Germany, France, Italy and Canada); (b) high but falling rates of institutional co-authorship with low and broadly stable international co-authorship rates (Brazil, China and India); (c) high and broadly stable rates of both institutional and international co-authorship rates (US and Russia). Japan appears as an exception to this scheme, since it shows high but falling rates of institutional co-authorship (like Brazil, China and India), but the rate of international co-authorship is rising in recent years from a relatively low level. Brazil, India and Russia, and to a lesser extent China, are distinguished from the other comparator countries by being the only ones with a rising rate of national co-authorship in recent years.

For the UK and most comparator countries, internationally co-authored articles are associated with high field-weighted citation impact, over and above that of institutionally-authored or nationally co-authored articles (see Table 5.1). UK international co-authorship is associated with 61% greater field-weighted citation impact when compared to institutional co-authorship, and 20% greater for national co-authorship over institutional co-authorship. These rates vary across other comparator countries, with some showing

[50] 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.

[51] Pan, R.K. *et al.* (2012) "World citation and collaboration networks: Uncovering the role of geography in science" *Scientific Reports* 2 article 902.

[52] Greene, M. (2007) "The demise of the lone author" *Nature* 450 (7173) pg. 1165.

[53] ATLAS Collaboration (2010) "Charged-particle multiplicities in pp interactions measured with the ATLAS detector at the LHC" *Physics Letters B* 688 (1) pp. 21–42.

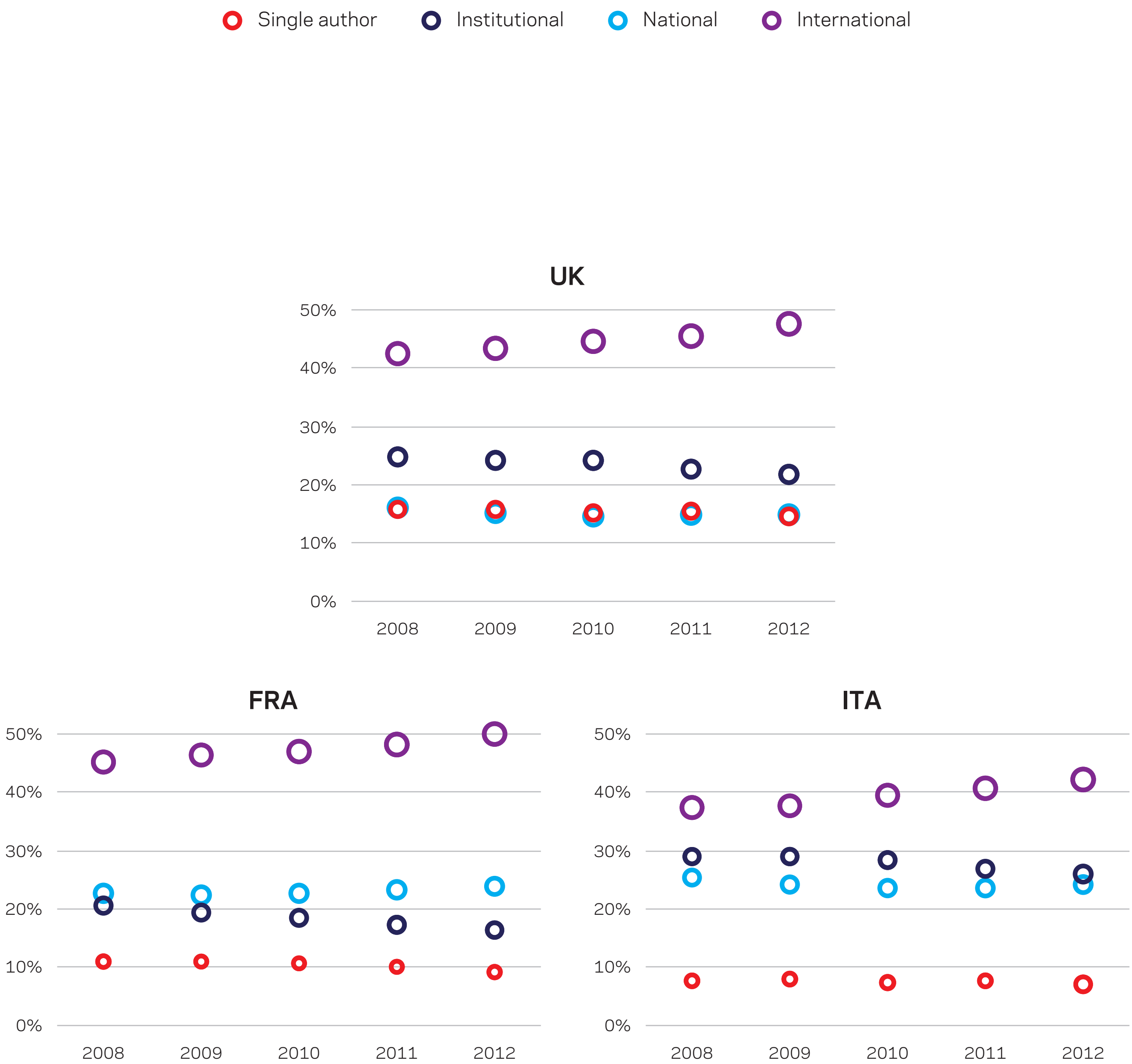
[54] Hand, E. (2010) "'Big science' spurs collaborative trend" *Nature* 463 (7279) pg. 282.

ratios very similar to the UK (such as Germany or the US) and others with a radically different pattern such as all four BRIC[55] countries which see either a modest increase or a decrease for national co-authorship, but a much greater increase for international co-authorship.

Across the UK and comparator countries there is a clear relationship between the share of internationally co-authored articles and the field-weighted citation impact of those articles (see Figure 5.2). The question of whether countries engaging frequently in international collaboration are able to do so with typically high-impact results by selecting the best partners to work with, or whether countries likely to create high-impact research outputs are actively sought out for collaborative partnerships by other countries, cannot be answered on the basis of this relationship alone (see the Case Study in this chapter).

[55] Brazil, Russia, India and China, a designation coined in a Goldman Sachs report: O'Neill J. (2001) "Building Better Global Economic BRICs" *Global Economics Paper* No: 66.

Figure 5.1 *— Share of articles for the UK and comparators (also Brazil, India and Russia) by co-authorship type, 2008-2012. Bubble size is proportional to field-weighted citation impact. Note that in the previous report in this series, institutional co-authorship included single-authored articles; these are now reported separately. Source: Scopus.*



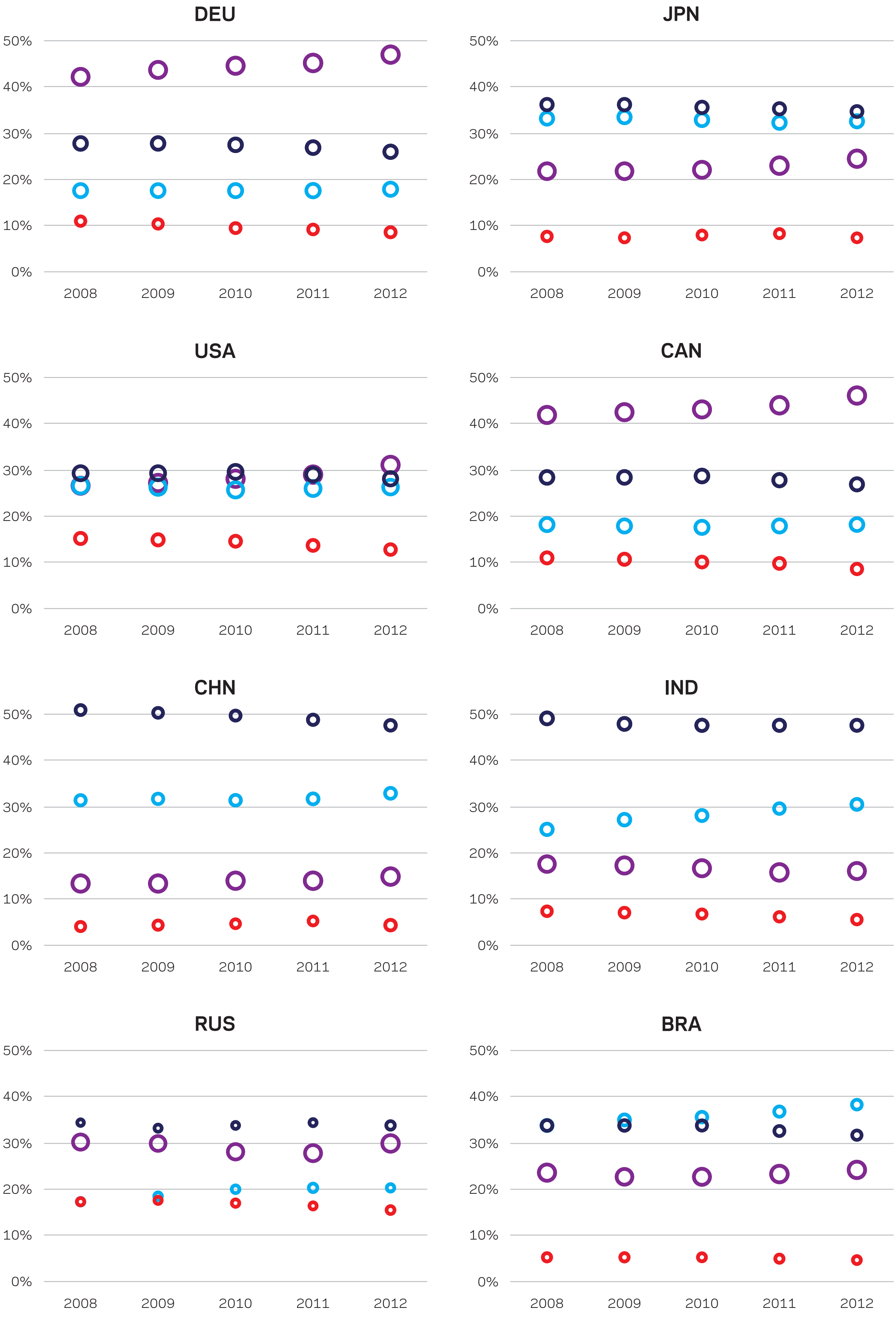
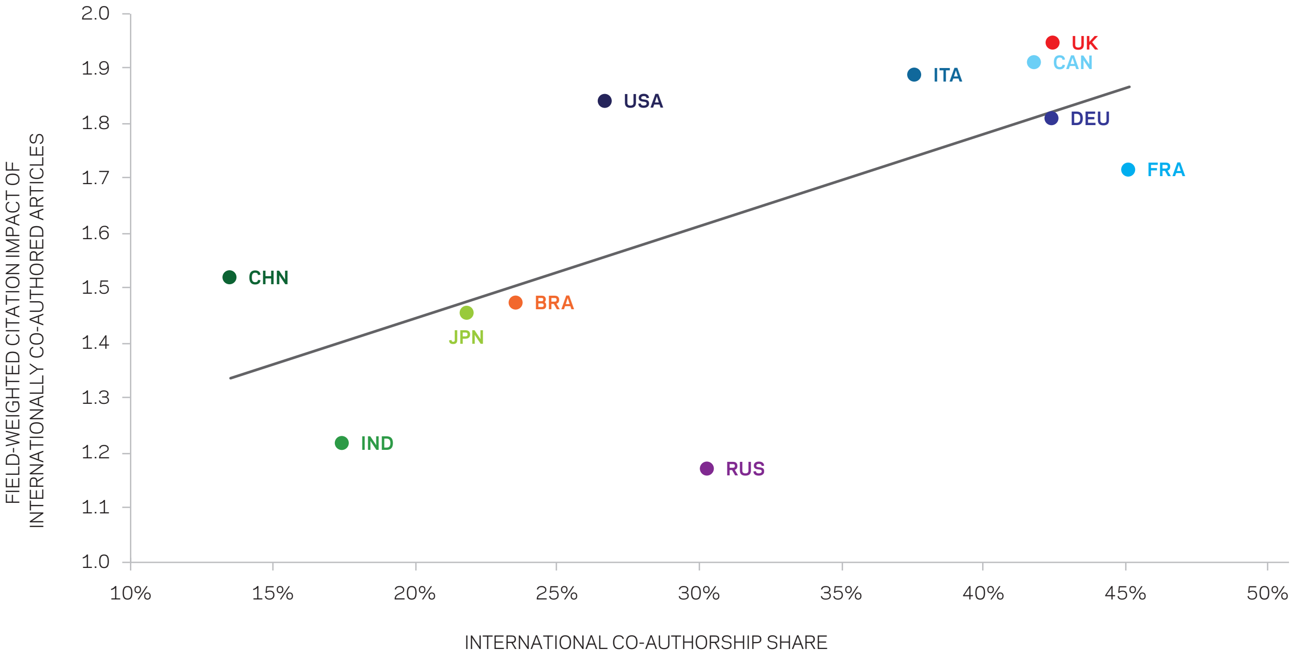

DEU
JPN
USA
CAN
CHN
IND
RUS
BRA
50%
40%
30%
20%
10%
0%
2008
2009
2010
2011
2012

***Table 5.1** — Field-weighted citation impact of single-authored, nationally- and internationally- co-authored articles relative to institutional co-authorship for the UK and comparators, 2012. Note that in the previous report in this series, institutional co-authorship included single-authored articles; these are now reported separately. Source: Scopus.*

Field-weighted citation impact relative to institutional co-authorship

Country	Single author	Institutional	National	International
UK	84%	100%	120%	161%
DEU	66%	100%	114%	174%
FRA	62%	100%	123%	200%
ITA	85%	100%	99%	167%
JPN	64%	100%	124%	221%
CAN	72%	100%	110%	181%
USA	63%	100%	121%	152%
BRA	70%	100%	108%	308%
CHN	101%	100%	107%	245%
IND	74%	100%	98%	211%
RUS	86%	100%	77%	376%
G8	70%	100%	127%	149%
E27	77%	100%	124%	166%
OEC	83%	100%	140%	141%

***Figure 5.2** — Correlation between international co-authorship share and field-weighted citation impact of internationally co-authored articles, 2008. The square of the correlation coefficient (R2) of the linear regression is 0.4577, meaning that the regression explains 45.77% of the variance, suggesting a relationship between them. Source: Scopus.*



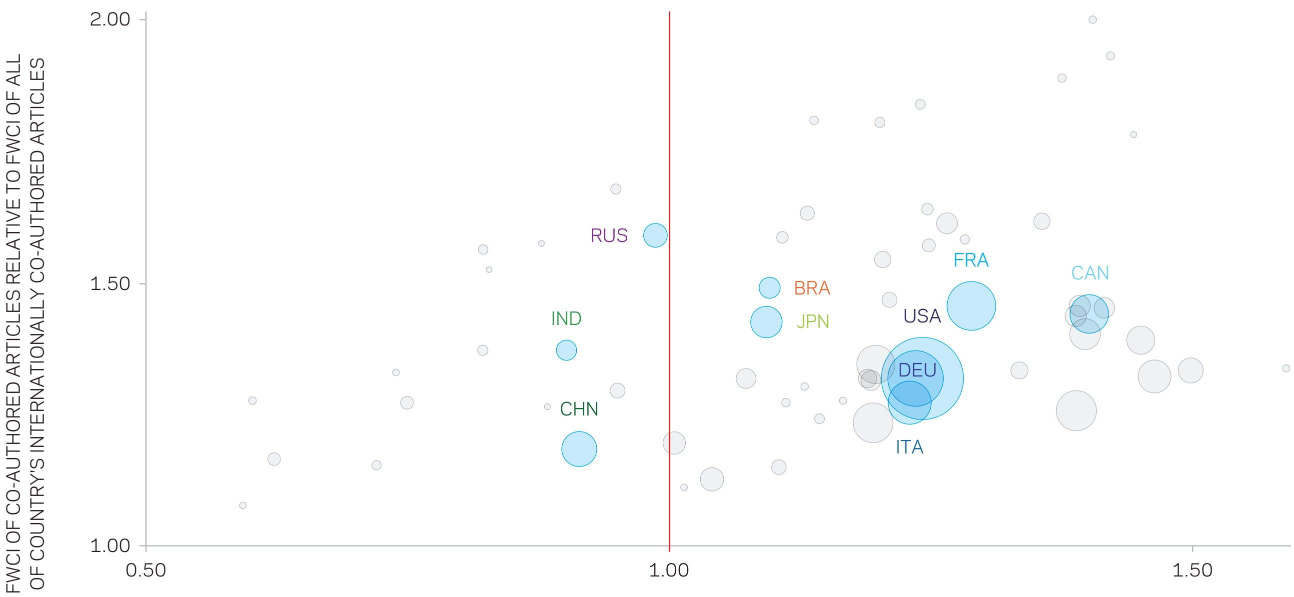
5.3.2 The UK's international co-authorship partnerships are typically associated with high field-weighted citation impact for both the UK and the partner country

International co-authorship may bring differential outcomes for each partner in terms of the field-weighted citation impact of the resulting outputs. While internationally co-authored articles have previously been shown to have a greater citation impact than those that are not[56], it is possible that this is not the case in all international co-authorship partnerships engaged in by a given country.

Figure 5.3 shows the UK's most frequent international co-authorship partners (with comparator countries emphasised) and the field-weighted citation impact of their articles co-authored with the UK, relative to the field-weighted citation impact of all internationally co-authored articles from each country (on the vertical axis) or from the UK (on the horizontal axis). For all countries shown, the field-weighted citation impact of the articles co-authored with the UK are greater than the field-weighted citation impact of all internationally co-authored articles of the partner country including those with the UK, since all countries are above the relative baseline (defined as 1.0). Conversely, for a number of countries the field-weighted citation impact of the articles co-authored with the UK are lower than the field-weighted citation impact of the UK's internationally collaborative articles overall, including Russia, India and China (representing three of the four BRIC countries).

For the UK, collaborations with those countries that have a higher overall field-weighted citation impact (c.f. Figure 4.7) tend to be associated with higher collaborative field-weighted citation impact, but not in all cases: for example, the UK's articles co-authored with Canada or with France show a higher field-weighted citation impact than papers co-authored with US authors, despite the US' much greater overall field-weighted citation impact than either Canada or France.

Figure 5.3 *— Field-weighted citation impact of UK internationally co-authored articles by co-authoring country, 2008-2012. Bubble size is proportional to the number of co-authored articles. Comparator countries (as well as Brazil, Russia and India) are highlighted. Source: Scopus.*



[56] Glänzel, W. (2001) "National characteristics in international scientific co-authorship relations" *Scientometrics* 51 (1) pp. 69–115; Levitt, J.M. & Thelwall, M. (2010) "Does the higher citation of collaborative research differ from region to region? A case study of Economics" *Scientometrics* 85 (1) pp. 171–183; Persson, O. *et al.* (2004) "Inflationary bibliometric values: The role of scientific collaboration and the need for relative indicators in evaluative studies" *Scientometrics* 60 (3) pp. 421–432.

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

The national origin of the partners in any research collaboration may have a profound effect on the outcomes of that research, from abstract contributions such as the mixing of different research approaches and traditions through to the more prosaic, such as access to research sites or materials. The sheer volume of research outputs produced by the largest research nations in the world means that international collaborations are most obvious between these countries (see Table 5.2, dominated by the prolific US), but collaborations involving less productive nations may nevertheless be important for one or both partners. For example, since 2009, the US's most frequent international collaborator has been China and not the UK, as had long been the case. However, this is at least in part a product of the sheer growth in the volume of article output from China in recent years, and may not wholly reflect an increase in the propensity of the US and China to collaborate.

To account for this, an indicator of the strength of the collaborative ties between country pairs that normalises by the volume of output of both partners has also been adopted here (see box "Salton's Index: An indicator of collaboration strength"). Table 5.2(b) presents a more nuanced view of global international collaboration on the basis of Salton's Index. While some of the same collaborations between larger research nations are still represented as being of a significant relative magnitude (such as Switzerland with Germany, and Canada with the US), some much smaller but very close collaborative ties are brought to the fore, such as that between Austria and Germany, or Belgium and the Netherlands, reflecting in both cases a shared sociocultural history as well as geographic proximity.

An holistic view of the relationships between all collaborative pairings globally is revealed by a network map of these connections in the period 2008-12, with each country (node) connected by lines (edges) weighted by Salton's Index and coloured by the field-weighted citation impact of the collaborative research outputs (see Figure 5.4).

Table 5.2 *— Major global co-authorship country partnerships, 2008-2012. Top 20 pairings as sorted by (a) count of co-authored articles, or (b) Salton's Index. The latter list excludes pairings for countries with fewer than 10,000 co-authored articles in this period. Source: Scopus.*

Partner A	Partner B	Co-authored articles ▼	Field-weighted citation impact of co-authored articles	Salton's Index
CHN	USA	100,935	1.735	0.050
UK	USA	89,579	2.746	0.071
DEU	USA	81,477	2.564	0.066
CAN	USA	77,640	2.452	0.080
FRA	USA	54,576	2.658	0.052
JPN	USA	46,711	2.084	0.039
ITA	USA	46,010	2.593	0.049
DEU	UK	45,250	2.751	0.071
KOR	USA	37,808	1.808	0.045
AUS	USA	37,003	2.653	0.045
DEU	FRA	34,765	2.718	0.066
FRA	UK	33,454	2.883	0.061
ESP	USA	33,122	2.553	0.038
NLD	USA	31,448	3.099	0.044
CHE	USA	29,352	3.041	0.048
CHE	DEU	28,150	2.509	0.092
UK	ITA	27,789	2.772	0.057
DEU	ITA	26,186	2.900	0.055
FRA	ITA	26,135	2.687	0.064
DEU	NLD	24,648	2.898	0.068

Partner A	Partner B	Co-authored articles	Field-weighted citation impact of co-authored articles	Salton's Index ▼
CHE	DEU	28,150	2.509	0.092
CAN	USA	77,640	2.452	0.080
AUT	DEU	17,740	2.327	0.079
BEL	NLD	11,884	2.712	0.077
DEU	UK	45,250	2.751	0.071
UK	USA	89,579	2.746	0.071
DEU	NLD	24,648	2.898	0.068
DEU	USA	81,477	2.564	0.066
DEU	FRA	34,765	2.718	0.066
UK	NLD	24,147	3.161	0.065
CHE	FRA	16,911	2.837	0.064
BEL	FRA	14,682	2.694	0.064
FRA	ITA	26,135	2.687	0.064
FRA	UK	33,454	2.883	0.061
UK	ITA	27,789	2.772	0.057
AUS	UK	24,403	2.734	0.057
ESP	ITA	18,881	2.680	0.056
DEU	ITA	26,186	2.900	0.055
CHE	ITA	12,784	3.046	0.054
ESP	FRA	20,497	2.594	0.054

Global
2008-2012

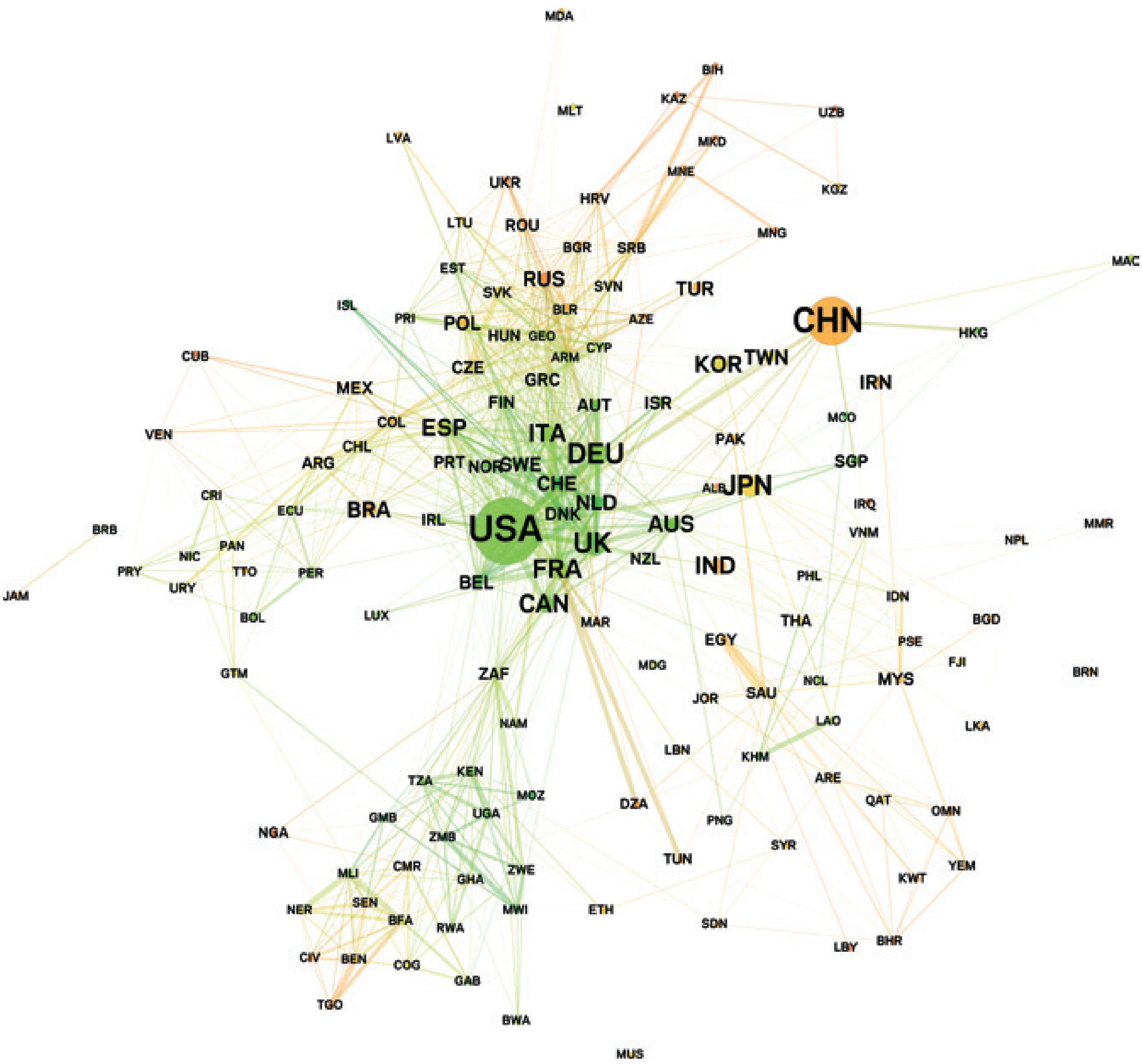
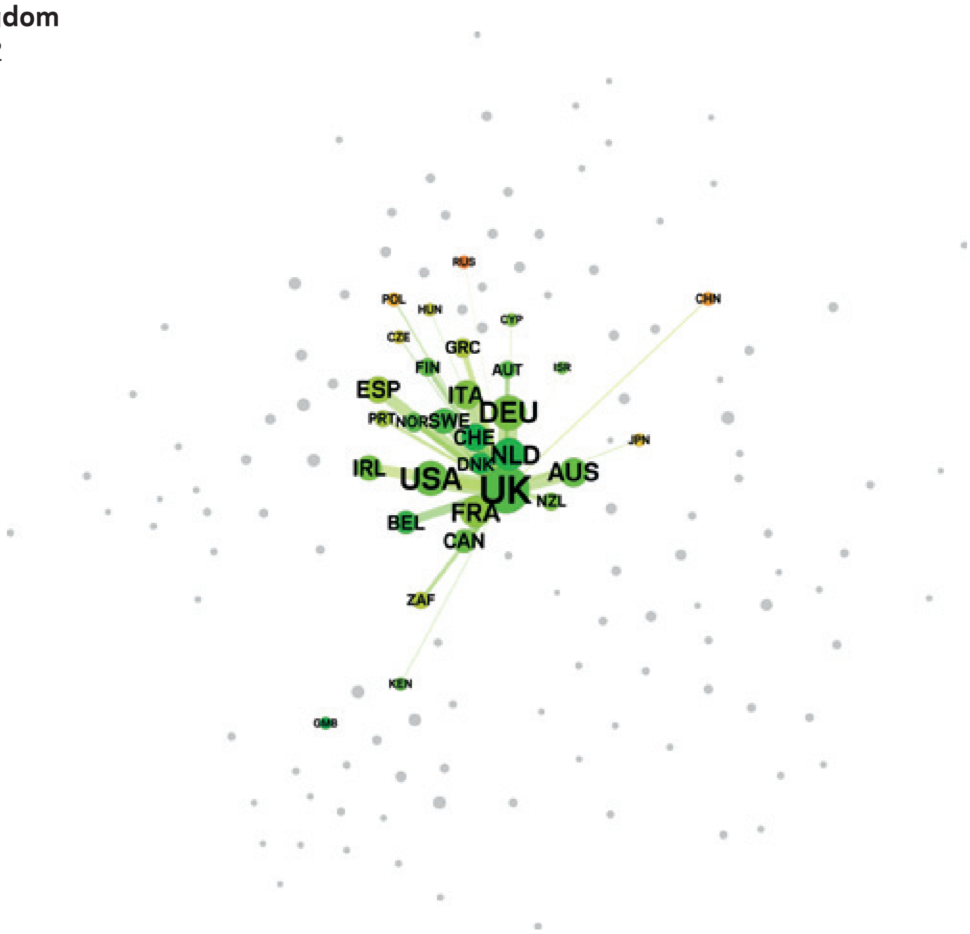


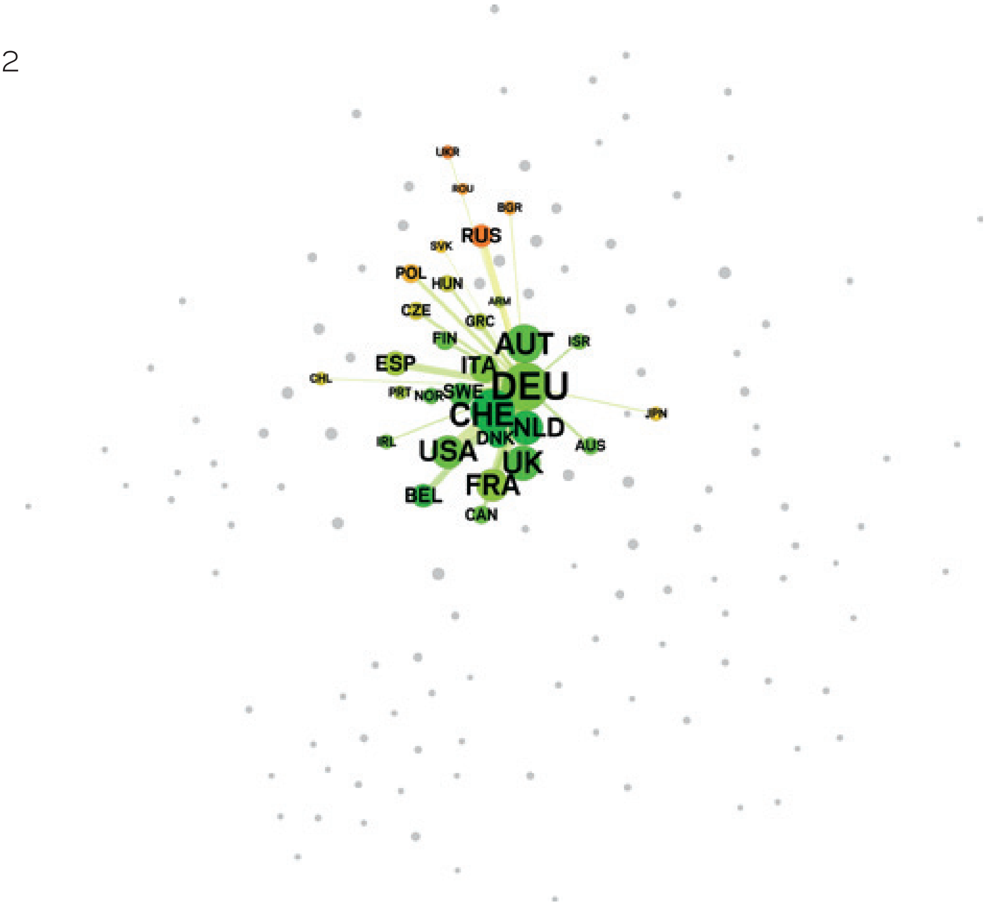
Figure 5.4 — *Global co-authorship map, 2008-2012. Node size is proportional to overall article output for each country, and node colour is the field-weighted citation impact of the overall article output for each country (on a scale from red (below 1.0) to green (above 1.0), with amber at the world average (1.0)). Edges are weighted by Salton's Index (all edges used for layout, only strongest shown after filtering) and edge colour is the field-weighted citation impact of the co-authored articles between each country pair (on a scale from red (below 1.0) to green (above 1.0), with amber at the world average (1.0)). Data were visualised with Gephi using the ForceAtlas2 layout algorithm. For a full list of countries and their three letter codes, see Appendix D: Countries included in Data Sources. Source: Scopus.*

Figure 5.5 — Global co-authorship map highlighting the top 30 co-authorship country partnerships for the UK and selected comparator countries, 2008-2012. Node size is proportional to Salton's Index for the collaboration with the selected country, and node colour is the field-weighted citation impact of the overall article output for these top 30 countries (on a scale from red (below 1.0) to green (above 1.0), with amber at the world average (1.0); all other countries in grey). Edges are weighted by Salton's Index (all edges used for layout, only connections between selected country and top-30 co-authorship countries are shown) and edge colour is the field-weighted citation impact of the co-authored articles between each country pair (on a scale from red (below 1.0) to green (above 1.0), with amber at the world average (1.0)). Data were visualised with Gephi using the ForceAtlas2 layout algorithm. For a full list of countries and their three letter codes, see Appendix D: Countries included in Data Sources. Source: Scopus.

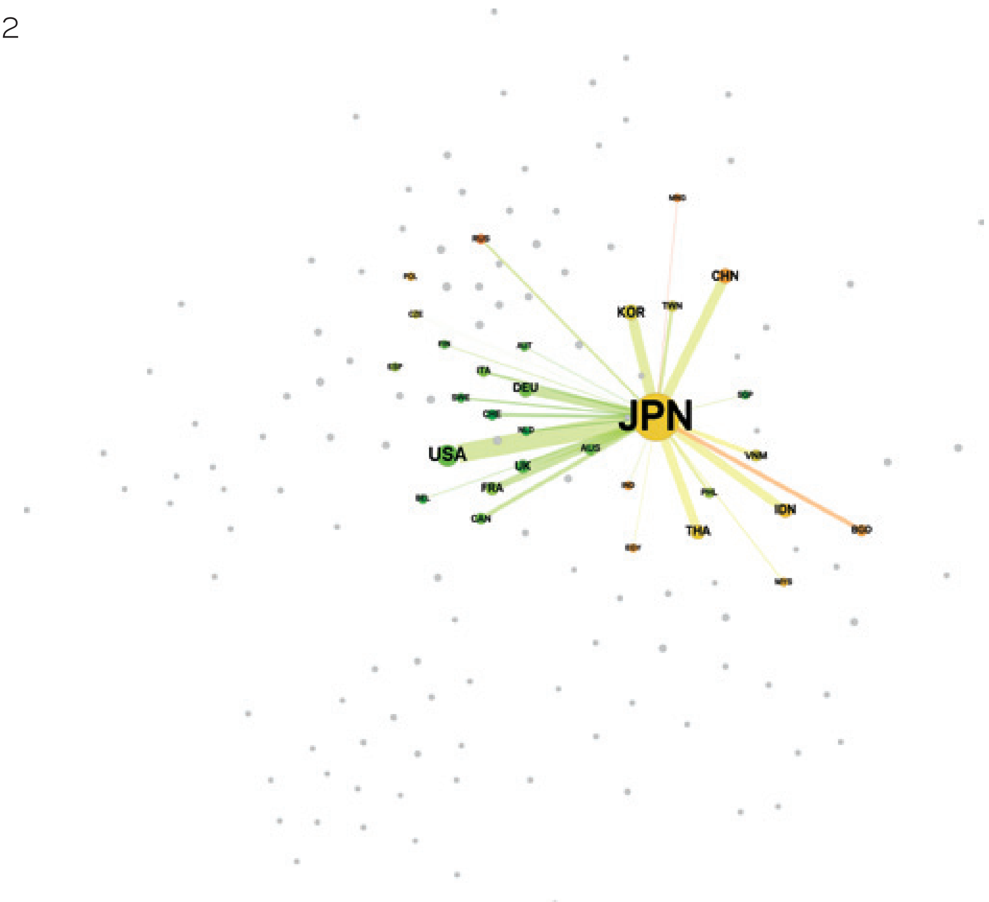
United Kingdom
2008-2012



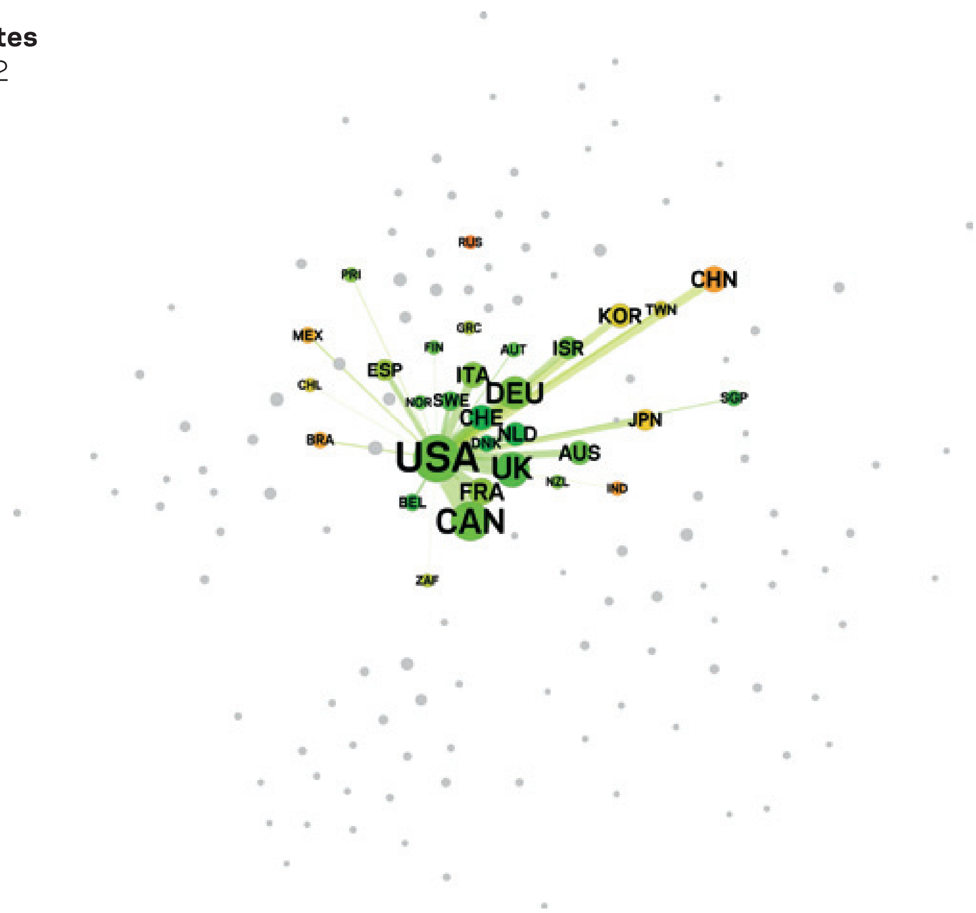
Germany
2008-2012



Japan
2008-2012



United States
2008-2012



China
2008-2012

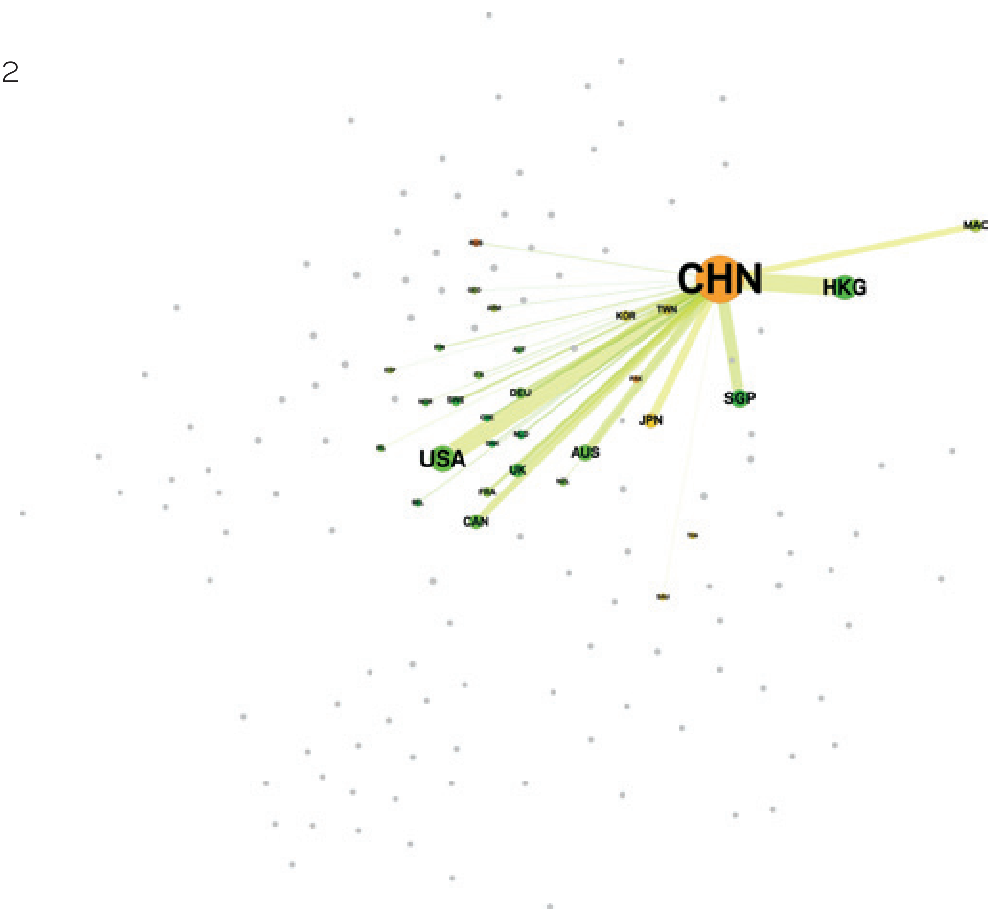


Figure 5.5 continued from previous page.

The network map shows the complex nature of research collaboration globally, with a clear 'core' of well-connected countries (typically highly productive countries with high field-weighted citation impact of both their overall article output and also of their co-authored research outputs) and a 'periphery' of developing scientific nations with typically lower field-weighted citation impact for both their overall output and their co-authored articles. As noted by others[57], it is unclear whether countries in the core are better-positioned to create knowledge because of greater access to information and researchers in other countries, or whether researchers in such countries - with greater opportunity to engage in international collaboration - are more productive than researchers in peripheral countries.

The map also reveals some very clear sub-networks: for example, the large group of African nations at the bottom of the map. Where groups of nations are separated from the centre of the collaboration network, there are typically individual or small numbers of countries which form a 'bridge' towards the core. South Africa plays this role for the African nations at the bottom of the map, while Brazil acts as the main connection to the Latin American nations at the left-hand side of the map.

Geopolitical, cultural, historical and linguistic ties are evident through the collaborations shown in the map: for example, Spain and Portugal have strong collaborative ties to Latin America, while France and Canada are closely grouped in the central area of the map. While the UK's strongest collaborative partnerships are within the high-impact centre of the network, it does have links with many of those countries on the outskirts of this core, including acting as a bridge for former colonies Australia, New Zealand and India.

While the UK clearly forms part of the densely-connected and prolific core of the global network map, the inclusion of all co-authorship pairings in this map means that although the structure of the map represents the global network very well, it may have a distorting effect on local connections that may be of considerable importance from the perspective of a given country. To highlight more clearly the most important (highest Salton's Index) collaborations from the perspective of a given country, the global map has been used as the basis to emphasise the top 30 co-authorship partnerships for the UK and selected comparators in Figure 5.5. The UK map clearly shows the relative importance of Western European collaborative relationships, close neighbour Ireland, and the US, Israel, Russia, China and Japan. In addition to the aforementioned links with former colonies Australia, New Zealand and India, the links with South Africa, Kenya and Gambia also become clearer. Comparison of the UK map with that for Germany similarly shows the importance of Western Europe for collaborative partnerships, but with a shift in focus away from Africa and towards Eastern Europe. While China is conspicuous by its absence from the Germany map, the collaborative link with Chile (which supports a large German ethnic minority) is brought to the fore. The US map includes the major research nations from across all continents but also emphasises local collaboration partners such as Mexico and Puerto Rico. In contrast to these first three maps, those for China and Japan both show a very regional focus with predominantly Pacific Rim nations along with several of the major research nations from elsewhere.

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 total article outputs of the two partners[58] - 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[59].

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 0.000 to 0.100 for most country pairings of significant size.

For example, the UK's major co-authorship country partnership in the period 2008-2012 is with Germany, accounting for 45,250 co-authored articles in that period. Taking this value in the context of the total article output of both countries in the same period (658,689 for the UK, 619,040 for Germany) using Salton's Index, the calculation $(45{,}250 / \sqrt{(658{,}689 \times 619{,}040)}) = 0.071$.

[57] 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.

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

[59] Leydesdorff, L. (2008) "On the normalization and visualization of author co-citation data: Salton's Cosine versus the Jaccard Index" *Journal Of The American Society For Information Science And Technology* 59 (1) pp. 77–85.

CASE STUDY
INTERVIEWS ON INTERNATIONAL COLLABORATION

INTRODUCTION

To establish a view of the issues surrounding international collaboration, 33 interviews were carried out with key individuals in the academic sector in the UK, along with 14 interviews in the US, 10 interviews in Germany and 10 interviews in China.

The interviewees were initially identified through an analysis of publication data in the broad research domains of Health Sciences, Life Sciences, Physical Sciences, Social Sciences and Arts and Humanities. In each domain, the largest 15 academic institutions from the UK, US, Germany, and China by article output in the period 2008-12 were determined. For each of these institutions and domains, the most prolific 15 authors who had collaborated internationally (i.e. one or more authors from outside the UK for the UK institutions, or one or more authors from the UK for the non-UK institutions) were determined. Interview invitations were then sent to these 15 authors in a selection of 4 of these 15 institutions as well as the Pro-Vice Chancellor of Research (PVCR) or equivalent position; the selection was done so as to give a good geographical representation within each country. In the UK, the PVCRs of *all* 15 universities were included, as well as those of all other Russell Group universities[60] and additional interviewees identified in the course of some interviews.

This case study is therefore based on anecdotal, qualitative information from a sample of individuals selected through a systematic approach; it is indicative of the thoughts of a group of highly collaborative researchers on the major themes outlined below.

This case study is directed at three major themes:

- the drivers and benefits of international collaboration;
- the process of finding international collaboration partners;
- barriers and possibilities for improving international collaboration.

Each theme is divided into key consensus statements from the interviews, with separate discussion and relevant quotations for each, with conclusions provided at the end of each major theme.

THE DRIVERS AND BENEFITS OF INTERNATIONAL COLLABORATION

Collaboration is driven by the desire to work with the best in the world in order produce high quality research.

Everyone interviewed had collaborated nationally and internationally and saw such collaboration as being just as essential to research as developing hypotheses and publishing results. They were aware of the citation benefits which come from such collaboration[61] and were clear about the wider benefits which come from working with the best in the world. The benefits are seen as: improving quality; extending impact; providing inspiration and challenge and benchmarking progress and success.

In addition the interviewees talked about the practical benefits of collaboration. Clinical trials need to be international in scale and large scale research projects often need access to specialist equipment as well as specialist research skills. In some scientific disciplines, projects are far too expensive for every nation to pursue its own individual experiments and the only sensible option is to collaborate across national borders.

> *"The number one reason is always to find the best partners to work with, and international collaboration gives us access to a wider set than is available in the UK alone. There are a number of global challenges – sustainability for example, poverty, energy, security – where the issues go more widely than in UK-specific programmes, so your natural peers will be international."*
>
> Professor Luke Georghiou, Vice-President for Research and Innovation at the University of Manchester and Professor of Science and Technology Policy and Management in the Manchester Institute of Innovation Research at Manchester Business School

[60] The Russell Group is an association of 24 British public research universities; for a full listing of members see *www.russellgroup.ac.uk/our-universities*.

[61] See Figure 5.1. 47.6% of UK authored published in 2012 were co-authored with at least one non-UK researcher; UK international co-authorship is associated with a 61% increase in field-weighted citation impact over institutional co-authorship.

"We focus on top universities… we hope to find some universities stronger than ourselves because we hope to improve our level and reputation through international collaboration… we should not only be a passive recipient but also a positive builder".

Professor of Higher Education, Shanghai Jiao Tong University

"One of the benefits of collaboration is that you get the best person for the job. When you are trying to solve a problem you tend to look back on your previous experience and try to adapt it. Someone else comes from a different perspective and brings a different angle."

Professor David Britton, Professor of Physics and GridPP Project Leader, University of Glasgow

"I think it helps solve problems more efficiently in the end, when you have a broad range of people thinking in different ways and taking different approaches. Sometimes, one approach is better for one problem, whilst sometimes, another approach is better for another".

Dr Christopher Hays, University Research Lecturer, Department of Physics, University of Oxford

"You're basically looking for expertise and you don't care so much if that expertise is coming from the US, or Russia, or England, or France, or Italy…"

Professor Tilman Spohn, Director of The German Aerospace Centre (DLR), Institute of Planetary Research

"Peking University has… 312 cooperative partners all over the world with those in Europe accounting for about one third… When we select partners, we usually select those first-class universities which could set up substantial exchanges with Peking University in concrete cooperative projects… There is another perspective… we need to train our students to develop their global vision… the universities in Britain are a priority for our cooperation… we have signed cooperative agreements with the Physical Institute of Sheffield and with Southampton… We have exchange programs with London School of Economics, University of Oxford, University of Cambridge, University of Edinburgh, Durham University and the University Of Exeter."

Li, Yansong (Dr.) Vice President, Peking University

Cross-disciplinary collaboration is becoming more important as its role in solving complex research problems is recognised.

Several interviewees discussed the strong drive towards more interdisciplinary research, particularly in the Arts and Humanities and Social Sciences; interviews with academics at Princeton and the University of California, San Diego emphasised the importance of cross-disciplinary collaboration in the US and its role in solving complex research problems. The key advantage was seen as the introduction of new perspectives into a project team and the key challenge as the identification of the most appropriate journal in which to publish interdisciplinary work, as well as having the value of the work being recognised by peers within a particular discipline.

"Bridging different scientific communities or disciplines is something that I always thought was very important for science."

Professor Paola Caselli, University of Leeds

"When I was doing my Libyan fieldwork, I worked with researchers from France, Spain, Italy, Holland, Germany, the US, Canada as well as other countries. The research looked at how people have lived in the Sahara. More specifically, we were trying to understand how the climate had an impact upon human communities. It was a project involving archaeologists, geographers and climatologists, but the main focus was on the human story."

David Mattingly, Professor of Roman Archaeology, University of Leicester

"Part of the University's strategy is to have a global reach and to have an inter-disciplinary portfolio…..the driver for this is the research questions you are trying to address and whether they require expertise from outside your own discipline."

Professor Ian Walmsley, Pro-Vice-Chancellor (Research ASUC), University of Oxford

"We very much value multidisciplinary approaches in investigations, whether those are locally funded, federally funded, or internationally funded. Faculty from multiple departments and divisions must work jointly in order for an Organized Research Unit to be funded by the university. I think it helps break down some of the common silos that emerge in our highly technical stage of research."

Sandra A Brown, PhD, Distinguished Professor of Psychology and Psychiatry, and Vice Chancellor for Research, University of California, San Diego

The definition of "partners" is now broader for many researchers and includes industry as well as third sector bodies, charitable trusts and arts organisations.

Partnerships with industry are widespread and are discussed in more detail in Chapter 7 and its accompanying case study. Several people, particularly in Arts and Humanities, referred to partnerships with cultural institutions. King's College London has a Cultural Institute which develops and sponsors knowledge exchange projects; the College also intends to open a Science Gallery at its Guy's Campus[62]. The University of Leicester's School of Museum Studies highlighted a number of international projects which involved collaboration with museums and galleries and with designers.

"Over the last ten or twelve years, I've been working with a number of UK-based design companies, initially on a series of conferences. Lots of the people who spoke at the conferences are now involved in other projects that we do."

Dr Suzanne MacLeod, Head of the School of Museum Studies, University of Leicester

"You're working with somebody with complementary expertise in order to do something that would be more difficult to do working in isolation."

David Hogg, Professor of Artificial Intelligence and Pro-Vice-Chancellor for Research and Innovation, University of Leeds

"We always encourage our students and faculty to do cooperation wherever... It means you have to seek to work with many people to find better ways to solve problems"

Wu Kai (Mr.) Cheung Kong Professor of Physical Chemistry, Dean, College of Chemistry and Molecular Engineering, Peking University

Summary

UK researchers require access to the widest range of expertise, perspectives, and facilities possible, which can only come through collaboration with experts across the world. Increasingly this collaboration may involve working across subject boundaries and with a wide range of partners.

There is a desire to see the value and importance of cross-disciplinary collaboration recognised and to ensure that it too is built into funding and award streams.

THE PROCESS OF FINDING INTERNATIONAL COLLABORATION PARTNERS

Partnership networks are forged early in a researcher's career.

Interviewees were asked about the process for identifying potential partners, how they established which ones of those they wanted to work with and how they sustained and embedded these relationships. Everyone interviewed talked about the relationships they forged when doing their doctorate and that their early research remained important during the course of their career. As a result they made a strong link between the teaching and learning role of a university and its research agenda. The process for identifying potential partners was seen, by individual researchers, as being very ad hoc. They talked about it being based on introductions from colleagues and getting to know people at conferences and seminars.

"Spending time in a context where people are coming from all over the world to an internationally-renowned programme allows you to build up contacts with people who you know are going places and doing interesting work. They are people I've kept in touch with: they've gone off and now have academic positions around the world."

Dr Jonathan Hale RIBA FRSA, Associate Professor & Reader in Architectural Theory, Department of Architecture and Built Environment, University of Nottingham

"You end up knowing which researchers you can trust to produce high quality work. You then talk to them about what is going on in these different areas, and the possibility of working together."

Dr Christopher Hays, University Research Lecturer, Department of Physics, University of Oxford

New ways of developing and maintaining contacts are emerging which can help with finding partners and which can enrich existing relationships by making it easier to exchange ideas and information.

For many interviewees, finding the right people to work with and knowing who is the best in the field was not seen as a problem. However they recognised that many people need assistance to forge the partnerships which are seen as underpinning high quality research. Several interviewees referred to the value of networks like Universitas 21 [63] and the World Wide University Network [64], while others spoke about discipline-specific networks like the European Vision Institute [65] and how they have used these to find partners and share information. They also talked about using tools like Skype, portals like Academia.edu and social networks like Twitter and Facebook as a way of sharing ideas, opening up discussion and making contact with other researchers around the world.

"People get to know your work through outlets like Academia.edu, and being on LinkedIn and Twitter generates new contacts and a new level of awareness because people are searching for information relevant to their own work. It's still very new though, so none of us are quite sure of the long-term value."

Dr Jonathan Hale RIBA FRSA, Associate Professor & Reader in Architectural Theory, Department of Architecture and Built Environment, University of Nottingham

Personal contact is still important in developing and cementing relationships.

Everyone interviewed agreed that despite all the benefits they could see from using online tools and portals to support their networks and their research, they were no substitute for personal contact. Constant reference was made to the strong personal relationships which underpin high quality collaborative research projects and everyone interviewed stressed the need to be able to meet in person to develop these. What has also emerged from some of the interviews is that different research cultures operate in different countries; this is seen as strengthening the research process but it reinforces the need for investment to support researchers in spending time together and getting to know each other.

"If there's not a personal relationship, and if you haven't exchanged long-term lab visits first, you can't use things like video calls to keep the collaboration going. You really have to know the people and understand what they're talking about, and what they're doing, before you can use long distance modes of collaboration."

Elliot M. Meyerowitz, George W. Beadle Professor of Biology, HHMI-GBMF Investigator, Division of Biology, California Institute of Technology

"From an academic perspective you want to collaborate with an individual. If they move institutions then you might well move your allegiance to the other institution, because the academic has moved."

David Hogg, Professor of Artificial Intelligence and Pro-Vice-Chancellor for Research and Innovation, University of Leeds

62 See *www.kcl.ac.uk/cultural/science-gallery/Science-Gallery-at-Kings-College-London.aspx*.

63 See *www.universitas21.com*.

64 See *www.wun.ac.uk*.

65 See *www.europeanvisioninstitute.org*.

Universities are increasingly building international collaboration into their long-term strategies.

Some UK universities already have campuses in other parts of the world and others are now opening them. Many universities are building on the networks of individual researchers to embed international collaboration into their long-term strategies and to establish formal partnership agreements aimed at driving forward research in particular areas; sharing their expertise and resources and supporting teaching and learning. In part this is in recognition of the need to try and embed and sustain international partnerships so that they are not lost when a researcher moves on or back to another university. It remains to be seen whether these strategies result in new or different types of relationships and whether they have any impact on the quality of the research being done. Several spoke of the need to ensure that, as universities develop a more strategic approach to partnership working, they avoid "matching" researchers to partners they cannot work with. It was a belief in the need to let collaboration be driven by researchers and faculty that led Princeton to review its own approach to collaboration, and to let faculty and students make decisions about their partnerships.

"If a school does not go international it is not a good school. We have taken many measures: we offer scholarships for student exchanges abroad while attract ing foreign students to China by offering courses in English, and we also invite foreign professors to China to teach. Later we began our exchange programmes with some top universities in the world. We have selected about seven or eight to cooperate with, and we have faculty exchange programmes as well as student exchange programmes. We also jointly publish papers, and we have done this with Cambridge and Oxford."

Professor and Academician, University of Science and Technology of China

"We have reviewed the way we work, giving up sovereignty and letting faculty and students take the decisions about their partnerships, which we as an institute enable and promote."

Dr Jeremy Adelman, Professor and Director, Council for International Teaching and Research, Princeton University

"We think having a South East Asia presence is very important. It is a good example of the sort of strategic element of what we are doing in addition to the individual researcher links. We looked at where we might build a new campus, and Malaysia seemed to offer quite a number of attractive possibilities: they clearly have a demand for undergraduate engineering education and our engineers are very strong, so it was a good fit."

Professor Philip Nelson FREng, Pro Vice-Chancellor, University of Southampton

"We're not great believers in signed-up general collaboration agreements, and where those do exist they are mostly at school or institute level. I have to say in most cases they're at the instigation of a partner, often in Asia, for whom it is more important to have that formalisation of the relationship. Many of our Chinese partners feel more comfortable with a written collaboration agreement, which is renewed every so many years…. same in Japan. However we always feel that collaboration should be driven by content rather than by form."

Professor Luke Georghiou, Vice-President for Research and Innovation at the University of Manchester and Professor of Science and Technology Policy and Management in the Manchester Institute of Research and Innovation at the Manchester Business School

Summary

Finding the right partners to collaborate with and being identified as a partner for high quality, high impact research projects is seen as critical.

The key driver for collaboration should be the quality of the scholarship and research of the partners with whom researchers want to work; it remains to be seen whether taking a more strategic approach to collaboration can help to improve this.

Whilst it is recognised that personal contact is expensive, the strong belief is that it has to continue to be supported and embedded into funding streams.

Many interviewees recommended the setting up of student exchanges to support the development of these critical networks; all were keen to see governments support researcher mobility and networking.

BARRIERS AND POSSIBILITIES FOR IMPROVING INTERNATIONAL COLLABORATION

Universities are increasingly building international collaboration into their long-term strategies.

As the drivers for and benefits from collaboration are clearly recognised and understood, internal barriers which prevent researchers from attempting to collaborate were perceived as existing but as lesser impediments. As is inevitable when personal connections are so important to a process, personal differences between researchers and clashes in personality can create difficulties in collaboration, as can the perception that sharing credit for a project with someone else will harm a researcher competitively. A strong response against this view was given by several interviewees who saw collaboration as a way of harnessing the competitive spirit to the benefit of the project overall.

"Collaboration is not the death of competitiveness; it simply harnesses the competitive spirit we all have into a structure which actually benefits the project."

Professor David Britton, Professor of Physics and GridPP Project Leader, University of Glasgow

UK visa issues are seen as undermining long-term research collaborations.

Administrative matters related to visa applications for non-UK researchers were identified by every interviewee as a significant external barrier to researcher mobility and so to deep, long-term research collaborations. Almost all interviewees had encountered this barrier, with the vast majority emphasising that difficulties around obtaining visas had prevented them from working with the best students, delayed or impeded their research, and hampered their longer-term collaborations with international colleagues. The long-term impact of this was raised in several interviews: the view was that post-graduate students should be seen as future collaborators and regarded as a "cherished investment".

Interviewees also talked about the personal and research benefits which come from taking sabbaticals or moving to work for a period in a different country, and of the need to ensure that visa issues don't obstruct this or prevent it from happening. Interviewees at Cornell felt that 2 years was an ideal length of time for a sabbatical or placement, arguing that partnerships are more impactful and have better outputs if they last for at least 2 years.

"I think that the UK needs to decide whether they want to be less bureaucratic and whether they want to be less costly for research, but everything I've seen is going in rather the other direction."

Professor for Cardiology, Germany

"The barriers that have been erected for foreign students, particularly post-graduate students, are damaging future collaborative prospects. They are often our greatest champions in their countries and should be seen as a cherished investment, not as some sort of back-door immigration."

Professor Luke Georghiou, Vice-President for Research and Innovation at the University of Manchester and Professor of Science and Technology Policy and Management in the Manchester Institute of Research and Innovation at the Manchester Business School

"Attracting the best researchers and students from around the world is central to our ability to function as a globally-leading, research-intensive University. The complexity and mutability of visa applications can delay the start of projects, and we are grateful to UKBA for continuing to work with us on clarifying regulations and simplifying administrative processes to reduce this impediment to international research activity."

Professor Ian Walmsley, Pro-Vice-Chancellor (Research ASUC), University of Oxford

Improving the alignment of national funding streams would help to support international collaboration.

An equally important external barrier discussed in all interviews was funding to develop contacts and support collaboration. The European Union framework program (FP7)[66], together with the forthcoming Horizon2020[67], were referenced as models which help to support international collaboration and partnerships. Interviewees talked about the benefits of dealing with one organisation, the greater ease of making one application and getting one decision, and the success of the UK in bidding for European funding.

Other international collaborations are affected by the individual funding applications each participant goes through. Many interviewees mentioned the situation where each partner needs to succeed in their distinct local funding proposals, each with their own timetable and outcomes before a collaborative project can commence. The general view was that differing funding cycles can make it more difficult to collaborate with research nations outside Europe and restrict potentially fruitful research collaborations.

Problems associated with the short-term nature and the uncertainties of many funding mechanisms were also referenced. They are seen as making it a challenge to attract and keep the best candidates for a role.

There was a general recognition that much is being done by the UK Research Councils and the UK Government to help overcome some of these barriers to collaboration. Whilst interviewees recognised and referenced the efforts being made in their own countries to support international collaboration, all felt that more could still be done to promote awareness of existing schemes to support tri-partite and non-European research programmes and to make them more problem-focused and more flexible. The feeling was that to attract the very best to a particular project; there needs to be as much stability as possible in the funding streams and they need to recognise the importance of supporting personal contact.

"For example, RCUK allows international partners on project in a formal way. The partner's institution has to say: "yes, we're committing this to the project in such and such a way, and we have an interest in the success of the project". This is great and it helps to support international collaboration. But Project Partners cannot receive funds from the grant to help support the collaborative research. So it is a little strange that even if the reviewers and panel find the case for collaboration compelling, one cannot support it with UK funding. Of course, some other means might be found within a programme, but the Project Partner route requires a commitment from an international collaborator with no reciprocal support from our end beyond an agreement to collaborate. I think we could be more supportive"

Professor Ian Walmsley, Pro-Vice-Chancellor (Research ASUC), University of Oxford

"My money cannot go to you and your money cannot come to me… It is a problem worldwide…. Governments are not willing to let their money go abroad …. Only the money offered by private businesses, like Bill Gates' foundation… can cross the border… government has to consider its own benefits, like intellectual property and so on and so forth. There are a lot of legal issues"

Wu Kai (Mr.) Cheung Kong Professor of Physical Chemistry, Dean, College of Chemistry and Molecular Engineering, Peking University

"There's obviously nothing that greases collaboration like access to funding."

Professor Daniel Rader, Chief-Division of Translational Medicine and Genetics, School of Medicine, University of Pennsylvania

"The advantage of European funding is that collectively you make one application, you get one decision, and you're dealing with one funding organisation."

Professor Steven P. Beaumont, OBE, MIET, FREng, FRSE, Vice-Principal for Research & Enterprise, University of Glasgow

"A lot of the difficulty in internationalising our own research is actually finding the sources of funding that we need in order to do it effectively. If there was a United Nations Research Council then that would be a remarkably good thing for the internationalisation of research."

Professor Philip Nelson FREng, Pro-Vice-Chancellor, University of Southampton

"The British are pretty good at framing these sorts of applications, which is consequently improving UK researchers' chances of being invited to be part of networks involving European partners."

David Mattingly,Professor of Roman Archaeology, University of Leicester

"European community money has increased collaboration."

Professor Dr. Eberhart Zrenner, University of Tübingen, Germany

The UK needs to be better at celebrating and showcasing its work.

Active, sustained recognition and celebration of the quality of UK research can help to foster international collaboration. Public recognition for high quality work was generally seen as playing an important role in attracting potential collaborations both at the personal level of researchers proposing research collaborations, and at the broader level of institutions mapping out future partnerships. Hosting conferences and events to showcase UK research to the public, as well as to business and the international community, were also discussed as ways of attracting further collaborations.

"What good things does Britain have? It is not always easy for us to know."

Li Minglu, Professor of Computer Science, Shanghai Jiao Tong University

Summary

The UK's visa policy for highly skilled workers, including researchers, is perceived to be a major barrier to maintaining the UK's competitive edge in researcher mobility and research collaboration.

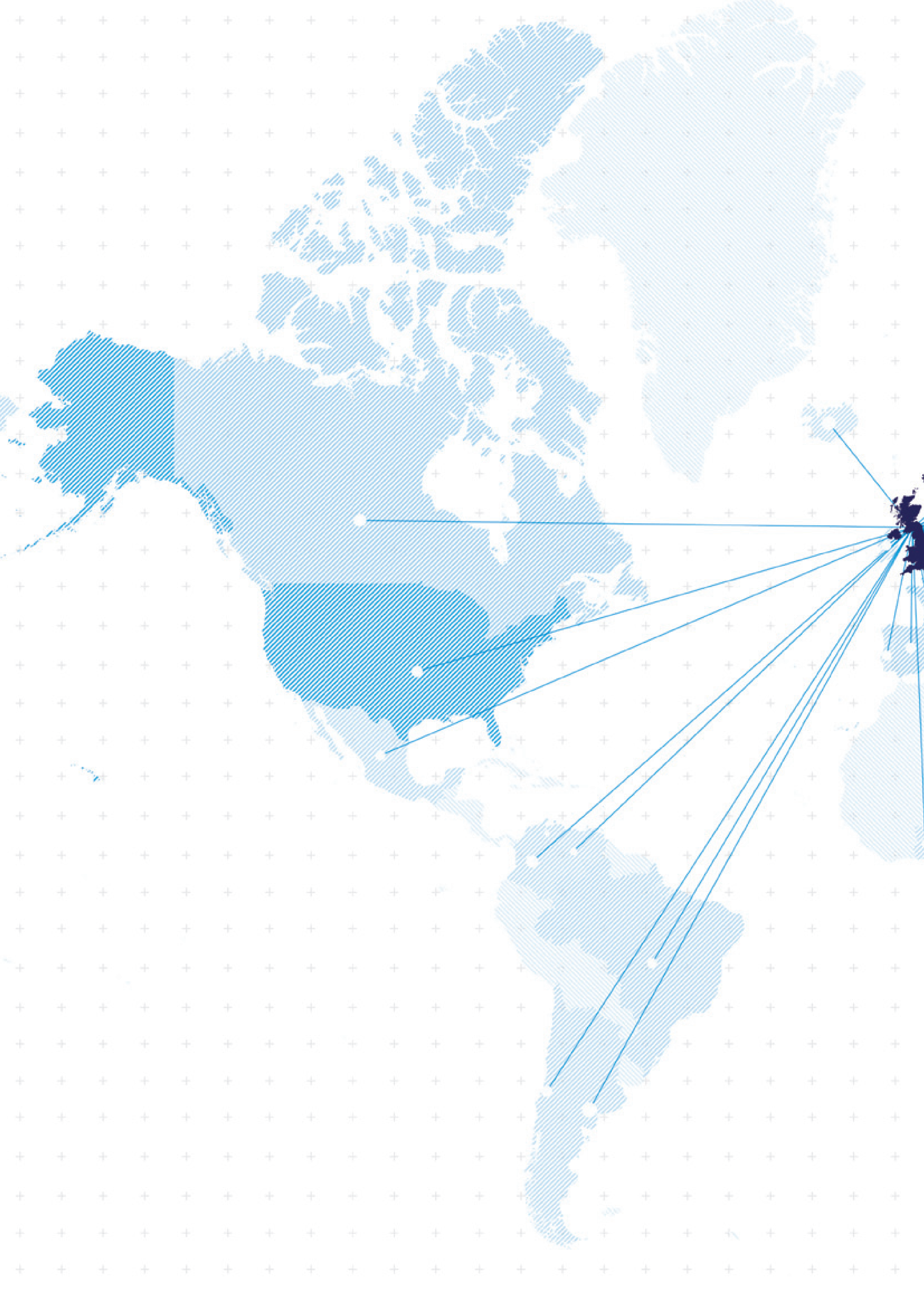
There are clear benefits from funding bodies and government taking a strategic, joined up and long-term view of collaboration; where this does exist, in the EU and in international collaborative projects like CERN it is helping to drive international collaboration forward. These examples could be used to put in place the funding mechanisms and legal frameworks which can support and underpin collaboration in the future.

"Sometimes the time delay when applying for funds means we have to delay cooperation."

Professor and Academician, University of Science and Technology of China

[66] See *cordis.europa.eu/fp7*.

[67] See *ec.europa.eu/research/horizon2020*.



Chapter 6

Research Productivity

UK PRODUCTIVITY PER UNIT R&D EXPENDITURE

3.9 articles per unit GERD in 2012

Increased at **3.6%** per year in the period 2008-12

Ranks **1st** amongst comparator countries in 2012

43.1 citations per unit GERD in 2012

Increased at **4.0%** per year in the period 2008-12

Ranks **1st** amongst comparator countries in 2012

UK HIGHER EDUCATION PRODUCTIVITY PER UNIT R&D EXPENDITURE

11.8 articles (Higher Education sector) per unit HERD in 2012

Increased at **3.2%** per year in the period 2008-12

Ranks **3rd** amongst comparator countries in 2012

141.0 citations (Higher Education sector) per unit HERD in 2012

Increased at **3.5%** per year in the period 2008-12

Ranks **1st** amongst comparator countries in 2012

UK PRODUCTIVITY PER RESEARCHER

0.5 articles per researcher in 2012

Increased at **0.8%** per year in the period 2008-12

Ranks **3rd** amongst comparator countries in 2012

5.87 citations per researcher in 2012

Increased at **5.4%** per year in the period 2008-12

Ranks **2nd** amongst comparator countries in 2012

6.1 Highlights

- The UK is a highly productive research nation in terms of articles and citation outputs per unit of R&D expenditure or per researcher.

- Recent research has suggested that research collaboration can have a positive effect on publishing productivity at the individual researcher level [68], and it may be that recent increases in UK research productivity have, at least to some extent, been driven by the increase in UK international research collaboration (see Figure 5.1).

- However, since there are finite limits on these drivers of research productivity, the question of how long it is possible to sustain increasing outputs from broadly stable or decreasing inputs remains to be seen.

6.2 Introduction

The concept of research productivity at a national level is the ability to convert research inputs (R&D expenditure and human capital) into research outputs (including articles and citations)[69]. As such, this chapter draws extensively on concepts and terminology introduced in Chapter 2 (input indicators such as GERD), Chapter 3 (human capital indicators such as researchers) and Chapter 4 (output indicators such as articles and citations).

Previous research has shown that, at least at the level of the individual researcher, the drivers of research productivity are manifold and include at least the following eleven factors: persistence, resource adequacy, access to literature, initiative, intelligence, creativity, learning capability, stimulative leadership, concern for advancement, external orientation, and professional commitment[70]. 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.

6.3 Key Findings

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

As noted in Chapter 2, Gross Domestic Expenditure on R&D (GERD) represents the total expenditure on R&D within a country. When the total article output for the UK is expressed per unit GERD, the UK's productivity on this indicator is greater than that of any comparator country (at 3.87 articles per unit GERD in 2012) and has increased at 3.61% per year in the period 2008-12 (see Figure 6.1). Of the comparator countries, Canada and Italy have very similar productivity levels and similar growth rates, while the remaining comparators generally show lower productivity with a slowly increasing trend (which is also reflected in the aggregate for the EU27 countries); the notable exception is China, where the trend is decreasing over time.

When the total citation output for the UK is expressed per unit GERD, the UK's productivity is considerably greater than that of any comparator country (at 43.1 citations per unit GERD in 2012) and has increased at 4.04% per year in the period 2008-12 (see Figure 6.2). Of the comparator countries, Canada and Italy have the next highest productivity levels and growth rates, while the remaining comparators generally show lower productivity but with an increasing trend (which is also reflected in the aggregate for the EU27 countries).

[68] Lee, S. & Bozeman, B. (2005) "The impact of research collaboration on scientific productivity" *Social Studies of Science* 35 (5) pp. 673-702.

[69] 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.

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

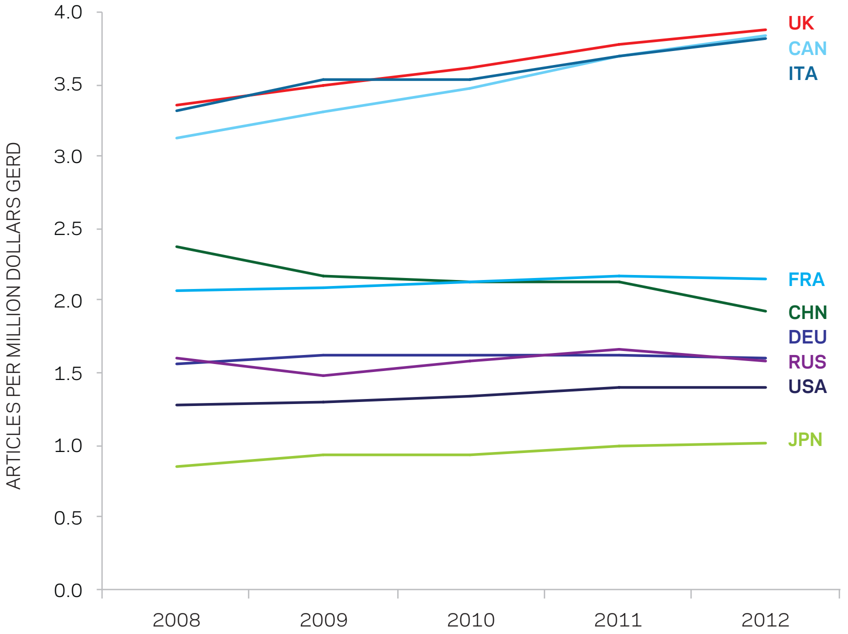


Figure 6.1 *— Articles per unit GERD for UK and comparators, 2008-2012. UK ranking in EU27 is amongst 22 (of 27) countries with available data. Source: Scopus and OECD MSTI 2013/1.*

	2008	2012	Change 2008-12	CAGR 2008-12	UK Rank 2008	UK Rank 2012
UK	3.35	3.87	0.51	3.61%	-	-
EU27	2.24	2.41	0.19	2.02%	10	10

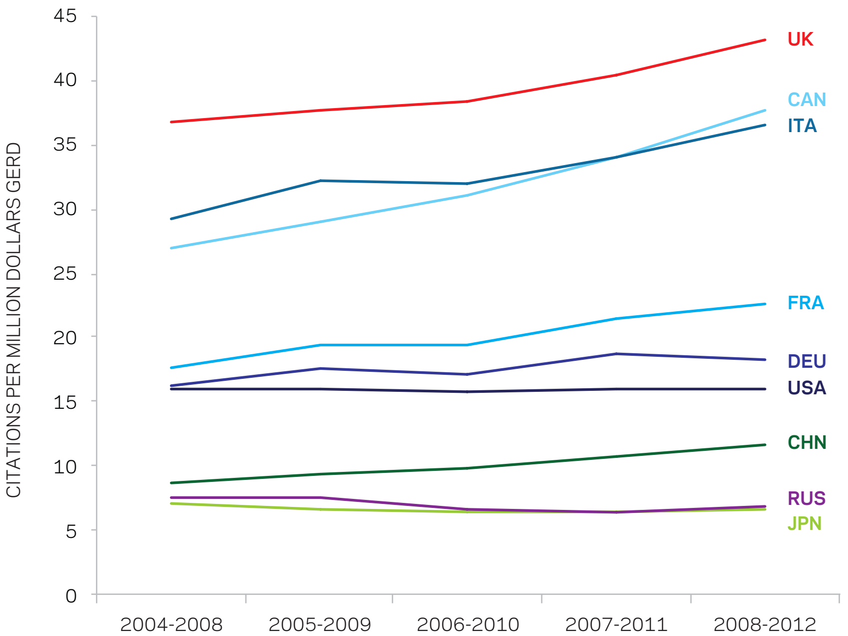


Figure 6.2 *— Citations per unit GERD for UK and comparators, 2008-2012. Each data point corresponds to articles published in the first year shown and citations to these articles over the subsequent 5 years, and GERD for the first year shown; i.e. the data point for 2008-2012 corresponds to 2008 articles and citations to these in the period 2008-2012, divided by 2008 GERD. Note that, owing to refinement of the methodology used to calculate citation indicators, these shares differ slightly from those presented in the previous report in this series. UK ranking in EU27 is amongst 22 (of 27) countries with available data. Source: Scopus and OECD MSTI 2013/1.*

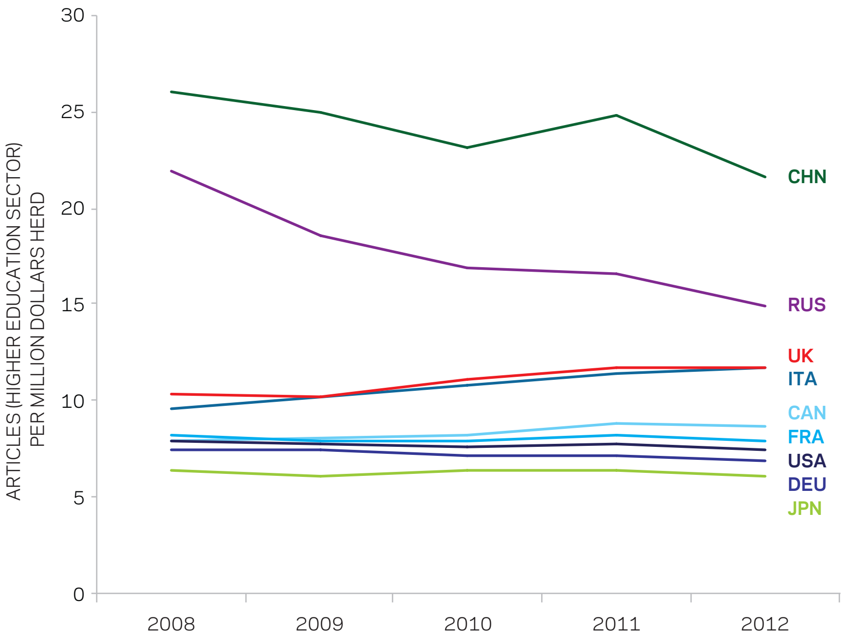
	2004-2008	2008-2012	Change	CAGR	UK Rank 2004-08	UK Rank 2008-12
UK	36.77	43.08	6.31	4.04%	-	-
EU27	19.27	21.84	2.58	3.19%	4	4

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

The majority of global article outputs are produced by the Higher Education sector, while the distribution of GERD by sector of performance varies by country but is generally greatest for the Business Enterprise sector (see Figure 2.3). As such, 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 Higher Education sector produces 11.8 articles per unit HERD in 2012, rising from 10.4 articles per unit HERD in 2008 and representing an increase of 3.23% per year over this period (see Figure 6.3). China and Russia show greater productivity than the UK, although this is decreasing over time, while Italy's Higher Education productivity is similar to that of the UK; the remaining comparator countries, as well as the EU27 country group, have considerably lower and quite stable levels of productivity.

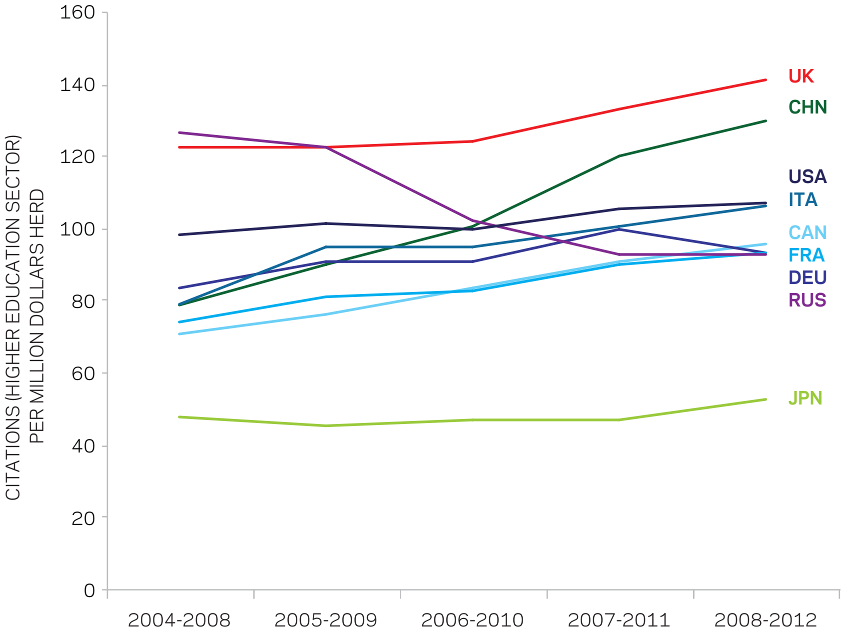
The UK Higher Education sector produces 141.0 citations per unit HERD in 2012, rising from 123.0 citations per unit HERD in 2008 and representing an increase of 3.49% per year over this period (a rate similar to the EU27 country group; see Figure 6.4). Russia previously showed greater productivity than the UK but has seen decreasing productivity over time to rank amongst the lowest of the comparator countries. China's Higher Education productivity is the next highest after the UK, followed by the remaining comparator countries as a close group with the exception of Japan, which is relatively low and stable.

Figure 6.3 *— Articles (Higher Education sector) per unit HERD for UK and comparators, 2008-2012. UK ranking in EU27 is amongst 22 (of 27) 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 2013/1.*



	2008	2012	Change 2008-12	CAGR 2008-12	UK Rank 2008	UK Rank 2012
UK	10.37	11.78	1.41	3.23%	-	-
EU27	8.15	8.42	0.27	0.82%	7	7

***Figure 6.4** — Citations (Higher Education sector) per unit HERD for UK and comparators, 2008-2012. Each data point corresponds to articles published in the first year shown and citations to these articles over the subsequent 5 years, and HERD for the first year shown; e.g. the data point for 2008-2012 corresponds to 2008 articles and citations to these in the period 2008-2012, divided by 2008 HERD. Note that, owing to refinement of the methodology used to calculate citation indicators, these shares differ slightly from those presented in the previous report in this series. The UK ranking in EU27 is amongst 22 (of 27) 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 2013/1.*



	2008	2012	Change 2008-12	CAGR 2008-12	UK Rank 2008	UK Rank 2012
UK	122.97	141.04	18.07	3.49%	-	-
EU27	74.59	85.27	10.68	3.40%	3	3

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

As noted in Chapter 3, researchers are the engine that drives the progress of research. When the total article output for the UK is expressed per researcher, the UK's productivity on this indicator is the 3rd highest amongst the comparator countries (at 0.51 articles per researcher in 2012) and has increased at 0.82% per year in the period 2008-12 (see Figure 6.5). Of particular note is Italy, which shows a very high but broadly stable productivity per researcher; as noted in the previous report in this series, this indicator may be overestimated owing to underestimation of researcher counts for Italy[71]. Canada has very similar productivity levels to the UK, while the remaining comparator countries show lower productivity and flatter trends.

When the total citation output for the UK is expressed per researcher, the UK's productivity (at 5.87 citations per researcher) is second only to Italy (but with the same caveat on Italian researcher counts as mentioned above) and has increased at 5.40% per year in the period 2008-12 (see Figure 6.6). Of the comparator countries, Canada has the next highest productivity levels and growth rate, while the remaining comparators generally show lower productivity but with an increasing trend which is also reflected in the aggregates for the G8, EU27, OECD and World.

[71] International Comparative Performance of the UK Research Base – 2011. Available at *www.bis.gov.uk/assets/BISCore/science/docs/I/11-p123-international-comparative-performance-uk-research-base-2011.pdf*. pp. 67.

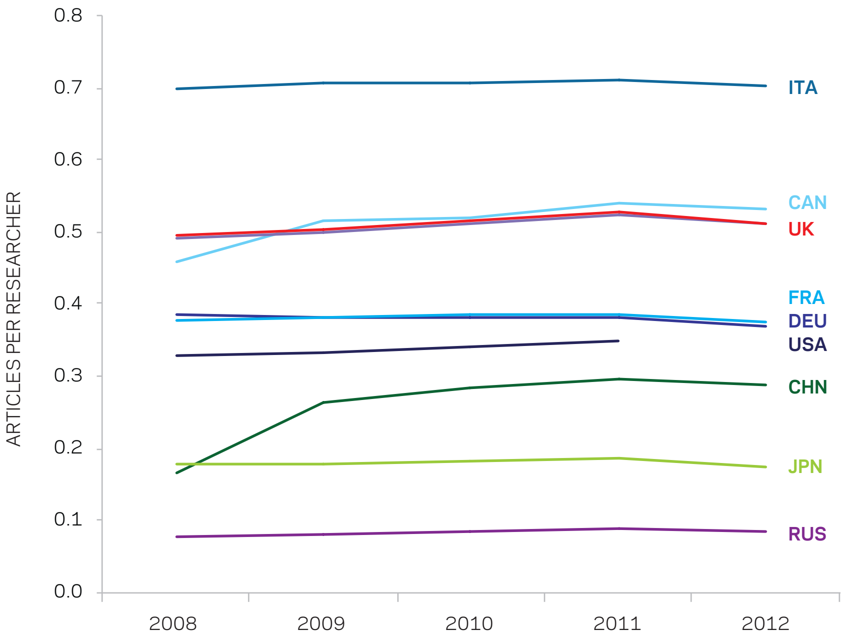


Figure 6.5 — *Articles per researcher for the UK and comparators, 2008-2012. UK ranking in EU27 is amongst 22 (of 27) countries with available data, in OECD is amongst 37 (of 41) countries with available data and for the World is amongst 40 countries with available data. Source: Scopus and OECD MSTI 2013/1.*

	2008	2012	Change 2008-12	CAGR 2008-12	UK Rank 2008	UK Rank 2012
UK	0.50	0.51	0.01	0.82%	-	-
G8	0.27	0.46	0.19	14.23%	2	3
EU27	0.39	0.40	0.01	0.88%	6	6
OECD	0.25	0.38	0.13	10.86%	7	9
World	0.29	0.42	0.13	9.52%	11	16

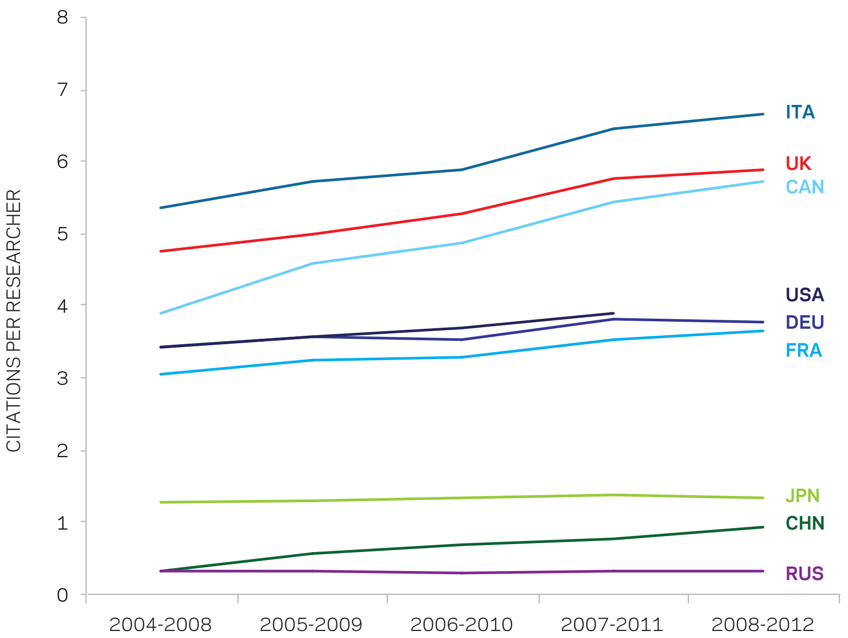


Figure 6.6 — *Citations per researcher for the UK and comparators, 2008-2012. Each data point corresponds to articles published in the first year shown and citations to these articles over the subsequent 5 years, and researchers for the last year shown; i.e. the data point for 2008-2012 corresponds to 2008 articles and citations to these in the period 2008-2012, divided by 2012 researchers. The UK ranking in EU27 is amongst 22 (of 27) countries with available data, in OECD is amongst 37 (of 41) countries with available data and for the World is amongst 40 countries with available data. Source: Scopus and OECD MSTI 2013/1.*

	2004-2008	2008-2012	Change	CAGR	UK Rank 2004-08	UK Rank 2008-12
UK	4.76	5.87	1.11	5.40%	-	-
G8	2.44	2.86	0.42	4.05%	2	2
EU27	3.36	3.84	0.48	3.38%	5	5
OECD	2.01	2.20	0.20	2.36%	5	5
World	2.04	2.25	0.22	2.57%	6	8

Chapter 7
Knowledge Exchange

UK LICENSE REVENUE PER UNIT R&D EXPENDITURE

$2,789 per unit GERD in 2011

Increased at **13.2%** per year in the period 2008-12

Ranks **3rd** amongst other countries with available data in 2011

UK PATENT APPLICATIONS

50,749 in 2011

Increased at **0.3%** per year in the period 2007-11

Ranks **6th** amongst comparator countries in 2011

Represents **2.4%** of the global total in 2011

UK PATENT CITATION SHARE

10.9% in 2012

Increased at **5.4%** per year in the period 2007-11

Ranks **3rd** amongst comparator countries in 2012

UK CROSS-SECTOR ARTICLE USAGE

61.7% of downloads of corporate-authored articles by academic users in 2008-12

52.6% of downloads by corporate users of academic-authored articles in 2008-12

UK INVENTION DISCLOSURES PER UNIT R&D EXPENDITURE

0.116 per unit GERD in 2011

Increased from **0.074** in 2010

Ranks **1st** amongst other countries with available data in 2011

UK START-UPS AND SPIN-OFFS PER UNIT R&D EXPENDITURE

0.007 per unit GERD in 2011

Ranks **2nd** amongst other countries with available data in 2011

UK CROSS-SECTOR RESEARCHER MOBILITY

Net movement of researchers from academia to industry within and beyond the UK in the period 1996-2012

7.1 Highlights

- The UK is successful at commercialising the IP derived from academic research when compared with other countries for which comparable indicators are available.
- Despite relatively low patenting activity overall, a high and rising proportion of UK journal articles are cited in patents.
- The UK also has strong cross-sector knowledge exchange processes, as indicated by article downloading and researcher moves.

7.2 Introduction

Knowledge exchange is a two-way transfer of ideas and information. In the context of this report, the focus is on academic-industry knowledge exchange as a conduit between public sector investment in research and its private sector commercialisation, ultimately leading to economic growth. Since knowledge resides with people and not in documents, much knowledge is tacit or difficult to articulate. Consideration is given here to indicators of both explicit (codified and transferable) and tacit (intuitive and unarticulated) academic-industry knowledge exchange such as licensing income, invention disclosures and start-up or spin-off company formation; patent applications and grants and patent citations; and cross-sector article downloads and researcher moves. Knowledge exchange can also include teaching, joint student supervision, staff exchange and consulting, but these elements are not addressed in this report.

Knowledge exchange is a complex and multi-dimensional phenomenon, the essence of which cannot be wholly captured with indicator-based approaches. As such, the findings above have been supplemented with extensive interviews with key individuals in the UK academic sector and business sectors in the Case Study in this chapter.

7.3 Key Findings

7.3.1 UK commercialisation of intellectual property derived from academic research is comparable to other countries

Despite the well-acknowledged dearth of systematically-collected data on knowledge exchange activities over time and across countries, sources are now emerging which apply a rigorous survey-based approach to tracking key indicators of the commercialisation of academic research, that is, of intellectual property created in higher education institutions[72]. Intellectual property (IP) describes intangible assets, such as discoveries and inventions, for which exclusive rights may be claimed. Common types of IP include that which is codified in copyright, trademarks, patents, and designs.

There is increasing interest in creating more and better indicators of commercialisation of research at a national level[73]. A small set of indicators have been proposed[74] for the commercial potential of research and its use by industry, including IP income (license revenue), IP disclosures (invention disclosures), and new and on-going start-up and spin-off companies. To allow for meaningful international comparisons, these output indicators are all normalised by the input indicator Gross Domestic Expenditure on R&D (GERD; see Chapter 2). Owing to the limited availability of robust data sources, it is not possible to include all members of the comparator country group used throughout the rest of this report, but only subset that includes the UK, Canada, Italy and the US, as well as Denmark and Spain.

IP income is revenue, typically in the form of fees and royalties, from the licensing of IP for use by a third party. The UK derived some $2,789 in IP income per unit GERD in 2011, and increase of 13.2% per year in the period 2008-11. The UK's level of IP income per unit GERD is well above that for Spain and Italy, and is similar to that for Canada and Denmark, but is less than half of the $6,675 per unit GERD in 2011 for the US.

IP disclosures are descriptions of discoveries or inventions for evaluation by patent experts to assess the potential for proceeding with a patent application. The UK had the highest level of IP disclosures per unit GERD in 2011 of the countries with available data, at 0.116 per unit GERD. This represents an increase from 0.074 in 2010. Of the remaining countries with available data, all but Italy show IP disclosure rates broadly similar to the UK, with Italy being approximately two-thirds lower at 0.023 per unit GERD.

Start-ups and spin-offs are companies created for the purpose of developing or exploiting IP under license or other agreement from the IP owner. The UK had the second highest level of start-ups and spin-offs per unit GERD in 2011 of the countries with available data, at 0.007 per unit GERD. This rate is similar to that of Italy and Spain, but significantly greater than that of Canada, the US and Denmark.

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72 Association of University Technology Managers (AUTM; see www.autm.net/Surveys.htm), ProTon Europe (see www.protoneurope.org/index2.php?m=proton_europe_en-5-reports) and the Higher Education - Business and Community Interaction survey in the UK (HE-BCI; see www.hefce.ac.uk/whatwedo/kes/measureke/hebci/).

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

74 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.

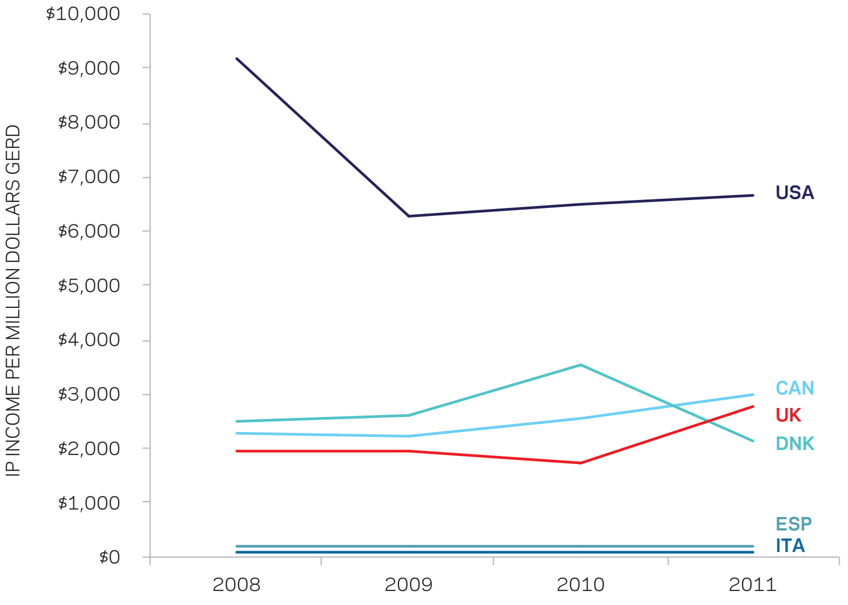


***Figure 7.1** — IP income per unit GERD for the UK and countries with available data, 2008-2011. Source: ProTon Europe Annual Survey Reports and Association of University Technology Managers STATT Database.*

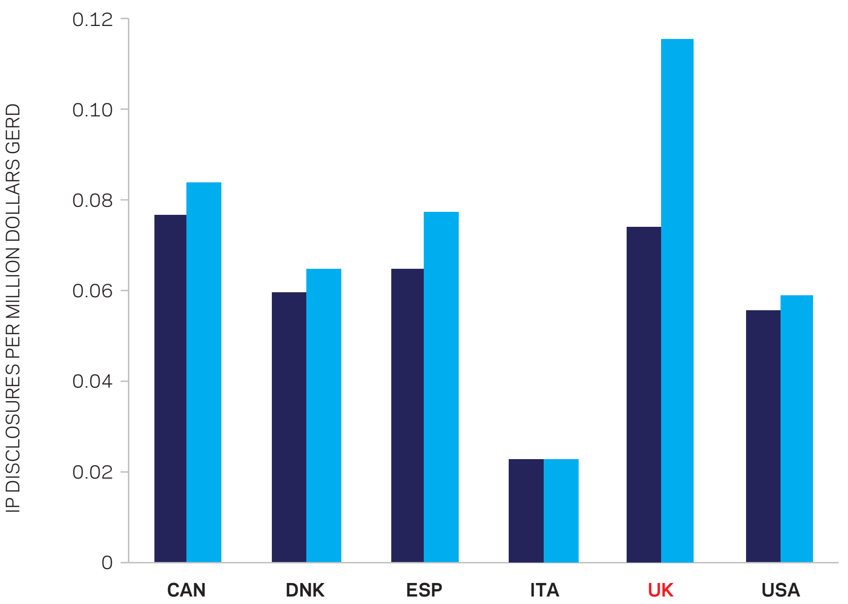


***Figure 7.2** — IP disclosures per unit GERD for the UK and countries with available data, 2010-2011. Source: ProTon Europe Annual Survey Reports and Association of University Technology Managers STATT Database.*

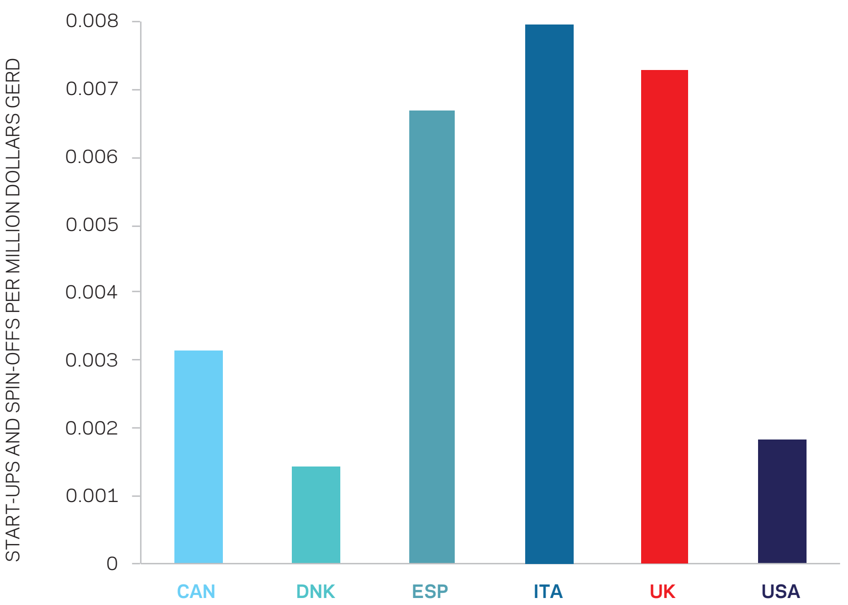


***Figure 7.3** — Start-ups and spin-offs per unit GERD for the UK and selected countries with available data, 2011. Source: ProTon Europe Annual Survey Reports and Association of University Technology Managers STATT Database.*

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

Patenting activity is an indicator of the existence of IP, not of knowledge exchange, but may be considered to indicate the existence of knowledge exchange processes. National patenting activity can be considered 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"). UK residents filed 50,749 patent applications in 2011, an increase of just 0.3% per year over the period 2007-11. Of the comparator countries, only Italy and Canada filed fewer patents in 2011. As a share of global patent applications in 2011, the UK has decreased to 2.4% in 2011 from 2.7% in 2007, a change of -3.2% per year over this period; the largest shares are represented by just four countries: Japan, US, China, and Germany (see Figure 7.4). In the period 2007-11, Japan and the US, and to a lesser extent, Germany, have seen a dramatic decrease in their share of global patent applications as a result of a marked rise in patenting activity from China. In 2011, China accounts for almost the same share of global patent applications as the US at 20.3% and 20.5% respectively.

The number of patents granted to UK residents in 2011 was 18,374, an increase of 5.4% per year in the period 2007-11. Of the comparator countries, only Italy and Canada had fewer patents granted in 2011. While the UK's share of global patents granted in 2011 is lower than its share of global patent applications (at 1.8% and 2.4% respectively), the decrease is less steep at -1.1% per year in the period 2007-11 (see Figure 7.5). While the largest shares of global patent grants are still dominated by Japan, the US, China, and Germany, the recent increase in the share of global patent applications from China is less marked, with only Germany still showing a clear trend to decrease in share.

The number of UK patents in force in 2011 was 83,216, an increase of 1.7% per year in the period 2007-11. Of the comparator countries, only Italy and Canada had fewer patents in force in 2011. The UK's share of global patents in force in 2011 is lower than its share of either global patent applications or global patent grants (at just 1.4%), with an even steeper decrease at -4.1% per year in the period 2007-11 (see Figure 7.6). While the largest shares of global patent grants are still dominated by Japan, US, China, and Germany, only China is showing a clear trend to increase in share.

Typically, a patent application must include one or more claims that define the invention, and these claims should be novel and non-obvious from the prior art (i.e. from existing publicly-available documentary sources). As such, many patent applications cite journal articles which either provide information that support or are related to the claims but that do not constitute prior art. The share of a country's articles cited in patent applications is therefore an indicator of the success with which research findings published in the journal literature are used to justify the patentability of an invention; this can be seen as a form of academic-industry knowledge exchange.

Analogous to the share of global citations from journal articles to other journal articles (see Figure 4.4), the share of global citations from patents (both applications and granted patents) offers an informative comparative view of knowledge exchange across countries. UK articles are

COUNTING PATENT APPLICATIONS, PATENTS GRANTED AND PATENTS IN FORCE

The patenting process can be divided into three distinct phases; filing an application for a patent and its examination; the registration of a decision (granted or not); and 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 and sectors have the same propensity to patent, and so national patenting activities may reflect national research field specialisation and industry focus[75].

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

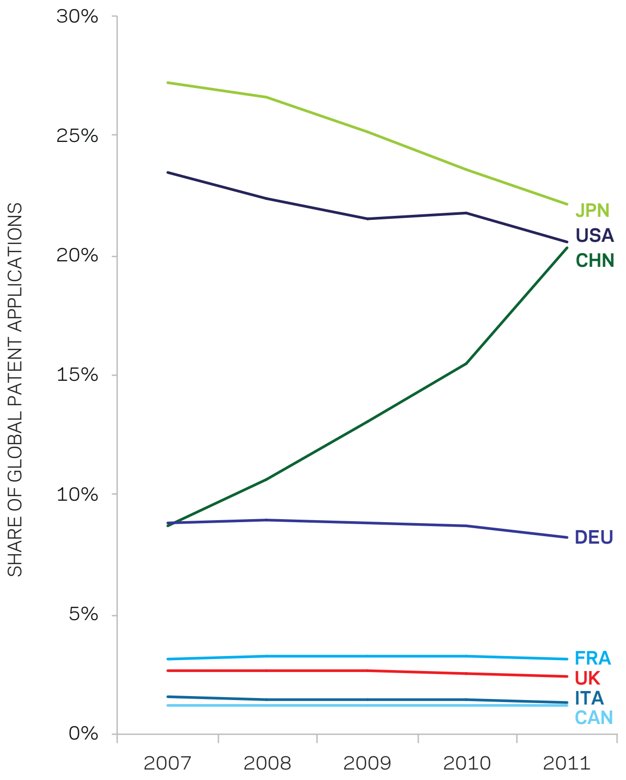


Figure 7.4 *— Share of global patent applications for UK and comparators, 2007-2011. Source: WIPO Statistics Database (March 2013).*

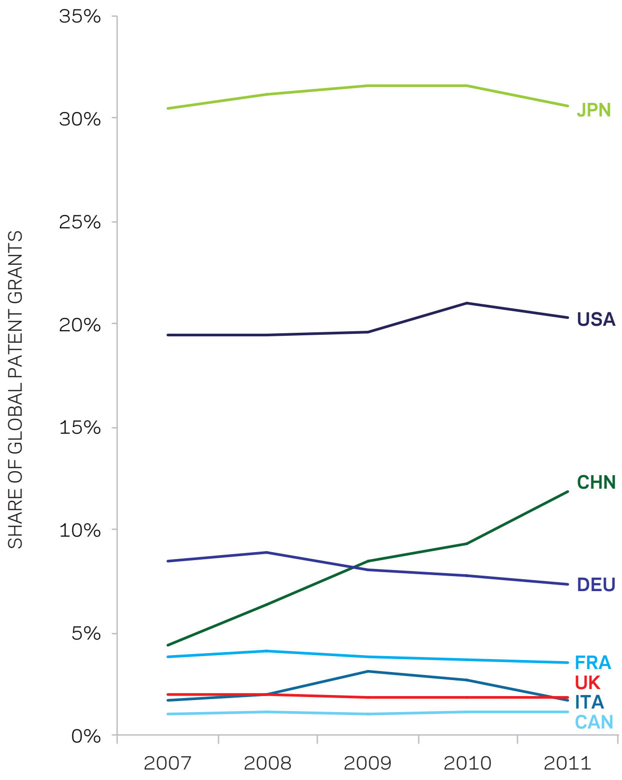


Figure 7.5 *— Share of global patent grants for UK and comparators, 2007-2011. Source: WIPO Statistics Database (March 2013).*

cited increasingly frequently in global patents (see Figure 7.7). While the UK produced 6.4% of global articles in 2012, its share of global patent citations was 10.9% in 2012 (c.f. its share of global citations at 11.6% in 2012). The UK's patent citation share increased at 5.4% per year in the period 2008-2012. In comparison, the patent citation shares of the US and Japan have decreased markedly in this period.

Since the global share of patent citations for a country is influenced by the number of journal articles published by that country (and therefore available to be cited in patents), an indicator of the relative share of patent citations that accounts for this is shown in Figure 7.8. For this indicator, the UK has a high and rising relative share of its journal article output that has been cited in global patents. The relative share of UK articles published in 2007 and cited in patents was 1.28, rising to 1.71 for articles published in 2011. Of the comparator countries, only Germany has a higher relative share of its 2011 journal articles cited in patents (at 2.04); it is also the only comparator country to have seen a similarly high rate of increase over this period. France and Japan saw decreases in this indicator for patent citations to 2011 journal articles, while Italy and Canada show the opposite trend. The US has shown a modest rate of growth in this period, while the BRIC countries show a tendency to decrease, with the exception of Russia, which increases slightly in its relative share of patent citations to 2011 journal articles.

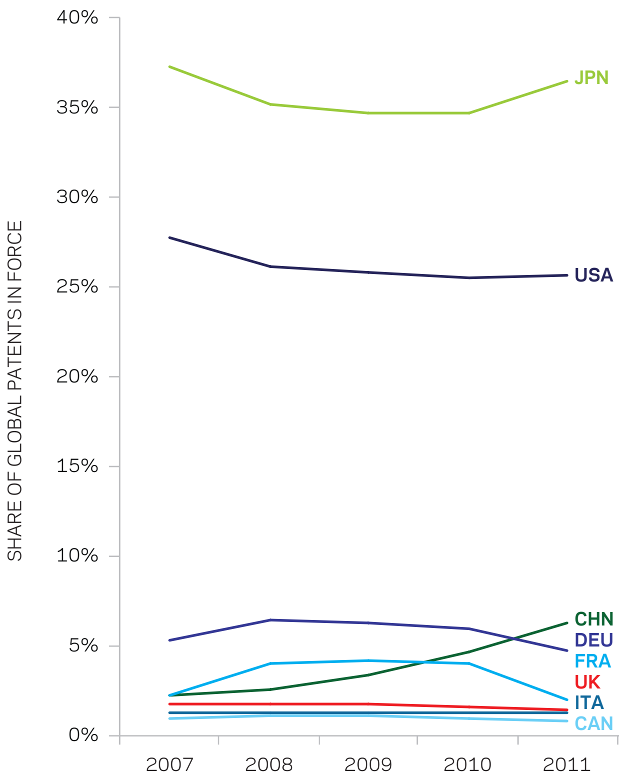


Figure 7.6 *— Share of global patents in force for the UK and comparators, 2007-2011. Source: WIPO Statistics Database (March 2013).*

Figure 7.7 *— Share of 2007-11 patent citations to articles published 2007-11 for the UK and comparators. Each data point corresponds to journal articles published in the year shown and citations to these articles from patent applications and granted patents in the period 2007-2011. Source: LexisNexis Univentio and Scopus.*

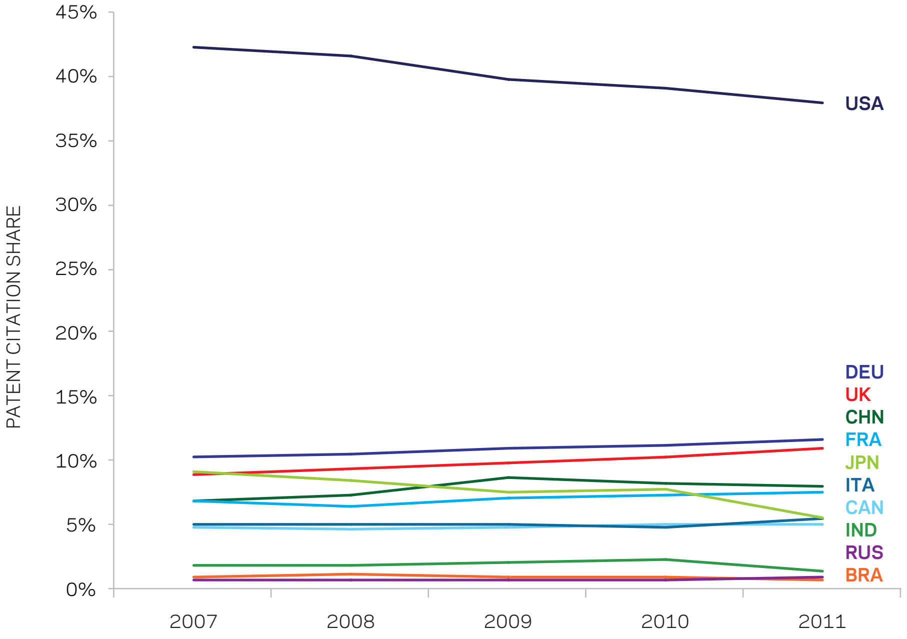
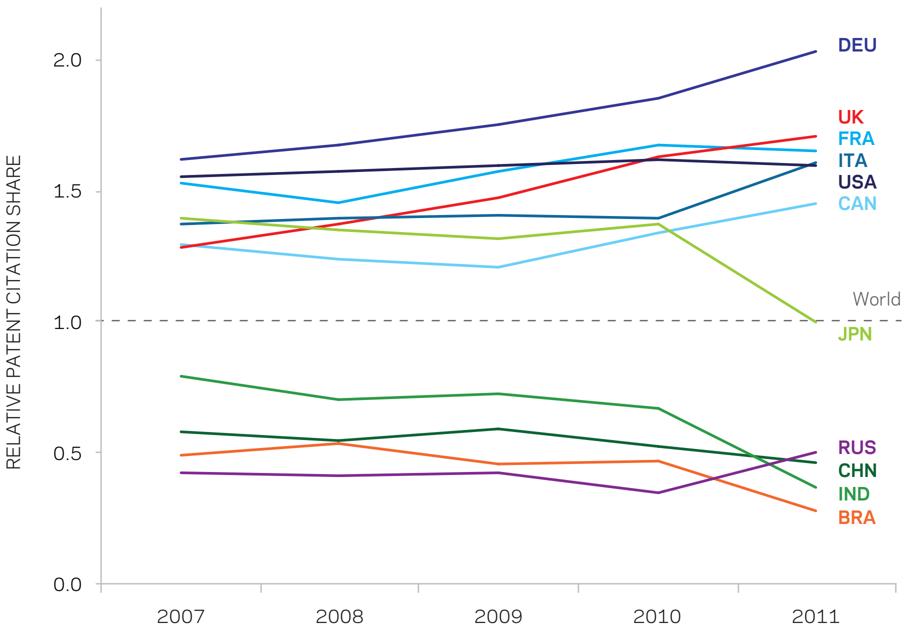


Figure 7.8 *— Relative share of 2007-11 patent citations to articles published 2007-11 for the UK and comparators. Each data point corresponds to the share of each country's total journal article output that year that were cited in patents in the period 2007-11, divided by the share of global journal article output that year that were cited in patents in the same period to give a global baseline defined at 1.0. Source: LexisNexis Univentio and Scopus.*



7.3.3 UK corporate-authored articles are increasingly downloaded by UK academic users, and UK corporate users are increasingly downloading UK academic-authored articles

Downloading of UK articles with one or more authors with a corporate affiliation by users in other UK sectors indicates strong cross-sector knowledge flows within the country. 61.7% of all downloads of corporate-authored articles in the period 2008-12 came from users in the academic sector (see Figure 7.9), an increase of 1.1% over the equivalent share of 60.6% for the period 2003-07. Users in the corporate sector themselves accounted for 35.2% of downloads of corporate-authored articles in the period 2008-12, a decrease of -1.0% on the 36.2% share in the period 2003-07. Taken together, these results indicate increasing usage of corporate-authored research by the academic sector.

Downloading of UK articles by users in the UK corporate sector also suggests increasing cross-sector knowledge flows within the country. Some 52.6% of all downloads by corporate users in the period 2008-12 were of articles with one or more authors with an academic affiliation, and 32.5% were of articles with one or more corporate authors (see Figure 7.10). Both of these shares have increased (by 1.3% and 2.1%, respectively) over the equivalent shares for the period 2003-07, while the share of articles with at least one author with a medical affiliation downloaded by corporate users has decreased from one period to the next. Taken together, these results indicate increasing usage of academic-authored research by the corporate sector.

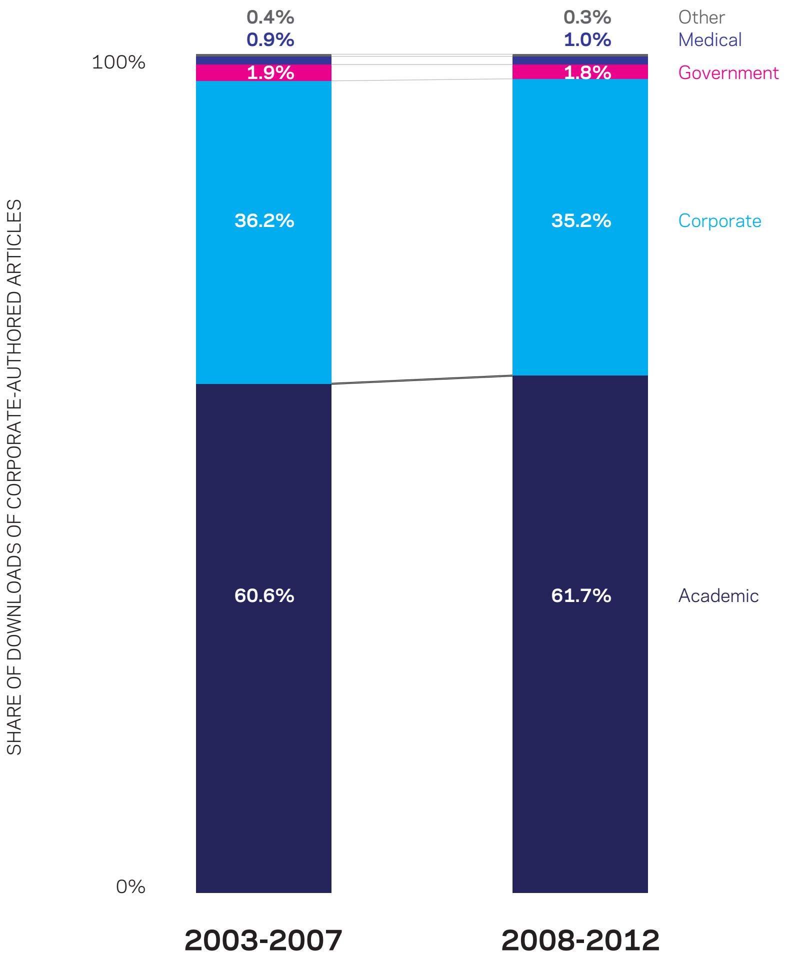


***Figure 7.9** — Share of downloads of articles with at least one corporate author by downloading sector, 2003-07 and 2008-12. Source: Scopus and ScienceDirect.*

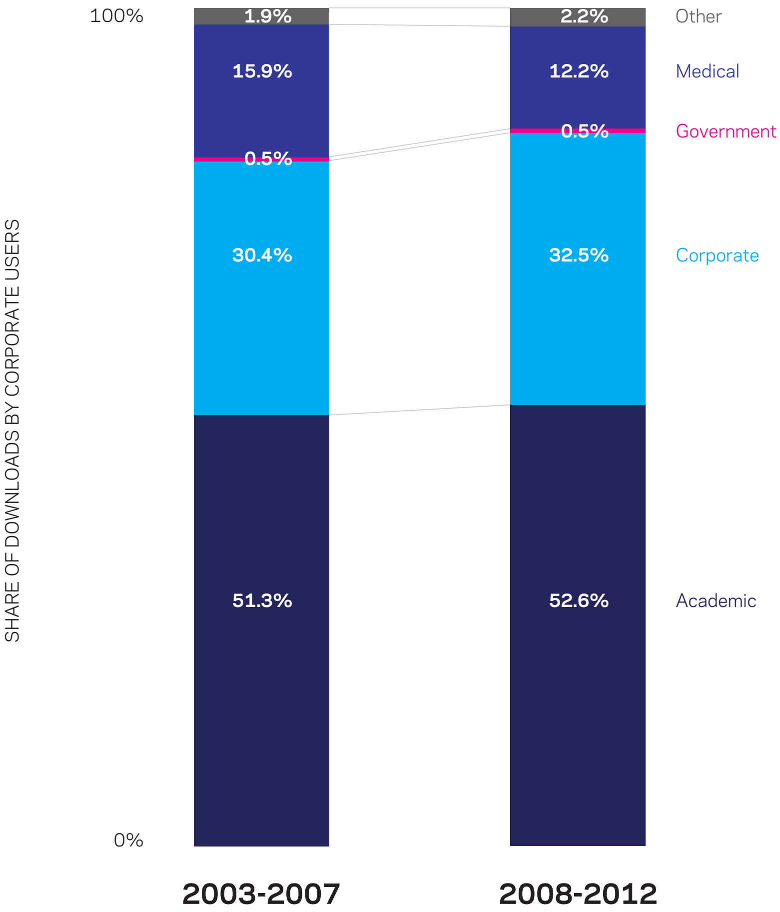


Figure 7.10 *— Share of article downloads by corporate sector, 2003-07 and 2008-12. Shares add to 100% despite co-authorship of some articles between sectors owing to the derivation of shares from the duplicated total download count across all sectors. Source: Scopus and ScienceDirect.*

7.3.4 UK researchers move between academic and industry affiliations within and beyond the UK, with a net movement towards industry

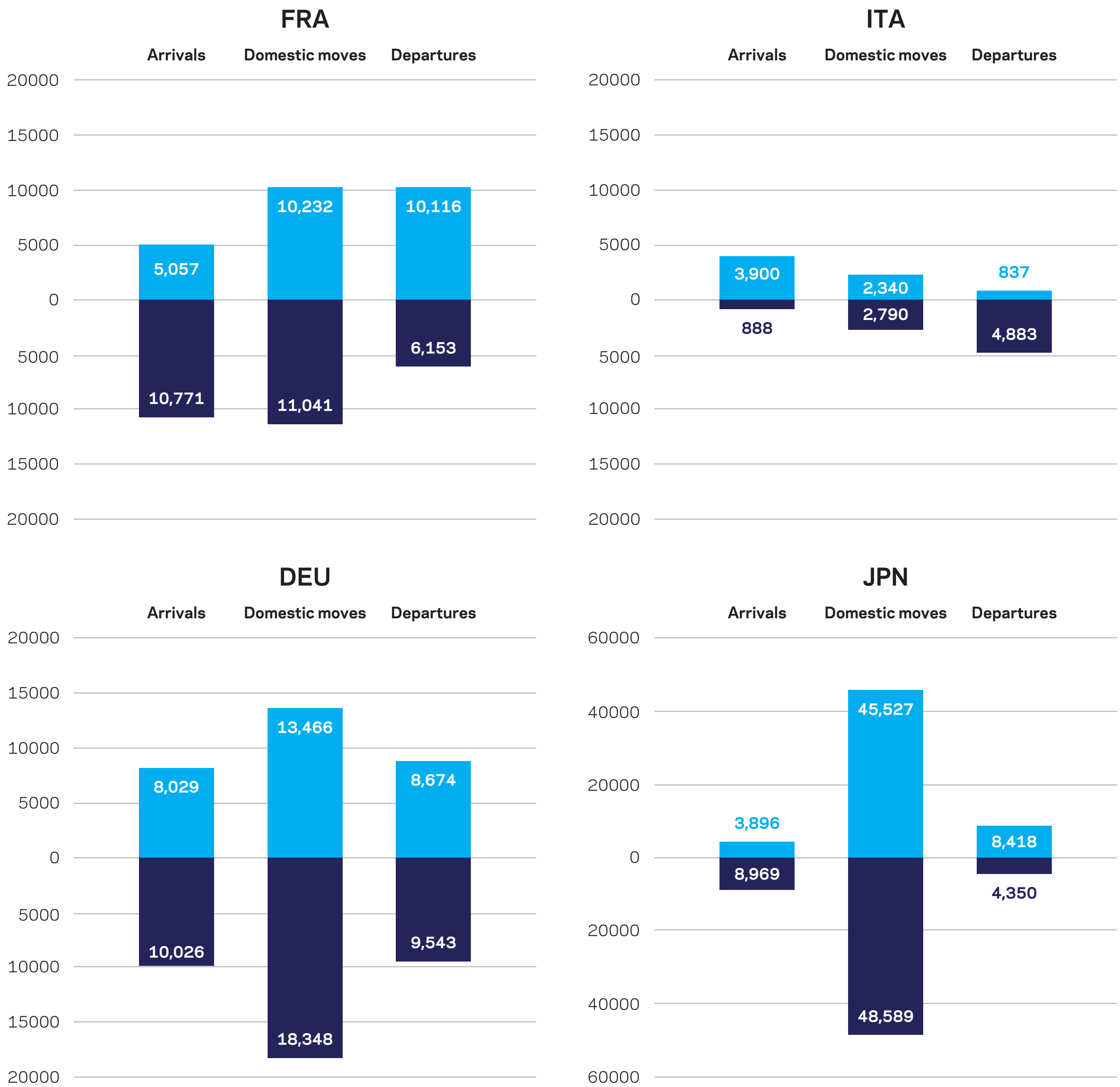
A key indicator of the existence of knowledge exchange is the cross-sector mobility of researchers between academia and industry, both within a country and internationally[76]. There were a significant number of cross-sector moves by researchers within the UK in the period 1996-2012, with some 10,283 moves from a UK academic to a UK corporate affiliation and 8,707 moving in the opposite direction in the same period (see Figure 7.11). This represents a net difference of 1,576 moves from academia to industry within the UK. Similarly, there were a positive net number of moves from academic affiliations within the UK to corporate affiliations internationally, with some 13,771 moves in the period 1996-2012 versus 11,782 in the opposite case (a difference of 1,989 moves). In contrast, moves from international academic affiliations to UK corporate affiliations (at 10,526) outnumbered moves in the opposite direction (at 11,953) by 1,427 moves. The general tendency for researchers to move from academia to industry may reflect not only the fact that there are more researchers working in the higher education sector than the business enterprise sector (see Figure 3.2), but also that academia is typically the source of higher-degree-trained researchers for all sectors.

Comparator countries show quite different cross-sector mobility patterns to the UK. While the UK's overall pattern shows more movement between academic and corporate affiliations internationally than domestically, most comparators (Germany, France, Japan, the US, Brazil, China, India and Russia) show more moves between academic and corporate affiliations within the country than beyond. Amongst these countries, only Italy and Canada have a different pattern, with the latter being most similar to the UK. Moreover, while the UK shows a more or less balanced pattern of international inflow and outflow (in common with Germany and Brazil), others have greater disparity: France and the US for example have considerably greater movement from international academic to domestic corporate affiliations than international corporate to domestic academic affiliations, and considerably greater movement from domestic corporate to international academic affiliations than domestic academic to international corporate affiliations. Conversely, Canada and China exemplify the opposite pattern.

[76] 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 7.11** — Cross-sector moves of researchers between academia and industry, either domestically or internationally for UK and comparators (also Brazil, India and Russia), 1996-2012. 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 ±150,000). Source: Scopus.*

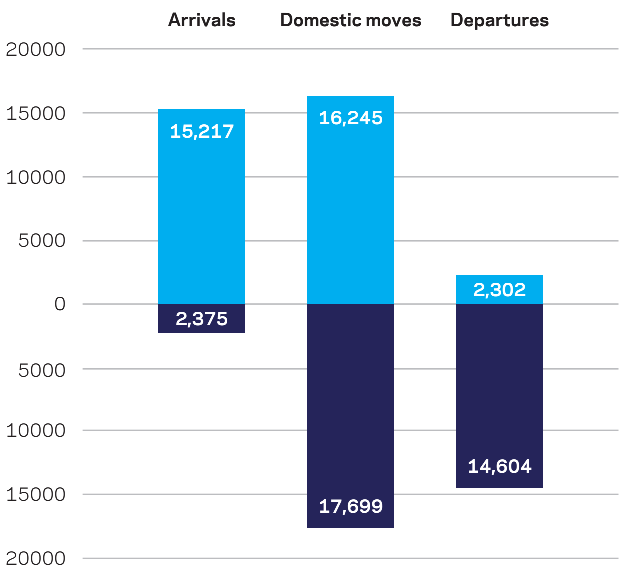
Industry to academia   Academia to industry



USA

CAN

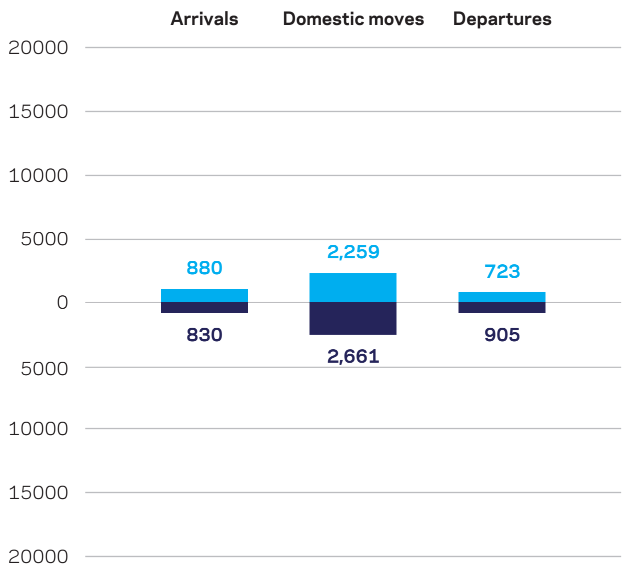
CHN



IND

RUS

BRA



CASE STUDY **INTERVIEWS ON KNOWLEDGE EXCHANGE**

INTRODUCTION

To establish a view of the issues surrounding knowledge exchange, 33 interviews were carried out with key individuals in the academic and industry sectors in the UK, along with 14 interviews in the US, 10 interviews in Germany and 10 interviews in China.

The academic interviewees were initially identified through an analysis of publication data in the broad research domains of Health Sciences, Life Sciences, Physical Sciences, Social Sciences and Arts and Humanities. In each domain, the largest 15 academic institutions from the UK, US, Germany, and China by article output in the period 2008-12 were determined. For each of these institutions and domains, the most prolific 15 authors who had collaborated internationally (i.e. one or more authors from outside the UK for the UK institutions, or one or more authors from the UK for the non-UK institutions) were determined. Interview invitations were then sent to these 15 authors in a selection of 4 of these 15 institutions as well as the Pro-Vice Chancellor of Research (PVCR) or equivalent position; the selection was done so as to give a good geographical representation within each country. In the UK, the PVCRs of *all* 15 universities were included, as well as those of all other Russell Group universities[77] as well as additional interviewees identified in the course of some interviews. In addition, in the UK the Business Schools and Enterprise Centres in the 4 academic institutions identified for the study were approached for potential interviewees. Interviews were also conducted with selected industry partners identified in the course of the academic interviews: Arup, Duncan McCauley GmBH, Rolls Royce, GlaxoSmithKline, Imorphics and Tokamak Solutions.

This case study is therefore based on anecdotal, qualitative information from a relatively small sample of individuals selected through a systematic approach; it is indicative of the thoughts of a group of highly collaborative researchers and their industry partners on the major themes outlined below.

This case study is directed at three major themes:

- the drivers and benefits of knowledge exchange;
- the process of finding knowledge exchange partners;
- barriers and possibilities for improving knowledge exchange.

Each theme is divided into key consensus statements from the interviews, with separate discussion and relevant quotations for each, with conclusions provided at the end of each major theme.

THE DRIVERS AND BENEFITS OF KNOWLEDGE EXCHANGE

Partnerships already in place have demonstrated benefits for both parties.

Discussions were full of positive examples of past and current partnerships, and such partnerships were said to be mutually beneficial. While the different drivers for engagement by universities and industry (as covered in more detail below) can lead to tensions, the most successful partnerships are characterised by a broader range of perspectives which lead to higher quality research, improved industry productivity and a desire for long-term engagement.

> *"If you collaborate you bring different things to the party. You are going to have better quality publications arising as a consequence if you both contribute different types of intellect to the programme."*
> Dr. Malcolm Skingle, Director of Academic Liaison, GlaxoSmithKline

> *"I think it's a learning process for all concerned actually, and certainly a two way learning process."*
> Clare Hudson, Business Development Manager, College of Arts, Humanities and Law, University of Leicester

[77] The Russell Group is an association of 24 British public research universities; a full listing of members is available at *www.russellgroup.ac.uk/our-universities.aspx*.

Drivers for engagement by universities include income generation, employability for students, and bringing different perspectives to the research agenda.

Academic interviewees gave examples of a wide range of partnerships, each with different goals: most frequently identified were the benefits to research from introducing new perspectives, the benefits to teaching through introducing students to the business world, and the income generation possible through interaction with industry. Industry perspectives can show new paths for research projects to take in order to have an impact. Student placements and collaborations on real projects help with the education of students but also in forging bonds between universities and industry, and the increased employability of students is seen as a key benefit of such interactions.

"Some of the best things that I've done have been driven by industry telling us that this is not good enough; it doesn't do this, and then suddenly you see things from a different perspective. So it's important."

David Hogg, Professor of Artificial Intelligence and Pro-Vice-Chancellor for Research and Innovation, University of Leeds

"Business also brings in problems which are very often a fantastic stimulus to the basic research because in the basic research you tend to ask questions and then you go and you try and solve them. If you bring in questions from business, very often those questions can be very stimulating, because they force you to look at things in different ways. As a result of that, you think you have a solution to a problem; you go and talk to people in industry who you believe have a need in that area, but what will come back to you is something that actually completely throws what you've achieved because it turns out that you haven't really solved the key problem, or the problems are not quite as you thought they were. So actually it's both a fantastic stimulus for the basic research but it's also very important that our work is relevant."

David Hogg, Professor of Artificial Intelligence and Pro-Vice-Chancellor for Research and Innovation, University of Leeds

Drivers for engagement by industry include access to cutting edge research and to new ideas, the reputation and credibility that comes from working with a university, access to facilities, spread of risk, and interaction with potential employees.

Industry interviewees likewise showed a wide range of motivations to partner with universities, with the most common being the access to the latest research and thinking in universities, the sharing of facilities and of the risk that goes with research, and engagement with students who will form part of the future workforce. The high quality research base of the UK was mentioned as a factor encouraging partnerships with universities in the UK, both as the source of new and innovative ideas in research for the development of new products and services, and also in order to increase the reputation and credibility of a project by association with academics and institutes well known for high quality work. Businesses appreciated interaction with students for the purposes of identifying candidates for recruitment. Other drivers for interaction included the longer-term perspective universities can bring, and access to the networks and contacts of academic researchers. Whatever the size of the business, there was recognition of the value of investing in longer-term collaboration because it can help to shape and develop their business; this is balanced by a need to demonstrate a return on the investment. Industry wants to know what is coming over the horizon and they want to work with the best to ensure that they can sustain and develop their business.

"Our academics travel the world to find out what is going on in their field, who is doing what research. They gain an understanding of it, work out its significance, co-define it and then transfer this knowledge to students. These students then take that knowledge out into industry."

Dr Tony Raven, Chief Executive of Cambridge Enterprise, the University of Cambridge's commercialisation arm

"Working with universities, we can get leverage from their existing knowledge and we can get enthusiastic people without building up a large, unwieldy team in-house."

Dr David Kingham, Chief Executive, Tokamak Solutions UK Ltd

"Multinational companies are attracted to the idea of funding a project that involves talented individuals from different countries. My collaborator at Cambridge and I have leveraged our NIH funding to obtain industry funding to continue to collaborate. Industry collaboration to advance the scientific agenda is important, and companies are not so nationalistic: they look for the best talent wherever it may reside."
Professor Daniel Rader, Chief - Division of Translational Medicine and Genetics, School of Medicine, University of Pennsylvania

"We look for access to good facilities and infrastructure, and some ability to share some of the risk, the cost, or the investment in what we are trying to do. As research is inherently risky, with no guarantee that it will come through with anything useful, we share some of that risk."
Mr Mark Jefferies, Chief of University Research Liaison for Rolls-Royce

"Obviously we don't have all the good ideas and we want to tap into as many strong science bases as we possibly can."
Dr. Malcolm Skingle, Director of Academic Liaison, GlaxoSmithKline

"We want talent in the universities, and we also want talent in our own business, so we are looking to them for assistance in identifying good people for recruitment in all levels."
Mr Mark Jefferies, Chief of University Research Liaison for Rolls-Royce

"So we want to help set the specification on the output of the science that's being developed in the UK to further our own needs."
Dr. Malcolm Skingle, Director of Academic Liaison, GlaxoSmithKline

Summary

There are many different types of partnerships in place at present, whether based on research projects, specific commissions, or student placements and broader engagement; while the drivers and benefits vary, foremost among them are broader perspectives leading to higher quality research, the development of new products and services and a desire for long-term engagement.

Any partnership will involve different goals for the two parties, so the mutual benefits should be clear from the outset.

The varied benefits of existing partnerships can be used to explain the advantages to institutes not currently taking part in such collaborations.

THE PROCESS OF FINDING KNOWLEDGE EXCHANGE PARTNERS

Partnerships are formed on an individual basis, rather than as part of a broader 'relationship with industry', each with different starting points and aims.

Interviewees spoke about the variety of partnerships and stressed that they tend to stand as distinct relationships, rather than fitting into a broad strategy. Partnerships tend to focus on specific aims. While partnerships are developed from different starting points, many interviewees said that these are often made through personal contacts and alumni networks. However, whilst industry has individual relationships with specific universities, in at least some cases these are formed and maintained as part of investment and development strategies. At the national level, interviews with public bodies such as the Technology Strategy Board and the Economic & Social Research Council reflected the fact that there is a drive to support these partnerships and create a framework that can support them.

"We have got about 2,500 different businesses that we are actively collaborating with, across a variety of research councils. We see co-production and knowledge sharing as a vital part of the whole excellence agenda"
Professor Boyle, Chief Executive, Economic & Social Research Council

"With industry, I tend to look first of all close to my institute. I prefer small / medium businesses in Berlin, because of the short connections: if you are building hardware, you want to be able to talk to these people easily and you don't want to travel or make phone calls to organisations that have time delays and time shifts."

Professor Tilman Spohn, Director of the German Aerospace Centre (DLR), Institute of Planetary Research

"I heard a presentation at an international academic meeting in the field and was interested in their technology, and sought them out after the meeting to have a face to face and just get to know them. That was the start."

Philip Conaghan, Professor of Musculoskeletal Medicine, University of Leeds & NIHR Senior Investigator

"We use a range of measures to identify good partners."

Mr Mark Jefferies, Chief of University Research Liaison for Rolls-Royce

Time is needed to build and maintain the strongest strategic links.

The strongest links are developed through long-term partnerships. Time is required to build trust and develop working practices, leading some interviewees to start partnerships with small-scale projects before investing in a deeper exchange.

"From the point of view of structuring research, it would be very helpful for funding organisations to recognise that the set-up of partnerships is time consuming and labour intensive: it takes lots of time."

Professor Linda Scott, DP World Chair for Entrepreneurship and Innovation, Saïd Business School, University of Oxford

"We'll typically start out by doing small pieces of work with a new group and see if it's mutually beneficial. For us, it's not just about the specific piece of research: Can we work with the group? Can the group work with us? Can we work with the university? Does the university want this? Does the university treat the relationship as a strategic investment? Can it attract additional investment from other people? It's not a decision we take lightly, because we rely on our core partnerships quite heavily. We are not duplicating the research they are doing in-house. They must get it right."

Mr Mark Jefferies, Chief of University Research Liaison for Rolls-Royce

Summary

While lessons can be taken from previous partnerships, new ones must be developed with a clear idea of the unique opportunities and goals possible.

As with international collaboration between academics, knowledge exchange often comes about through personal networks.

The strongest partnerships take time to build; smaller projects may be necessary before a relationship of trust is developed where the strongest work can be carried out.

BARRIERS AND POSSIBILITIES FOR IMPROVING KNOWLEDGE EXCHANGE

Industrial and academic research can have conflicting timelines and aims, which act as an important barrier to knowledge exchange.

Most interviewees discussed the differing aims of industry and universities when carrying out research; industry's aims are characterised as having an increased focus on short-term results and economic impact, while academic research has a longer-term focus alongside a desire to carry out blue-sky research. These preconceptions can be a barrier to knowledge exchange even where goals align: occasionally industry researchers can see universities as disconnected from practical concerns, while academic researchers may feel they cannot contribute to the business world. Some interviewees also mentioned that problems can arise when research doesn't meet expectations: industry requires clearer financial motivation to continue with a line of research whilst academic researchers may be more inclined to follow the research wherever it leads. These viewpoints may well be misconceptions: for example, some academic interviewees stated that there is no interest from industry in early or blue-sky research, whilst industry interviewees confirmed their interest in such research as long as there is a balance with relevance and long-term impact. However, all interviewees had been able to negotiate successful partnerships despite these actual and perceived tensions.

"I think that there are two different goals when you bring in research staff and faculty. If you don't have a collaborative goal, then you are moving down two separate paths. Generally, research faculty produce high-quality academic research regardless of its impact or its applicability to the practical world. On the commercial side and the business side, they are looking for knowledge that increases the trajectory of their business. Those are two different goals at that point."

James Hall, Executive Director of the Entrepreneurship Centre, University of Oxford's Saïd Business School

"We need to be able to work with people who understand that we are trying to develop technology with a purpose that will have an impact in our business."

Mr Mark Jefferies, Chief of University Research Liaison for Rolls-Royce

"Every engagement with industry is a negotiation of one form or another, on price, and deliverables, and warranties, and liabilities, and so on and so forth. That's just part and parcel of the routine of getting to a contract."

Professor Steven P. Beaumont, OBE, MIET, FREng, FRSE, Vice-Principal for Research and Enterprise, University of Glasgow

"What you need to do is create a social eco-system that brings business and academia together, because they live in such different worlds that it's only by putting them together that you can get communication."

Chris Mottershead, Vice-Principal: Research and Innovation, King's College London

"In-house we focus the majority of our Engineering resource primarily on the short- and medium-term, though of course we do have people on longer-term activities, horizon scanning and so on. But the academics should be at the cutting edge of what will be happening years down the line, so we are looking for them to highlight those opportunities or threats for the future."

Mr Mark Jefferies, Chief of University Research Liaison for Rolls-Royce

"Blue-sky research is absolutely something that we would like to keep an eye on."

Professor Jeremy Watson CBE FREng, Arup's Director for Science and Technology

[78] Small and Medium Enterprises: Companies employing fewer than a certain number of personnel, typically fewer than 250 staff.

Small businesses often require more support in knowledge exchange than large businesses.

In speaking about the size of business, interviewees spoke about the increased challenges faced by SMEs [78] in finding and supporting knowledge exchange: difficulties can include making academic contacts, building awareness of their business, and securing investment in a project.

"Full Economic Costing is sort of justifiable if you are a huge company. But from the start up point of view, where every penny is crucial, it is a significant turn off. We have actually stopped including universities as grant partners for the reason that we just can't afford to do it."

Dr. Mike Bowes, CEO, Imorphics

"But the expectation might be, for example, that there's £15,000 input from the company. Certainly, with the very small companies, it means it's impossible to do that work. So I think if there was something specific, it would be factoring those SMEs into the thinking when funding calls are being devised which are about driving collaboration."

Dr Suzanne MacLeod, Head of the School of Museum Studies University of Leicester

"There's a lot more optimism about business and new technology in the States than there is in Europe. The whole system for European research is very bureaucratised, they are much more entrepreneurial in the States: the supply of capital is better and they have better grant funding for small technology business."

Dr David Kingham, Chief Executive, Tokamak Solutions UK Ltd

"Large companies have people you naturally meet who go and survey the landscape, and they also have representatives at conferences. Where it's really difficult is SMEs, and it currently comes down to local knowledge and people within the institution who just know the SME scene locally; people who know the hundreds of SMEs working in different areas, and who can steer engagement by constantly talking to the SMEs. That is the big challenge area."

David Hogg, Professor of Artificial Intelligence and Pro-Vice-Chancellor for Research and Innovation, University of Leeds

For the collaboration between industry and universities to continue and develop it needs sustained and long-term strategic investment.

While some interviewees could point to success in obtaining funds to set up partnerships between businesses and universities, many more suggested that extra incentives were required to encourage these collaborations. The need for long-term, high level investment, and support for research and for collaboration, was reiterated by numerous interviewees, along with the need for funding to take into account the time required to set up a new relationship which could be fruitful in the future. Several industry interviews emphasised the international nature of their partnerships and the fact that these are constantly under review.

"Long-term funding commitment is really important: to keep industry involved we've got to have that confidence that the spending continues to support scientific research, and if it is just cut off, then we'll be in a pretty difficult position."

Professor Jeremy Watson CBE FREng, Arup's Director for Science and Technology

"Local enterprise partnerships are being expected to help direct investment funding, perhaps European funding, where it needs to be going. I think that needs to be aligned with a more strategic overview, and an organisation such as the Technology Strategy Board might be able to provide some of that oversight."

Mr Mark Jefferies, Chief of University Research Liaison for Rolls-Royce

"We use an MoU [memorandum of understanding] approach to create strategic relationships with just a few universities. We will consider signing an MoU and then we will put some money behind that to create a joint strategic research agenda with the university."

Professor Jeremy Watson CBE FREng, Arup's Director for Science and Technology

"A lot of our key collaborators and external organisations are having funding cuts left, right and centre. They haven't got money to pay for resources."

Clare Hudson, Business Development Manager, College of Arts, Humanities and Law, University of Leicester

"We're very much part of regional efforts to generate knowledge-based, innovation-led, economic growth for the region. And the reason is not just to be a good neighbour… industries close by the university are an attractor for the best people around the world …. good people come in, train here and then move into the region as entrepreneurs that, I think, is going to be increasingly necessary to be globally competitive"

Professor Ian Walmsley, Pro-Vice-Chancellor (Research ASUC), University of Oxford

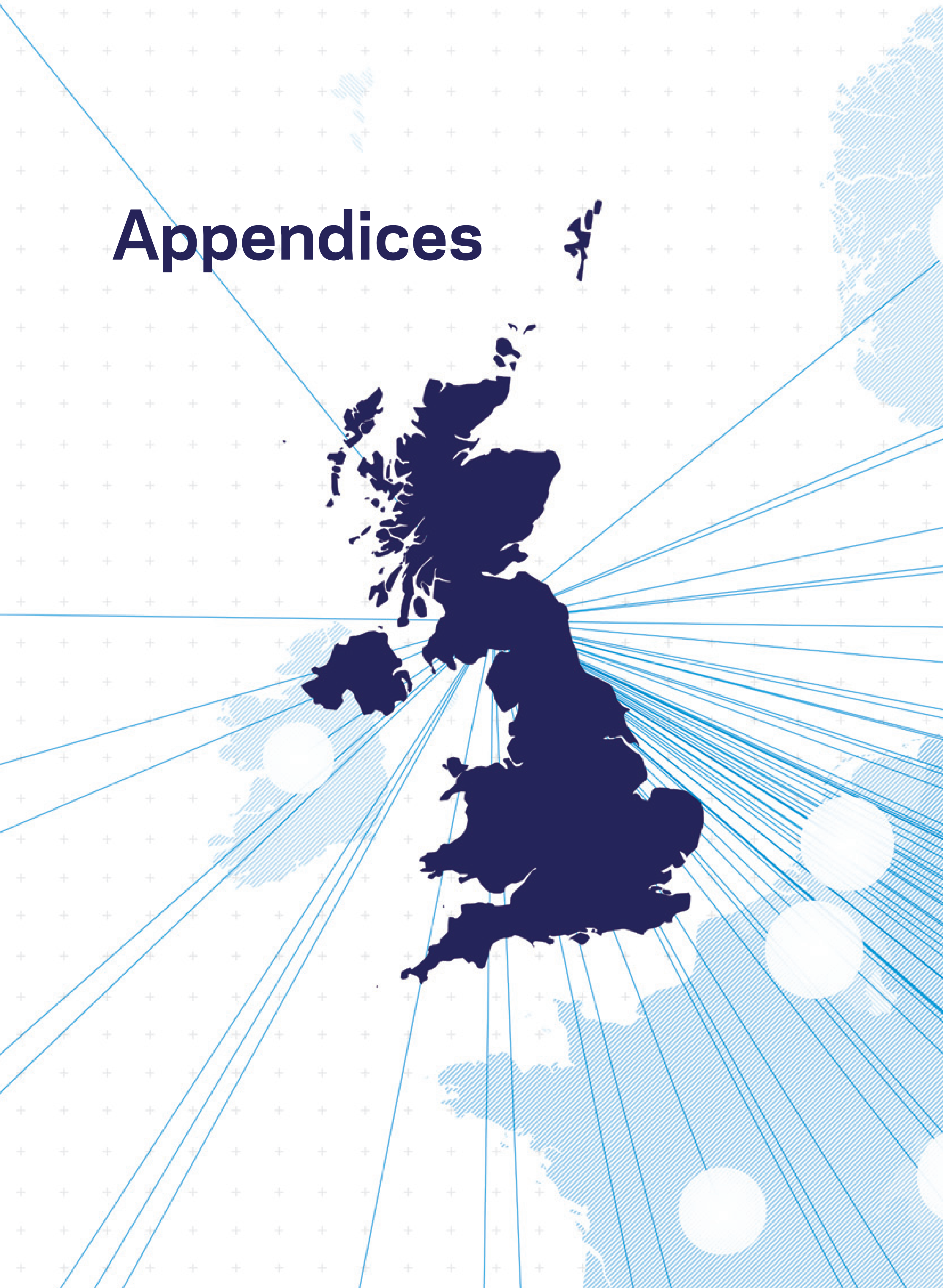
Summary

There are perceived and inaccurate differences in the aims and timescales of academic and industry research, such as the shorter-term nature of industry research; a successful partnership requires mutual understanding of the specific goals and methods of working.

SMEs require more support than large businesses, and factoring these into funding calls would drive better collaboration between universities and SMEs.

Incentives are necessary for long-term partnerships and to encourage industry to work more with universities, particularly in the early stages of research and in maintaining long-term funding; collaboration between industry and universities needs to be built into long-term planning and strategy.

Appendices



APPENDIX A
AUTHOR CREDITS, ADVISORY GROUPS, AND ACKNOWLEDGEMENTS

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The report is available online via the UK's Department of Business, Innovation and Skills *(www.bis.gov.uk)*.

APPENDIX B
GLOSSARY OF TERMS

Activity Index
See box "Activity Index" in Chapter 4.

Article
Unless otherwise indicated, the term 'article' is used in this report to denote the main types of peer-reviewed documents published in journals: articles, reviews and conference papers.

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). All 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.

BRIC
A grouping acronym that collectively refers to the countries of Brazil, Russia, India and China.

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 indicated by articles with at least two different countries listed in the authorship byline.

Competency
Groups of article clusters identified in SciVal competency map in which a significant proportion of the articles include at least one author from a selected country; competencies are typically multidisciplinary in nature.

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.

Measuring impact: Citation windows and field weighting
See box "Field-weighted citation impact" in Chapter 4.

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 recognized 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.

Hypercollaboration
See box "Hypercollaboration" in Chapter 5.

Interdisciplinary
Interdisciplinary research is that which combines two or more academic disciplines into one activity (e.g. a research project).

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, and 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.

Pareto Principle
See box "The Pareto Principle" in Chapter 4.

Purchasing power parity
Rates of currency conversion that equalize the purchasing power of different currencies by eliminating the differences in price levels between countries.

Research & Development (R&D)
Any creative systematic activity undertaken in order to increase the stock of knowledge, including knowledge of man, 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.

Researcher
See box "What is a 'researcher'?" in Chapter 3.

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.

Sector
Sectors in this report are used to delimit the parts of the national research base, and is mainly split into Business Enterprise, Higher Education, and Government sectors.

APPENDIX C
DATA SOURCES

Data conventions
UK standard usage for the term 'billion', which is defined as one thousand million (10^9), is adhered to throughout this report[1].

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.

Association of University Technology Managers (AUTM; *www.autm.net*)
AUTM is a non-profit association of technology managers and business executives who manage intellectual property. AUTM conducts annual surveys of licensing activities at US and Canadian universities, hospitals and research institutions and the data are available in the STATT database *(www.autm.net/source/STATT/index.cfm?section=STATT)*. Data are presented for the most recent year(s) for which data are available.

LexisNexis Univentio
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 80 patent countries. For this report, a static version of the LexisNexis Univentio database covering the period 2007-2011 inclusive was analysed for citations to the journal literature indexed in Scopus.

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 the OECD data also typically include the non-member countries Argentina, China, Romania, Russian Federation, Singapore, South Africa, and Taiwan (also known as Chinese Taipei).

The OECD collects internationally comparable data on research and development and the data are available in the Main Science and Technology Indicators database (MSTI 2013/1; *www.oecd.org/sti/msti*). A useful history of the development of the OECD's R&D statistics is available[2]. 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 Dr Edwin Martens at Statisticor *(www.statisticor.nl)*. Financial data are given in constant US$ at 2005 prices and corrected for

ProTon Europe *(www.protoneurope.org)*
ProTon Europe is the pan-European Association of Knowledge Transfer Offices affiliated to universities and public research organizations, created in 2003 to promote innovation in Europe through more effective knowledge transfer from universities and other public research organisations.

ProTon Europe conducts annual surveys of knowledge transfer activities in Europe and the data are available to ProTon Europe members. Data are presented for the most recent year(s) for which data are available.

ScienceDirect *(www.sciencedirect.com)*
ScienceDirect is Elsevier's full-text journal article platform with coverage of over 2,000 journals across a wide range of research fields, and accounting for approximately 16% of the articles indexed in Scopus in 2012. ScienceDirect has a large customer base, including some 12,000 institutions worldwide, with more than 11 million active users and over 700 million full-text article downloads in 2012. For this report, a static version of the ScienceDirect usage analytics database covering the period 2003-2012 inclusive was aggregated by country, region, and subject. The usage statistics from ScienceDirect are compliant with the COUNTER Code of Practice[3].

Scopus *(www.scopus.com)*
Scopus is Elsevier's abstract and citation database of peer-reviewed literature, covering 50 million documents published in over 21,000 journals, book series and conference proceedings by some 5,000 publishers.

Scopus coverage is multi-lingual and global: approximately 21% of titles in Scopus are published in languages other than English (or published in both English and another language). In addition, more than half of Scopus content originates from outside North America, representing many countries in Europe, Latin America, Africa and the Asia Pacific region.

Scopus coverage is also inclusive across all major research fields, with 6,900 titles in the Physical Sciences, 6,400 in the Health Sciences, 4,150 in the Life Sciences, and 6,800 in the Social Sciences (the latter including some 4,000 Arts & Humanities related titles).

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 has begun to increase book coverage in 2013, aiming to cover some 75,000 books by 2015.

For this report, a static version of the Scopus database covering the period 1996-2012 inclusive was aggregated by country, region, and subject. Subjects were defined by BIS 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, to maintain continuity with previous reports in this series.

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 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.

SciVal competency map *(info.scival.com/spotlight)*
The SciVal competency map is part of Elsevier's SciVal suite of solutions for research institutions, funders and policy makers built around Scopus. For more details on the methodology behind the SciVal competency map, see box 'SciVal competency map and co-citation analysis' in the report.

World Intellectual Property Organisation *(www.wipo.int)*
World Intellectual Property Organization, 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 *(ipstatsdb.wipo.org)*. Methodological notes on the collection and usage of these data are available[4]. Data are presented for the most recent five years for which data are available.

Office for National Statistics *(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)*.

[1] See Cracknell. R. & Bolton, P. (2009) "What is a billion? And other units" Statistical literacy guide from the House of Commons Library Social & General Statistics section.

[2] 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.

[3] See *www.projectcounter.org/code_practice.html*.

[4] 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 3-character code	Comparator group	G8	EU27	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					

Country	ISO 3-character code	Comparator group	G8	EU27	OECD (member)	OECD (non-member)
Switzerland	CHE				✓	
Chile	CHL				✓	
China	CHN	✓				✓
Côte d'Ivoire	CIV					
Cameroon	CMR					
Congo, the Democratic Republic of the	COD					
Congo	COG					
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[5]	✓	✓	✓	✓	
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					

[5] UK used throughout this report.

Country	ISO 3-character code	Comparator group	G8	EU27	OECD (member)	OECD (non-member)
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			✓	✓	
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	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			✓		
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					

Country	ISO 3-character code	Comparator group	G8	EU27	OECD (member)	OECD (non-member)
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					
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	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					

Country	ISO 3-character code	Comparator group	G8	EU27	OECD (member)	OECD (non-member)
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					
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	✓	✓		✓	
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					
Viet Nam	VNM					
Vanuatu	VUT					
Wallis and Futuna	WLF					
Samoa	WSM					
Yemen	YEM					
South Africa	ZAF					✓
Zaire	ZAR					
Zambia	ZMB					
Zimbabwe	ZWE					

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[6].

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.

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
- "Measuring impact: citation windows and field-weighting" in Chapter 4
- "Measuring article downloads" in Chapter 4
- "SciVal competency map and co-citation analysis" in Chapter 4
- "Counting patent applications, patent grants and patents in force" in Chapter 7

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[6] 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.

Notes

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