Analytical Services

A Metrics-Based Assessment of Scotland's Science Landscape (2007-2016)

ELSEVIER

Key Findings

Scotland's researchers are **highly productive**

Scotland is a very strong performer of research in the UK - while accounting for about 8% of the UK population[1] and researchers[2], for the period of 2007-2016; it produced 12% of the UK output.

- Scotland had the highest average number of publications per researcher (0.53) for the entire 2007-2016 period, compared with all the comparator counties in this report.
- Scotland's share of world publications has declined by 4.2% from Period 1 (2007-2011) to Period 2 (2012-2016), a decline which is higher than England (-3.1%) and the UK average (-2.9%), but better than Northern Ireland (-6.3%) and Wales (-7.9%), due to other nations becoming more research active.
- Scotland's researchers are highly productive and have the second highest ratio of publications per £m expenditure among UK nations.

Scotland continues to Invest in Scientific Research and Development

- Between 2007—2016, Scotland's gross expenditure on R&D as a share of GDP increased by 21.3%, ahead of many of the comparators. However, at 1.5% it remains below the EU average (2.0%) the rest of the UK and comparators.

Scotland's research is **high quality**

- Scotland had the highest citation impact among the UK nations and performs well against EU and non-EU comparators. From 2012-2016 Scotland FWCI 1.79, UK FWCI 1.58.
- Scotland has the highest share of top 1% most cited publications in the world among UK nations and sits comfortably among comparator nations.
- Scotland has the highest number of citations per researcher out of the UK and all other nations Scotland was compared to, 27% higher than the nearest comparator Wales, and 63% ahead of the UK average. *(Average number of citations per researcher 2007-2016: Scotland 16.03, UK 9.81 and Wales 12.66).*
- Academic-corporate joint publications are increasing in Scotland and have a 33% higher impact than the UK average

[1] UK Office for National Statistics, mid-2016 population estimates.
https://www.ons.gov.uk/aboutus/transparencyandgovernance/freedomofinformationfoi/ukpopulation2017
[2] Eurostat Total R&D personnel and researchers by sectors of performance, sex and NUTS 2 regions, 2015 data

Scotland's researchers are **highly mobile**

- Scottish researchers are highly mobile: over 89% of active researchers published at least one article under a non-Scottish affiliation during 1997-2016 (this includes UK and international addresses).
- Researchers who come to Scotland for less than two years (termed 'transitory' here) have higher citation impact (FWCI of 2.2) than sedentary researchers (FWCI of 1.8)
- Transitory researchers in Scotland had a higher citation impact (FWCI 2.2) than transitory researchers in the rest of the UK.
- Transitory researchers from the EU have the highest citation impact in Scotland (FWCI 2.4) suggesting that Brexit uncertainties may be more of a concern to Scotland.

Scotland is a **global collaborator**

- Scotland is highly international, with 49.4% of its publications having an international co-author during 2007-2016, slightly ahead of England and Wales.
- International collaboration results in an average citation impact that is more than twice the global average (Field Weighted Citation Impact (FWCI) 2.0).
- Collaboration involving EU countries results in even higher citation impact (FWCI of 2.7 in Period 2), and Scotland has a higher share of collaboration with EU countries compared to England and Wales.
- Scotland's most frequent collaborator is the USA and most impactful collaborations on average are with Sri Lanka, mainly due to the large multinational projects that both countries are involved in.
- While Scotland's share of business expenditure on R&D is the lowest in the UK, its share of academic-corporate collaborations (4.7% in Period 2) is only slightly below the UK average (5.0% in Period 2).
- Engineering has the highest share of corporate co-publications (6.4% in Period 2) whereas academic-corporate co-publications in Clinical Science have the highest impact (FWCI of 6.5).
- For the 2012-2016 period, GlaxoSmithKline was the top corporate collaborator.

Subject Science Strengths

- Publications in Physical Sciences account for the largest share of Scottish publications in 2007-2016 but publications in Clinical Sciences have the highest average citation impact.
- Humanities had the largest output and citation impact increase from Period 1 to Period 2.
- Scotland is the only country among the comparator countries to increase its share of publications in Physical Sciences from Period 1 (2007-2011) to Period 2 (2012-2016).
- Environmental Science and subjects around energy have increased in both output and impact for Scotland

Foreword by Professor Paul Boyle, Chair of the Scottish Science Advisory Council

Scotland has a long-held reputation for producing excellent science, encouraging innovative thinking and building international collaborative partnerships. Its research base helps drive the economy and attracts students, researchers and academics from around the world, enriching its society

To learn more about the relative performance of Scotland's science base, the Scottish Science Advisory Council (SSAC) commissioned Elsevier to produce a metrics-based assessment of the Scientific Research Base from 2007-2016. We have compared Scotland to the other UK nations and selected EU and non-EU countries of similar population and economic size.

This report demonstrates that the quality and productivity of Scotland's research base is impressive: Scotland produces more academic publications per researcher, and these works are cited more often by their peers, than any of the comparator nations. In 2016, Scotland had more publications in the top 1% of the most cited publications in the world than any other UK nation or EU comparator nation.

Perhaps not surprisingly, therefore, Scotland is highly successful at obtaining funding from charities, research councils, EU and global funding streams. Scotland has increased its gross expenditure on Research and Development as a share of GDP in the ten-year study period, at a higher rate than any other UK nation and comparator with the exception of Norway.

Business collaborations are also increasing in Scotland; while Business Enterprise Research and Development investment rates have been low in Scotland compared to England, this investment doubled between 2007 and 2016. It is also clear that Scottish researchers are collaborating strongly with business, and these partnerships lead to more highly cited work than elsewhere in the UK. These are among a number of achievements identified in this report that are worth celebrating.

Yet, there are results that require strategic attention.

The research world is changing, with emerging research-intensive nations such as Singapore growing their capability and capacity. This has resulted in Scotland, along with other established research countries, experiencing a decrease in its share of global publications. Scotland will need to consider how it responds to the challenges in this changing landscape, as well as the inherent opportunities for building new partnerships.

In addition, a critical part of Scotland's success is the mobility of its research base, attracting world-class researchers to teach and research here. Scotland benefits more than the rest of the UK from European collaborations. But, with Brexit looming, the risk to Scottish research is therefore potentially greater than for the rest of the UK if a satisfactory post-Brexit deal for science and innovation cannot be secured in a timely manner.

The scientific research base plays a critical role in Scotland's economy and society, driving innovation and tackling today's global issues. We should all take pride in the many successes and achievements of the universities, research institutes and other bodies who contribute to Scotland's science successes. This research excellence should be nurtured, so that Scotland remains a great science and innovation nation, continuing to punch above its weight in an increasingly competitive environment.

Professor Paul Boyle
CBE FBA FRSE

Table of Contents

Introduction

Elsevier was commissioned by the Scottish Science Advisory Council (SSAC), to undertake a bibliometric-based assessment of the performance of Scotland's scientific research base to provide ministers, officials and interested stakeholders with an objective overview. Similar analysis has been conducted for the UK, Scotland and Wales separately, in the past. Of course, publication outputs relate to only one of the many facets of the research system, but they do at least give an indication of the publication performance relative to other countries.

The report tracks the performance of Scotland's scientific research base over a ten-year period (2007-2016), analysing a number of indicators relating to the number and citation impact of publications from Scotland, compared with other UK nations ,selected European counties (Denmark, Finland, Ireland, Netherlands and Sweden) and non-European countries (Israel, Norway, New Zealand, Singapore and Switzerland) that are similar in population and economic size.

This report builds on two previous reports on Scotland in 2003 and 2009[3] and a series of UK-wide reports by the UK Government, Department for Business, Energy and Industrial Strategy (BEIS) in 2011[4], 2013[5] and 2016[6]. The subject fields chosen in this report are the same as in the BEIS 2016 report. As the three Scottish reports (2003, 2009 and 2019) do not follow a consistent methodology, so direct comparisons are not always possible. Where they are possible, they are provided.

The report is structured into six chapters, Chapter 1 provides an overview of Scotland's scientific publication output and the citation impact of these publications, comparing Scotland with the UK and some selected European and non-European nations. Chapter 2 provides the relative performance in ten subject fields, with a more detailed subject level analysis provided in Chapter 5. Chapter 3 focuses on academic/collaborations and Chapter 4 considers researchers mobility. Annex 1 presents a new analysis which indicates research fields gaining momentum in Scotland.

Scotland's Higher Education Landscape

Scotland is one of the four nations of the UK and has a special status as a devolved territory with its own parliament with devolved powers. Higher education is among the devolved responsibilities, with "funding and policy decisions affecting higher education taken primarily by the Scottish Government, Scottish Parliament and the Scottish Funding Council"[7]. With a population of nearly 5.5 million, Scotland makes up around 8% of the UK[8]. Scotland's GDP per capita has been increasing since 2009, after a decline between 2007 and 2009; this is a similar trend to the rest of the UK. Scotland has a reputation for excellent science, with five of Scotland's universities in the Top 200 of the Times Higher Education World University Rankings

[3] International Comparative Performance of Scotland's Research Base (2009). http://www.gov.scot/Resource/Doc/981/0093770.pdf

[4] https://www.gov.uk/government/publications/uk-research-base-international-comparative-performance-2011

[5] https://www.gov.uk/government/publications/performance-of-the-uk-research-base-international-comparison-2013

[6] https://www.gov.uk/government/publications/performance-of-the-uk-research-base-international-comparison-2016

[7] http://www.universitiesuk.ac.uk/about/Pages/universities-scotland.aspx

[8] ONS 2016 population estimates:
https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates#timeseries

2019[9]. Going back to 2017, Scotland had more universities in the top 200 in the world per head of population than any other country except Luxembourg. In the 2017 QS World University rankings, three Scottish universities appeared in the top 100, a slight decline in performance compared to 2016 was noted which reflects increasing international competition[10] and investment in research excellence around the world.

Scotland has a total of 19 higher education institutions, represented by Universities Scotland receiving grant funding from the Scottish Funding Council (SFC), allocated through the UK Research Excellence Framework. This funding enables universities to leverage additional funding in research grants from UK Research Councils, UK charities,[11] EU and international funding opportunities. These funding mechanisms tie the Scottish higher education institutions closely with the UK research system. However, there are differences between the UK nations in terms of their higher education policies with the UK government implementing tuition fees and the Scottish Government continuing to offer funded university places to eligible students, encouraging every person, no matter their background, to have an equal chance of entering and succeeding in higher education.

University funding is supplemented by funding successfully gained from a variety of other sources, such as the Wellcome Trust, CRUK and European Funding. Scotland's share of the total Wellcome Trust funding to Scottish Universities has fluctuated, the lowest share in 2008 at 8.4% to the highest share in 2013 at 20%. In 2016 Scotland's share was 13.2% of the UK total with the average yearly share over the last ten years of 14.2%. Horizon 2020 is the EU's main programme for funding research and innovation projects. The programme was launched on 1 January 2014 and has a total budget of €76.4 billion. Scotland has secured over €505 million in total[12]. This represents 1.62% of the total allocated Horizon 2020 budget to date. Higher education institutions and research institutes in Scotland are collectively the main beneficiaries by organisation type, securing over 78% (almost €396 million) of the funding. Under the Excellent Science pillar, which includes Marie Skłodowska-Curie Actions and the European Research Council, almost €270 million has been awarded (almost 53.5% of the overall €505 million) to Scotland. Under the Industrial Leadership pillar, over €63 million has been awarded (12.5% of the funds awarded to Scotland). Under the Societal Challenges pillar, over €165.5 million has been awarded (almost 33% of the funds awarded)[13].

[9] https://www.timeshighereducation.com/world-university-rankings/2019/

[10] http://www.sfc.ac.uk/web/FILES/AboutUs/SFC_Annual_Report_and_Accounts_2017-18.pdf

[11] Since April 2018 the UK Research Councils have all moved under the newly formed UK Research and Innovation (UKRI).

[12] Science with and for Society; Spreading Excellence and Widening Participation; Euratom and the European Institute of Innovation and Technology. The Commission's Joint Research Centre also receives some funding.

[13] Scotland Europa (2018) Scotland's engagement in Horizon 2020: Ninth performance monitoring and analysis update

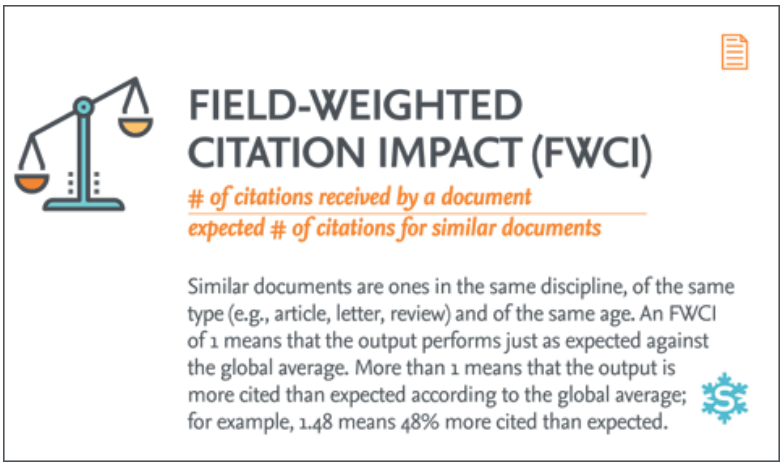
Data Sources and Methodology

Using journal articles and conference proceedings as a measure of performance

Scientific research outputs can take many forms, including articles in journals, books and monographs, as well as non-textual media such as music and art. This report focuses on academic research publications in journals[14], review articles and conference proceedings and how often these publications are cited in other publications. This analysis of scientific publications and their citations (bibliometric assessment) can provide useful insights into the comparative performance of a country or nation's research base.

Field-Weighted Citation Impact

Field Weighted Citation Impact (FWCI) is used throughout this report as an indicator of research impact. FWCI divides the number of citations received by a publication by the average number of citations received by publications in the same field, of the same type, and published in the same year, see Figure 1 below. Calculating the score within disciplines, accounts for field-dependent citation differences. This is a normalised metric, that allows comparisons across countries.



Measuring Change

Most of this report analyses the 2007-2016 period. At the time this report was commissioned the latest complete data set available for publications and associated data was for 2016. Throughout the report the total period is divided into two: Period 1 (P_1) from 2007-2011 and Period 2 (P_2) from 2012-2016 to track changes between them.

In some analysis we use Compound Annual Growth Rate (CAGR) which is the year on year constant growth rate over a specified period.

Subject Classifications

For most of this report, analyses are undertaken for ten 'subject fields', matching the 2016 and previous BEIS reports. The ten subject fields are groupings of 27 ASJC (All Sciences Journal Classification) 'subject areas' which are groupings of 334 'subjects' in the Scopus database. (see Appendix A). The ten subject areas are:

[14] Research and the Scholarly Communications Process: Towards Strategic Goals for Public Policy A Statement of Principles (2007) Research Information Network http://www.rin.ac.uk/system/files/attachments/Research-scholarly-communications-principles.pdf

Biological Sciences, Business, Clinical Sciences, Engineering, Environmental Sciences, Health & Medical Sciences, Humanities, Mathematics, Physical Sciences and Social Sciences.

Subject Area Analysis

In the subject area analyses a minimum threshold of 100 publications per period was applied to ensure that changes were not unduly influenced by small numbers. Therefore, some smaller Humanities subjects do not feature in certain analysis.

Data Sources

Most of the data presented in this report are derived from Scopus (bibliometric data), supplemented by national and OECD statistics (R&D expenditure and researchers). All these data sources aggregate information from large numbers of primary sources.

Comparators

Four main comparison groups are used in this report: the UK, other UK nations, selected EU countries and selected non-EU countries. It should be noted that Northern Ireland has only two main institutions that account for more than 95% of all publications. When Scotland is compared to the UK, this data includes all for UK Nations (England, Scotland, Wales and Northern Ireland) which means Scotland is being compared, in part to itself.

The comparator countries were chosen based on matching: populations, publication numbers, Gross Expenditure on R&D (GERD) as a percentage of GDP, and GDP per population. The Project Steering Committee was also consulted.

Selected EU countries are: Denmark (DNK), Finland (FIN), Ireland (IRL), the Netherlands (NLD), and Sweden (SWE).

Selected non-EU countries are: Israel (ISR), Norway (NOR), New Zealand (NZL), Singapore (SGP), and Switzerland (CHE).

Hyper collaborated Papers

Hyper collaborated papers, defined for the purposes of this study as papers with more than 100 authors, are included in the analysis, consistent with previous Scottish reports and the UK BEIS report.

Caveats and Limitations

Citation impact

Citation impact is an important proxy indicator for scholarly impact and has long been established in the field of bibliometric analysis, allowing for consistent comparisons between different countries and for trend analyses. Nevertheless, citation measures are only one part of the research performance picture.

Journal articles and citation-based indicators capture research performance better in some fields than in others. In fields where journal articles provide a less comprehensive view of the outputs (e.g. the arts and humanities), the results must be interpreted with caution. Bibliometrics also do not consider more recent, nontraditional measures, such as those derived from blogs, Twitter, Facebook and other forms of social media.

A full account of the methodology used in this publication is provided in Appendix B.

Time lag between research inputs and research outputs

There is a time-lag between expenditure on research and the publication outputs, and a second time-lag before these outputs are cited. It is common for conference proceedings to be published first, with journal publications following two to three years after completion of the research and, where applicable, patent applications follow an even longer delay. Time lags can vary by indicator, country and subject field, and may shift in magnitude over time. Due to the complexities in determining and accounting for the time lags between research input and output, this has not been attempted in the report[15]. However, it is important that time lags are considered when interpreting the outputs from this report, even the latest year's data will report on research carried out two to three years previously.

High impact multidisciplinary journals

It should be noted some high impact journals, such as *Science* and *Nature*, are classified in this analysis as 'multidisciplinary', in accordance with the Scopus ASJC classification, as it is not possible to allocate reliably the individual publications within them to individual subjects.

Note that the multidisciplinary category is included in the overall publication and citation counts for the countries analysed here but is not included in subject level assessments. This is consistent with other bibliometric assessments such as the UK BEIS 2016 report.

This means that the subject level assessments provided in this report show an incomplete picture of the total publications and their impact in any subject field. The number of high impact multidisciplinary journal publications of Scotland is increasing, up 131% from P_1 to P_2. This is a positive story that reflects the high quality, often ground-breaking scientific research being carried out in Scotland. These high-impact multidisciplinary journal publications by their very nature tend to be more highly cited and have a higher FWCI.

Note that all the limitations identified here apply to all the countries equally.

[15] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/263729/bis-13-1297-international-comparative-performance-of-the-UK-research-base-2013.pdf

Chapter 1

Output and Impact – Country Views

Highlights

SCOTLAND'S PUBLICATION CHANGE

15%

Increase in publication numbers from P_1 (2007-2011) to P_2 (2012-2016)

UK'S PUBLICATION CHANGE

17%

Increase in publication numbers from P_1 (2007-2011) to P_2 (2012-2016)

SCOTLAND'S FIELD-WEIGHTED CITATION IMPACT

1.79

Average FWCI for all publications from Scotland for 2012-2016

UK'S FIELD-WEIGHTED CITATION IMPACT

1.58

Average FWCI for all publications from UK for 2012-2016

SCOTLAND'S PUBLICATIONS IN TOP 1% MOST CITED

2.3%

Percentage of publications from Scotland fin the top 1% 2012-2016

UK'S PUBLICATIONS IN TOP 1% MOST CITED

1.9%

Percentage of publications from the UK in the top 1% for 2012-16

SCOTLAND'S CITATIONS PER RESEARCHER

16.03

Average number of citations per Scottish researcher per year for 2007-2015

UK'S CITATIONS PER RESEARCHER

9.81

Average number of citations per UK researcher per year over for 2007 to 2015

SCOTLAND'S PUBLICATIONS PER RESEARCHER

0.53

Average number of publications per Scottish researcher per year for 2007-2016

UK'S PUBLICATIONS PER RESEARCHER

0.38

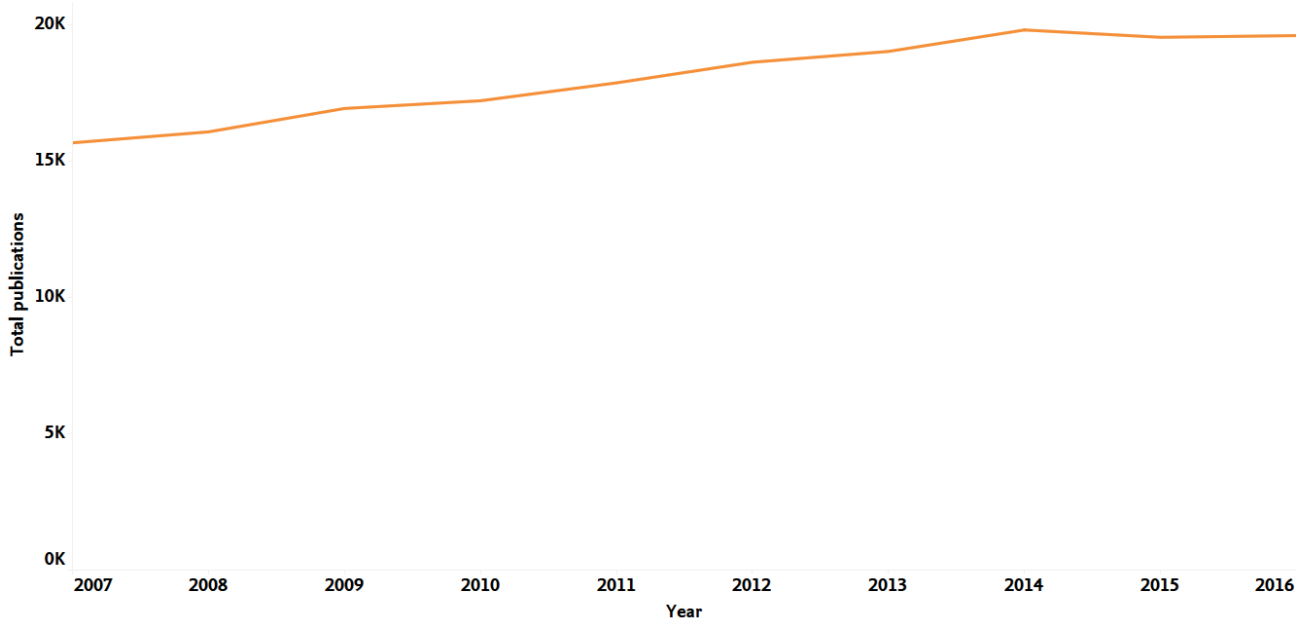
Average number of publications per UK researcher per year for 2007-2016

1.1. Scotland's scholarly output

Scotland's scholarly output is steadily increasing but at a slower rate than the world trend.

Researchers affiliated to Scottish institutions, including universities, corporates and other sectors have produced over 180,000 publications during the 2007-2016 period as captured in Scopus. Annual scholarly output has increased from over 15,000 in 2007 to over 19,000 in 2016 (Figure 1.1). Scotland has a compound annual growth rate (CAGR)[16] of 2.5%, which is lower than the world trend of 3.3% only slightly less than England (2.7%) and the UK (2.6%) growth rate. The growing trend in Scotland has slowed down in the last two years, which mirrors global trends.

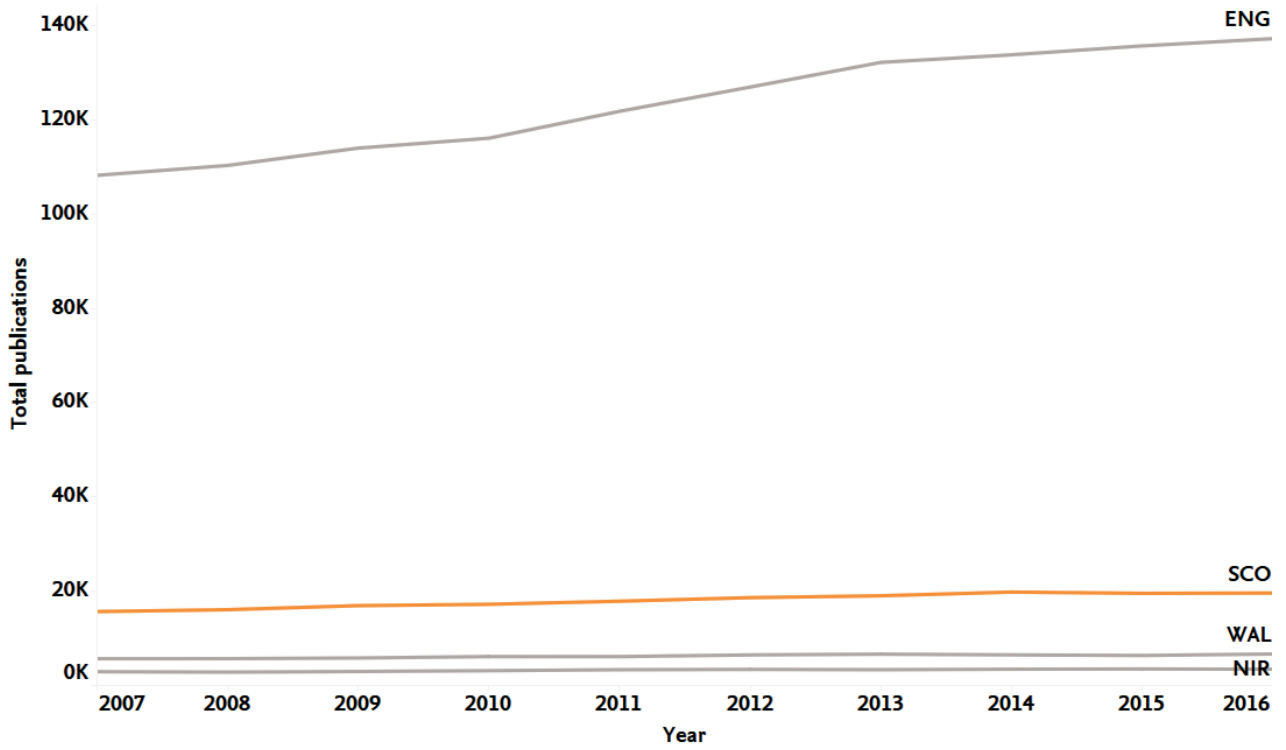
Figure 1.1— *2007-2016 total publication output for all subjects for Scotland, 2007-2016. Source: Scopus.*



In comparison with other UK nations, Scotland's publication growth is behind England and ahead of Wales and Northern Ireland (Figure 1.2). From P_1 to P_2, England's publications increased by 16.7%, compared with 15.3% for Scotland, 12.8% for Northern Ireland and 10.9% for Wales.

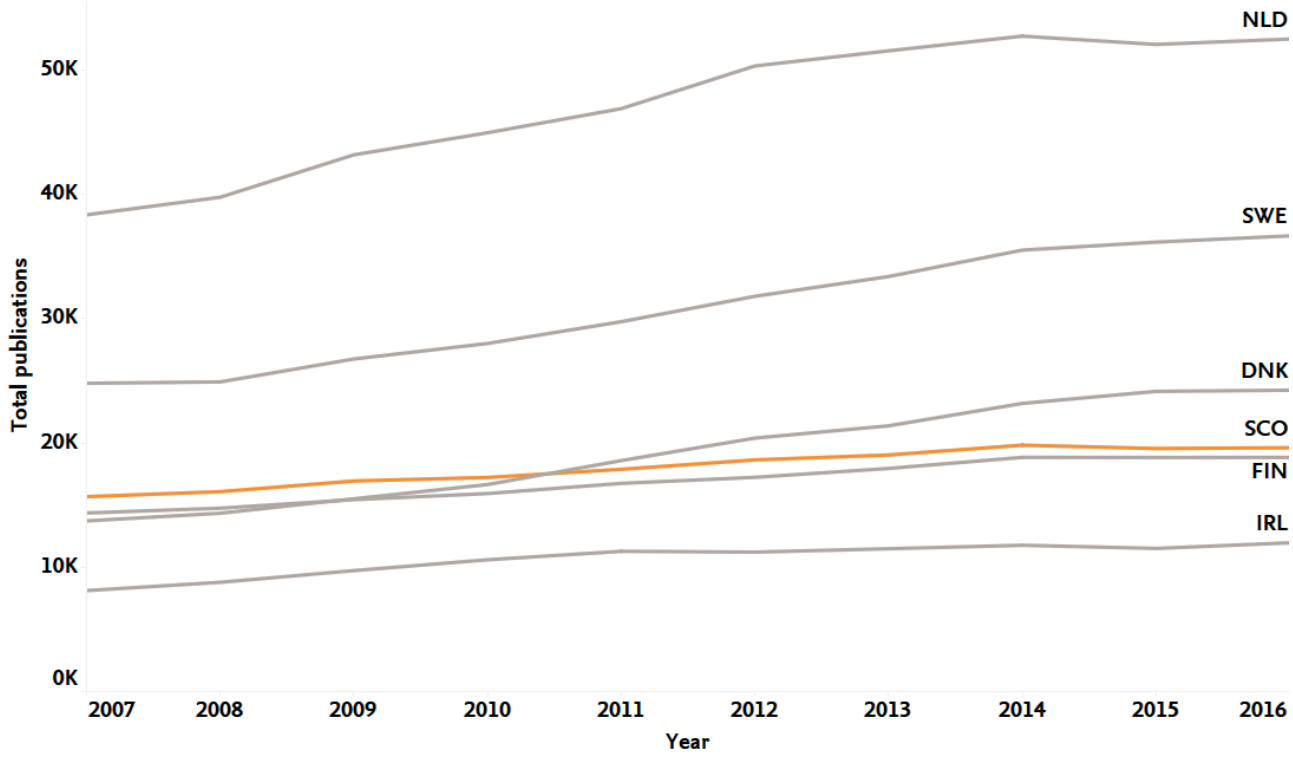
[16] CAGR is defined as the year-on-year constant growth rate over a specific period of time and is more reliable for stable trends rather than a trend with many peaks and dips.

Figure 1.2— *2007-2016 total publication output for all subjects for UK nations, 2007-2016. Source: Scopus.*



Among the EU comparators, Denmark had the highest publication increase (43.8%) from P_1 to P_2, followed by Sweden (29.3%) (Figure 1.3). Compared to the EU comparators, Scotland had the slowest increase and changed from third position in 2007 to fourth position in 2016 in terms of publication output. While other factors may be relevant, it is noticeable that countries like the Netherlands, Sweden and Denmark, which have excelled in their publication numbers, spend 2-3% of their GDP on R&D, compared with 1.5% in Scotland. Research funding and output links are discussed in more detail in section 1.5.

Figure 1.3— *2007-2016 total publication output for all subjects for Scotland and selected EU countries, 2007-2016. Source: Scopus.*



In comparison to selected non-EU countries Scotland had the second highest number of publications behind Switzerland throughout the 2007-2016 period. However, Singapore had the highest growth from P_1 to P_2 (35.5%), followed by Norway (33%) whereas Israel had the most modest increase (12.1%) Scotland's growth was (15.34%) (Figure 1.4a and b).

Figure 1.4a — *Total publication output for all subjects for Scotland and selected non-EU countries, 2007-2016 and a focus on the last five years excluding Scotland. Source: Scopus.*

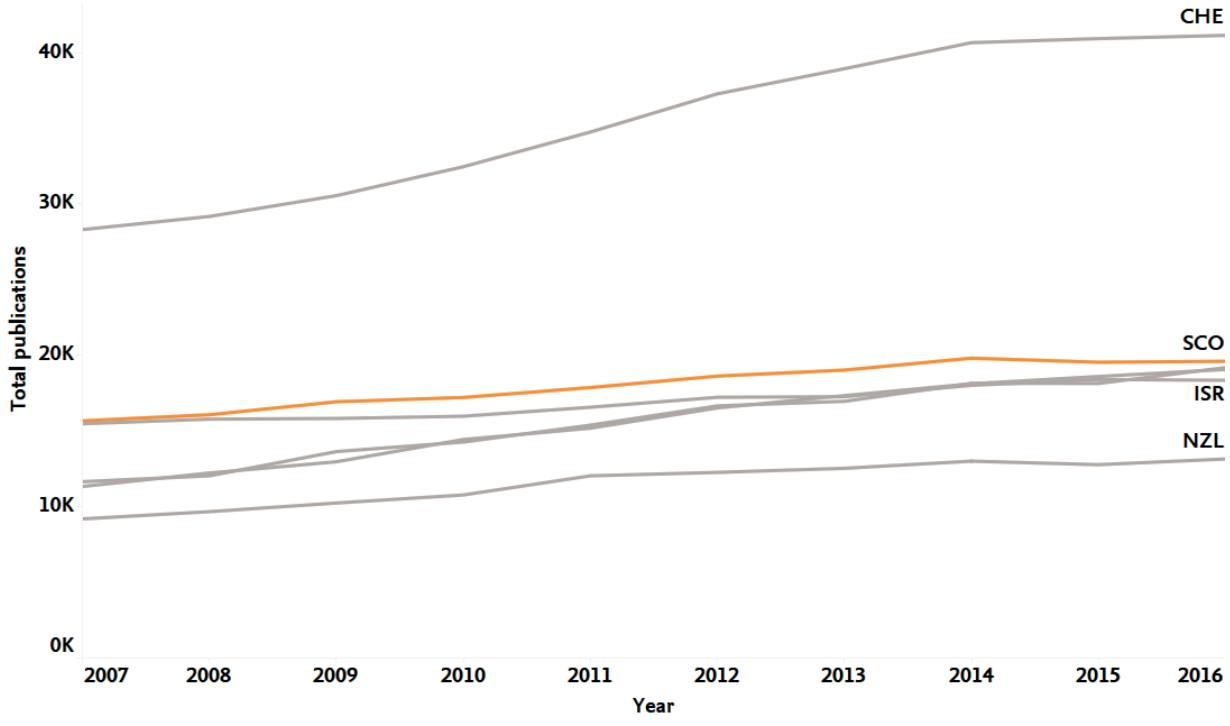
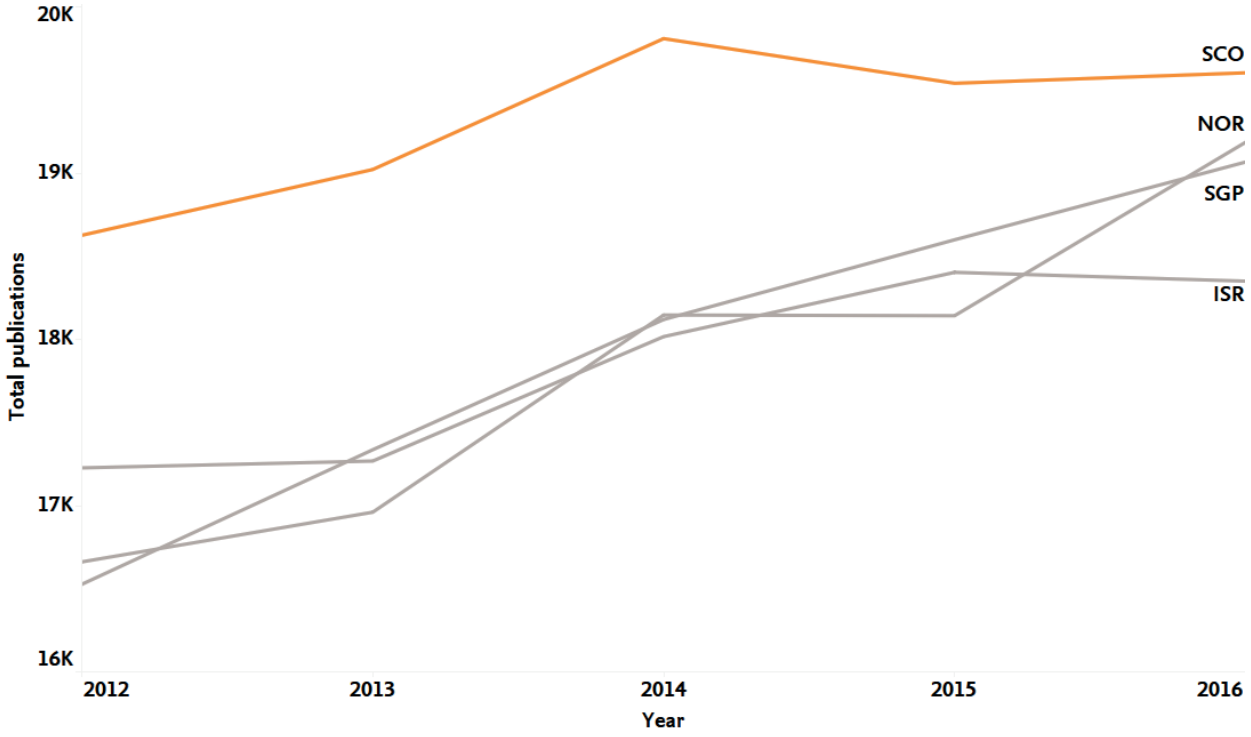


Figure 1.4b — *Total publication output for all subjects for Scotland and selected non-EU countries, focus on the last five years (2012-2016) excluding Switzerland. Source: Scopus.*



Scotland's share of global publications continues to decline as others increase their publication output.

Scotland's absolute publication numbers have been increasing, but rate of increase (15% from P_1 to P_2) is only ahead of Northern Ireland, Wales and Israel and below the world average of 20%. Scotland's share of world publications has declined from an average of 0.82% in P_1 to 0.78% in P_2. The decline can be partially attributed to the increasing publication numbers from large developing nations like China, India and Brazil, and the growing publications in some countries that are improving their research base, such as Iran. Even so, countries such as Denmark and Singapore managed to increase their share of world publications during this period. One explanation is the higher R&D expenditure in these countries.

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Table 1.1— *Average share of world publications for all comparators in order from highest change in share. Source: Scopus.*

Country	P_1 (2007-2011)	P_2 (2012-2016)	P_1-P_2 change
DNK	0.77%	0.92%	19.4%
SGP	0.65%	0.73%	12.5%
NOR	0.65%	0.72%	10.5%
SWE	1.31%	1.41%	7.4%
CHE	1.51%	1.61%	6.4%
NZL	0.51%	0.52%	1.9%
NLD	2.08%	2.10%	1.0%
IRL	0.47%	0.47%	-0.8%
FIN	0.75%	0.74%	-1.4%
GBR	6.71%	6.52%	-2.9%
ENG	5.57%	5.40%	-3.1%
SCO	0.82%	0.78%	-4.2%
NIR	0.15%	0.14%	-6.3%
ISR	0.78%	0.72%	-6.9%
WAL	0.29%	0.26%	-7.9%

If we look at the World share across subject areas in Scotland (Table 1.2), the subject with the largest World share is Humanities (as it is for the UK as a whole). Social Sciences and Health & Medical Sciences and Social Sciences has the second and third largest shares (similar again to the UK). Engineering had the lowest world share in Scotland and the UK. In Scotland all ten subject fields declined between P1 and P2, while in the UK Business increased its share. Biological Sciences had the largest decline, in Scotland and the UK (which is consistent with the 2009 report). Scotland's decline was more than that of UK average in all subjects except Physical Sciences and Clinical Sciences.

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Table 1.2— *Average share of world publications for Scotland and UK per subject field. Source: Scopus.*

	Scotland			United Kingdom		
Subject Field	**P1**	**P2**	**P1-P2 Change**	**P12**	**P23**	**P1-P2 Change4**
Biological sciences	1.0%	0.9%	-10.2%	7.1%	6.7%	-6.5%
Business	0.9%	0.8%	-0.5%	8.6%	8.9%	3.1%
Clinical sciences	0.9%	0.9%	-1.3%	8.1%	8.0%	-1.6%
Engineering	0.5%	0.5%	-8.0%	4.4%	4.1%	-6.7%
Environmental sciences	1.0%	0.9%	-6.1%	6.9%	6.7%	-3.6%
Health & Medical sciences	1.1%	1.0%	-8.4%	9.2%	9.0%	-2.1%
Humanities	1.3%	1.2%	-7.3%	11.2%	10.7%	-3.7%
Mathematics	0.8%	0.7%	-8.4%	6.2%	5.8%	-5.8%
Physical Sciences	0.7%	0.7%	-0.3%	5.6%	5.5%	-2.3%
Social Sciences	1.1%	1.1%	-3.1%	10.4%	10.3%	-0.9%

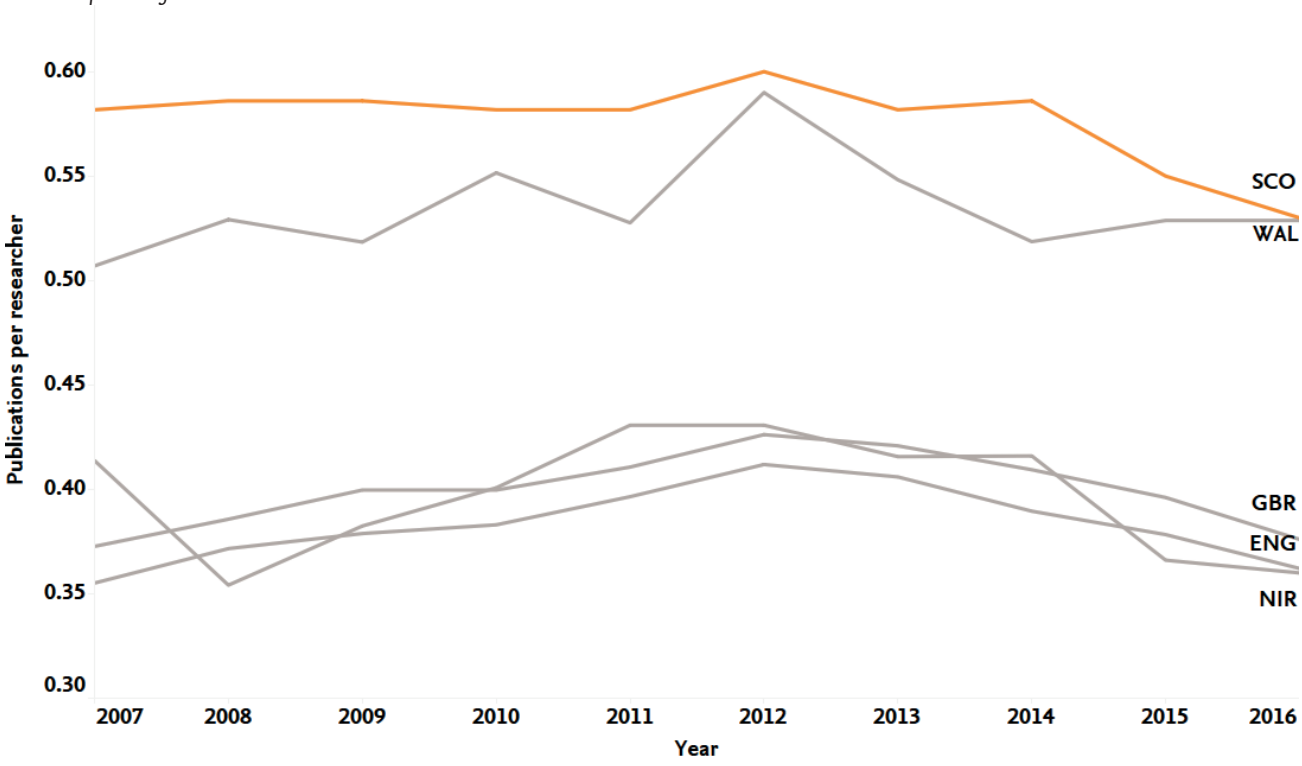
1.2. Scotland's publications and citations per researcher

Scotland has the highest number of publications per researcher, but the gap is closing.

As a size-dependent indicator, scholarly output alone is not adequate for assessing the research productivity of a country. A better approach is to normalize the number of outputs by the number of R&D personnel. We compare these results to the rest of the UK and the EU comparator countries (data on researcher numbers were not available In OECD or UNESCO for some of the non-European comparator countries which are not included). Figure 1.5 shows that Scotland has the highest number of publications per researcher (average of 0.58), higher than all comparators that data were available for and higher than the UK average (average of 0.40). In the first period Scotland's publication to researcher ratio remained stable whereas other nations increased this ratio, with England having nearly 12% compound annual growth rate (CAGR). For England the CAGR of publications in P_1 (over 12%) was significantly higher than the growth in researcher numbers (0.7%), which led to an increase in the publication to researcher ratio. In the second period the trend almost reversed as the researcher numbers in England and Scotland increased by over 20%, with publication growth remaining at around 8% for England and 5% for Scotland. Hence, there was a decline in the publication/researcher ratio. One of the reasons for the publication growth being less than the research growth could be the distribution of research across disciplines. In the 2007-2015 period, the number of researchers in the business sector had a compound annual growth rate of 3.4% for the UK, whereas it was 5.9% for Scotland and 9.8% for Northern Ireland[17]. Researchers in the business sector publish less than in some other disciplines, causing a relative decline in publications per researcher. However, in the same period the number of researchers in the higher education sector also increased by 3%, so the business sector cannot account for all the difference.

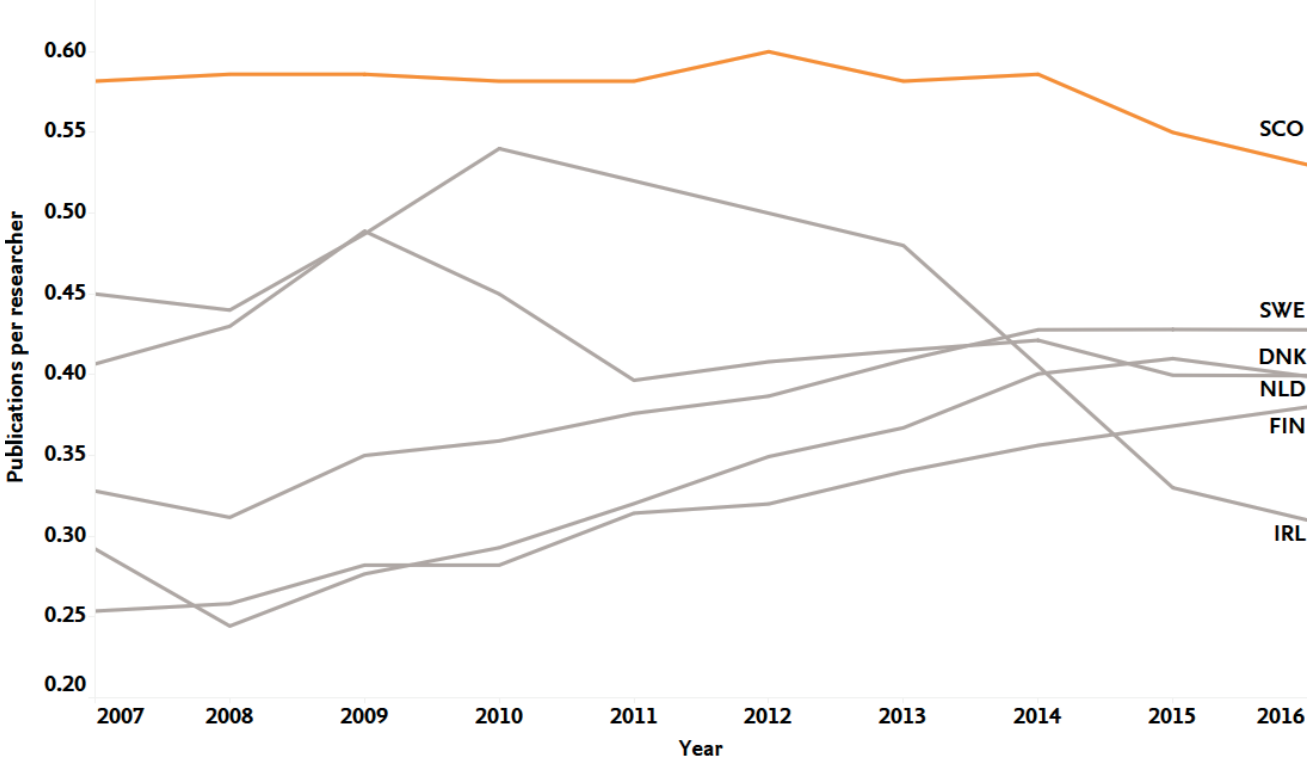
[17] Eurostat Science, Technology and Innovation statistics.

Figure 1.5— *Number of publications per total R&D personnel (FTE) for UK nations, 2007-2016. R&D personnel data has been extrapolated for 2016. Source: Eurostat*



Scotland also has the highest number of publications per R&D personnel when compared with the selected EU countries, although the Nordic countries are catching up (Figure 1.6). Denmark increased its publication to researcher ratio by 35% from P_1 to P_2, followed by Finland (28%) and Sweden (21%). In the case of Denmark and Sweden, this is due to the high growth in publication numbers not matched by researcher growth whereas in the case of Finland there has been a decline in the number of R&D personnel. Ireland's ratio declined by 17%, which can be related to a high increase in the number of R&D personnel (50%).

Figure 1.6— *Number of publications per total R&D personnel (FTE) for Scotland and selected EU countries, 2007-2016. R&D personnel data has been extrapolated for 2016. Source: Eurostat*



Scotland has the highest number of citations per researcher compared to all comparator nations for the entire study period.

The 2009 Evidence report noted that Scotland ranked third in the comparator group in terms of citations per researcher, with a rising trend. Although the comparator group is different and time series data are incomplete for Israel, Switzerland and New Zealand, the results in Table 1.3 shows that Scotland has ranked first among comparators throughout the entire study period. Note that the decline in the more recent years for all countries is expected as publications from last years have not had time to accrue citations.

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Table 1.3— *Number of citations per researcher, 2007-15. Average for Singapore was calculated for 2007-2014. Data for citation numbers is extracted from SciVal based on 14th Dec 2018 data. Data for researcher numbers (FTE) is extracted from EuroStat and OECD.*

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
CHE	…	18.22	…	…	…	14.18	…	…	7.88	
DNK	11.94	9.54	10.38	9.83	9.61	9.65	8.30	7.66	6.26	**9.24**
ENG	11.70	11.54	11.26	10.62	9.67	9.09	7.73	6.15	4.72	**9.16**
FIN	7.84	7.63	7.30	7.43	6.95	6.79	6.14	5.74	4.70	**6.72**
GBR	12.79	12.50	12.19	11.34	10.28	9.64	8.13	6.49	4.94	**9.81**
IRL	14.33	13.35	15.04	14.54	12.63	11.68	9.18	6.64	4.50	**11.32**
ISR	…	…	…	…	5.86	4.88	…	…	…	
NIR	11.93	9.28	10.18	9.05	9.26	9.27	8.83	6.19	5.18	**8.80**
NLD	16.13	15.70	17.34	15.23	11.88	11.05	9.42	7.62	5.89	**12.25**
NZL	13.09	…	11.84	…	10.67	…	8.74	…	5.52	
SCO	21.53	21.22	19.50	18.38	15.78	16.28	12.90	10.88	7.78	**16.03**
SGP	10.00	10.54	10.50	11.20	10.27	11.35	9.48	7.99	…	**10.17**
SWE	12.00	10.82	11.28	10.98	10.25	9.59	8.63	7.36	5.83	**9.64**
WAL	15.62	14.49	14.81	15.07	13.09	14.68	10.47	8.39	7.33	**12.66**

1.3. Scotland's spend on research and development

Scotland has increased its spending on R&D, but still lags behind the rest of the UK and most comparator nations.

Scotland has been dedicating more funding to R&D in the last decade. From 2007 to 2016 its expenditure on R&D as a share of GDP increased from 1.27% to 1.54% (Table 1.4). The percentage increase from 2007 to 2016 of 33% is second only to Norway and is significantly higher than the overall UK percentage increase in R&D investment of 5.1%. However, despite this increase Scotland still spends less than the UK average of 1.67% and all of the comparator countries for which data are available, with the exception of Ireland.

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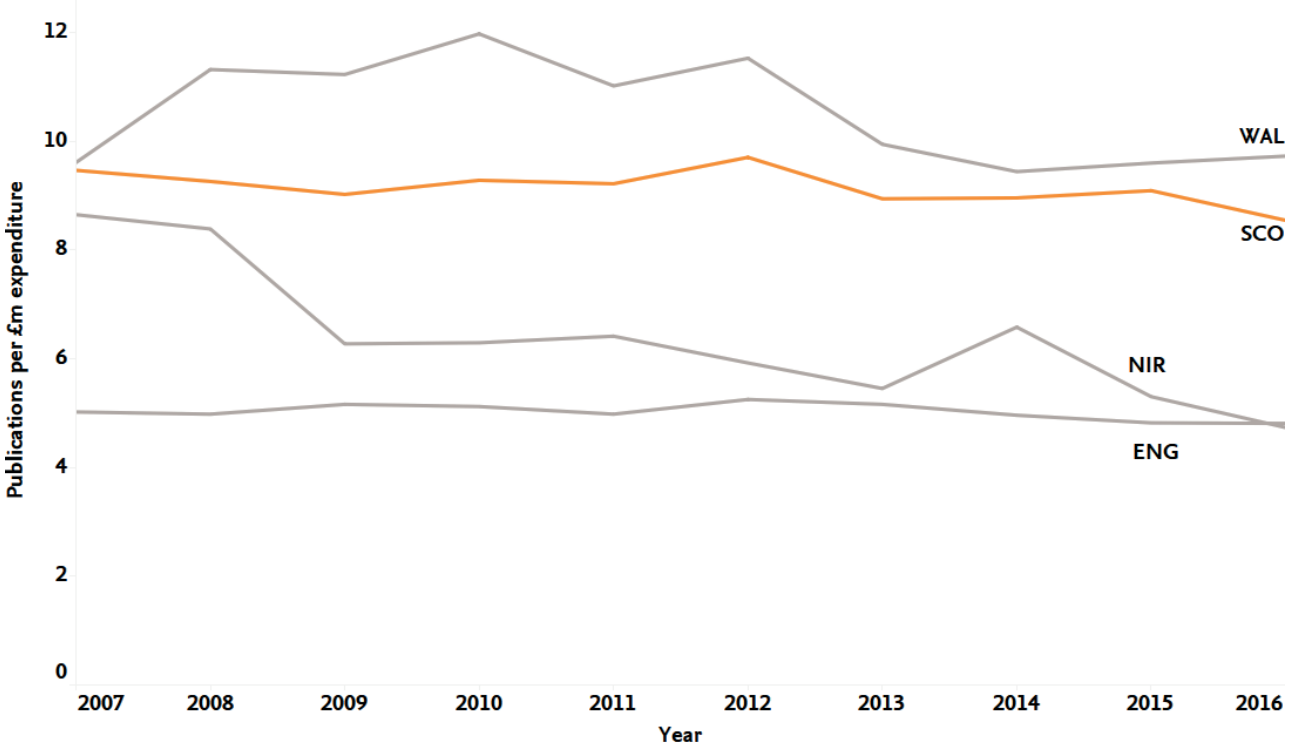
Table 1.4—*Gross Expenditure on R&D as a share of GDP. Source: OECD Main Science and Technology Indicators and Scottish Government (for Scotland)*

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	% Change
SCO	1.27	1.31	1.42	1.41	1.42	1.39	1.46	1.51	1.52	1.54	21.3%
GBR	1.59	1.63	1.66	1.64	1.67	1.6	1.64	1.65	1.67	1.67	5.1%
DNK	2.52	2.77	3.06	2.92	2.94	2.98	2.97	2.91	2.96	2.87	14.1%
FIN	3.35	3.55	3.75	3.73	3.64	3.42	3.29	3.17	2.9	2.75	-17.9%
IRE	1.23	1.39	1.61	1.59	1.55	1.57	1.58	1.53	1.2	1.18	-4.6%
ISR	4.43	4.35	4.13	3.94	4.01	4.16	4.15	4.2	4.27	4.25	-4.0%
NLD	1.69	1.64	1.69	1.72	1.9	1.94	1.95	2	2	2.03	20.5%
NOR	1.56	1.55	1.72	1.65	1.63	1.62	1.65	1.71	1.93	2.04	30.3%
NZL	1.16	..	1.25	..	1.23	..	1.16	..	1.28	..	
SGP	2.34	2.62	2.16	2.01	2.15	1.99	1.99	2.16	...	...	
SWE	3.26	3.5	3.45	3.22	3.25	3.28	3.31	3.15	3.27	3.25	-0.1%
CHE	..	2.71	..	..	..	3.19	..	..	3.37	..	

Scotland's researchers are highly productive and have the second highest ratio of publications per £m expenditure among UK nations.

Scotland has the second highest publication to £m expenditure ratio among the UK nations. In 2016 8.5 publications were produced per £m expenditure, with Wales leading at 9.7 publications (Figure 1.7). During 2007-2016, Scotland's publication to expenditure ratio had a CAGR of -1.1%, which is lower than England (-0.5%) and Wales (0.1%) but better than Northern Ireland (-6.5%). The visible decline in Northern Ireland was driven by the large increase in GERD, (Gross Domestic Expenditure on Research and Development) (over 40% from P_1 to P_2), which has not been mirrored by the number of publications.

Figure 1.7— *Number of publications per £m research and development expenditure for UK nations, 2007-2016. Expenditure data has been extrapolated for 2016. Source: StatWales.*



A striking difference between the UK nations is the distribution of the research expenditure across sectors (Table 1.5). Scotland is the only UK nation where expenditure by the higher education sector is on a par with the business sector. In all other UK nations, business sector expenditure constitutes a considerably higher share of GERD. In the last decade the share of higher education expenditure on R&D (HERD) for Scotland declined from 50% to 45% (Figure 1.8), and 2016 was the first year where business expenditure on R&D (BERD) was higher than HERD. From 2015 to 2016 Scotland's BERD increased from £953m to £1072m, an increase of 12.5%[18], compared with an overall UK increase of 5.6%.

[18]https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/businessenterpriseresearchanddevelopment/2016

*Table 1.5—Percentage of GERD performed by different sectors, 2016 values. Values with a * indicated the latest available figures for 2015. Source: ONS Research and Development Expenditure Statistics and OECD Main Science and Technology Indicators*

Country	Government	Higher Education	Business
CHE	0.9%*	26.7%*	71.0%*
DNK	2.2%	31.6%	65.8%
ENG	6.7%	22.3%	68.7%
FIN	8.2%	25.1%	65.8%
GBR	6.6%	24.2%	67.0%
IRL	4.1%	25.2%	70.7%
ISR	1.7%	11.7%	85.8%
NIR	2.1%	23.5%	74.3%
NLD	11.6%	31.5%	56.9%
NOR	14.1%	32.6%	53.3%
NZL	20.3%*	29.9%*	49.8%*
SCO	**7.0%**	**45.5%**	**46.0%**
SGP	…	…	…
SWE	3.4%	26.8%	69.6%
WAL	2.1%	37.0%	60.7%

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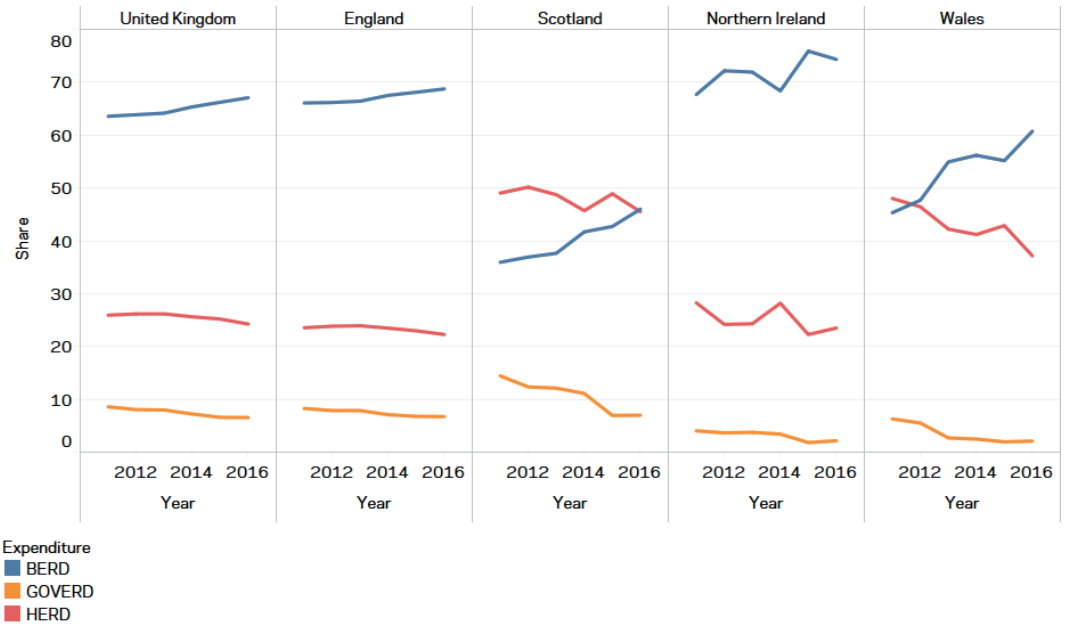
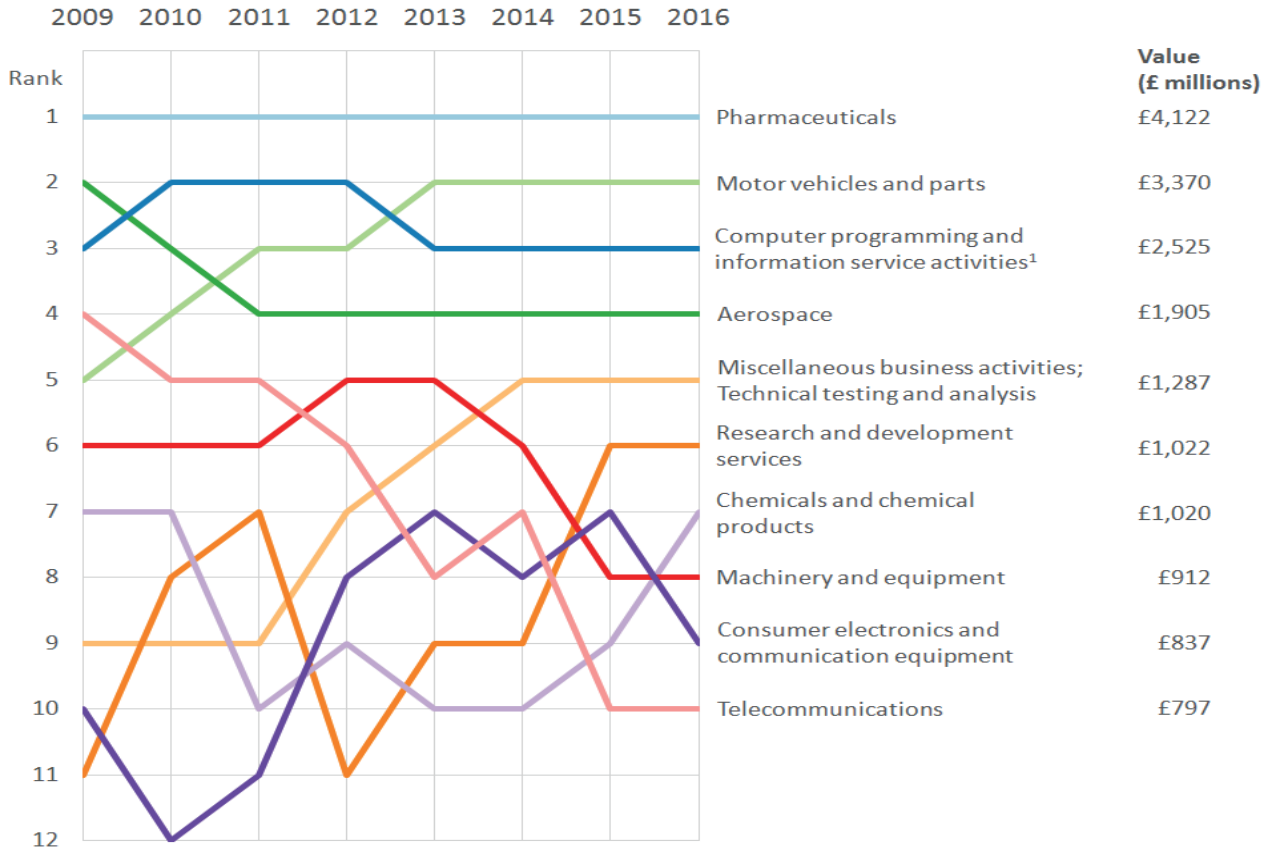
Figure 1.8—*Business, Government and Higher Expenditure on R&D as a share of Gross Expenditure on R&D for UK nations, 2007-2016. Source: UK Office of National Statistics*



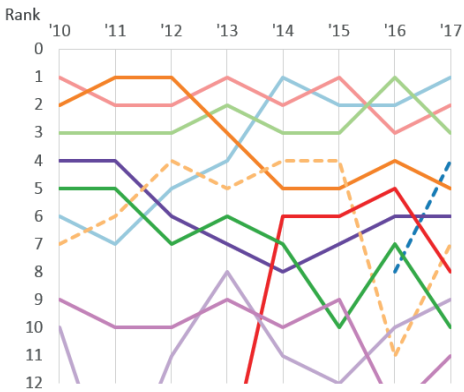
Looking at different business sectors in the UK, as a whole (Figure 1.9a) the Pharmaceutical's sector has the highest investment throughout the period. In recent years, the motor vehicle and parts sector has moved into second place, taking over from computer programming and information services R&D. In Scotland there is more annual variation in funding from different sectors, and most recently the miscellaneous sector has provided most funding. (Figure 1.9b). This is followed by Pharmaceuticals and Consumer electronics and communication equipment. Overall there has been an increase in research funding in information technology related research and a decline in extractive indurates (Oil and Gas) in R&D.

Figure 1.9a— *Expenditure by UK businesses on performing research and development in current prices, by largest product groups, 2009 to 2016*[19]



[19] https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/businessenterpriseresearchanddevelopment/2016

Figure 1.9b— *Expenditure by Scottish businesses on performing research and development in current prices, by largest product groups, 2010 to 2016 from the ONS.*



	Value £ million	% of Scotland total
Miscellaneous business activities; Technical testing and analysis	309	25
Pharmaceuticals	164	13
Consumer electronics and communication equipment	135	11
Software development [1]	72	6
Precision instruments and optical products; Photographic equipment	61	5
Research and development services	55	4
Computer programming and information service activities [1]	51	4
Public administration	48	4
Electrical equipment	45	4
Extractive Industries	40	3
Machinery and equipment	36	3

1 Prior to 2016 Software development is included in the product group Computer programming and information service activities.

1.4. Scotland's citation impact

Scotland has the highest citation impact among UK Nations and performs well compared to comparator nations.

Field-weighted citation impact (FWCI) is perhaps the most robust indicator of citation impact, as it considers the distribution across publication year and subject field.

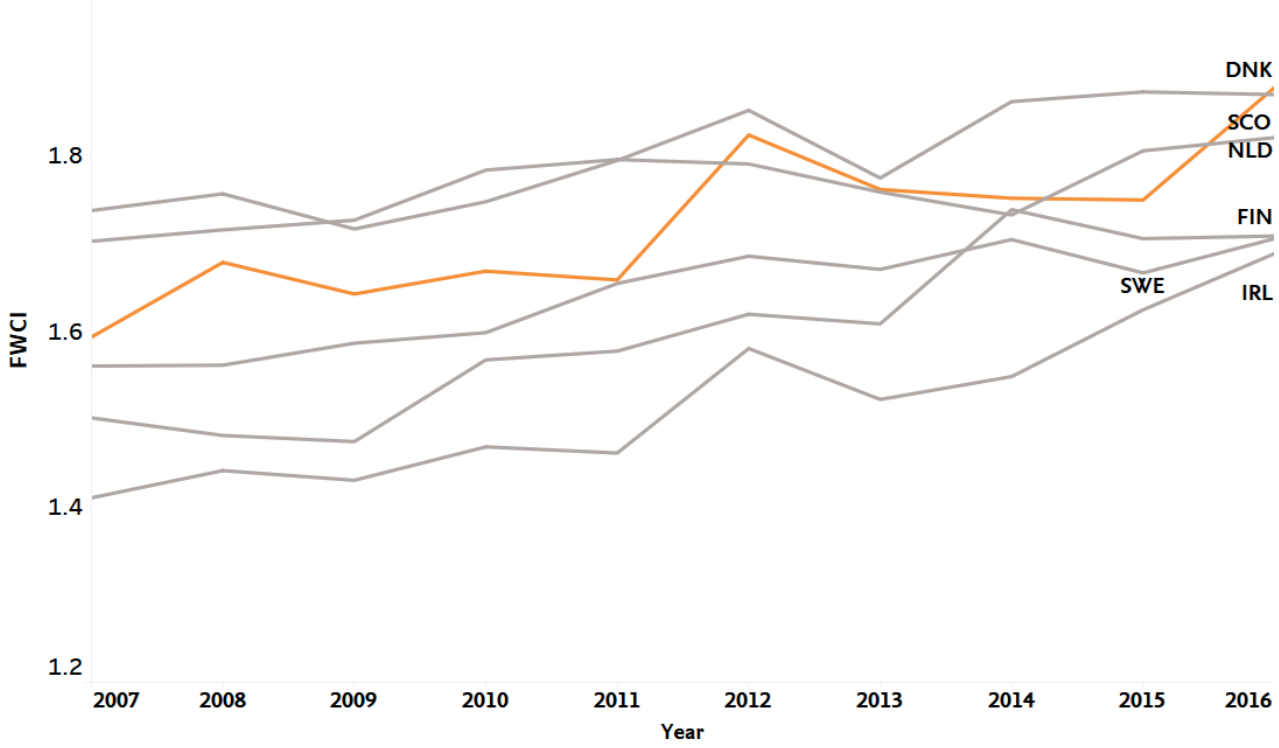
Scotland has a high FWCI, which increased from 1.59 in 2007 to 1.88 in 2016, staying well ahead of the global average of 1.00, and showing an increase of 17.8%. This means that in 2016 Scotland's citations were on average 88% more cited than the global average.

For most of the study period, Scotland's FWCI has been higher than the other UK nations (Figure 1.10). Northern Ireland has a slightly higher score in 2013 and 2015, but these two peaks were caused by two specific research projects which accrued an extraordinary number of citations. Wales had the second highest increase in FWCI, rising nearly 17% from 1.49 in P_1 to 1.74 in P_2.

Figure 1.10— *Field-weighted citation impact for UK nations, 2007-2016. Source: Scopus.*

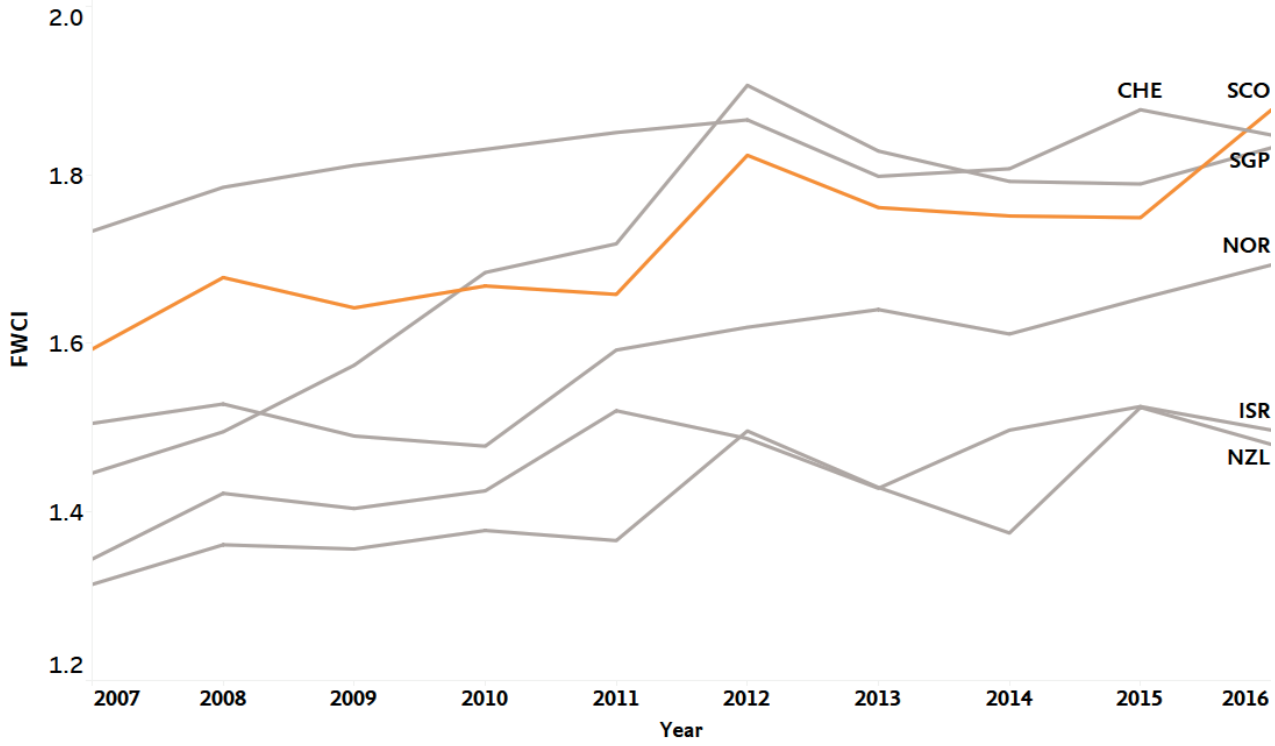
Compared with selected EU countries, Scotland performs well in terms of FWCI, rising to first in 2016 (Figure 1.11). Denmark had the highest FWCI throughout most of the analysis period, with the Netherlands performing well. The percentage increase from P_1 to P_2 were highest for Ireland (10.3%) and Finland (10.2%) followed by Scotland (8.7%).

Figure 1.11— *Field-weighted citation impact for Scotland and selected EU countries, 2007-2016. Source: Scopus.*



In comparison with the non-EU group (Figure 1.12), Scotland had the highest FWCI in 2016. For most of the analysis period Switzerland had the highest FWCI, but experiences the lowest growth from P_1 to P_2, (1.9%). Singapore had the highest increase from P_1 to P_2, (14.6%), followed by Scotland (8.7%) and Norway (8.2%).

Figure 1.12— *Field-weighted citation impact for Scotland and selected non-EU countries, 2007-2016. Source: Scopus.*



1.5. Scotland's share of the top 1% most cited publications

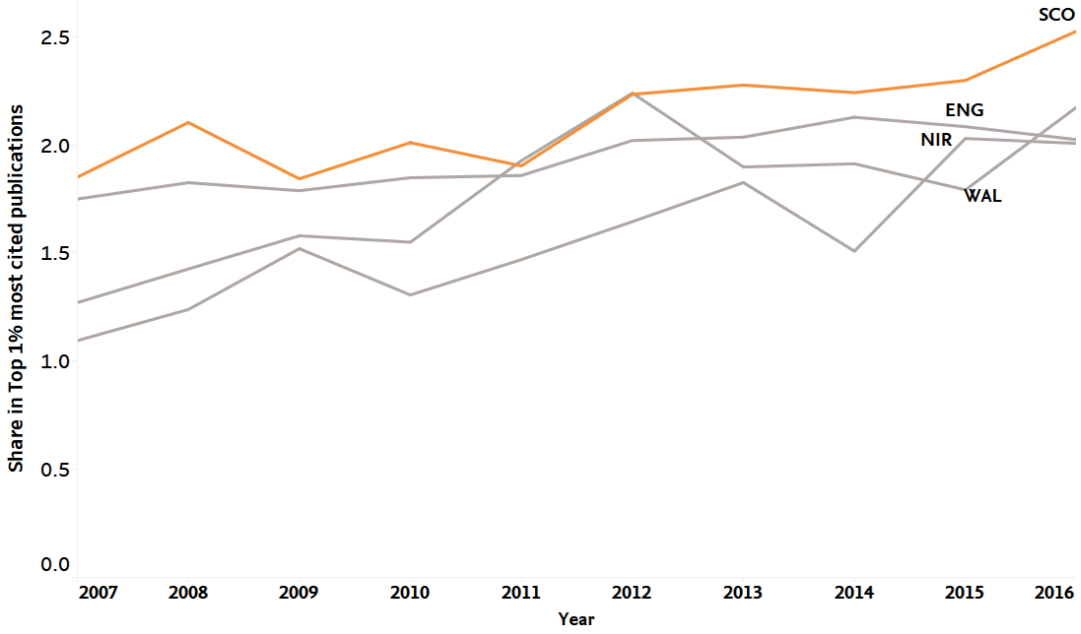
Scotland has the highest share of top 1% most cited publications in the world among UK nations and sits comfortably among comparator nations.

The Top 1% indicator is a Snowball Metric which shows what fraction of an entity's outputs have reached a citation threshold (1% in this case) in the data universe[20].

In 2016, 2.52 % of Scotland's publications were among the top 1% most cited publications worldwide (Figure 1.13). This was the highest share, among the UK nations. Northern Ireland showed the highest growth, increasing its share by nearly 36.5% from 1.33% in P_1 to 1.80% in P_2. Scotland's increase between the two periods was 19.2%, behind Wales (29.2%), but ahead of England (13.5%). Most Scotland's publications in the top 1% most cited publications are in Clinical Sciences.

[20] https://www.snowballmetrics.com/wp-content/uploads/0211-Snowball-Metrics-Recipe-Book-v7-LO.pdf

Figure 1.13— *Share of publications within top 1% most cited publications in the world, for UK nations, 2007-2016. Source: Scopus.*



Scotland also had the highest share of publications in the top 1% most cited in 2016, compared with the selected EU countries (Figure 1.14). In terms of change from P_1 to P_2, Ireland (24.3%) and Finland (20.6%) had the highest growth. Denmark and the Netherlands had comparatively lower increases of 6.9% and 5.2% respectively.

Figure 1.14— *Share of publications within top 1% most cited publications in the world, for Scotland and selected EU countries, 2007-2016. Source: Scopus.*

When compared with the selected non-EU comparator countries, Scotland ranked in the middle for most of the period, rising to second in 2016 (Figure 1.15). Singapore, which had on average 1.98% of its publications

in the top 1% in P1, increased this share by more than 36% to 2.7% in P2, having the highest average among all comparators.

Figure 1.15— *Share of publications within top 1% most cited publications in the world, for Scotland and selected non-EU countries, 2007-2016. Source: Scopus.*

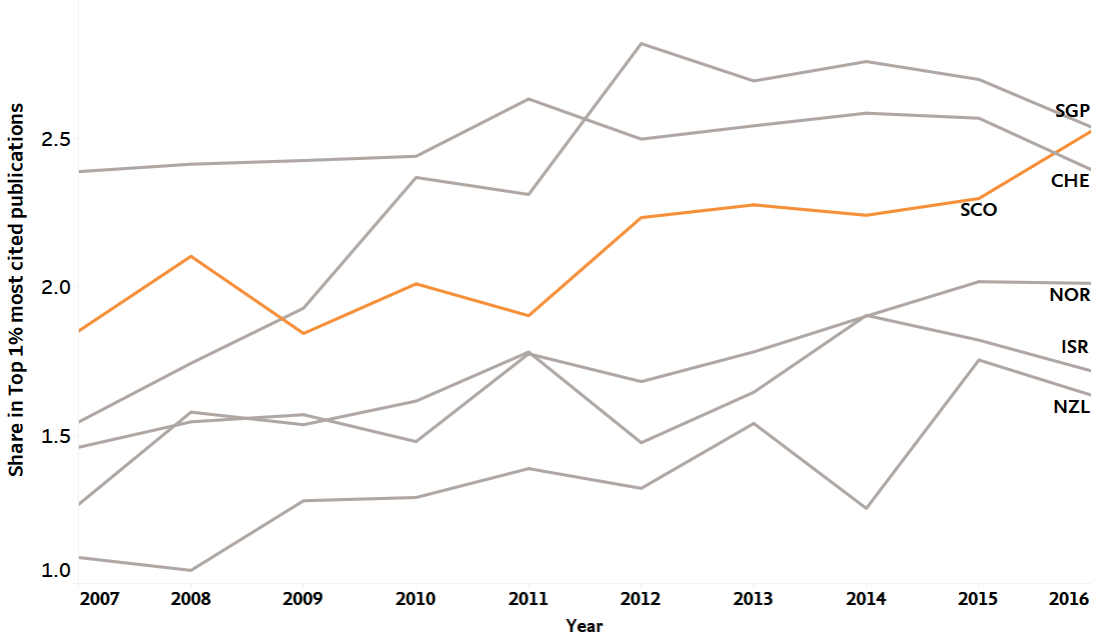


Table 1.6— *Share of highly cited publications and world publication share for Scotland and comparators, P1 and P2. Source: Scopus*

	Highly cited papers share		World publication share	
Country	P1	P2	P1	P2
CHE	4.1%	4.5%	1.5%	1.6%
DNK	1.9%	2.4%	0.8%	0.9%
ENG	11.4%	12.6%	5.6%	5.4%
FIN	1.4%	1.7%	0.8%	0.8%
GBR	12.9%	14.3%	6.8%	6.6%
IRL	0.8%	0.9%	0.5%	0.5%
ISR	1.3%	1.3%	0.8%	0.7%
NIR	0.2%	0.3%	0.2%	0.1%
NLD	5.0%	5.3%	2.1%	2.1%
NOR	1.1%	1.4%	0.7%	0.7%
NZL	0.7%	0.8%	0.5%	0.5%
SCO	**1.7%**	**1.9%**	**0.8%**	**0.8%**
SGP	1.5%	2.2%	0.7%	0.8%
SWE	2.5%	3.1%	1.3%	1.4%
WAL	0.5%	0.5%	0.3%	0.3%

Chapter 2

Output and Impact - Subject Views

Highlights

HIGHEST PUBLICATION SHARE FOR SCOTLAND IN THE LAST 5 YEARS

Physical Sciences

34.4% of all Scottish publications in 2007-2016 were in the field of Physical Sciences

HIGHEST PUBLICATION SHARE FOR THE UK IN THE LAST 5 YEARS

Clinical Sciences

35.3% of all UK publications in 2007-2016 were in the field of Clinical Sciences

HIGHEST OUTPUT INCREASE IN SCOTLAND

Humanities

37.8% increase from P_1 (2007-2011) to P_2 (2012-2016) for Scotland

HIGHEST OUTPUT INCREASE IN THE UK

Humanities

43.2% increase from P_1 (2007-2011) to P_2 (2012-2016) for the UK

HIGHEST IMPACT (FWCI) INCREASE IN SCOTLAND

Humanities

15.8% increase from P_1 (2007-2011) to P_2 (2012-2016) (0.9% decrease for the UK in the same subject field)

HIGHEST IMPACT (FWCI) INCREASE IN THE UK

Environmental Sciences

5.7% increase from P_1 (2007-2011) to P_2 (2012-2016) (8.2% increase for Scotland in the same subject field)

2.1. Subject share of Scottish publications

The two largest subject fields by publication share in Scotland are Physical Sciences and Clinical Sciences

Here we analyse the ten subject fields: (Biological Sciences, Business, Clinical Sciences, Engineering, Environmental Sciences, Health & Medical Sciences, Humanities, Mathematics, Physical Sciences and Social Sciences) in more detail. Throughout the analysis period, publications in Physical Sciences accounted for the largest share, followed closely by Clinical Sciences and Biological sciences (Table 2.1). The largest percentage increase was in the Humanities where the publication share increased by over 27% from 4.5% in 2007 to 5.8% in 2016. Despite having a fall from P1 to P2, publications in Engineering also increased by 12% from 2007 to 2016, followed by Environmental Sciences (11%). Biological Sciences accounted for over 25% of Scottish publications in 2016 but show a declining trend over the period. The largest decline was in Health & Medical Sciences, where the publication share steadily declined from 5.8% in 2007 to 4.8% in 2016.

Table 2.1— *Share of publications per subject area for Scotland, per year for 2007-16. Source: Scopus.*

Subject	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	10-year average	10-year trend
Biological Sciences	27.6	26.8	25.9	26.1	26.2	26.8	26.1	25.5	25.0	25.3	26.1	
Business	4.3	4.3	4.4	4.0	4.1	4.1	4.4	4.2	4.3	4.5	4.3	
Clinical Sciences	30.6	30.4	31.1	31.6	32.4	32.9	33.5	35.5	34.8	32.5	32.5	
Engineering	15.4	17.4	16.4	15.7	15.1	14.6	14.6	16.3	16.3	17.2	15.9	
Environmental Sciences	5.9	5.4	5.4	5.8	5.8	5.7	5.7	6.5	6.4	6.5	5.9	
Health & Medical Sciences	5.8	5.8	5.5	5.3	5.7	5.6	5.5	5.1	5.0	4.8	5.4	
Humanities	4.5	4.5	5.0	5.4	5.5	6.1	6.4	6.1	5.6	5.8	5.5	
Mathematics	6.6	6.6	6.9	6.4	6.2	6.1	6.1	6.1	6.4	6.7	6.4	
Physical Sciences	32.6	34.7	35.9	33.8	34.1	33.5	33.0	35.1	35.6	35.7	34.4	
Social Sciences	10.2	9.9	9.4	10.1	10.1	10.7	11.1	10.5	10.5	10.6	10.3	

For most of the comparator countries in this report, the view is similar - publications in Physical Sciences, Clinical Sciences and Biological Sciences have considerably higher shares than the other subject fields. For Singapore, publications in Physical Sciences account for more than half of all publications and Engineering publications also account for nearly 40%. For Ireland, Northern Ireland and Sweden Engineering also accounts for 19% of their total publications. Table 2.2 shows the change in the share of publication by subject area and country. The Scottish decline in share in Biological Sciences, Engineering, Health & Medical Sciences and Mathematics are matched in most of the comparator countries, although note that the decline in Biological Sciences and Health & Medical Sciences greater for Scotland than for the other UK nations. Most noticeably, Scotland is the only country that had an increase in the share of publications in Physical Sciences, all other countries saw declining shares.

Table 2.2— *Change in the share of publications of subject areas per country, from P_1 to P_2. Blue fill indicates an increase and yellow fill increase a decline.*

	Biological Sciences	Business	Clinical Sciences	Engineering	Environmental Sciences	Health & Medical	Humanities	Mathematics	Physical Sciences	Social Sciences
SCO	**-2.9%**	**2.3%**	**8.3%**	**-1.0%**	**8.8%**	**-7.5%**	**19.5%**	**-3.7%**	**1.1%**	**7.3%**
ENG	-0.9%	5.5%	6.5%	-0.2%	10.9%	-3.3%	21.9%	-1.9%	-2.6%	8.9%
WAL	3.6%	-6.1%	7.2%	-1.6%	12.7%	5.1%	12.2%	-3.8%	-3.2%	-0.8%
NIR	5.6%	-1.6%	10.6%	-4.0%	21.0%	-6.4%	20.2%	-4.0%	-8.5%	6.8%
GBR	-0.4%	4.4%	6.4%	-0.9%	10.1%	-2.5%	22.4%	-2.4%	-2.4%	8.2%
DNK	-4.2%	13.7%	8.6%	3.5%	8.9%	-1.6%	25.3%	-9.9%	-5.4%	23.0%
FIN	-2.7%	14.3%	4.0%	-6.2%	14.9%	0.2%	53.6%	-0.3%	-2.7%	19.7%
IRL	1.7%	6.6%	14.8%	-3.0%	10.1%	0.6%	24.7%	-18.3%	-8.4%	22.3%
NLD	6.0%	5.7%	11.3%	-12.6%	13.7%	0.5%	29.5%	-14.1%	-9.0%	17.7%
SWE	-6.5%	14.7%	4.2%	2.6%	15.6%	-5.3%	46.9%	-1.9%	-0.8%	26.6%
CHE	2.0%	10.1%	9.9%	-7.0%	12.4%	-4.5%	50.7%	1.5%	-5.2%	19.3%
ISR	-0.4%	5.0%	9.2%	-2.9%	8.7%	-0.5%	27.5%	-6.6%	-3.6%	14.6%
NOR	-2.5%	7.7%	4.1%	5.6%	11.1%	-0.3%	26.8%	-7.3%	-4.4%	15.0%
NZL	3.7%	-2.3%	11.4%	0.4%	-0.3%	4.4%	21.4%	-3.6%	-2.5%	4.8%
SGP	10.4%	4.6%	23.4%	-9.1%	42.3%	23.8%	41.3%	-11.0%	-3.5%	9.3%

2.2. Publication and citation impact

Scotland's citation and publication impact are above the world average in every subject area.

Scotland's FWCI is above the global average in every subject. Figure 2.1 shows the changes from P_1 to P_2 in output and FWCI per subject field for Scotland. In terms of the increase in publication output Humanities had the largest percentage growth (38.7%), followed by Environmental Sciences (25.5%), Clinical Sciences (24.9%). In terms of citation impact, Humanities also had the highest increase (15.8%) followed by Biological Sciences (12.2%), Social Sciences (10.7%). While none of the fields had a decline in their publication output, Engineering and Mathematics had minor declines in their citation impact (-0.9% and -0.8% respectively). Changes in the citation impact across subject fields for all comparators can be found in Chapter 5.

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Figure 2.1— *Change in the average scholarly output and FWCI per subject field for Scotland from P_1 (2007-11) to P_2 (2012-16). Source: Scopus.*

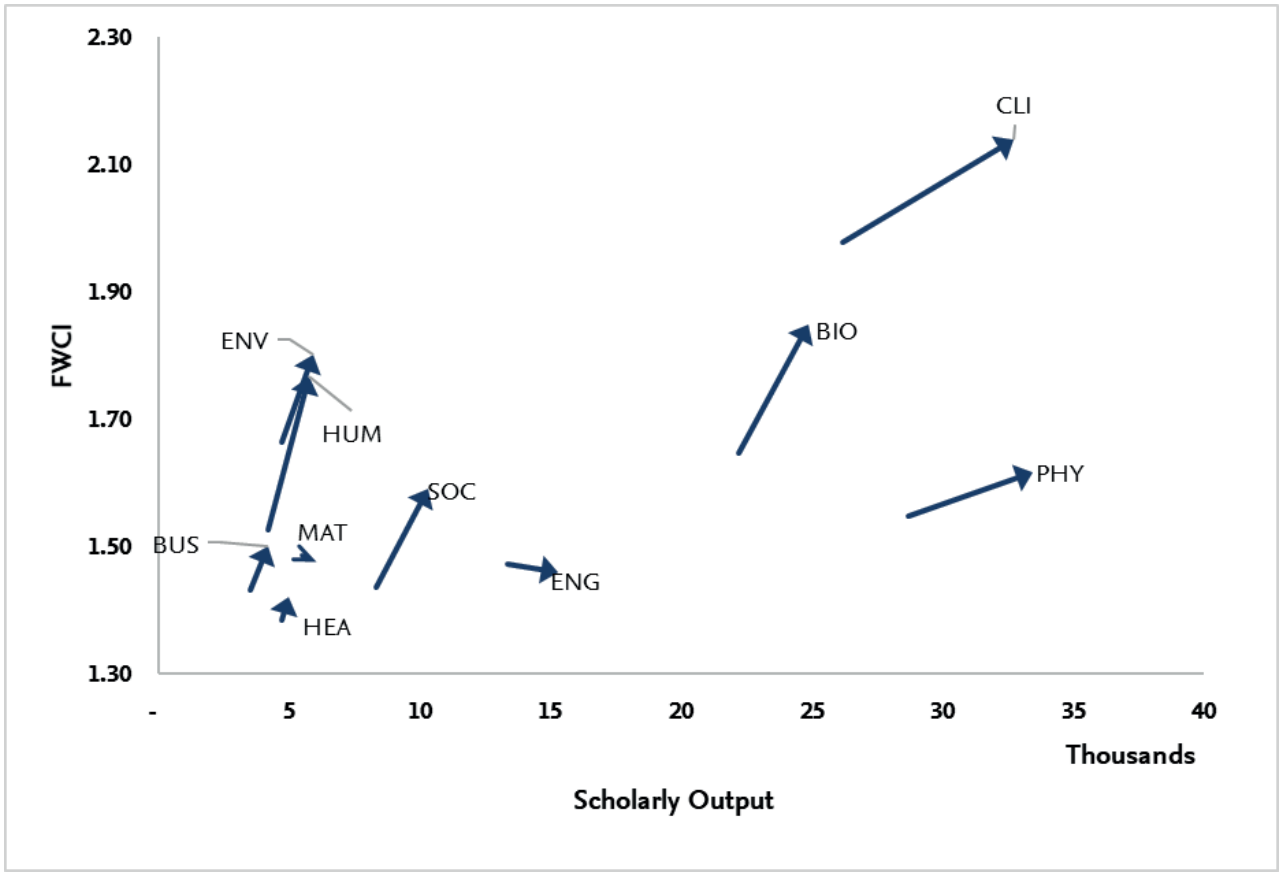

Table 2.3 below shows the top ten largest growing and declining ASJC sub-fields in terms of scholarly output and citation impact. The ten subject fields used in this report are aggregations of the 26 ASJC subject fields, which in turn have 333 sub-categories. A minimum threshold of 100 publications per period was applied to ensure that the changes were not affected unduly by small numbers. Therefore, the smaller Humanities subjects do not feature in the table, despite Humanities having the largest increase at the subject area level. The largest increases in output were in the sub-categories of Multidisciplinary, General Biochemistry, Genetics and Molecular Biology and General Agricultural and Biological Sciences. The Multidisciplinary

category includes large journals such as Nature or Science, which span many fields. Scotland's citation per publication ratio in this sub-category is nearly three times its overall ratio for all subjects. For the world, the citation per publication ratio in Multidisciplinary journals is around twice of average journals. Control and Optimization, Life-span and Life-course Studies and Music were some other high growth fields, but as they had less than 100 publications in the first period they were not included in the table.

Another important area of interest to the Scottish Government is the Renewable Energy, Sustainability and the Environment field where there was a significant growth of outputs. The growth in outputs may reflect political priorities to an extent, but it should also be noted, that the change from P_1 to P_2 is less than the UK and world rates and more importantly for Scotland there was a decline in the impact by 4.3%, whereas the UK and world FWCI averages in this field have improved.

The largest decline in terms of output were in the sub-categories of Applied Microbiology and Biotechnology, Psychiatric Mental Health and Structural Biotechnology.

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Table 2.3— *Top ten growing and declining ASJC subcategories by number of publications from P_1 (2007-11) to P_2 (2012-16). Source: Scopus.*

Largest increase P_1-P_2 (Min. 100 publications per period)	Change P_1-P_2	Largest decline P_1-P_2 (Min. 100 publications per period)	Change P_1-P_2
Multidisciplinary	131.1%	Applied Microbiology and Biotechnology	-43.7%
General Biochemistry, Genetics and Molecular Biology	115.5%	Psychiatric Mental Health	-34.7%
General Agricultural and Biological Sciences	104.4%	Structural Biology	-33.7%
Aging	101.6%	Library and Information Sciences	-32.5%
Archaeology	83.1%	Sensory Systems	-22.9%
Biological Psychiatry	78.5%	Radiation	-22.7%
Renewable Energy, Sustainability and the Environment	78.4%	General Dentistry	-21.2%
General Medicine	73.9%	Computational Theory and Mathematics	-20.8%
Archaeology (arts and humanities)	72.4%	Ophthalmology	-19.1%
Anthropology	71.4%	Food Science	-19.0%

Publications in the sub-categories of Neuropsychology and Physiological Psychology and General Arts and Humanities more than doubled their FWCI scores. For the case of Neuropsychology and Physiological Psychology, many comparator countries in this report experienced a decline in their impact which suggests that this is a unique area of improvement for Scotland. Publications in the Multidisciplinary sub-category saw a decline in their FWCI over the two time periods, despite the increase in the number of publications. However, this declining trend is visible for the other comparator countries as well.

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Table 2.4— *Top 10 growing and declining ASJC subcategories by FWCI from P1 (2007-11) to P2 (2012-16). Source: Scopus.*

Largest increase P1-P2 (Min. 100 publications per period)	Change P1-P2	Largest decline P1-P2 (Min. 100 publications per period)	Change P1-P2
Neuropsychology and Physiological Psychology	118.7%	Multidisciplinary	-38.8%
General Arts and Humanities	101.4%	Small Animals	-38.2%
Archaeology (arts and humanities)	77.0%	Electrochemistry	-36.7%
Social Sciences (miscellaneous)	70.5%	Process Chemistry and Technology	-36.4%
Library and Information Sciences	68.0%	Sensory Systems	-33.4%
Ecological Modelling	62.1%	Atmospheric Science	-32.2%
Hepatology	60.7%	Computational Mathematics	-31.3%
General Earth and Planetary Sciences	57.9%	General Agricultural and Biological Sciences	-24.2%
Instrumentation	52.0%	Fluid Flow and Transfer Processes	-24.1%
Gastroenterology	50.6%	Mechanics of Materials	-23.7%

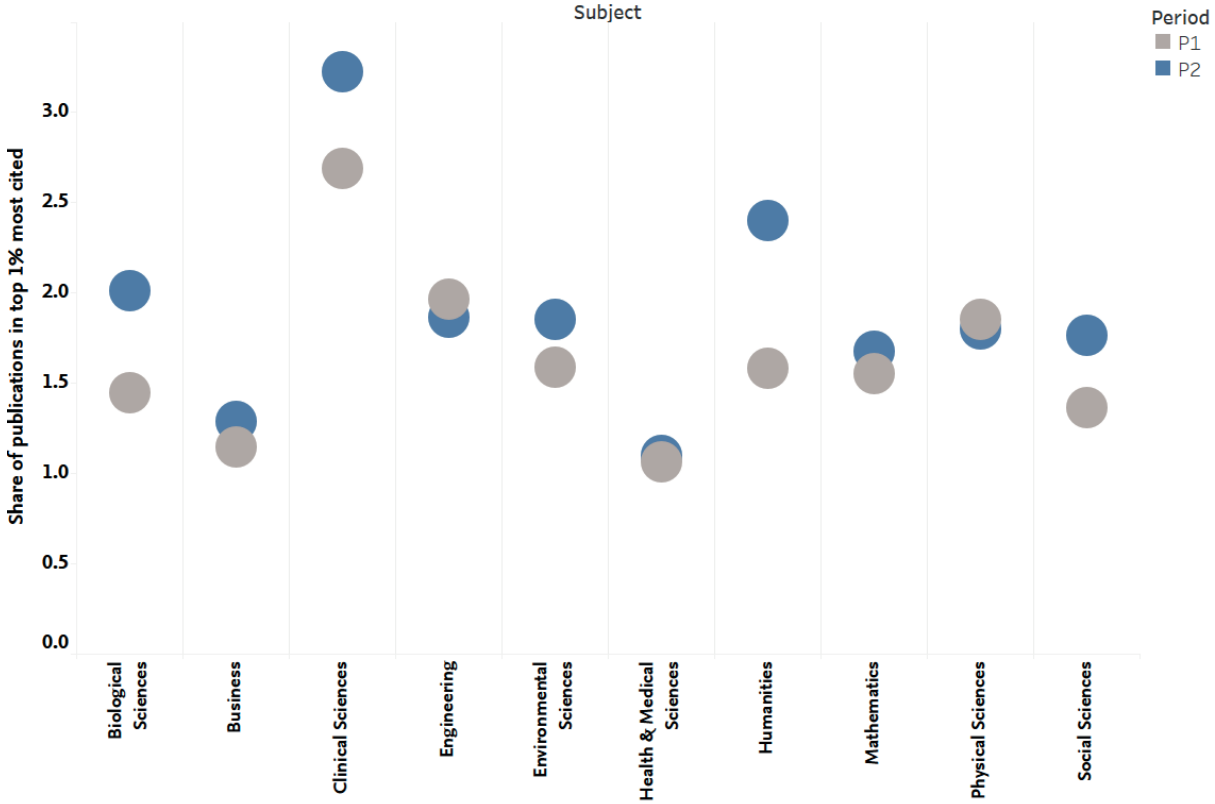
2.3. Scotland's share of the world's most cited publications

Humanities had the highest increase in share of the world's top 1% most cited publications in Scotland.

Between P_1 and P_2, Scotland's share of the most cited publications in Humanities increased by 52% from 1.6% to 2.4%. Biological Sciences and Social Sciences also saw increases of 39% and 30% respectively, whereas the largest declines were in the fields of Engineering (-5%) and Physical Sciences (-3%) (Figure 2.2). Other countries that had noticeable increases in the share of top cited publications in Humanities were Ireland (240%, though with a very limited number of publications), Sweden (77%), and Norway (48%).

Among the UK nations, only Scotland experienced a decline in the share in Engineering: for the UK the share increased by 7%. On the other hand, several comparators like Switzerland, Denmark, Israel, the Netherlands and Norway had larger declines than Scotland. In the field of Physical Sciences, the UK average increased by 0.7% whereas Scotland is the only UK nation with a declining share at -3%. Among the comparator countries Israel had the largest decline (-16.1%), followed by Switzerland (-8.7%) and the Netherlands (-6.5%). For Scotland, all subject areas except for Physical Sciences and Engineering increased the share of publications in the top 1% most cited publications with Clinical Sciences having the highest percentage share in P_2 (3.2%).

Figure 2.2— *Change in the share of publications in top 1% most cited publications worldwide, from P1 to P2. Source: Scopus.*



Case Study: Humanities in Scotland

For Scotland, Humanities stands out among other subjects as it has the largest increase in both outputs (38%) and citation impact (16%).

2007-2011	2012-2016
Number of Publications: 4,188	Number of Publications: 5,773
FWCI: 1.53	FWCI: 1.77
Share of Scottish publications: 5.0%	Share of Scottish publications: 6.0%

Among Humanities sub-categories, the largest number of outputs were in History, followed by Language & Linguistics and Philosophy (Table 2.5). The largest increase from one period to the other was in Conservation and the Classics, although there were less than 100 publications in each of these areas in both periods. For areas with more than 100 publications, Archaeology (72%), Visual Arts & Performing Arts (62%) and Philosophy (60%) stand out.

For FWCI, Conservation, Museology, and Religious Studies, all increased their citation impact from below to above the world average over the period, while Literature and Literary Theory field fell below the world average. The most impactful areas in P_2 were Archaeology and Language and Linguistics, as well as the General Arts and Humanities area.

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Table 2.5 - *Change in the output and impact across different Humanities subjects by ASJC category, for Scotland, from P_1 to P_2.*

ASJC subject area	Output P_1	Output P_2	P_1-P_2 Change	FWCI P_1	FWCI P_2	P_1-P_2 Change
Archeology (arts and humanities)	268	462	72.4%	1.76	3.12	77.0%
Classics	34	78	129.4%	1.27	1.60	26.3%
Conservation	24	59	145.8%	0.89	1.15	28.3%
General Arts and Humanities	137	131	-4.4%	1.34	2.69	101.4%
History	1004	1323	31.8%	1.22	1.32	8.5%
History and Philosophy of Science	260	361	38.8%	1.60	1.59	-0.6%
Language and Linguistics	783	963	23.0%	1.74	2.47	41.6%
Literature and Literary Theory	414	598	44.4%	1.18	0.93	-21.6%
Museology	23	26	13.0%	0.62	1.69	171.4%
Music	69	129	87.0%	2.06	1.73	-16.2%
Philosophy	535	858	60.4%	1.88	1.65	-11.8%
Religious Studies	364	417	14.6%	0.87	1.17	34.9%
Visual Arts and Performing Arts	242	391	61.6%	1.60	1.31	-18.3%

All comparator countries increased their outputs in Humanities and at a higher rate than Scotland except for Northern Ireland and Wales. However, despite a large increase in the number of publications, many countries displayed either a decline or modest growth in their FWCI in this subject. Scotland's FWCI increased by nearly 16%. Ireland, Northern Ireland and Norway were the only comparator countries which had a larger increase in FWCI over the two periods.

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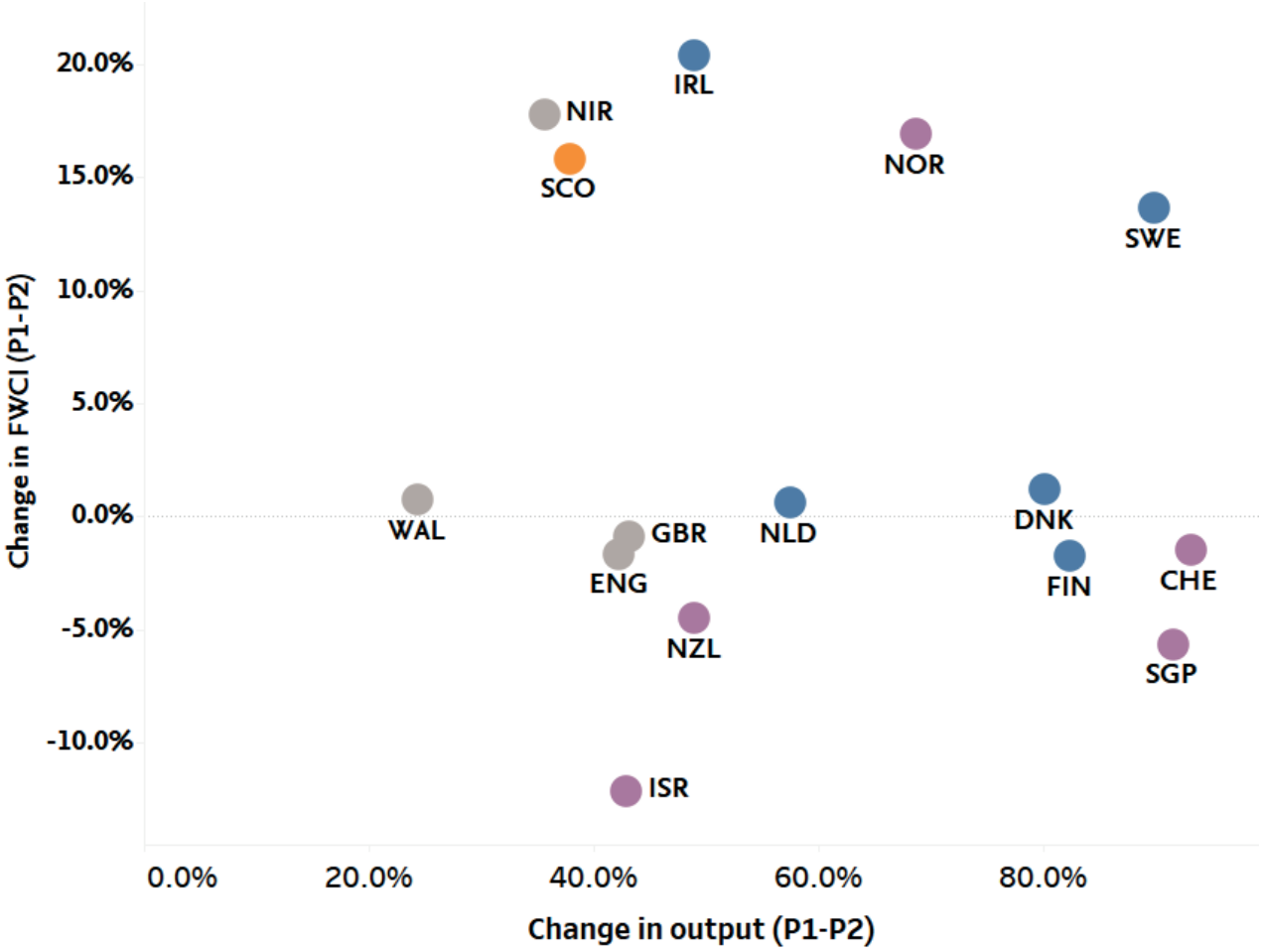
Figure 2.3- *Change in the output and impact in Humanities for comparators, from P1 to P2. Source: Scopus*



Chapter 3

Research Collaboration

Highlights

SCOTLAND'S INTERNATIONAL COLLABORATION SHARE

56.9%

of Scottish publications had international collaboration in 2016 with Biological Sciences having the largest share (67%)

UK'S INTERNATIONAL COLLABORATION SHARE

56%

of UK publications had international collaboration in 2016 with Biological Sciences having the largest share (69%)

SCOTLAND'S EU COLLABORATION SHARE

56.3%

of Scotland's international publications had an EU partner in P_2.

ENGLAND EU COLLABORATION SHARE

52.7%

of England's international publications had an EU partner in P_2.

INTERNATIONAL COLLABORATION IMPACT OF SCOTLAND

2.25

FWCI of international collaborations in P_2.

INTERNATIONAL COLLABORATION IMPACT OF THE UK

2.02

FWCI of international collaborations in P_2.

EU COLLABORATION IMPACT OF SCOTLAND

2.67

FWCI of EU collaborations in P_2.

EU COLLABORATION IMPACT OF ENGLAND

2.29

FWCI of EU collaborations in P_2.

SCOTLAND PUBLISHED MOST FREQUENTLY WITH THE USA

16,983

Joint publications between Scottish and US institutions in 2007-2016.

INTERNATIONAL PUBLICATIONS INVOLVING SRI LANKA HAD THE HIGHEST FWCI FOR SCOTLAND (127 JOINT PUBLICATIONS)

24.58

3.1. Academic collaboration

We define five types of academic collaboration: single author, institutional, national, intra-UK and international. Single author publications are self-explanatory. Institutional collaboration is where all authors of a publication are affiliated to the same institution (usually a university). National collaborations are where all authors of a publication are from at least two institutions in the same country. For the scope of this report, we have further limited this for the UK nations such that in the case of Scotland, for example, national collaboration refers to the case when all authors of a publication are from Scotland and the same is valid for other UK nations as well.

For this report, we have used a strict definition of international collaboration. Publications involving authors from more than one UK nation, and no other nation outside the UK, are intra-UK publications. To be clear, a publication with an author from Scotland and an author from England is not considered national or international, but intra-UK. International collaboration is where there is at least one author from a Scottish institution and one from a country outside the UK. The same definition is used for UK publications as well. The table below gives some further examples to clarify the methodology.

	England	Scotland	Denmark	Classification
Publication A	X	X		Intra UK
Publication B		X	X	International
Publication C	X	X	X	International
Publication D		X X		Institutional or National

3.2. Scotland's international collaboration

Scotland's share of international collaboration continues to rise

Scotland's share of publications involving international collaboration rose from 43% in 2007 to 57% in 2016 (a 17% increase from P_1 to P_2), with all other publication types decreasing (Figure 3.1). Publications with international collaboration have consistently higher citation impact on average than other types of publications (Figure 3.2), a trend observed across the world. The share of international collaboration is highest in Biological Sciences and Physical Sciences (67% and 65% respectively in 2016). Humanities is the only field in which the share of single author publications is higher than any other type, which is also a common trend elsewhere. There is a similar picture for the Business field, although the trend is towards a higher share of international publications.

Figure 3.1— *Share of collaboration types for Scotland, 2007-16. Source: Scopus.*

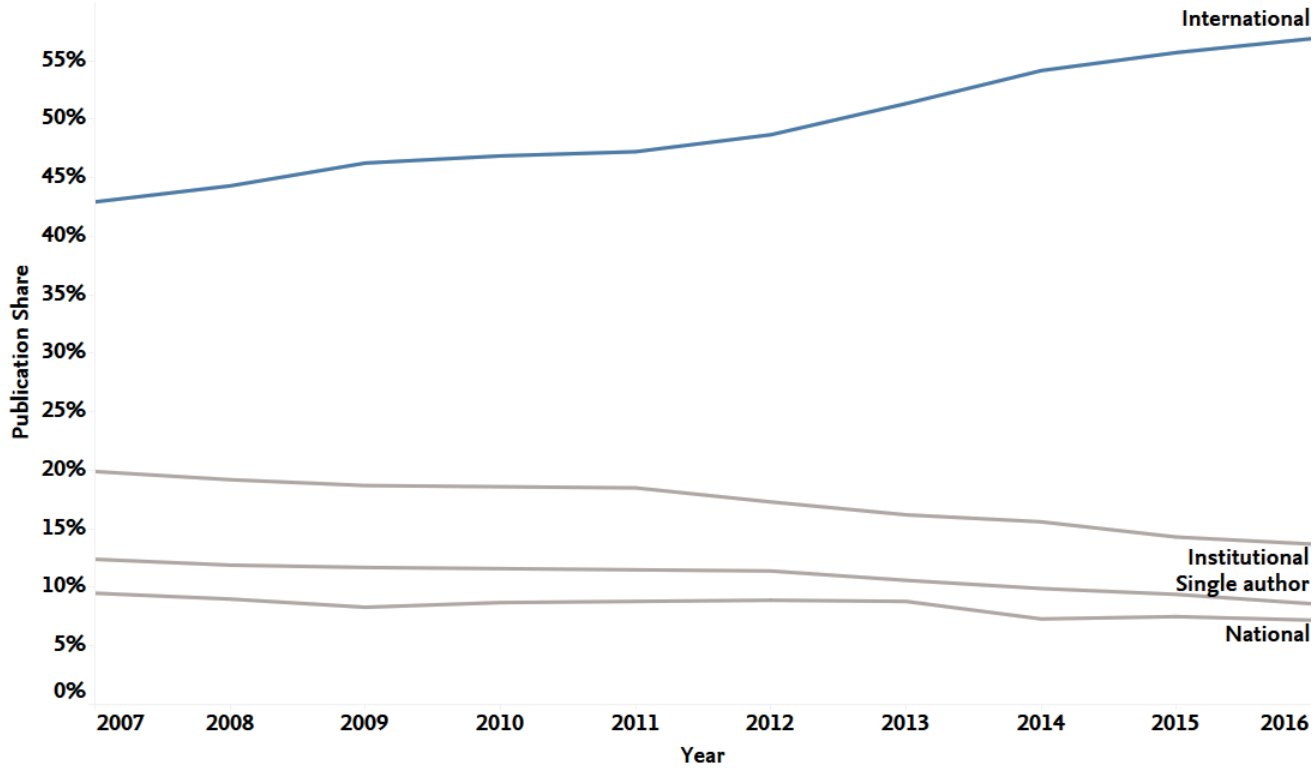


Figure 3.2— *FWCI of collaboration types for Scotland, 2007-16. Source: Scopus.*

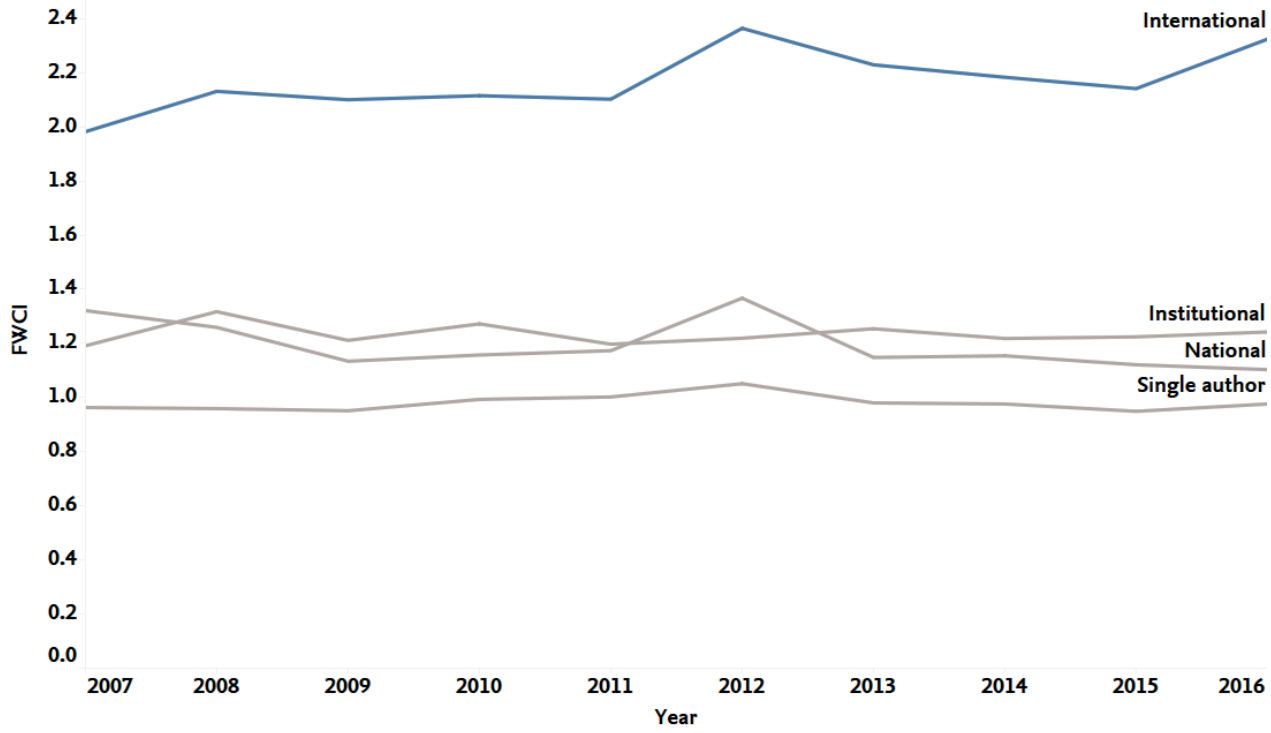
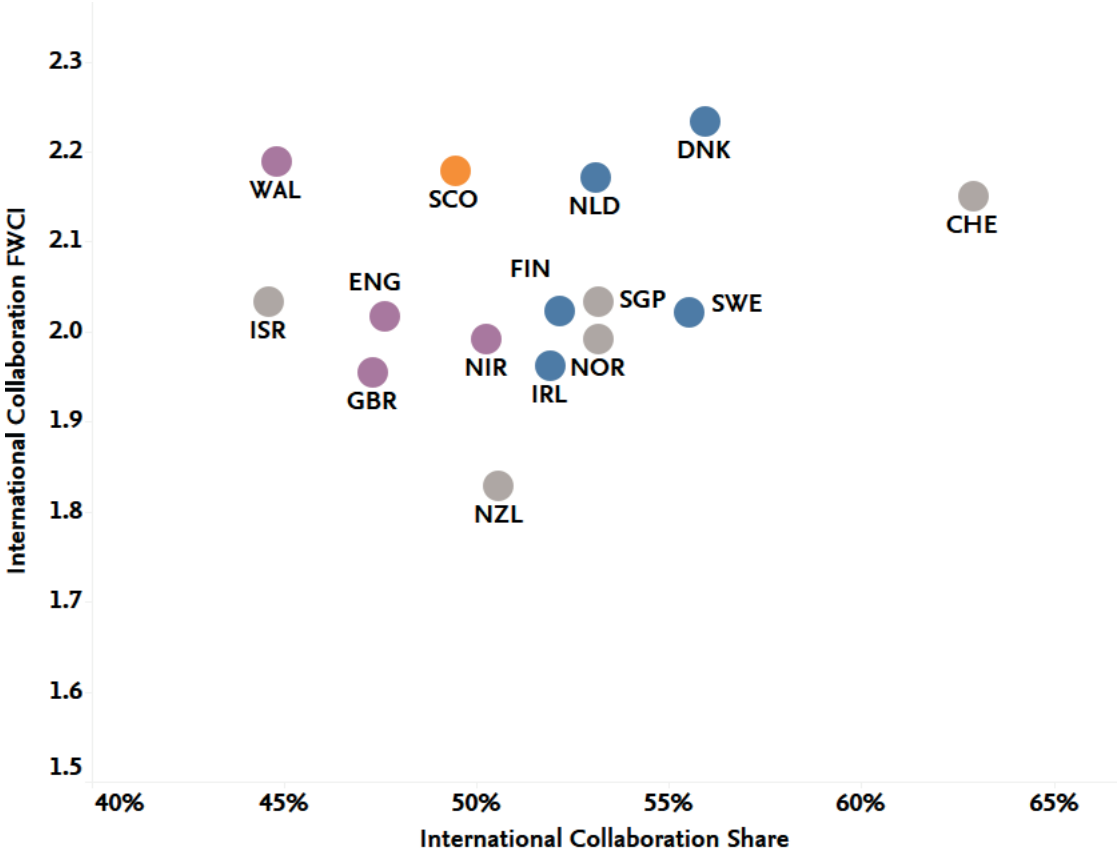


Figure 3.3 shows that of the UK countries, Northern Ireland has the largest share of international collaboration (50.3%), followed closely by Scotland (49.4%). Both Northern Ireland and Wales increased their share of international collaboration by over 22% from P_1 to P_2. Scotland's international collaboration share increased by 17%, which is slightly lower than that of England and UK average, which is 19%.

Among the comparator nations in this report, Switzerland has the highest share of international collaboration (63%) on average for the ten-year period. The majority of Switzerland's international collaboration is with the US and Germany, followed by other EU countries, and most articles are medical. Singapore on the other hand showed the highest growth in international collaboration, increasing its absolute number of internationally collaborated publications from around 5,000 in 2007 to nearly 12,000 in 2016 (an increase of 135%) and share by 23% from P_1 to P_2. Singapore's most frequent collaborator is China (focusing on Engineering and Computer Science), followed by the US (focusing on Medicine and Engineering among others). One could suggest that China comes out as the top collaborator due to volume, but this is not the case – China is not among the top 5 collaborating countries for any other comparator nation in this report, suggesting that the Singapore - China link may be due to geography, language and cultural affinity.

For 2007-2016, Denmark has the highest average FWCI resulting from international collaboration (2.23), followed closely by Wales (2.19), Scotland (2.18), the Netherlands (2.17) and Switzerland (2.15). Scotland's international collaboration FWCI is higher than that of the UK average (1.95) and England (2.02).

Figure 3.3— *Share of internationally collaborated publications vs citation impact resulting from these publications. Average values for the 2007-16 period. Colours of circles indicate different groups- UK nations: purple, EU: blue, non-EU grey. Source: Scopus.*



3.3. Scotland's collaborations involving EU countries

Scotland EU collaborations has increased, and second among UK Nations to Wales.

In the context of Scotland and Brexit, a valid question is to understand the importance of EU collaborations with Scotland. While funding received from the Scottish Funding Council is the largest source of funds for Scottish institutions, universities received £97m of funding from various EU sources, which accounted for around 10.1% of the total research income for universities.[21] According to Scotland Europa figures, as of March 2018 Scotland had secured over €468 million from Horizon 2020, which accounts for 1.61% of the total allocated Horizon 2020 budget, and represents 11.1% of the total funding awarded to UK organisations[22]. While England received the largest amount of funding in absolute terms, Scotland received the most income per capita (€55) compared with the UK average (€40)[23].

Figure 3.4 shows that among the UK nations Northern Ireland had the highest share of international publications with an EU partner in P_2 (58.2%), followed by Scotland (56.3%). The shares for England and Wales were 52.7% and 53.6% respectively. Publications involving EU partners have even higher impact on average than the average of all international publications in the UK and Scotland benefits most from these collaborations in P_1 and was second only to Wales in P_2 (Figure 3.5). From P_1 to P_2, all UK nations increased their share of international collaborations with the EU, except for Northern Ireland, and in each case the impact increased.

In most subject fields, the citation impact for international collaborations with the EU were higher throughout the analysis period. The difference is most visible in Clinical Sciences (20% higher FWCI in P_2 for publications with EU partners compared to all international publications in the same subject) and least pronounced in Mathematics (8% higher FWCI with EU partners).

[21] https://beta.gov.scot/policies/science-and-research/university-research/
[22] Scotland's Position Paper on the 9th Framework Programme for Research and Innovation. https://portal.scotlandeuropa.com/file/download?id=2334
[23] Technopolis (2017). The role of EU funding in UK research and innovation. https://www.raeng.org.uk/publications/reports/eu-funding-in-uk-research-and-innovation

Figure 3.4— *Share of international collaborations involving EU countries for UK nations, for P1 and P2. Source: Scopus.*

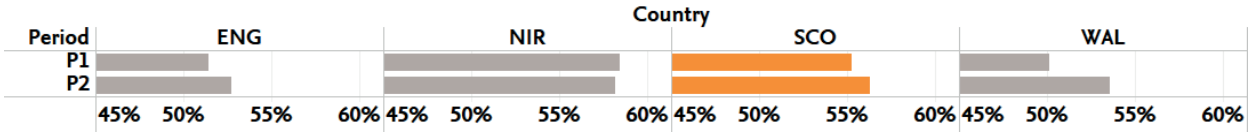


Figure 3.5—*FWCI of international collaborations vs international collaborations involving EU countries, for P1 and P2. Source: Scopus.*

Period	Type	ENG	NIR	SCO	WAL
P1	All International	2.02	1.78	2.09	2.01
	EU International	2.24	1.97	2.38	2.29
P2	All International	2.02	2.15	2.25	2.32
	EU International	2.29	2.56	2.67	2.91

3.4. Share and impact of international collaboration

The share and impact of international collaboration has increased the most in Social Sciences and Humanities

For Scotland, the share of international collaboration increased in all subject areas from P1 to P2, most noticeably in Humanities (27.5%) and Social Sciences (27.4%) (Figure 3.6). The citation impact resulting from collaboration increased most for the Humanities (27.8%) and Social Sciences (19.2%). The impact declined in some areas including Engineering (-2.5%), Health & Medical Sciences (-1.2%) and Clinical Sciences (-0.7%).

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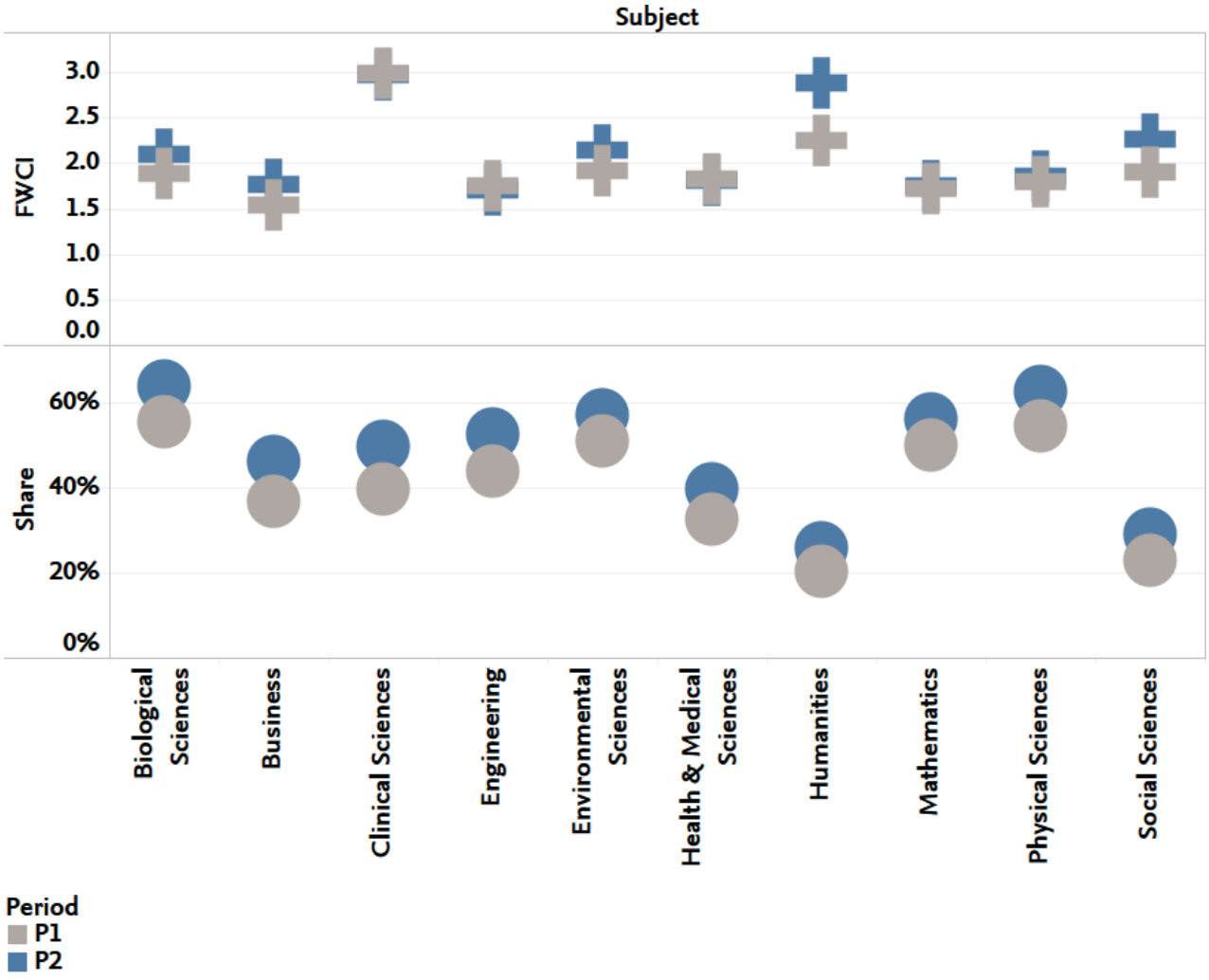
Figure 3.6— *Share and impact of international collaboration for Scotland across subject fields, for P1 and P2. Source: Scopus.*



3.5. Scotland's frequent and impactful collaborators

Scotland's most frequent collaborator is the USA, but the most impactful collaborations are with Sri Lanka

For 2007-2016, Scotland collaborated most with the USA, followed by Germany and France and joint publications with the top 20 collaborators were at least three times the citation impact of the global average (Table 3.1). Sorting by FWCI shows that collaborations with Sri Lanka, Ghana and Uganda have the greatest impact. This is mainly due to large multinational projects such as the Global Burden of Disease Study which Scottish institutions participate in.

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Table 3.1— *Top collaborating countries for Scotland, sorted by co-publication numbers and FWCI of co-published publications impact, 2007-2016. A filter of minimum 100 publications was applied for the FWCI list. Source: Scopus.*

Sorted by co-publications			Sorted by co-publication FWCI		
Collaborator	**Co-publications**	**Co-publication FWCI**	**Collaborator**	**Co-publications**	**Co-publication FWCI**
USA	16,983	3.43	LKA	127	24.58
DEU	10,631	3.57	GHA	118	22.74
FRA	7,526	4.19	UGA	144	19.41
ITA	6,819	4.17	PHL	129	18.51
AUS	6,477	4.23	IDN	147	15.76
NLD	6,236	4.58	BGD	136	15.65
ESP	6,076	3.99	JOR	151	14.91
CHN	5,782	3.48	KEN	261	12.39
CAN	5,754	4.34	NGA	279	12.08
CHE	4,308	4.75	PER	136	11.85
SWE	3,729	5.42	EST	430	11.08
JPN	3,113	5.09	LVA	105	10.91
DNK	2,873	5.51	HKG	451	10.55
BEL	2,642	5.21	TZA	176	10.30
NOR	2,586	5.42	BGR	296	10.26
POL	2,516	3.96	LUX	116	9.95
IRL	2,473	4.09	QAT	263	9.78
RUS	2,404	5.14	MEX	743	9.43
BRA	2,373	4.73	IRN	421	9.21
AUT	2,241	5.35	ISL	466	8.92

Figure 3.7 below shows a collaboration map for Scotland, filtered to those with there are at least 100 co-publications. The size of the circles indicates the collaboration output whereas the colour indicates the citation impact resulting from collaboration. Scotland is clearly a global collaborator.

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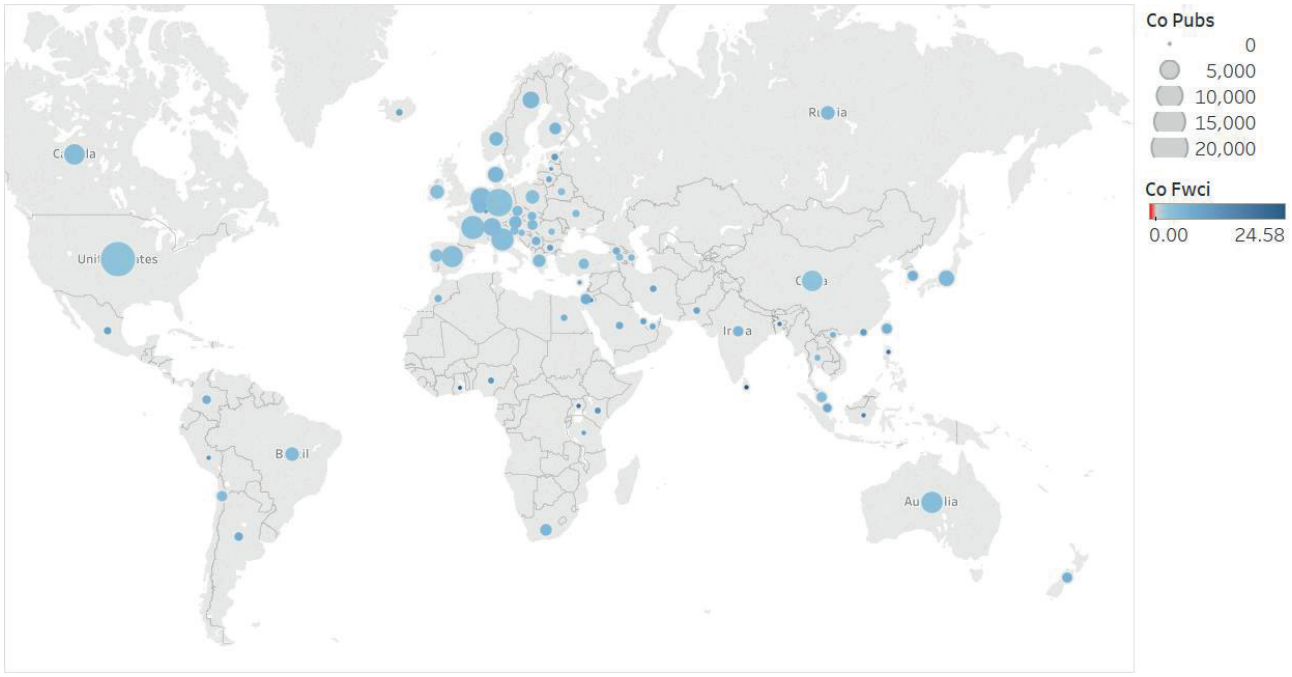
Figure 3.7— *Collaboration output and impact of international collaboration for Scotland with countries where there are at least 100 co-publications. Source: Scopus.*



3.6. Top international collaborators

Scotland's institutions collaborate most with Harvard University.

For both periods, Scotland's most frequent collaborator was Harvard University, with these joint publications having a citation impact more than 6.5 times the world average in P2. Most of the institutions in the top 20 most frequent collaborators list for P1 and P2 are the same, although there are new entrants from Australia, France and the USA, as well as the Chinese Academy of Sciences in P2.

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Table 3.2— *Top 20 international collaborators for Scotland, based on joint publication numbers. First table for 2007-2011 and second table for 2012-2016. Source: Scopus.*

2007-2011			2012-2016		
Institution	Joint publications	Joint publication FWCI	Institution	Joint publications	Joint publication FWCI
Harvard University	1,400	4.82	Harvard University	2,394	6.66
Spanish National Research Council	1,303	2.45	Universite Paris Saclay	2,065	4.59
Universite Paris Saclay	1,210	3.15	Spanish National Research Council	1,843	3.54
University of Toronto	925	4.05	University of Copenhagen	1,728	6.42
Universite Pierre et Marie Curie	890	3.81	Universite Pierre et Marie Curie	1,706	5.02
University of Padova	886	2.43	University of Toronto	1,604	6.61
University of Rome La Sapienza	871	3.60	University of Heidelberg	1,583	6.12
Universite Paris-Sud	828	2.99	Universite Paris-Sud	1,578	4.63
Massachusetts Institute of Technology	817	3.41	University of Melbourne	1,396	7.17
McGill University	801	3.35	University of Sydney	1,373	6.36
University of Wisconsin	794	3.38	University of Rome La Sapienza	1,355	4.64
The Ohio State University	772	3.01	Aix Marseille Universite	1,344	3.73
Johns Hopkins University	756	3.92	Massachusetts Institute of Technology	1,326	4.54
University of British Columbia	755	3.51	University of British Columbia	1,294	6.76
University of Pennsylvania	750	3.40	Stanford University	1,283	7.13
University of Copenhagen	747	5.34	University of Amsterdam	1,261	5.09
Stanford University	742	4.31	University of Washington	1,252	8.99
University of California at Los Angeles	724	4.03	Universite Paris 7	1,237	4.32
University of Heidelberg	720	4.55	Chinese Academy of Sciences	1,231	4.11
California Institute of Technology	719	3.25	University of Michigan	1,214	5.27

3.7. Mobility

Scottish researchers were highly mobile, with over 89% of active researchers having published at least one article using a non-Scottish institutional address.

In this section we present an overview of research mobility using Scopus author profile data to derive a history of Scottish author affiliations, recorded in their published articles. They are assigned to mobility classes, defined by the type and duration of observed moves. Note that tracking of affiliation history of researchers may be less reliable in the Social Sciences and Humanities as proportionally more of their publications are in the form of books, monographs and non-textual data which are not captured in this report.

A total of 148,450 author profiles were identified in Scopus of which 52,466 were identified as active researchers. The 'active researcher' filter is used to exclude author profiles with relatively few articles over the 21-year period of analyses, as these profiles are likely to represent individuals who have left the research system. The filter therefore restricts the analysis to those authors with at least one article in the latest 5-year period (2012-2016) and at least ten articles in the entire 21-year period (1996-2016), or those with fewer than ten articles in 1996-2016, but have at least four articles in 2011-2015.

Mobility classes

The measurement of international researcher mobility in the published literature is complicated due to the difficulties in teasing out long-term mobility from short-term mobility (such as doctoral research visits, sabbaticals, secondments, etc.), which might be deemed instead to reflect a form of collaboration. In this study, researchers who stayed overseas for two years or more were considered 'migratory' and were further subdivided into those where the researcher remained abroad, or where they subsequently returned to their original country. Researchers who stayed overseas for less than two years were deemed 'transitory' and were also further subdivided into those who mostly published under a Scottish and non-Scottish 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 most of their articles (for transitory mobility). In individual cases, these criteria may result in authors being assigned migratory patterns that may not accurately reflect the real situation, but such errors are assumed to be evenly distributed across the groups and so the overall pattern remain valid. Researchers without any apparent mobility based on their published affiliations were considered 'non-migratory'.

This mobility analysis is based on each author's output for the period 1996-2016, which captures a mixed cohort of researchers. Some researchers may publish articles during the entire period, others have become active only relatively recently, and yet others may have (mostly) stopped publishing. This means that researchers who have entered the cohort relatively recently will not have had as many opportunities to be included in the Migratory and Transitory groups. Moreover, the set of short publication history researchers also includes PhD students, who typically do not move between different institutions. Therefore, because of the methodology, the relative mobility of researchers with short publication histories will be lower.

Also, although researchers classified as non-migratory may have travelled and collaborated internationally in this period, their activities did not lead to a peer-reviewed article with an affiliation to a non-Scottish institution, captured in the Scopus database.

Mobility indicators

To better understand the composition of the groups defined above, three aggregate indicators were calculated for each to represent the productivity and seniority of the researchers they contain, and the FWCI scores for their articles.

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

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

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

All three indicators are calculated for each author's entire output in the period (i.e., not just those articles listing a Scottish address for that author).

Figure 3.8— *International mobility of Scottish researchers, 1996-2016. Source: Scopus*

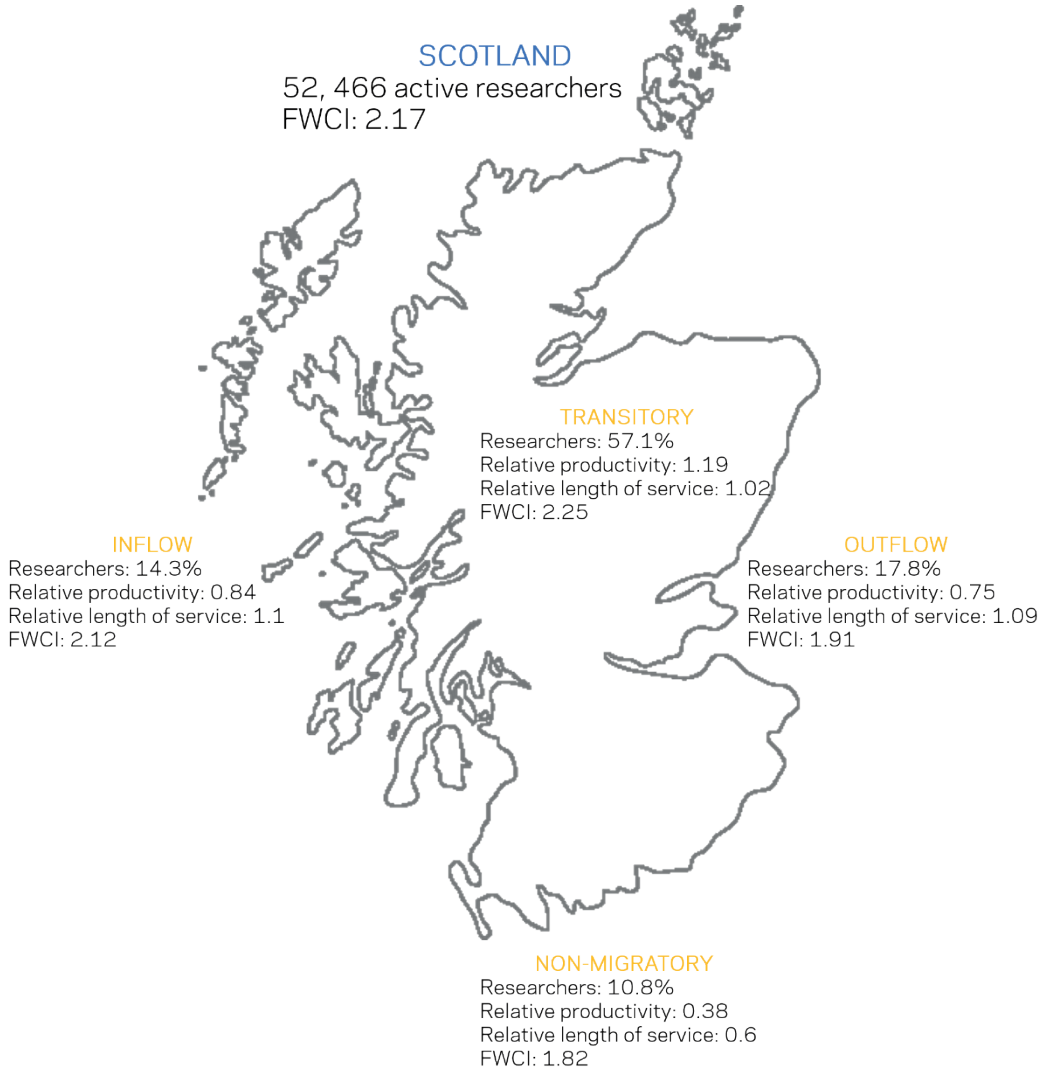

Figure 3.8 gives a snapshot of researcher mobility patterns based on the available data at the author level for the 1996-2016 period. Scottish active researchers were highly mobile internationally, with over 88% of active researchers having published at least one article under a non-Scottish affiliation (total of Inflow, Transitory and Outflow categories). This is much higher than the UK average of 72%, as indicated in the 2016 BEIs report; the methodologies in both reports follow a consistent approach.

As well as being more senior, the relative productivity rates (articles published per year since first appearance as an author) of all active researchers who were mobile were at least twice those of the non-migratory researchers. Researchers in the Outflow group were associated with relatively lower productivity and citation impact than those who come to Scotland for short (Transitory) or long (Inflow) periods. The Transitory group accounted for 57% of all the active researchers and were associated with the highest productivity and citation impact compared to other groups. This is similar to the findings of the 2016 BEIS report which showed that Scotland, as with other UK nations, has a net outflow of researchers and a large group of transitory researchers.

Table 3.3 further breaks down the mobility showing the overall international mobility, mobility to the UK, mobility within the EU and mobility outside the EU. The highest productivity (1.89) and FWCI (2.43) is

associated with those researchers that are transitory inside the EU, and mobility from within the UK has the lowest productivity among transitory researchers (1.29). Another point worth mentioning is that while Scotland has a net outflow of researchers overall, it has a net inflow of researchers from other UK nations (8.5% of inflow from GBR vs 6.5% of outflow to GBR).

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Table 3.3— *International mobility of Scottish researchers broken down by region of migration: overall, within the UK, outside the EU and inside the EU, 1996-2016. Source: Scopus*

	INFLOW	TRANSITORY	OUTFLOW
Scotland	Researchers: 14.3% Relative Productivity: 0.84 Relative length of service: 1.10 FWCI: 2.11	Researchers: 57.1% Relative Productivity: 1.19 Relative length of service: 1.02 FWCI: 2.25	Researchers: 17.8% Relative Productivity: 0.75 Relative length of service: 1.09 FWCI: 1.91
GBR	Researchers: 8.4% Relative Productivity: 0.89 Relative length of service: 1.17 FWCI: 2.12	Researchers: 33.9% Relative Productivity: 1.29 Relative length of service: 1.05 FWCI: 2.35	Researchers: 6.5% Relative Productivity: 0.69 Relative length of service: 1.12 FWCI: 1.94
Inside EU	Researchers: 2.7% Relative Productivity: 0.76 Relative length of service: 1.04 FWCI: 1.86	Researchers: 22.9% Relative Productivity: 1.89 Relative length of service: 1.10 FWCI: 2.43	Researchers: 3.6% Relative Productivity: 1.15 Relative length of service: 1.07 FWCI: 2.37
Outside EU	Researchers: 5.4% Relative Productivity: 1.01 Relative length of service: 1.13 FWCI: 2.29	Researchers: 35.2% Relative Productivity: 1.51 Relative length of service: 1.10 FWCI: 2.34	Researchers: 5.7% Relative Productivity: 0.79 Relative length of service: 1.06 FWCI: 1.89

When Scotland is compared with the other UK nations (Figure 3.4), we see that Scotland has the highest share of incoming and outgoing researchers. Although Wales has the highest share of transitory researchers (58.4%), Scotland has the highest FWCI associated with transitory researchers (2.25). For all UK nations, transitory researchers have the highest productivity. For the incoming researchers the productivity is visibly higher for England (1.01) whereas for other countries it is around 0.85.

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Table 3.4— *International mobility of UK researchers broken down by country, 1996-2016. Source: Scopus*

	INFLOW	TRANSITORY	OUTFLOW
Scotland	Researchers: 14.3% Relative Productivity: 0.84 Relative length of service: 1.10 FWCI: 2.11	Researchers: 57.1% Relative Productivity: 1.19 Relative length of service: 1.02 FWCI: 2.25	Researchers: 17.8% Relative Productivity: 0.75 Relative length of service: 1.09 FWCI: 1.91
	INFLOW	TRANSITORY	OUTFLOW
England	Researchers: 11% Relative Productivity: 1.01 Relative length of service: 1.15 FWCI: 2.27	Researchers: 51.8% Relative Productivity: 1.19 Relative length of service: 1.04 FWCI: 2.19	Researchers: 16.5% Relative Productivity: 0.88 Relative length of service: 1.15 FWCI: 2.07
	INFLOW	TRANSITORY	OUTFLOW
Wales	Researchers: 13.3% Relative Productivity: 0.84 Relative length of service: 1.11 FWCI: 1.93	Researchers: 58.4% Relative Productivity: 1.16 Relative length of service: 1.01 FWCI: 2.02	Researchers: 17.3% Relative Productivity: 0.81 Relative length of service: 1.07 FWCI: 1.91
	INFLOW	TRANSITORY	OUTFLOW
Northern Ireland	Researchers: 12.2% Relative Productivity: 0.85 Relative length of service: 1.09 FWCI: 1.66	Researchers: 55.7% Relative Productivity: 1.22 Relative length of service: 1.04 FWCI: 1.64	Researchers: 17.5% Relative Productivity: 0.85 Relative length of service: 1.09 FWCI: 1.66

The above analyses show the importance of researcher mobility for Scotland and how it contributes to the impact of research. The EU mobility has the highest citation impact for Scotland which is a concern given Brexit. Uncertainties around Brexit and research collaboration with EU countries, particularly around the EU Framework Programmes, are particularly concerning for Scotland as a small nation benefiting highly from mobility.

Chapter 4

Knowledge Exchange

Highlights

SCOTLAND'S CORPORATE COLLABORATION SHARE

4.7%

of Scottish publications had corporate collaboration in P2 (2012-2016).

UK'S CORPORATE COLLABORATION SHARE

5.0%

of UK publications had corporate collaboration in P2 (2012-2016).

SCOTLAND'S CORPORATE COLLABORATION IMPACT

3.51

Average FWCI of publications with corporate collaboration from 2007-2016.

UK'S CORPORATE COLLABORATION IMPACT

2.64

Average FWCI of publications with corporate collaboration in 2007-2016.

TOP SUBJECT BY CORPORATE COLLABORATION SHARE FOR SCOTLAND

Engineering

6.4% of all publications are with corporate collaboration in P2 (2012-2016).

(Engineering for the UK average was 7%)

TOP SUBJECT BY CORPORATE COLLABORATION IMPACT FOR SCOTLAND

Clinical Sciences

Average FWCI of 6.5 for publications with corporate collaboration in P2 (2012-2016).

(Clinical Sciences for the UK had an equivalent score of 3.9)

TOP CORPORATE COLLABORATOR FOR SCOTLAND

GlaxoSmithKline

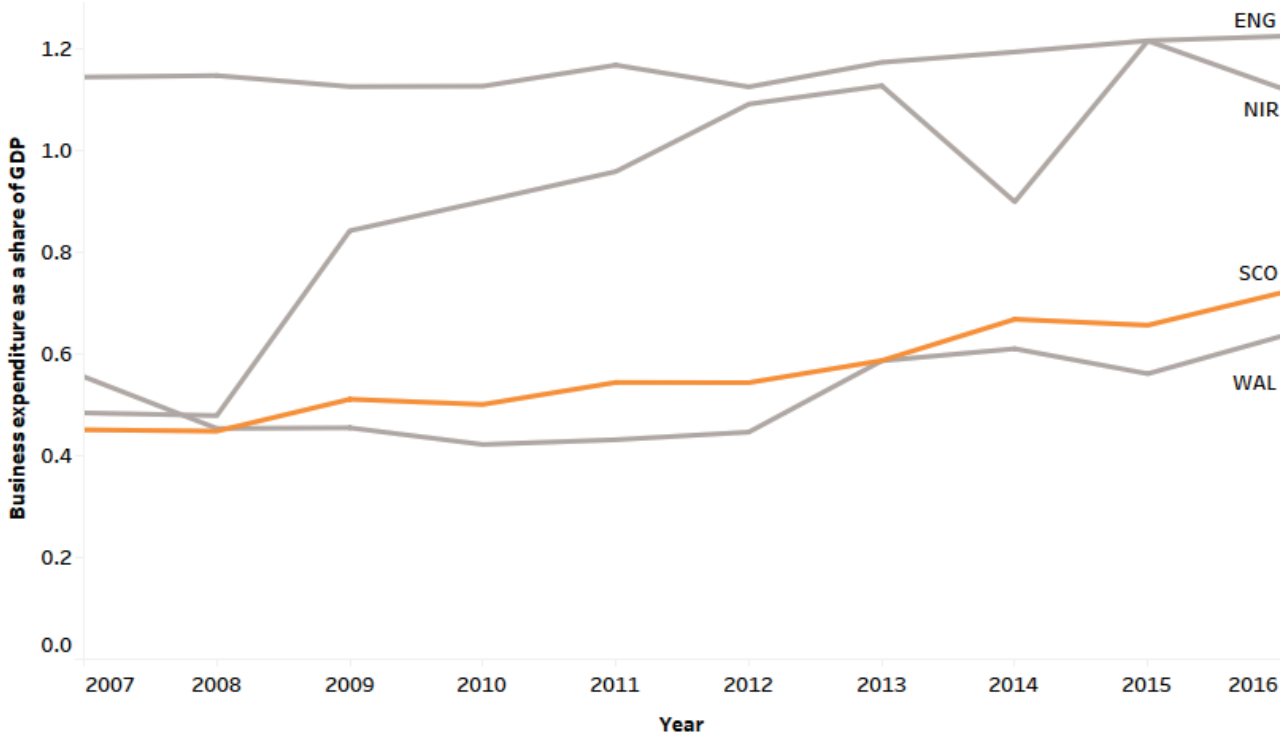
510 publications in 2012-2016 with an average FWCI of 3.7

4.1. Academic-corporate publications

Academic-corporate publication numbers are increasing, and their impact is increasing

As indicated in section 1.5, Scotland's share of business research and development expenditure is lower than that of other UK nations: 46% in 2016 compared with 67% for the UK. The 2015 Economic Strategy document[24] identified the challenge of increased R&D investment from Scottish businesses and pointed out that business expenditure on R&D (BERD) as a share of GDP remained below that of many OECD comparators, including Denmark, Sweden and Finland. Scotland's BERD as a share of GDP is third among UK nations (Figure 4.1).

Figure 4.1 - *BERD as a percentage of GDP for UK nations, 2007-16. Source: ONS*



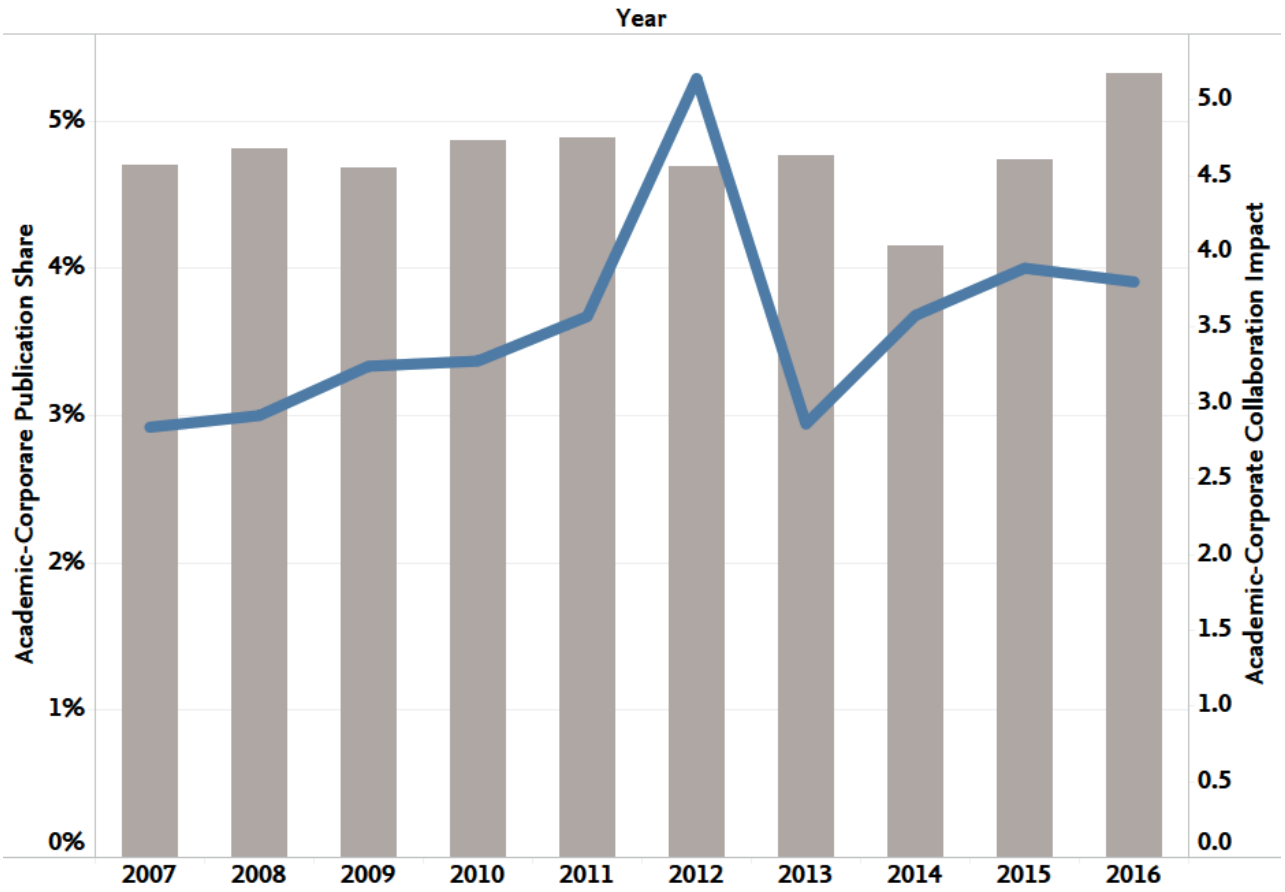
[24] Scottish Government (2015) Scotland's Economic Strategy

In this section we consider university-industry co-publications as one of the indicators of knowledge exchange between the two sectors. An academic-corporate joint publication is defined as a publication where there is at least one author from an academic institution and another one or more from a corporate entity.

Scotland's absolute number of academic-corporate joint publications increased by 14% from P_1 (4,014) to P_2 (4,572), but the share of these publications within the total publications of Scotland has decreased by 1% during the same period. An increasing trend can be observed from 2014 onwards, but it is yet to be seen whether this trend will continue. The decline in the share from P_1 to P_2 is not limited to Scotland; all comparators except Ireland, Northern Ireland and Wales experienced the same declining trend. Wales had the largest increase in share from P_1 to P_2 with 16%, followed by Northern Ireland (13%).

In terms of citation impact, all countries experienced an increase in the FWCI associated with corporate collaboration between P_1 and P_2. For Scotland, it rose 21% from 3.2 in P_1 to 3.8 in P_2. The largest increase in impact was for Northern Ireland (an increase of 152%, from 2.23 to 5.61), followed by Wales (90%) and New Zealand (70%).

Figure 4.2— *Share and FWCI of academic-corporate publications for Scotland, 2007-16. The bar indicates the share and the line indicates the FWCI. Source: Scopus*



Among the UK nations, Scotland has the second highest share of academic-corporate publications (Figure 4.3). For both England, which has the highest share, and Scotland there has been a decline for most of the 2007-2016 period, but both have experienced an increasing trend in the last couple of years. For the smaller nations of Northern Ireland and Wales, the shares have fluctuated across the years and it is difficult to tell the direction of the trend.

Corporate collaborations were less common in Scotland than in the EU comparator countries (Figure 4.4). As of 2013, Denmark had the highest share of academic-corporate publications across the comparator EU countries followed by Sweden and Finland. For Denmark, the top collaborator is the pharmaceutical company Novo Nordisk, which accounts for nearly a quarter of all academic-corporate publications. For both Finland and Sweden, there has been a decline in the absolute number of publications involving corporate collaboration. For Finland, the largest corporate collaborators were Nokia and Lucent. For Sweden, in 2007, AstraZeneca accounted for more than 20% of all corporate publications, which declined to around 14% in 2016. Interestingly, while AstraZeneca Swedish collaborations have been declining, publications with institutions in other countries have increased and have larger impact. Corporate collaborators of Scotland are discussed in Section 4.1.

Figure 4.3– *Share of academic-corporate joint publications for UK nations, 2007-16. Source: Scopus.*

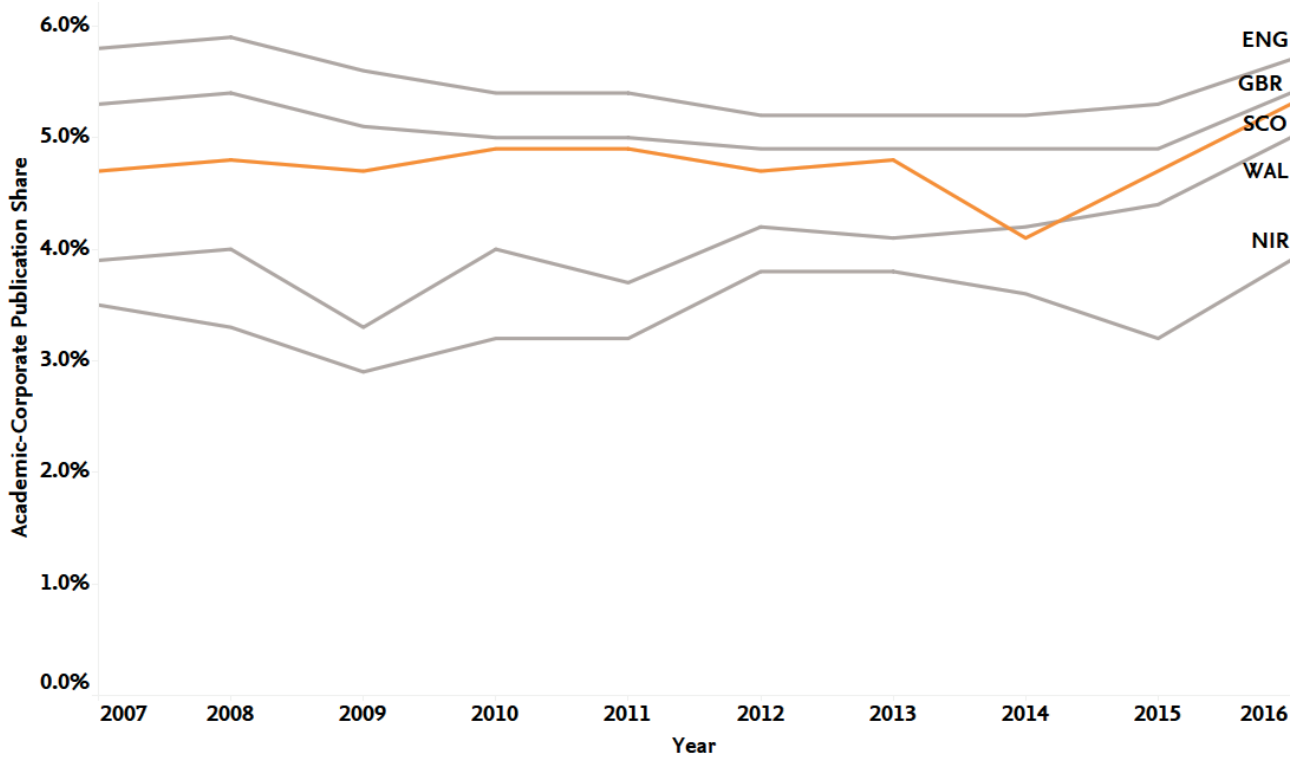
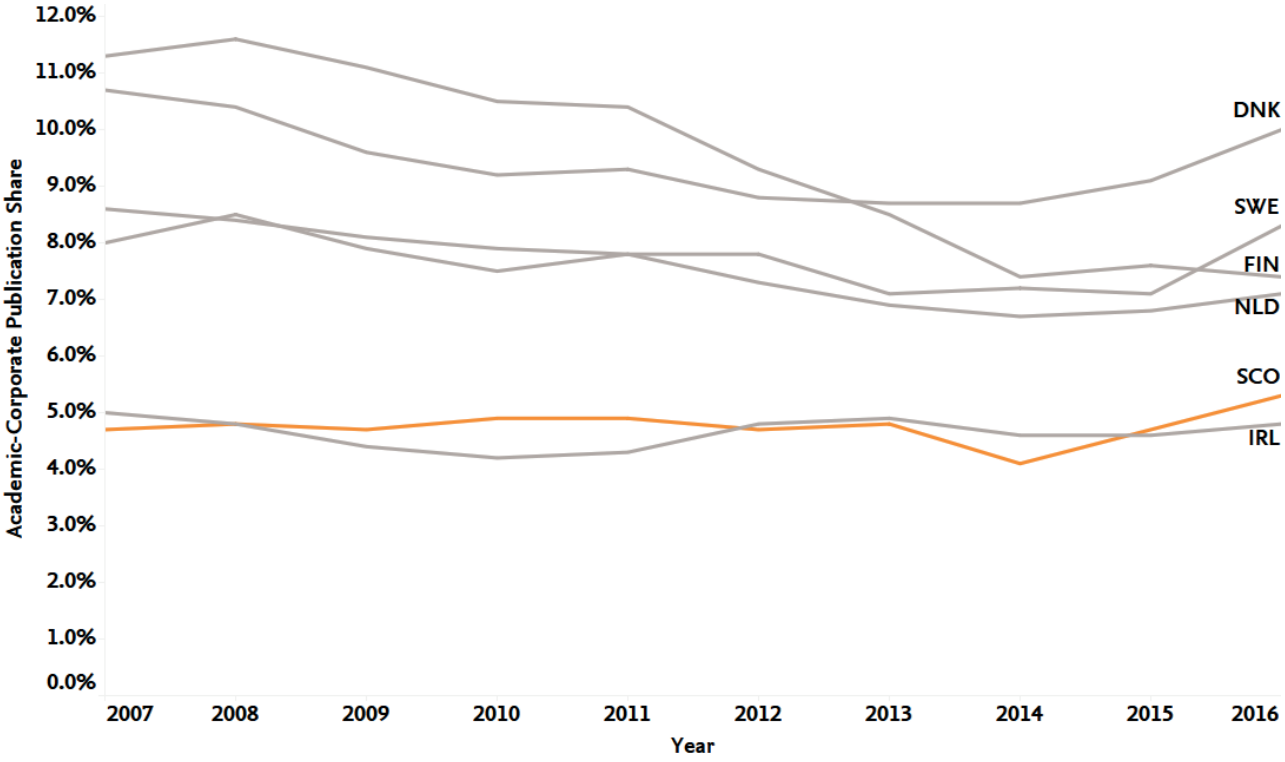
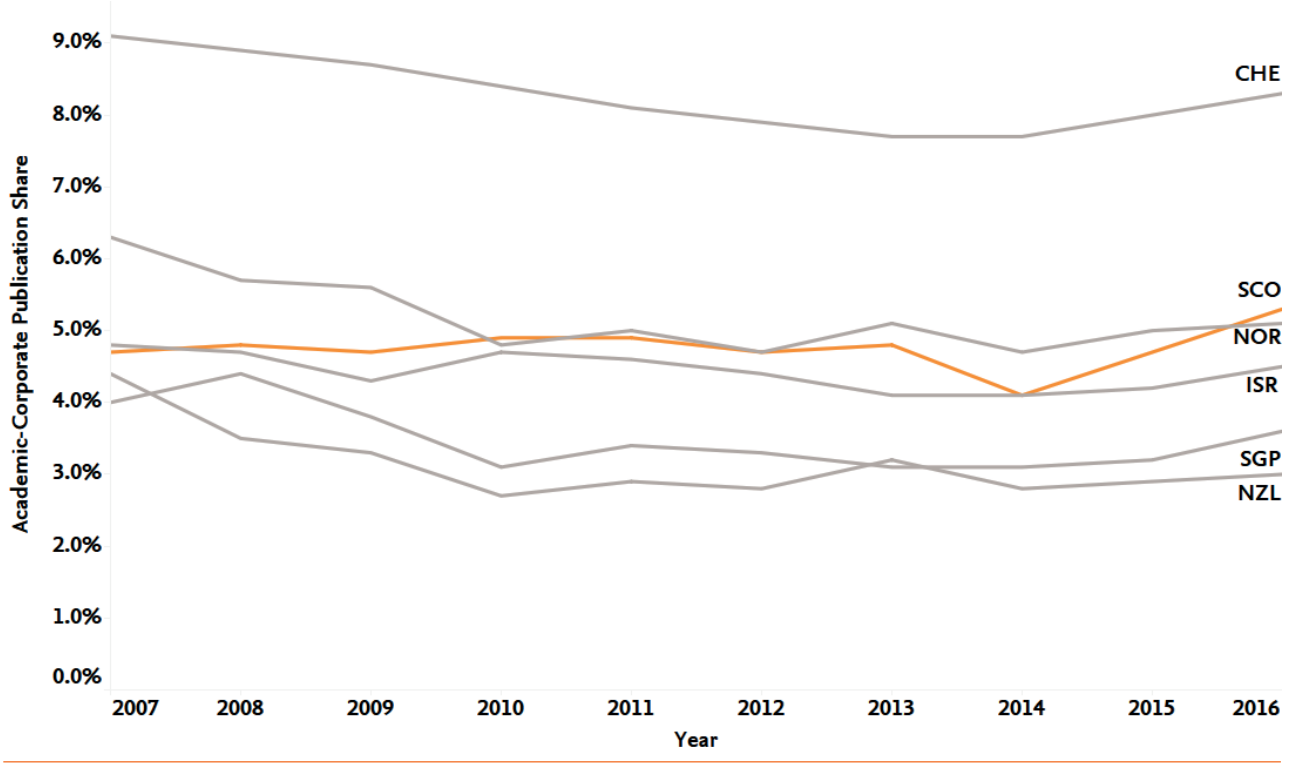


Figure 4.4 – *Share of academic-corporate joint publications for Scotland and EU countries, 2007-16. Source: Scopus*



Scotland ranks better when compared with the non-EU countries, ranking second in 2016 (up from fourth in 2007) (Figure 4.5). Switzerland has the highest share (and absolute number) of academic-corporate publications among the non-EU countries. Swiss multinational pharmaceutical company Novartis accounts for around 20% of all corporate collaborations.

Figure 4.5 – *Share of academic-corporate joint publications for Scotland and non-EU countries, 2007-16. Source: Scopus*



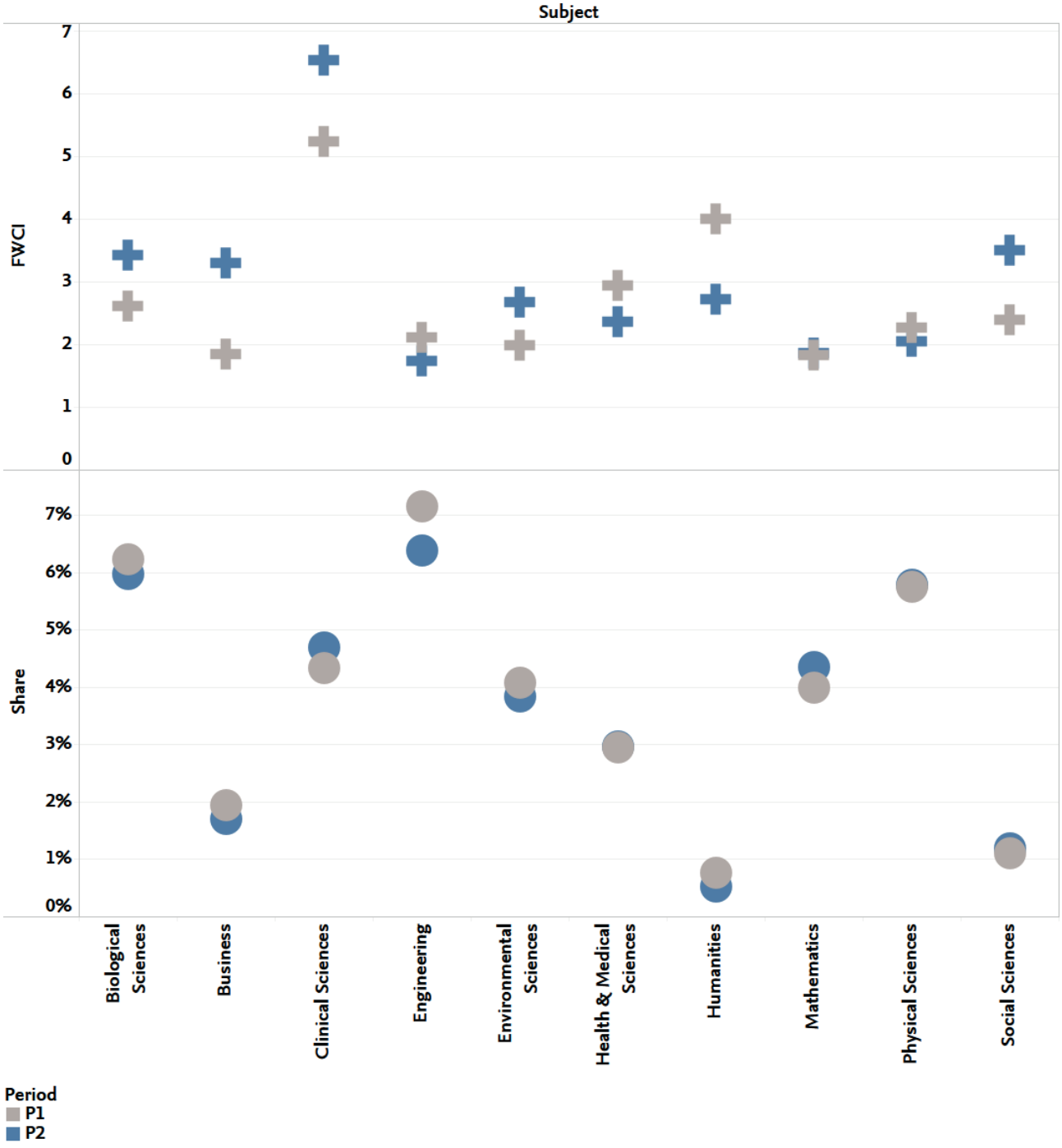
4.2. Corporate collaboration at the subject level

Corporate collaboration has increased most in the Clinical Sciences and Mathematics

In Scotland, the absolute number of publications with corporate collaboration increased across all subjects, except for the Humanities. The largest increase was in Clinical Sciences (35.2% from P_1 to P_2), followed by Social Sciences (34.1% from P_1 to P_2). In terms of share of corporate publications there is a different picture with Mathematics increasing its share by 9% and Clinical Sciences by over 8% (Figure 4.6). On the other hand, there were declines in the share of corporate publications in Engineering (-10.6%), Biological Sciences (-4.1%), Business (-12%), Environmental Science (-5.8%), and Humanities (-30.9%).

In terms of FWCI, publications in Business and Social Sciences had the largest increases but considering that the publication numbers are very limited (less than 100 per period), these increases should be interpreted with caution. Environmental Sciences and Biological Sciences publications with corporate collaboration also saw FWCI increases of over 30% from one period to the other. The largest decline in FWCI was in Health & Medical Sciences (-20%) and Engineering (-17%). For Engineering, there has also been a decline for England and Wales, though at a much smaller scale and for Northern Ireland there was a significant increase. For Health & Medical Sciences the only country that saw an increase in impact among UK nations was England.

Figure 4.6— *Share and impact of corporate collaboration for Scotland across subject fields, for P1 and P2. Source: Scopus.*



4.3. Corporate collaborators for Scotland

GlaxoSmithKline is the most frequent corporate collaborator in Scotland

Across the ten-year period, the largest number of joint corporate publications has been with GlaxoSmithKline (GSK), followed by Pfizer and AstraZeneca (Table 4.1). The volume of publications with GSK decreased from P_1 to P_2, although the impact of joint collaborations increased. The decrease in volume is not unique to Scotland; there has been a decrease in the joint publications for GSK overall. GSK, Pfizer and AstraZeneca are also among the top collaborators for England and Wales. Note that in P_2, the relative importance of IT companies such as Microsoft and IBM increased.

Rolls Royce is one of the corporate collaborators which is not in the top 20 for Scotland in P_2, whereas it is among the top collaborators for England and Wales, accounting for around 4% of their academic-corporate collaborations. While there are other corporate entities with which joint publications result in much higher citation impact, these should be interpreted with caution as the number of publications is small.

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Table 4.1— *Top 20 corporate collaborators for Scotland based on joint publication numbers. First table for 2007-11 and second table for 2012-16. Source: Scopus.*

2007-2011			2007-2011		
Institution	Joint publications	FWCI	Institution	Joint publications	FWCI
GlaxoSmithKline	510	3.71	GlaxoSmithKline	345	5.30
Pfizer	167	3.69	AstraZeneca	187	3.08
AstraZeneca	134	2.14	Pfizer	167	5.36
Institute of Occupational Medicine	128	2.72	Institute of Occupational Medicine	136	2.00
Electricite de France	122	1.54	Microsoft USA	111	4.75
Novartis	83	3.50	Novartis	102	5.49
Merck	72	4.23	Novo Nordisk AS	85	6.79
Microsoft USA	66	4.92	Eli Lilly	77	8.24
AstraZeneca Sweden	65	6.05	deCODE Genetics	72	14.59
Fera Science Ltd.	50	1.80	Merck	62	8.12
Novo Nordisk AS	40	7.25	IBM	59	2.08
Rolls-Royce	39	1.17	Amgen Incorporated	54	7.85
STMicroelectronics	38	3.74	AstraZeneca Sweden	52	3.47
Airbus Group	38	1.52	Genentech Incorporated	50	22.15
deCODE Genetics	35	17.64	STMicroelectronics	47	2.71
Atomic Weapons Establishment	35	2.62	Electricite de France	47	1.36
BP plc	34	2.06	Boehringer Ingelheim GmbH	44	4.63
Statoil ASA	33	2.81	Johnson & Johnson	38	5.67
Unilever	33	2.39	Statoil ASA	38	1.85
IBM	33	1.87	Hamad Medical Corporation	37	38.12

4.4. Patent citation / article ratio

Scotland's patent to article ratio is higher than for the rest of the UK

One of the ways of looking at knowledge transfer from university to industry is by looking at patent citation counts, i.e. how many times an entity is cited by patents in a given year. Table 4.2 gives the count of patent citations per thousand articles for Scotland and comparators. It should be noted that just as with citation data, patent citation data dips towards the end of the period as the time to accrue citations is not long. For most of the decade, Denmark and Switzerland had the highest ratio and while Switzerland maintained its leading position Denmark lost rank. Israel and Singapore increased their patent citation ratios in the last couple of years. In the case of Singapore, the largest applicant/owner of patents is A*STAR (Agency for Science, Technology and Research), the lead agency in Singapore driving mission-oriented research[25]. In Israel, the lead is with Yeda Research and Development Company, which is the technology transfer arm of the Weizmann Institute of Science. Patents citing Swiss research on the other hands are not driven by a national entity, but the multinational health company Roche.

If you look at the average number of patent citation counts across the nine-year period, Scotland is in ninth place out of 15 countries but leads all other UK Nations and is ahead of the UK average. The institutions which received highest patent citation numbers are University of Edinburgh and University of Glasgow in the second period.

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Table 4.2 — *Patent citation counts per 1000 scholarly output, for Scotland and comparators for 2007-16. The shading is per year, showing the leading countries in darker bluer Source: Lexis Nexis Univentio and Scopus.*

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	9-year average
CHE	65.8	58.0	50.6	43.5	35.6	28.6	18.1	11.0	1.2	34.7
DNK	70.8	57.7	53.0	42.8	30.4	27.2	16.6	9.8	0.7	34.3
ENG	46.2	43.0	35.1	30.2	23.2	17.4	13.3	7.9	0.8	24.1
FIN	46.0	42.3	38.6	32.4	24.4	20.4	16.1	8.9	0.6	25.5
GBR	43.7	41.1	34.3	28.7	22.2	17.1	12.6	7.4	0.8	23.1
IRL	56.3	50.9	37.9	36.2	25.3	20.6	10.8	7.0	0.8	27.3
ISR	55.0	49.6	43.2	39.7	29.9	25.9	16.0	11.9	1.2	30.3
NIR	36.6	32.6	30.7	24.2	20.7	18.8	9.0	4.6	0.6	19.8
NLD	59.5	54.8	47.9	41.8	32.5	21.7	17.9	9.9	0.8	31.9
NOR	36.0	32.1	27.6	23.8	18.7	14.3	9.7	4.9	0.7	18.7
NZL	30.3	21.7	19.3	15.3	12.8	11.7	6.2	4.6	0.5	13.6
SCO	42.5	43.2	39.3	30.3	22.9	20.2	13.5	7.6	0.8	24.5
SGP	46.6	44.3	45.8	35.6	31.1	30.0	20.6	13.3	1.3	29.9
SWE	64.1	58.9	44.3	37.7	29.1	25.0	15.6	10.4	0.9	31.8
WAL	37.1	31.3	31.2	25.0	21.9	13.1	9.5	6.8	0.3	19.6

[25] https://www.a-star.edu.sg/About-A-STAR/Overview

Chapter 5

Subject Field Analyses

Introduction to subject field analysis

In this section a more detailed view is given at a subject field level. As indicated in Appendix A, the ten subject fields used in this report are groupings of 27 ASJC subject areas. ASJC subject areas have further subfields - 334 in total. In the following sections two views are given per subject area.

First is a scatter plot for Scotland, for changes in the publication numbers and impact per ASJC 334 areas where there was a minimum of 100 publications per period. The threshold was introduced to limit the effect of outlier publications which can distort the results. Subject areas in the upper right corner increased in both indicators, whereas the below left corner indicates a decrease for both. The blue coloured circles indicate ASJC 334 subject areas which have improved more than the subject field average, which is marked in orange. The red coloured circles indicate subject areas which have decreased in both output and impact.

The second graph shows the publication number and impact change per subject field and per country from P_1 to P_2.

This chapter gives an overview of how subject areas change and precedes Appendix A on topics. The two sections are complementary in the sense that while this chapter is a broader view on more traditional subject areas, the following chapter looks at research areas in a much more granular level.

Table 5.1 shows ASJC 334 subjects which had more than 100 publications in P_2 and have at least twice the global FWCI score, independent of the direction of change from P_1 to P_2.

Figure 5.1— *ASJC 334 subjects with more than 100 publications in P2 and with an average FWCI of at least 2 (twice the global impact) in 2012-2016.*

ASJC subject	Subject field	P2 publications	P2 FWCI
Multidisciplinary	Multidisciplinary	1544	5.50
Archaeology (arts and humanities)	Humanities	462	3.12
Gastroenterology	Clinical Sciences	382	3.08
Emergency Nursing	Health & Medical Sciences	35	3.05
Global and Planetary Change	Environmental Science	444	3.01
General Medicine	Clinical Sciences	9762	3.00
Engineering (miscellaneous)	Engineering	260	2.99
Neuropsychology and Physiological Psychology	Clinical Sciences	318	2.74
General Arts and Humanities	Humanities	131	2.69
Rheumatology	Clinical Sciences	334	2.69
Archaeology	Social Sciences	443	2.60
Agricultural and Biological Sciences (miscellaneous)	Biological Sciences	200	2.59
Immunology and Allergy	Clinical Sciences	807	2.54
Hepatology	Clinical Sciences	204	2.54
General Earth and Planetary Sciences	Physical Sciences	559	2.53
Language and Linguistics	Humanities	963	2.47
Cardiology and Cardiovascular Medicine	Clinical Sciences	1651	2.40
Pulmonary and Respiratory Medicine	Clinical Sciences	680	2.39
General Health Professions	Health & Medical Sciences	19	2.34
Environmental Science (miscellaneous)	Environmental Science	292	2.30
Care Planning	Health & Medical Sciences	3	2.29
Automotive Engineering	Engineering	169	2.27
Genetics	Biological Sciences	3021	2.25
Oncology	Clinical Sciences	1374	2.25
Linguistics and Language	Social Sciences	947	2.24
Reproductive Medicine	Clinical Sciences	388	2.23
Colloid and Surface Chemistry	Engineering	187	2.21
Hematology	Clinical Sciences	470	2.21
General Physics and Astronomy	Physical Sciences	2782	2.19
Pharmacology	Biological Sciences	1086	2.19
General Immunology and Microbiology	Biological Sciences	717	2.19
Nuclear and High Energy Physics	Physical Sciences	1818	2.18
Immunology	Biological Sciences	1624	2.16
Medical Laboratory Technology	Health & Medical Sciences	75	2.13
Computer Science (miscellaneous)	Physical Sciences	153	2.12
Stratigraphy	Physical Sciences	149	2.11
Physics and Astronomy (miscellaneous)	Physical Sciences	889	2.11
General Engineering	Engineering	933	2.11
General Pharmacology, Toxicology and Pharmaceutics	Biological Sciences	266	2.10
Physiology	Biological Sciences	1098	2.10
Neurology (clinical)	Clinical Sciences	1471	2.09
Internal Medicine	Clinical Sciences	721	2.09
Plant Science	Biological Sciences	1045	2.09
Ecology	Environmental Science	1599	2.08
General Social Sciences	Social Sciences	374	2.08
Astronomy and Astrophysics	Physical Sciences	2301	2.07
General Environmental Science	Environmental Science	998	2.04
Forestry	Biological Sciences	446	2.03
Nuclear Energy and Engineering	Engineering	178	2.00

5.1. Biological Sciences

For Biological Sciences, Scotland has the highest overall FWCI among comparator countries, despite being positioned in the middle in terms of output (Figure 5.2). In terms of publication output, Singapore had the largest growth from P1 to P2 (49%), followed by Denmark (38%). For impact, however, a different picture emerges whereby Northern Ireland had a 21% increase, followed by Wales (13% increase) and Scotland (12%).

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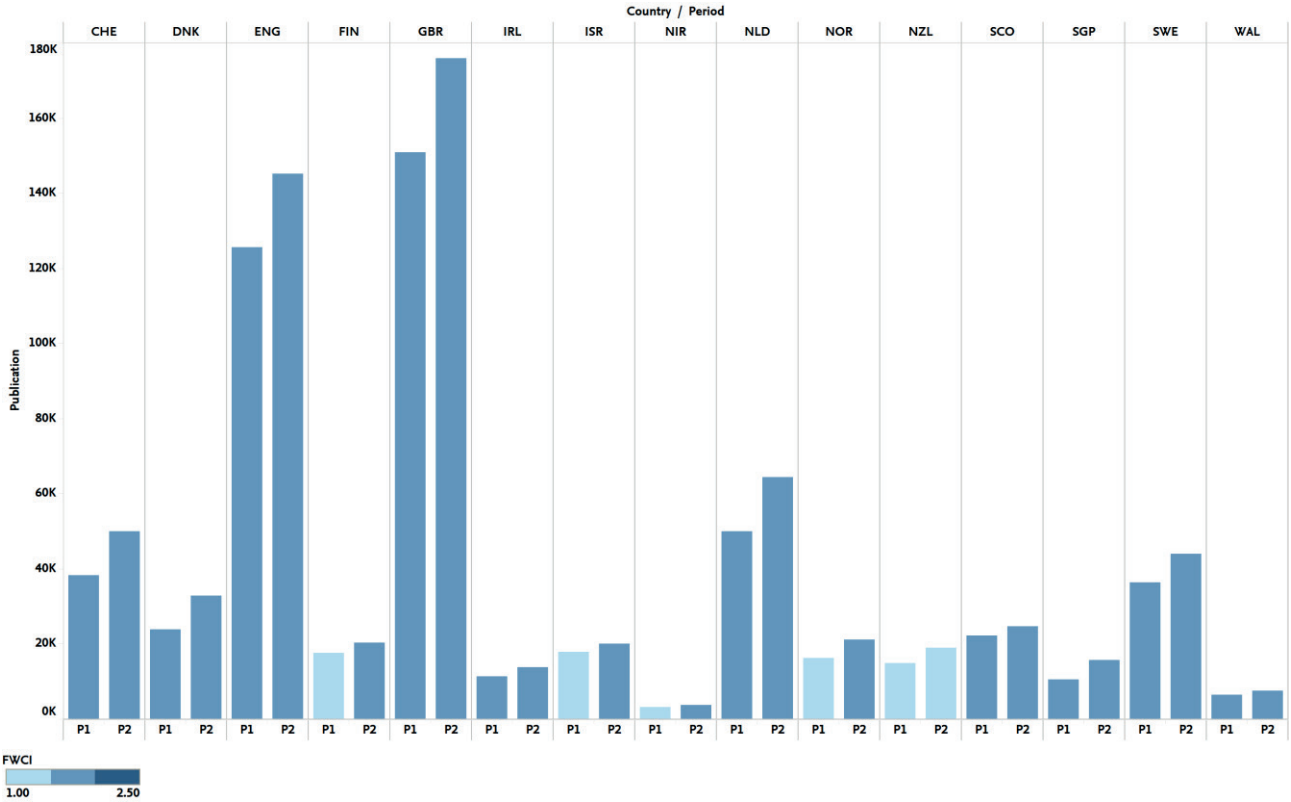
Figure 5.1— *Publication output and impact change from P1 to P2 per country, in the field of Biological Sciences. Color-coding reflects FWCI. Source: Scopus.*



Between 2007-2011 and 2012-2016, the volume and impact of publications in Biological Sciences increased by 11% on average (Figure 5.2). Many subfields have increased their impact and about half of them increased their publication volume. Publications in Virology, Insect Science, Forestry, Aging, Genetics, Physiology and General Pharmacology, Toxicology & Pharmaceutics saw increases in volume and impact above the average for Biological Sciences. Publications in Animal Science and Zoology, Applied Microbiology, and Food Science have decreased both in volume and impact.

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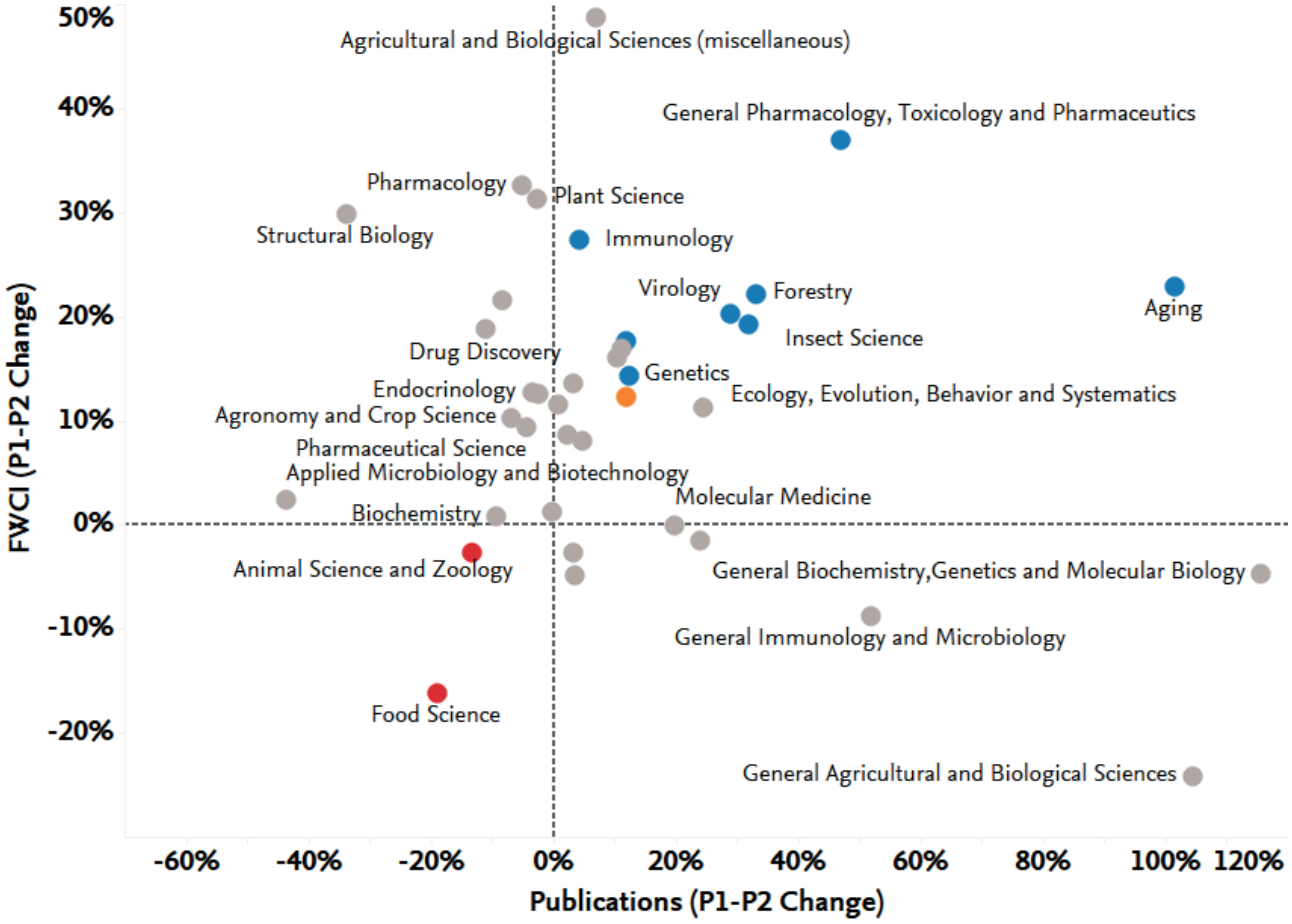
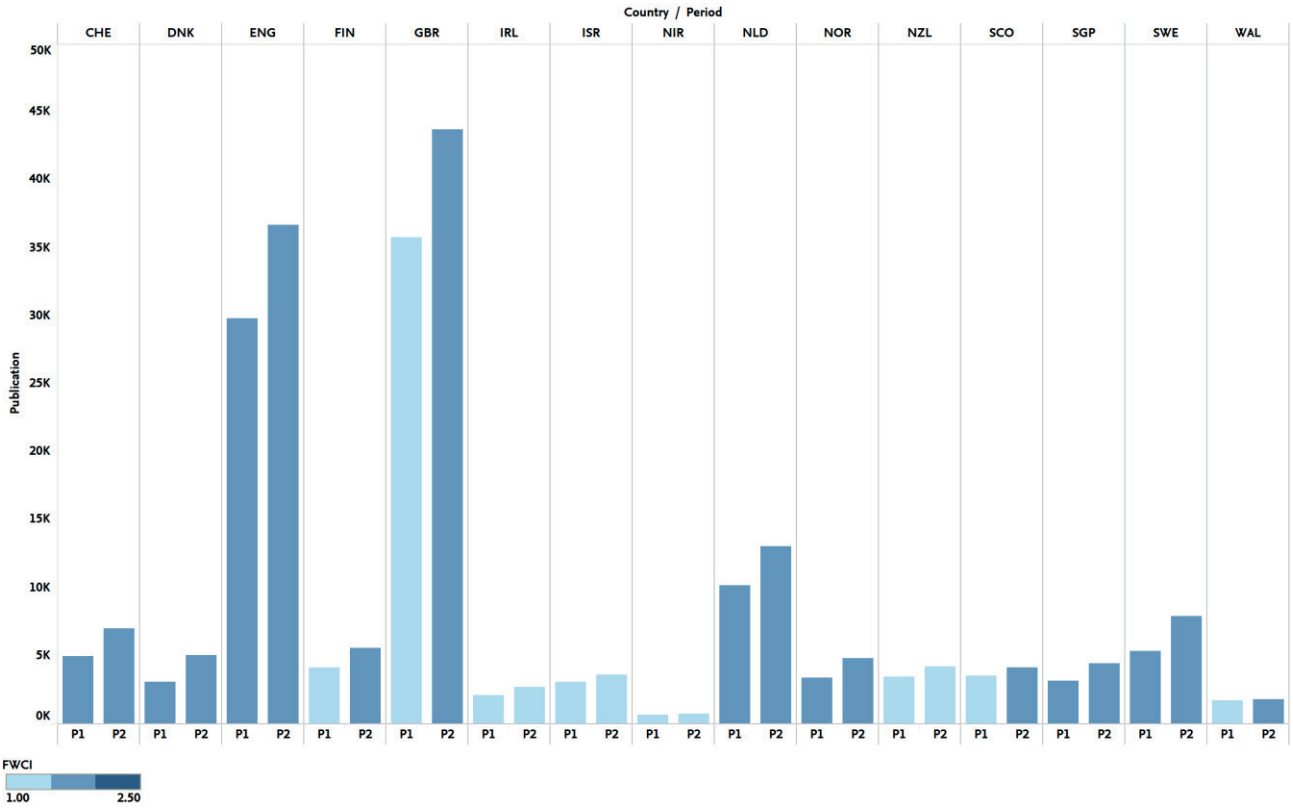
Figure 5.2— *Output and impact change per ASJC 334 subject area from P_1 to P_2 within Biological Sciences, with a minimum of 100 publications per period. Source: Scopus.*



5.2. Business

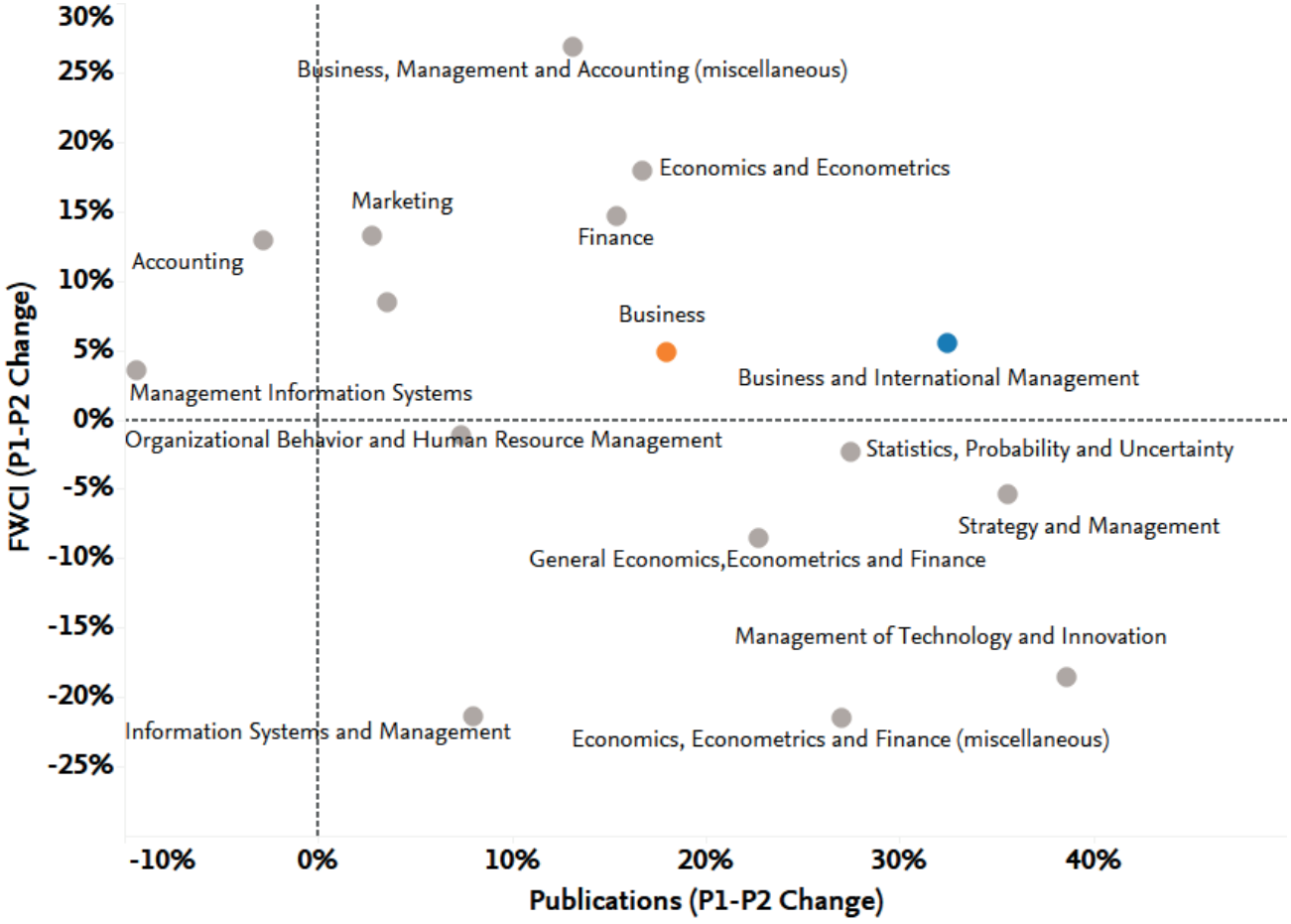
The largest increase in publication output within the Business field was by Denmark (64%), followed by Sweden (48%) (Figure 5.3). In P_2, the Netherlands had the highest citation impact, although its impact declined by 2% from the previous period. The largest increase in citation impact was in Finland (13%) and Wales (10%), with Scotland having a modest increase of 54%. Besides the Netherlands, the only country that saw a decline in impact was Israel (-13%).

Figure 5.3— *Publication output and impact change from P_1 to P_2 per country in the field of Business. Color-coding reflects FWCI. Source: Scopus.*



Publication volume in Business has increased by 18% on average from P_1 to P_2 whereas the impact has increased by 5% (Figure 5.4). While the volume of publications in most subfields have increased, impact in nearly half of the subfields saw a decline. Business and International Management was one subfield where both the volume and impact have increased beyond the average for the subject area. Two other subfields where the FWCI increased visibly were Business, Management & Accounting and Economics & Econometrics.

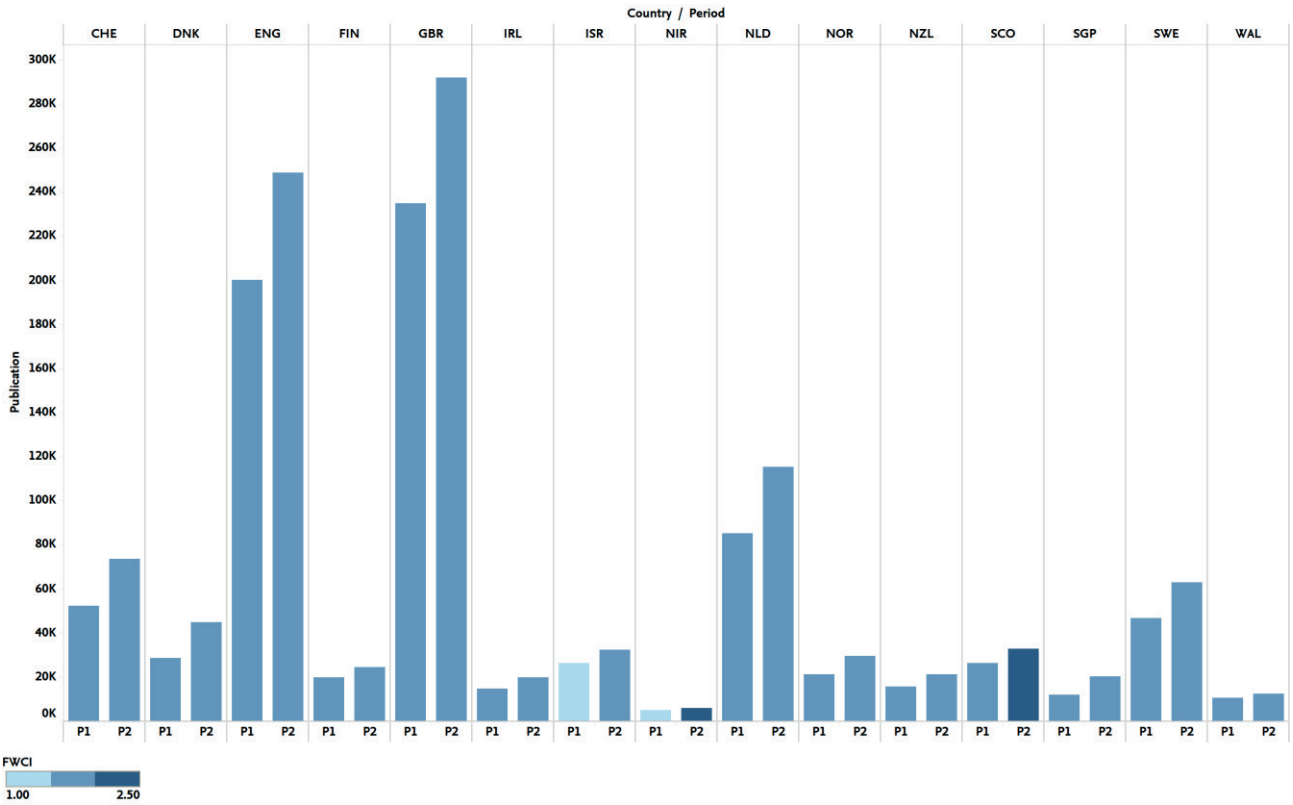
Figure 5.4 — *Output and impact change per ASJC 334 subject area from P_1 to P_2 within Business, with a minimum of 100 publications per period. Source: Scopus.*



5.3. Clinical Sciences

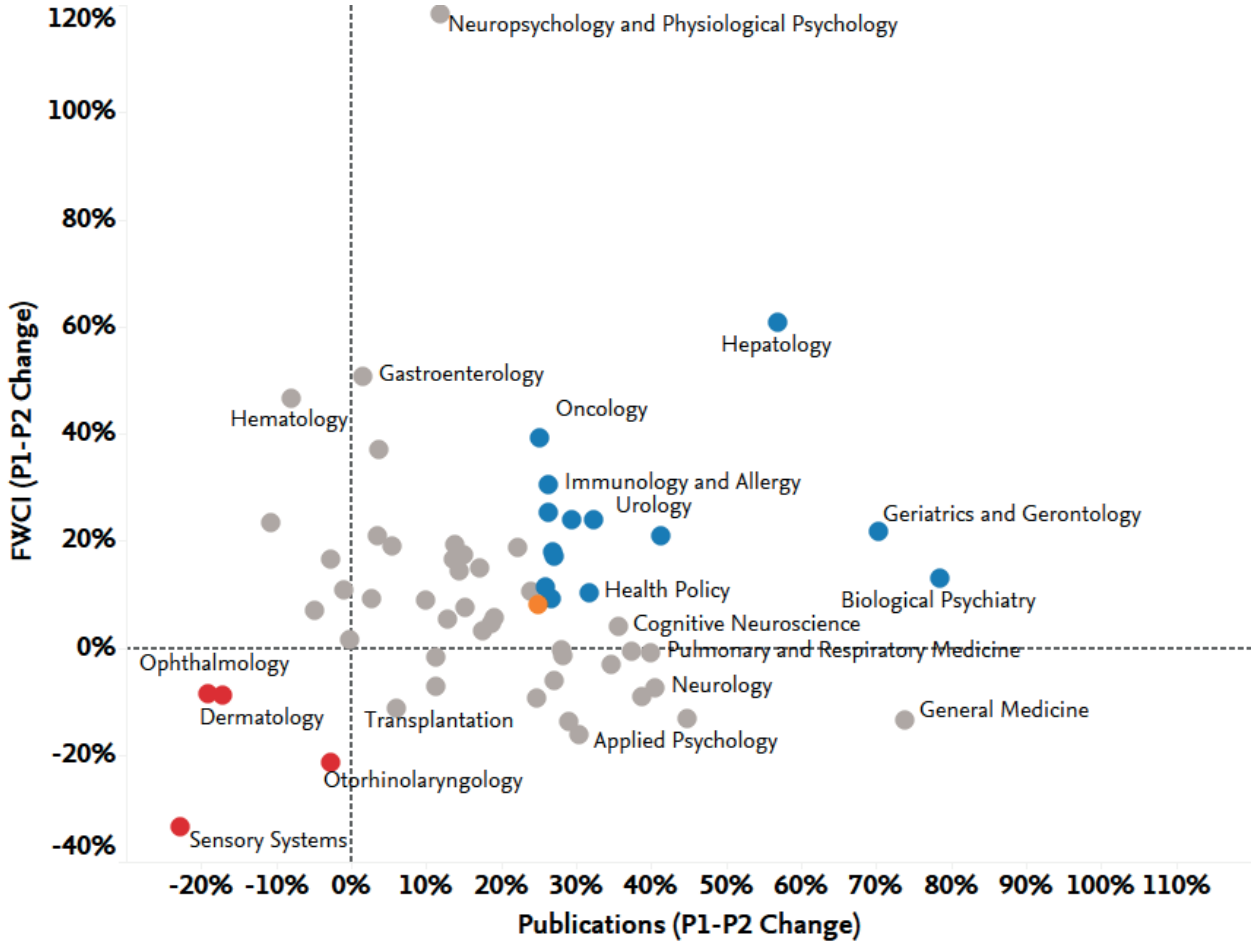
In Clinical Sciences, Singapore had the largest increase from P1 to P2 (67%), followed by Denmark (56%), whereas Scotland increased its number of publications by 25%, which is similar to many comparators. Northern Ireland had the largest increase in citation impact (36%), followed by Wales (28%) with half of the comparators having less than 10% increase (with Scotland at 8%).

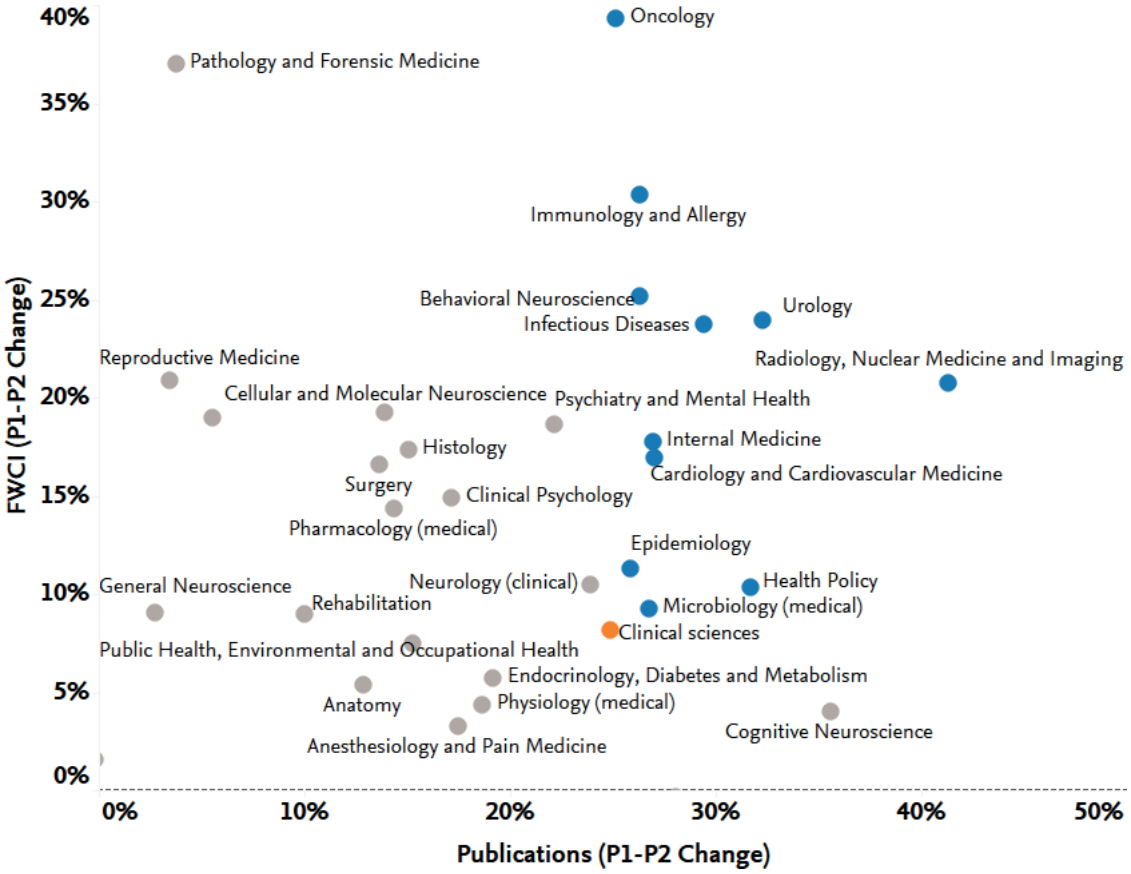
Figure 5.5— *Publication output and impact change from P1 to P2 per country in the field of Clinical Sciences. Size of the bars indicate publication output, color-coding reflects FWCI. Source: Scopus.*



Publications in Clinical Sciences in Scotland have increased by 25% from P1 to P2 and the average impact has increased by nearly 8%. Multiple subfields have increased both the volume and impact beyond the subject average (Figures 5.6a and b). Hepatology is one area with a large increase in both aspects, along with Oncology, Immunology and Allergy, Behavioral Neuroscience, Urology, Internal Medicine, Cardiology & Cardiovascular Medicine, Epidemiology, Microbiology (medical), Radiology, Nuclear Medicine & Imaging, Health Policy, Infectious Diseases, Biological Psychiatry, Geriatrics & Gerontology had among the largest increases in publications. Neuropsychology and Physiological Psychology had a slightly smaller increase in output compared to the field average but had the largest FWCI increase among the subfields. Ophthalmology, Dermatology, Sensory Systems, and Otorhinolaryngology were subfields that saw a decline both in volume and impact.

Figure 5.6a and b— *Output and impact change per ASJC 334 subject area from P1 to P2 within Clinical Sciences, with a minimum of 100 publications per period. Second graph shows a zoom-in on the subdisciplines not visible in first. Source: Scopus.*




40%
35%
30%
25%
20%
15%
10%
5%
0%
FWCI (P1-P2 Change)
0%
10%
20%
30%
40%
50%
Publications (P1-P2 Change)
Oncology
Pathology and Forensic Medicine
Immunology and Allergy
Behavioral Neuroscience
Urology
Infectious Diseases
Reproductive Medicine
Radiology, Nuclear Medicine and Imaging
Cellular and Molecular Neuroscience
Psychiatry and Mental Health
Internal Medicine
Histology
Cardiology and Cardiovascular Medicine
Surgery
Clinical Psychology
Pharmacology (medical)
Epidemiology
General Neuroscience
Neurology (clinical)
Health Policy
Rehabilitation
Microbiology (medical)
Clinical sciences
Public Health, Environmental and Occupational Health
Endocrinology, Diabetes and Metabolism
Anatomy
Physiology (medical)
Cognitive Neuroscience
Anesthesiology and Pain Medicine

5.4. Engineering

Denmark had the highest increase in Engineering publications from P_1 to P_2 (49%) followed by Norway (40%), with Scotland ranking in the middle with a 14% increase (Figure 5.7). Several countries had small declines in their citation impact in this field, including Scotland (-1%), whereas Singapore (19%), Northern Ireland (13%) and Finland (12%) had considerable increases. Singapore and Finland had both very steep increases in their publication output in the field of Energy and Singapore had a considerable impact improvement in the field of Material Science.

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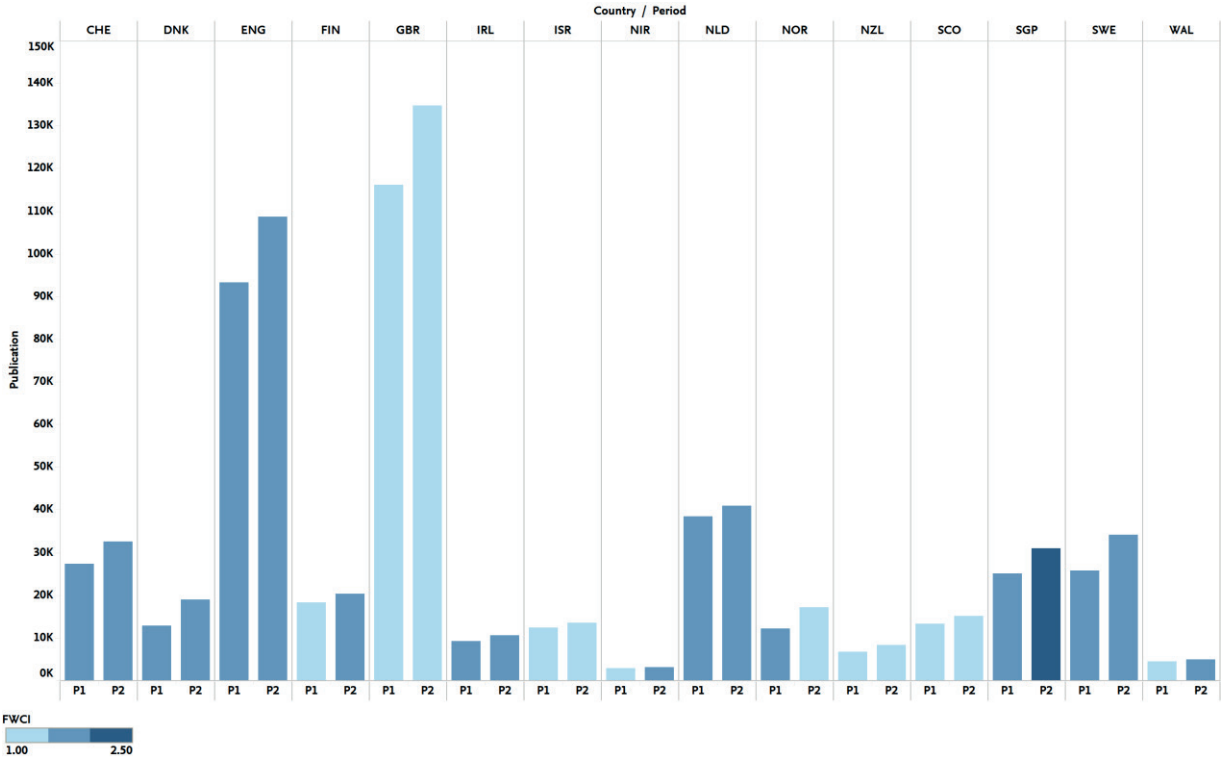
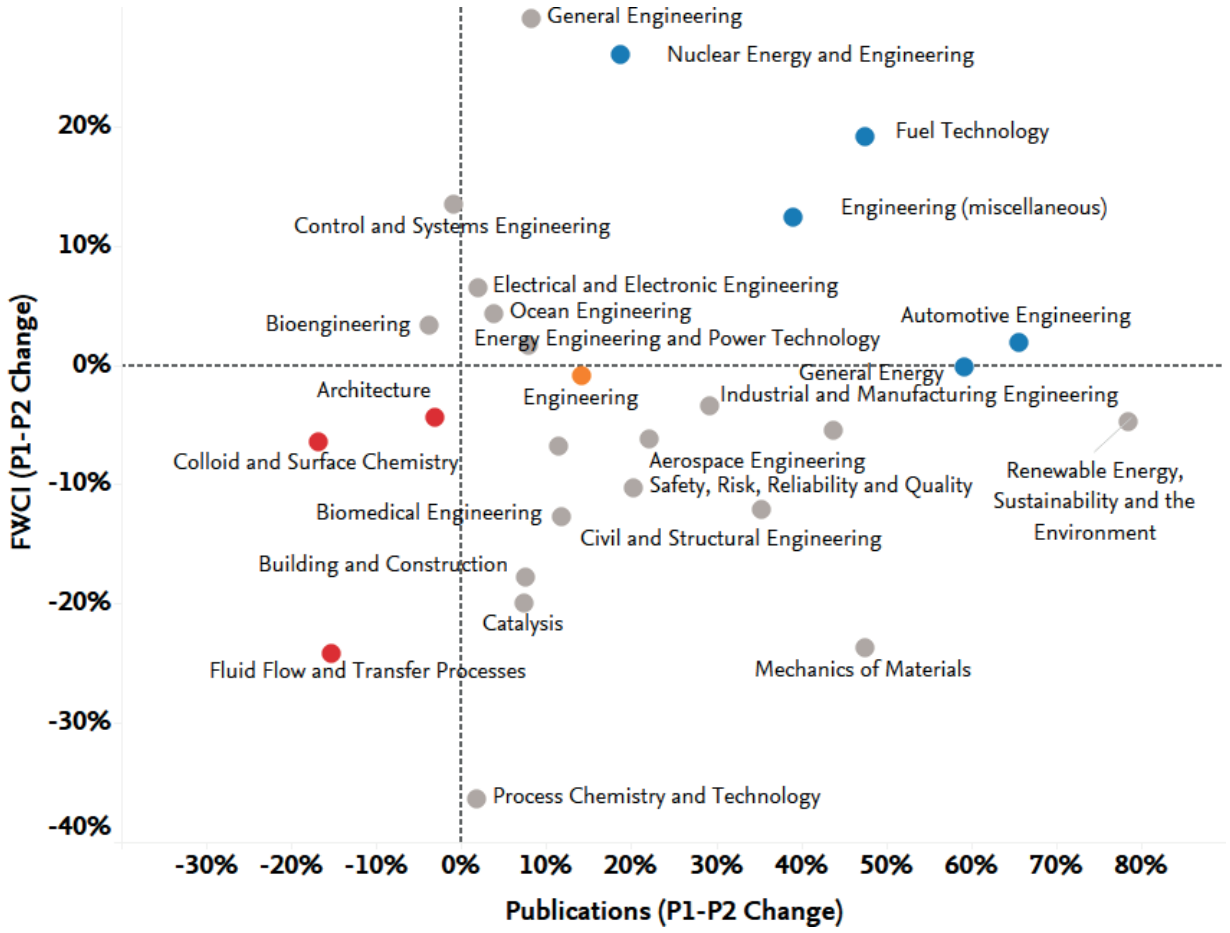
Figure 5.7— *Publication output and impact change from P_1 to P_2 per country in the field of Engineering. Color-coding reflects FWCI. Source: Scopus.*



While Scottish publications in Engineering have increased by nearly 14% on average from P1 to P2, citation impact decreased by 1% (Figure 5.8). Among the subfields most increased their publication numbers, but the majority experienced a decline in their impact. Nuclear Energy & Engineering was the subfield that had the highest FWCI increase among those subfields that had a better output and FWIC increase than the subject increase. Fuel Technology, General Energy and Automotive Engineering were other subfields that had publication and FWCI increases than the subject average. Architecture, Colloid & Surface Chemistry, Fluid Flow & Transfer Process are subfields that declined in both output and impact. Process Chemistry & Technology also stands out as it had a decline of nearly 40% in its FWCI.

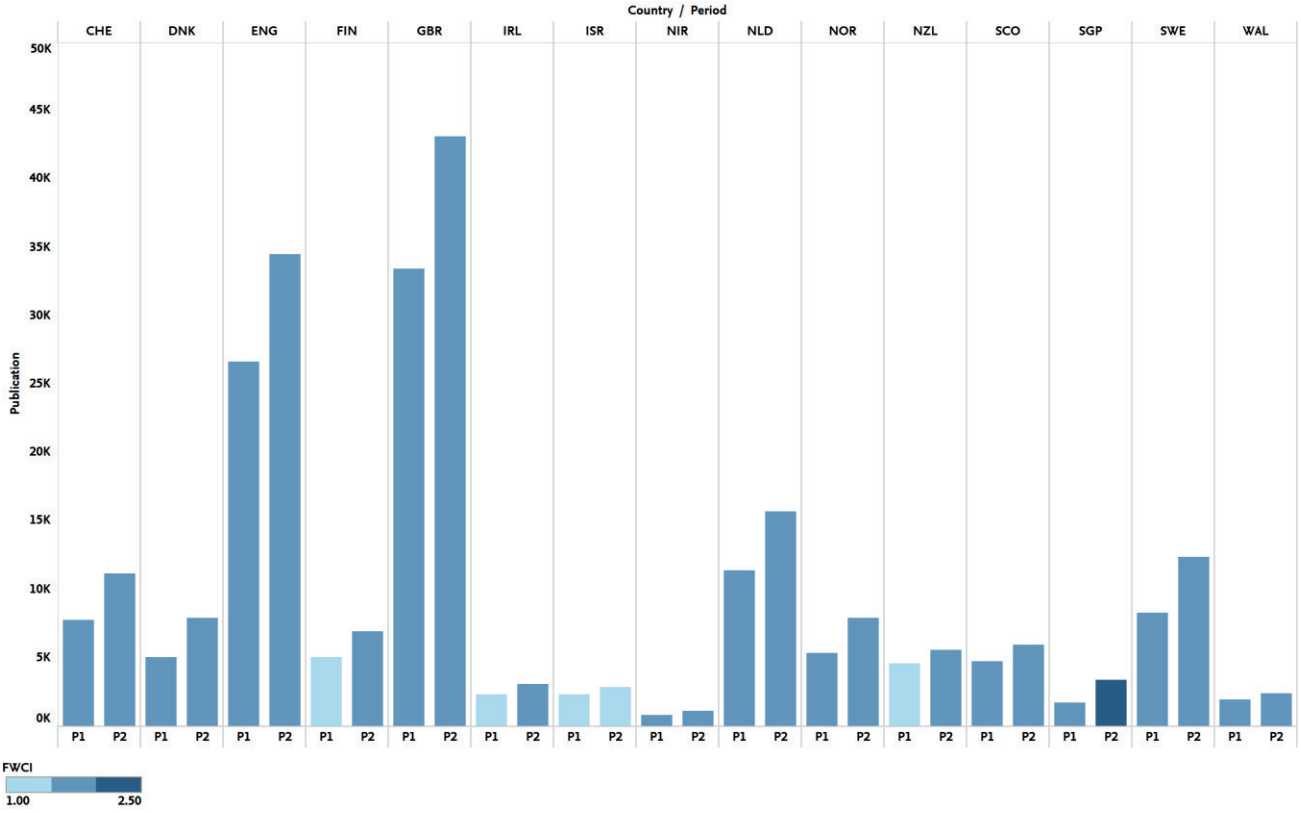
Figure 5.8— *Output and impact change per ASJC 334 subject area from P1 to P2 within Engineering, with a minimum of 100 publications per period. Source: Scopus.*



5.5. Environmental Science

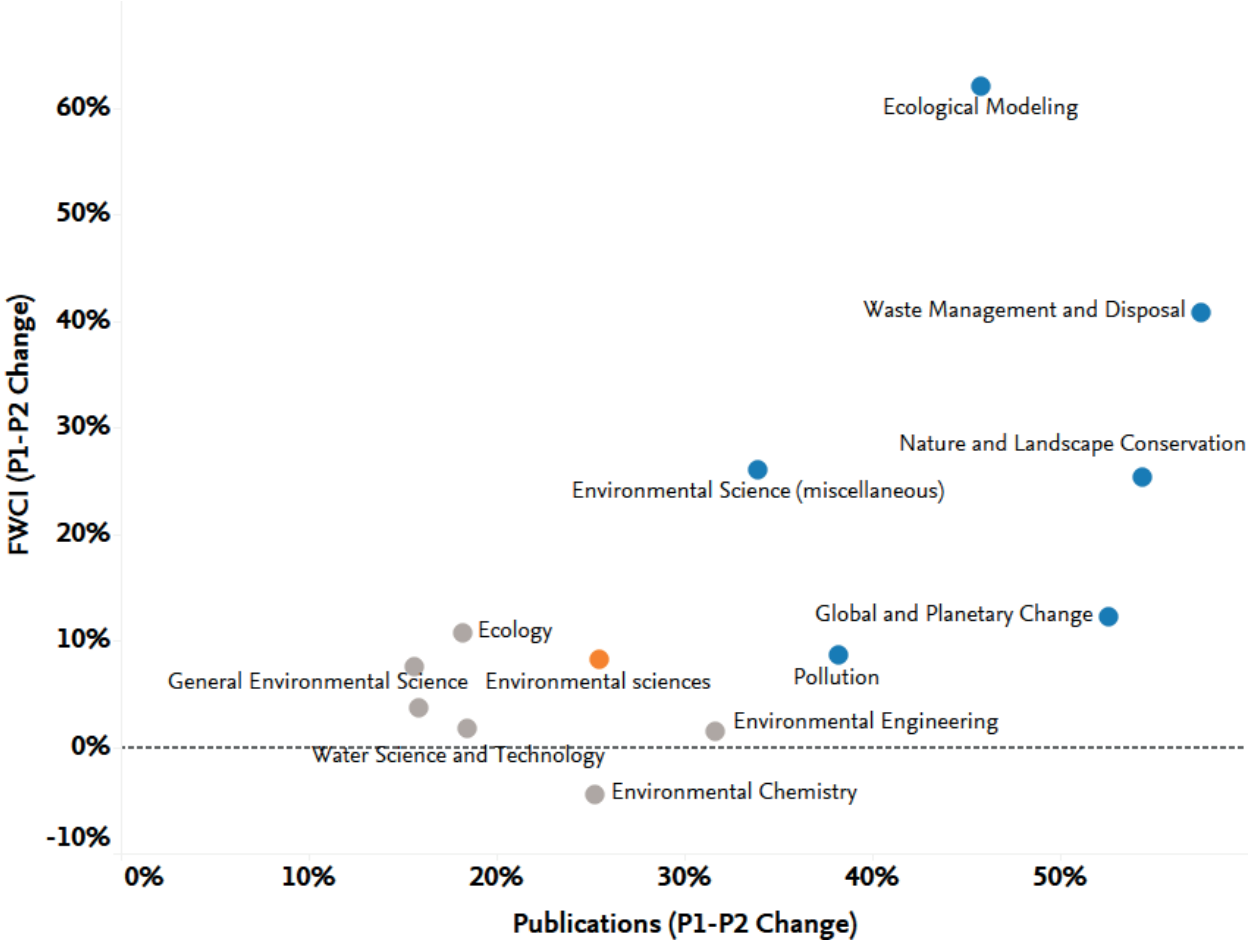
All comparator countries increased their publication output by more than 20% in Environmental Sciences, with Singapore increasing its publication numbers by 93% (Figure 5.9). Singapore's lead in output increases was paralleled by an impact increase of 17%, going from 1.74 in P_1 to 2.04 in P_2. In P_2, the top ten publications in Singapore were all in the *Energy and Environmental Science* journal from the Royal Society of Chemistry, which ranks 1st in several subject areas. Singapore's improvement in environmental sciences is also visible in patent citations; while in P_1 it ranked 13th among comparator countries by the patent citation count, it moved to 4th place in P_2.

Figure 5.9— *Publication output and impact change from P_1 to P_2 within Biological Sciences per country in Environmental Sciences. Size of the bars indicate publication output, color-coding reflects FWCI. Source: Scopus.*



Environmental Science stands out as an area of growth for Scotland. The publication volume increased 25% from P1 to P2 and the FWCI increased by 8% (Figure 5.10). Almost all fields, except for Environmental Chemistry, also had increases in the volume and impact. Ecological Modelling, Waste Management & Disposal, Nature Landscape Conservation, Global & Planetary Change and Pollution were subfields which saw particularly improvements in both indicators beyond the subject average.

Figure 5.10— *Output and impact change per ASJC 334 subject area from P1 to P2 within Environmental Sciences, with a minimum of 100 publications per period. Source: Scopus.*



5.6. Health & Medical Sciences

Except for Scotland and Northern Ireland, all countries grew their publication output in Health and Medical Sciences by more than 10%, led by Singapore which had a 68% increase in outputs (Figure 5.11). Increases in FWCI were more modest with Ireland leading (12%), followed by England and Singapore both at 7%.

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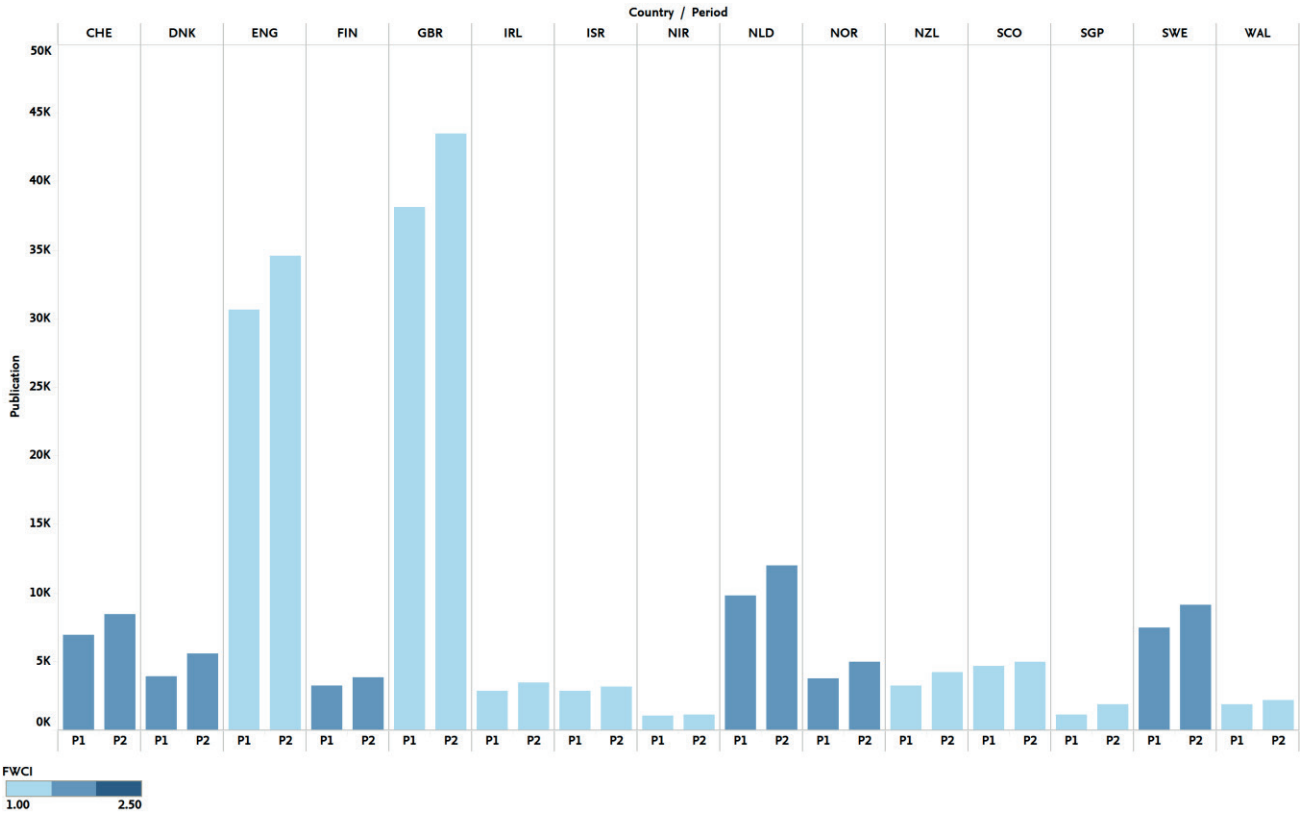
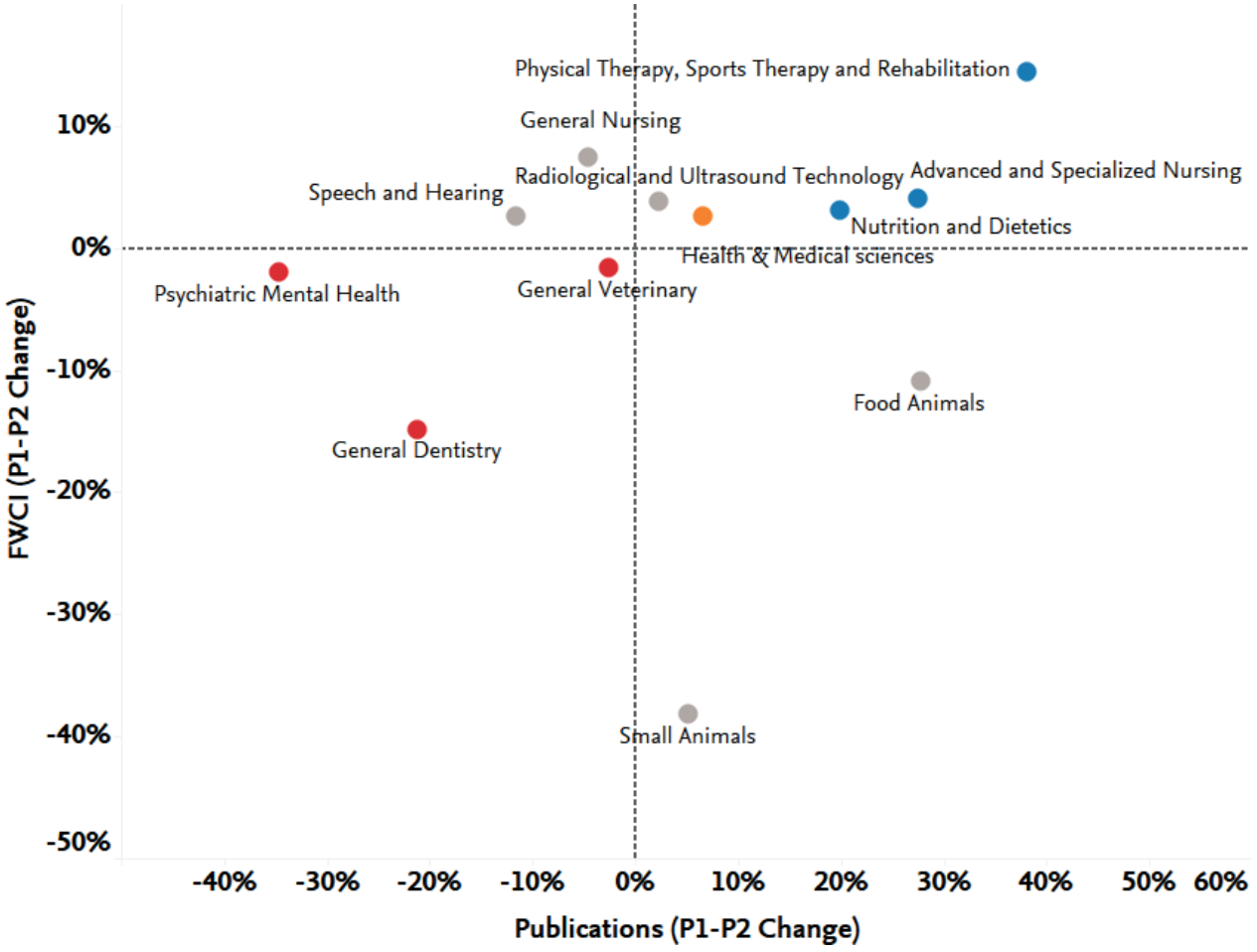
Figure 5.11— *Publication output and impact change from P1 to P2 within Health & Medical Sciences per country in Biological Sciences. Size of the bars indicate publication output, color-coding reflects FWCI. Source: Scopus.*



The Health & Medical Sciences field had a modest growth in publications in Scotland (7%) and impact (3%) (Figure 5.12). Physical Therapy, Sports Therapy & Rehabilitation was the subfield that had the highest increase in publication volume and impact with Advanced & Specialized Nursing and Nutrition & Dietetics also having output and FWCI increases beyond the subject average. General Dentistry, General Veterinary and Psychiatric & Mental Health subfields decline both in output and FWCI. Small Animals also stands out with a significant decline in FWCI.

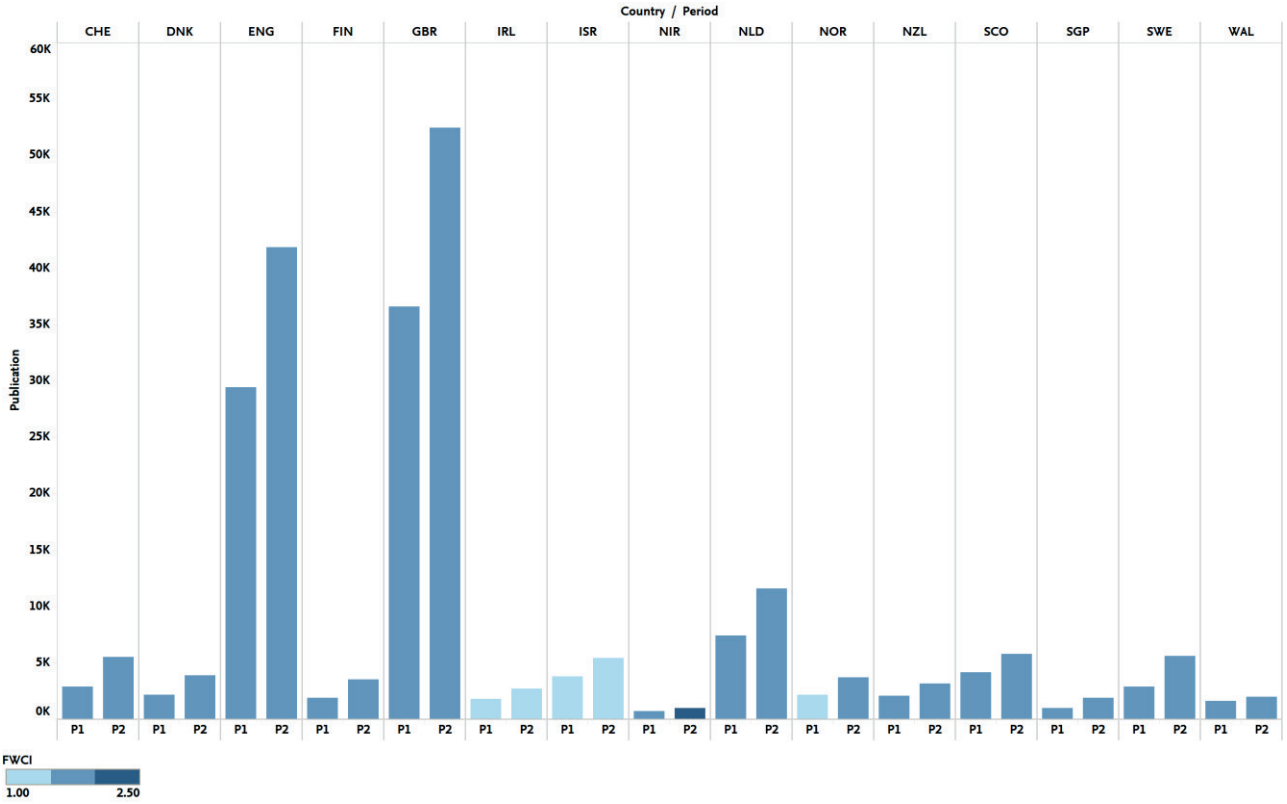
Figure 5.12— Output and impact change per ASJC 334 subject area from P_1 to P_2 within Health & Medical Sciences, with a minimum of 100 publications per period. Source: Scopus.



5.7. Humanities

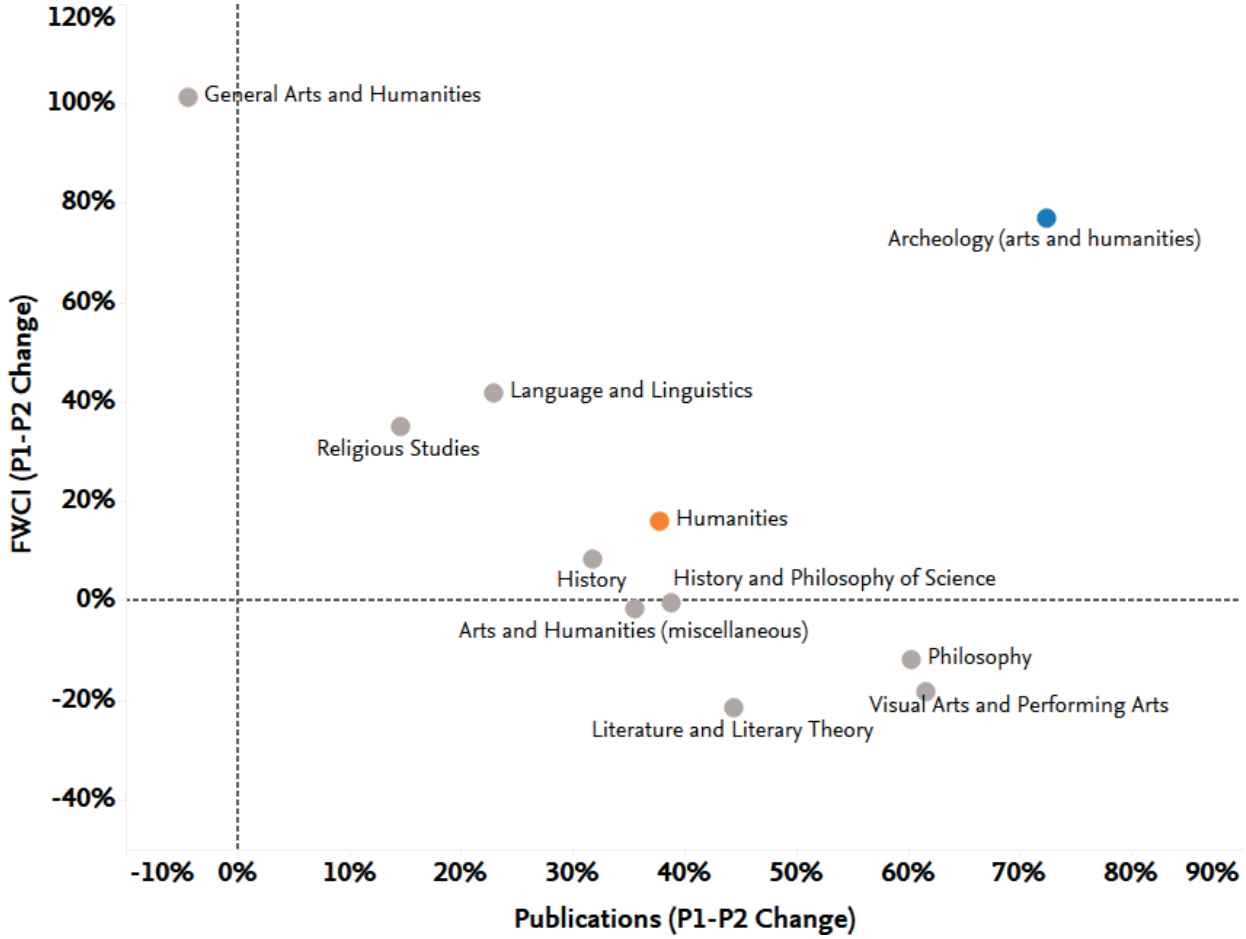
All the comparator countries experienced output increases over 25% in Humanities, with Switzerland, Singapore and Sweden having more than a 90% increase. Although Humanities was the largest growing field for Scotland, among the comparator countries the relative growth was higher in all countries except Wales and Northern Ireland. On the other hand, some countries saw a decline in the FWCI, including Switzerland and Singapore whereas Ireland (20%), Northern Ireland (18%), Norway (17%), Scotland (16%) and Sweden (14%) grew considerably (Figure 5.13).

Figure 5.13— *Publication output and impact change from P_1 to P_2 within Biological Sciences per country in Humanities. Size of the bubbles indicate publication out, color-coding reflects FWCI. Source: Scopus.*



The Humanities field experienced a remarkable growth in Scotland from P1 to P2, with publication volume increasing by 38% and citation impact increasing by 16% (Figure 5.14). Several subfields grew in both output and impact, such as Language & Linguistics and Religious Studies. Archaeology performed exceptionally well, growing by more than 70% in terms of both publication volume and impact and beyond the average of Humanities subject average. Other subfields, such as Conservation and Museology, also had positive output and impact changes, but were not included in the graphs as their publication numbers were below 100 per period. Only the General Arts and Humanities subfield experienced a decline in publications, although the FWCI had the highest increase at 100%.

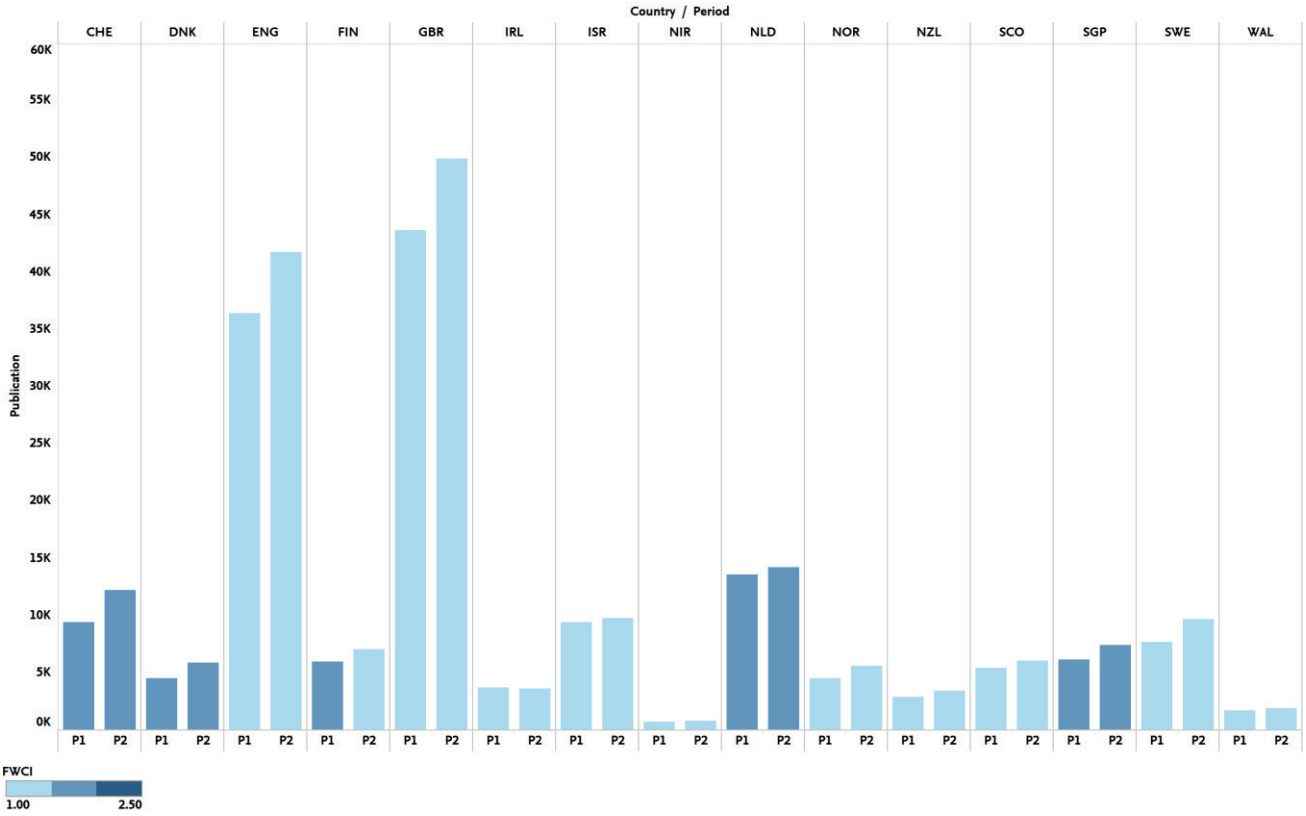
Figure 5.14— *Output and impact change per ASJC 334 subject area from P1 to P2 within Humanities, with a minimum of 100 publications per period. Source: Scopus.*



5.8. Mathematics

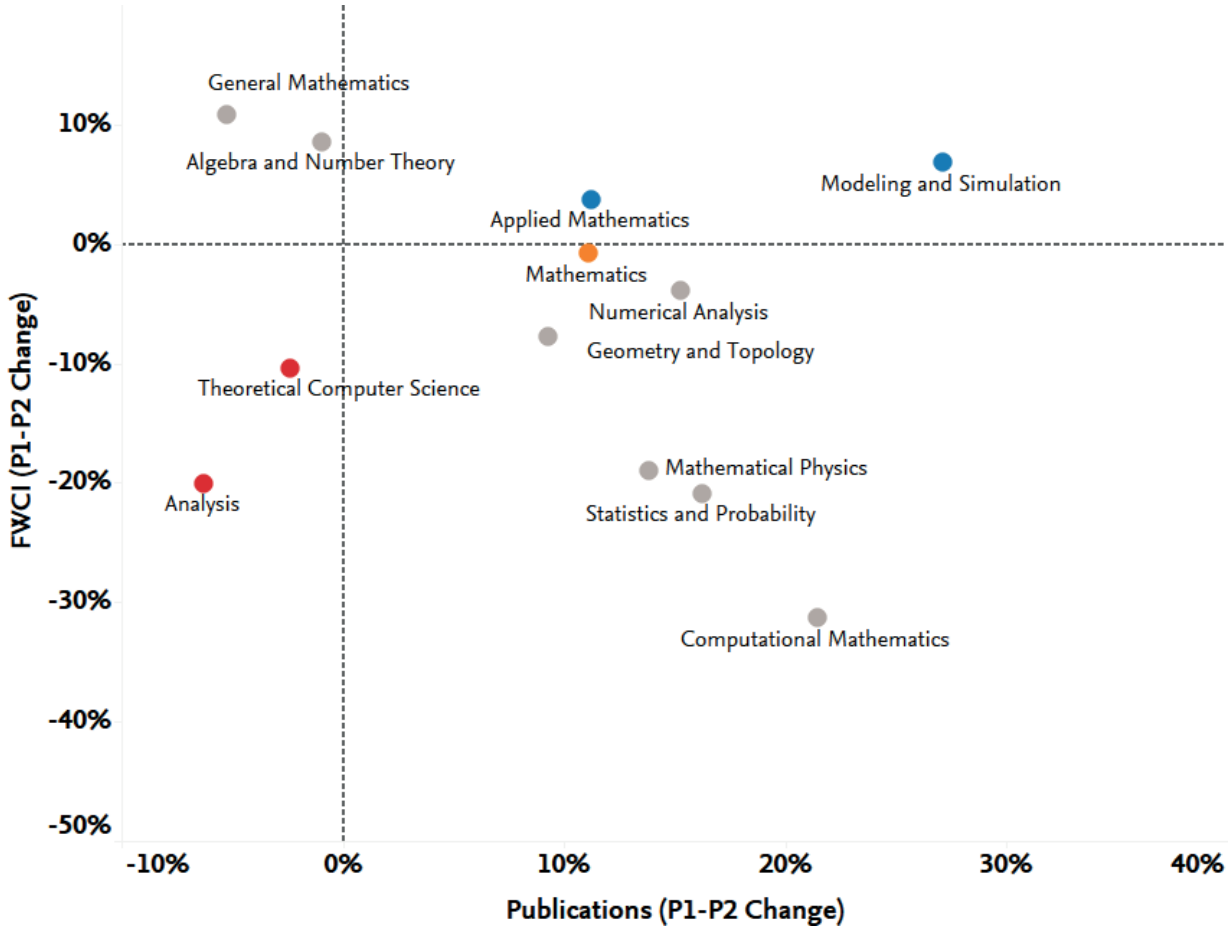
Except for Ireland, all countries had an increase in their Mathematics publication outputs with Switzerland (30%) and Denmark (29%) leading (Figure 5.15). Citation impact declined or increased very modestly for most countries except Northern Ireland (9% increase), Singapore (9% increase) and Sweden (6%).

Figure 5.15— *Publication output and impact change from P_1 to P_2 within Biological Sciences per country in Mathematics. Size of the bubbles indicate publication out, color-coding reflects FWCI. Source: Scopus.*



While there wasn't much change in the average citation impact of publications in the field of Mathematics in Scotland (a small decline of -1%), the volume of publications increased by 11% (Figure 5.16). Modelling & Simulation had an increase in both volume and impact and Applied Mathematics also increased its FWCI beyond the subject average. Analysis and Theoretical Computer Science were two subfields that had a decline in both volume and impact and multiple subfields had a decline in their citation impact. Computational Mathematics has the most visible decline in FWCI despite having one of the largest increases in publication output.

Figure 5.16— *Output and impact change per ASJC 334 subject area from P_1 to P_2 within Mathematics, with a minimum of 100 publications per period. Source: Scopus.*



5.9. Physical Sciences

Denmark and Singapore had the largest increase in Physical Science output at 36% and 31% respectively. Singapore had the highest FWCI increase of 16% (Figure 5.17). For Singapore the increase is not due to an outstanding year, but sustained increases in average citation impact across P_2. Singapore's average citation impact for Physical Sciences was 1.95, the highest among the comparators with the nearest comparator being Switzerland at 1.83. Singapore had particularly high FWCI scores in Chemistry and Material Science.

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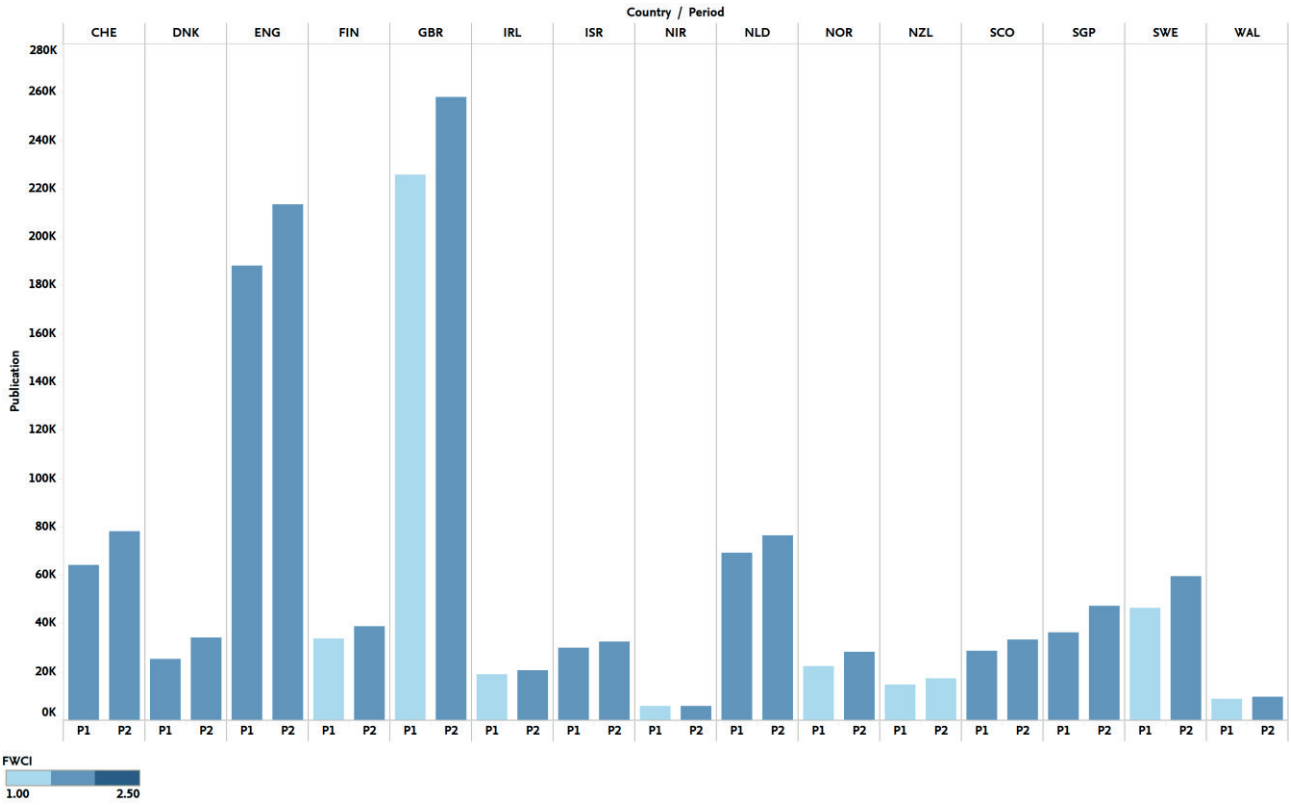
Figure 5.17— *Publication output and impact change from P_1 to P_2 within Biological Sciences per country in Physical Sciences. Size of the bars indicate publication output, color-coding reflects FWCI. Source: Scopus.*



While the publication volume of the Physical Sciences field increased by 17% on average, its FWCI increased by 5% (Figure 5.18). General Earth & Planetary Sciences, Nuclear & High Energy Physics, General Physics & Astronomy, Signal Processing, Computer Graphics & Computer-Aided Design Computer Vision & Pattern Recognition, Computer Networks & Communications, Stratigraphy, Astronomy & Astrophysics and Polymers & Plastics are areas which had output and FWCI increases beyond the subject average. Ceramics & Composites, Surfaces, Coatings & Films, Inorganic Chemistry, Surfaces & Interfaces and Computational Theory & Mathematics were subfields that had a decline in both output and impact.

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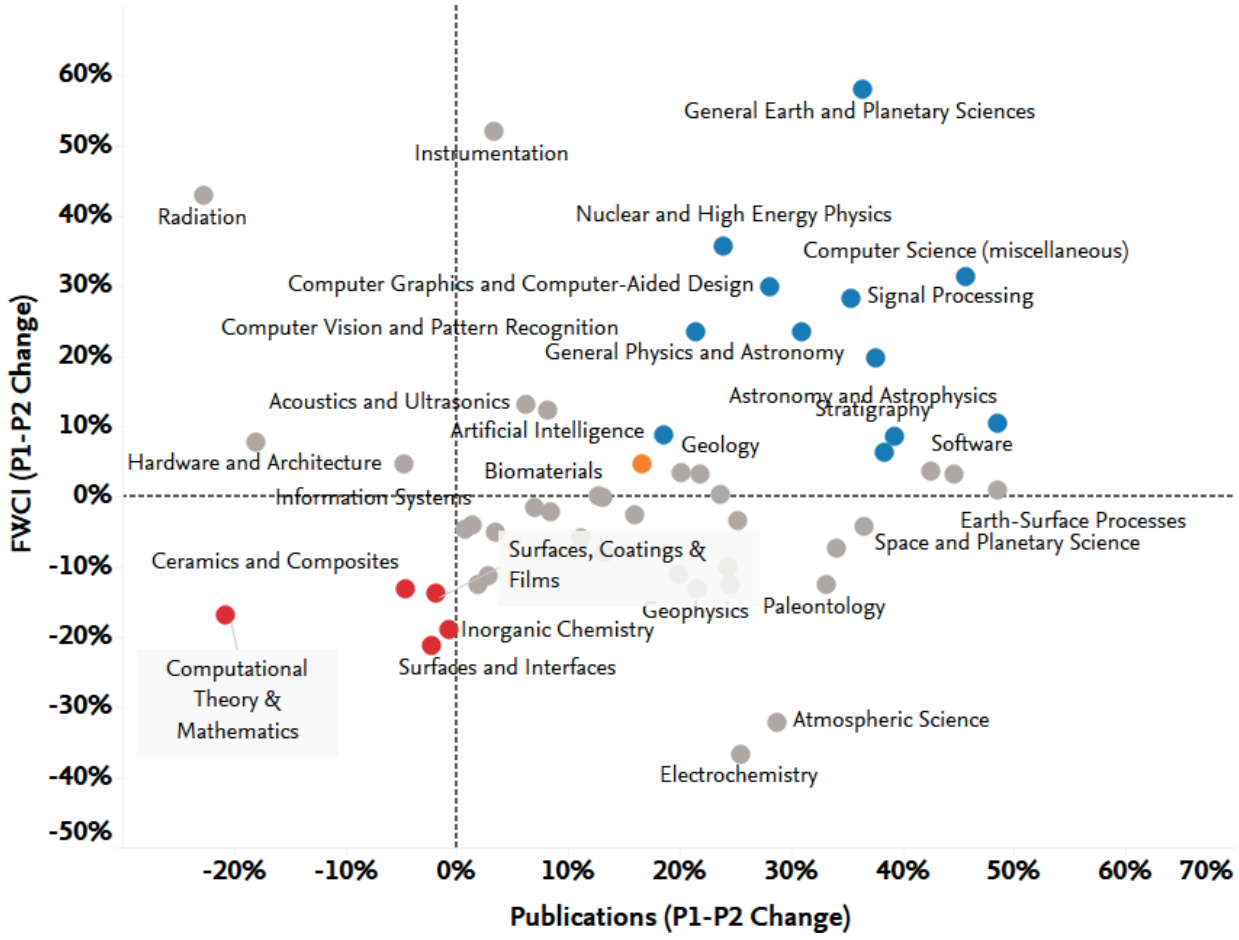
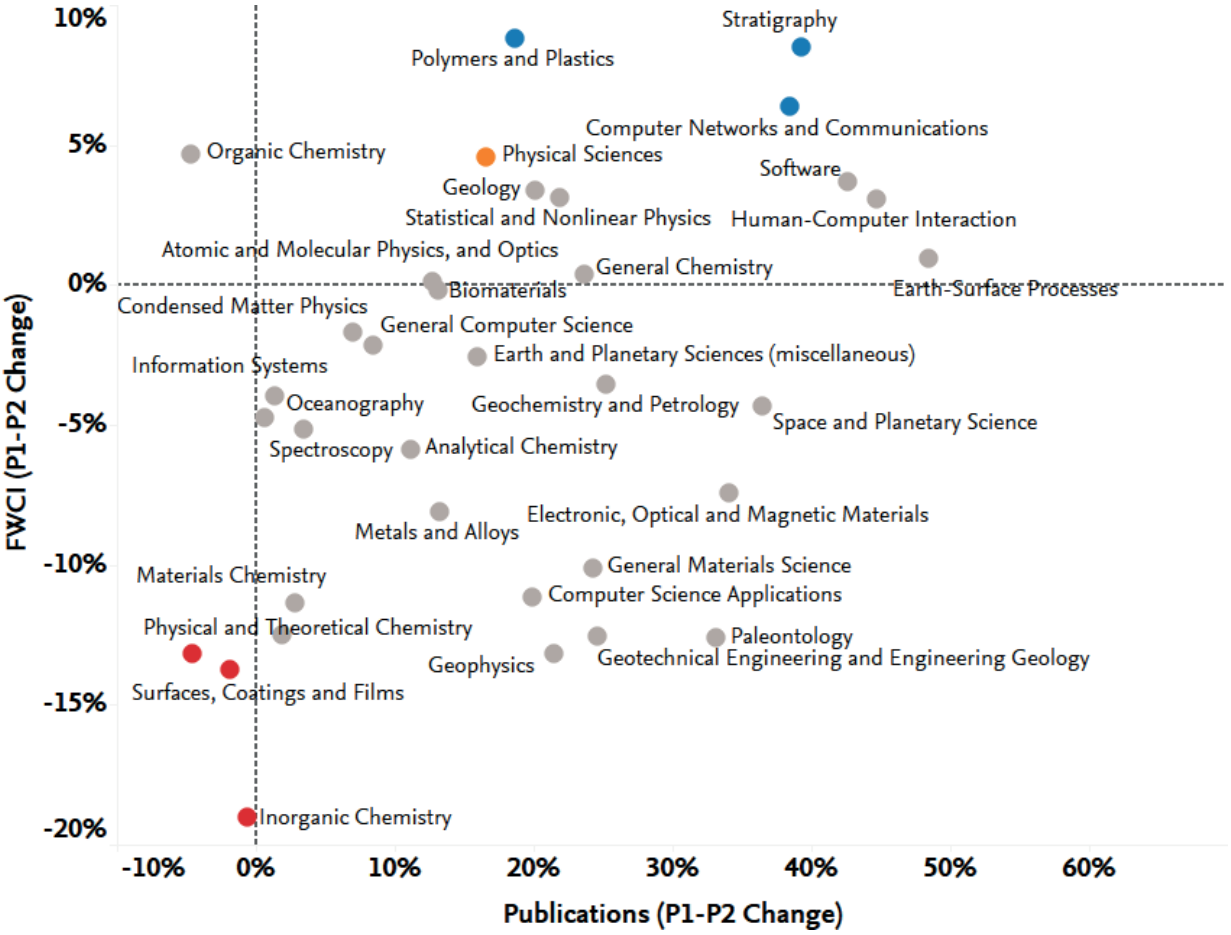
Figure 5.18a and b— *Output and impact change per ASJC 334 subject area from P1 to P2 within Physical Sciences, with a minimum of 100 publications per period. Second graph shows a zoom-in on the subdisciplines not visible in first. Source: Scopus.*

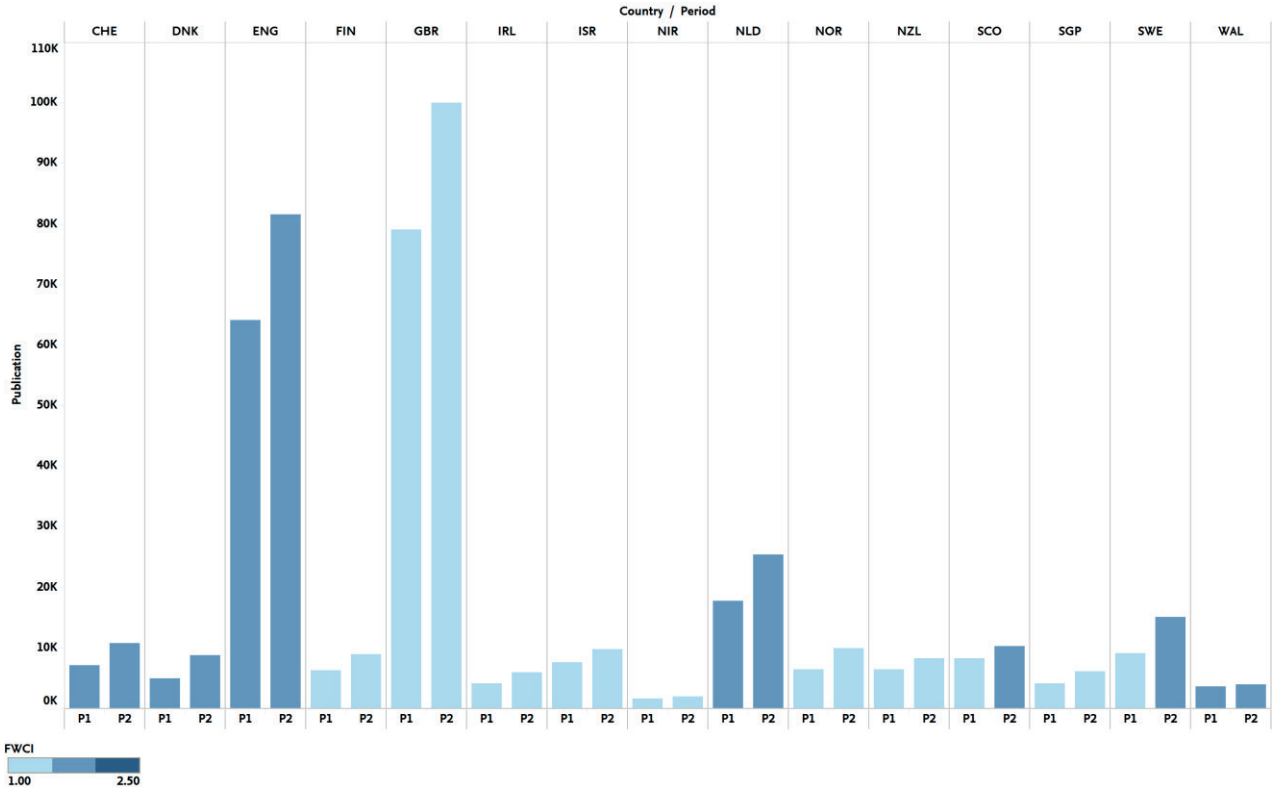



10%
5%
0%
-5%
-10%
-15%
-20%
FWCI (P1-P2 Change)
-10%
0%
10%
20%
30%
40%
50%
60%
Publications (P1-P2 Change)
Stratigraphy
Polymers and Plastics
Computer Networks and Communications
Organic Chemistry
Physical Sciences
Software
Geology
Statistical and Nonlinear Physics
Human-Computer Interaction
Atomic and Molecular Physics, and Optics
General Chemistry
Earth-Surface Processes
Biomaterials
Condensed Matter Physics
General Computer Science
Earth and Planetary Sciences (miscellaneous)
Information Systems
Oceanography
Geochemistry and Petrology
Space and Planetary Science
Spectroscopy
Analytical Chemistry
Electronic, Optical and Magnetic Materials
Metals and Alloys
General Materials Science
Materials Chemistry
Computer Science Applications
Physical and Theoretical Chemistry
Paleontology
Geophysics
Geotechnical Engineering and Engineering Geology
Surfaces, Coatings and Films
Inorganic Chemistry

5.10. Social Sciences

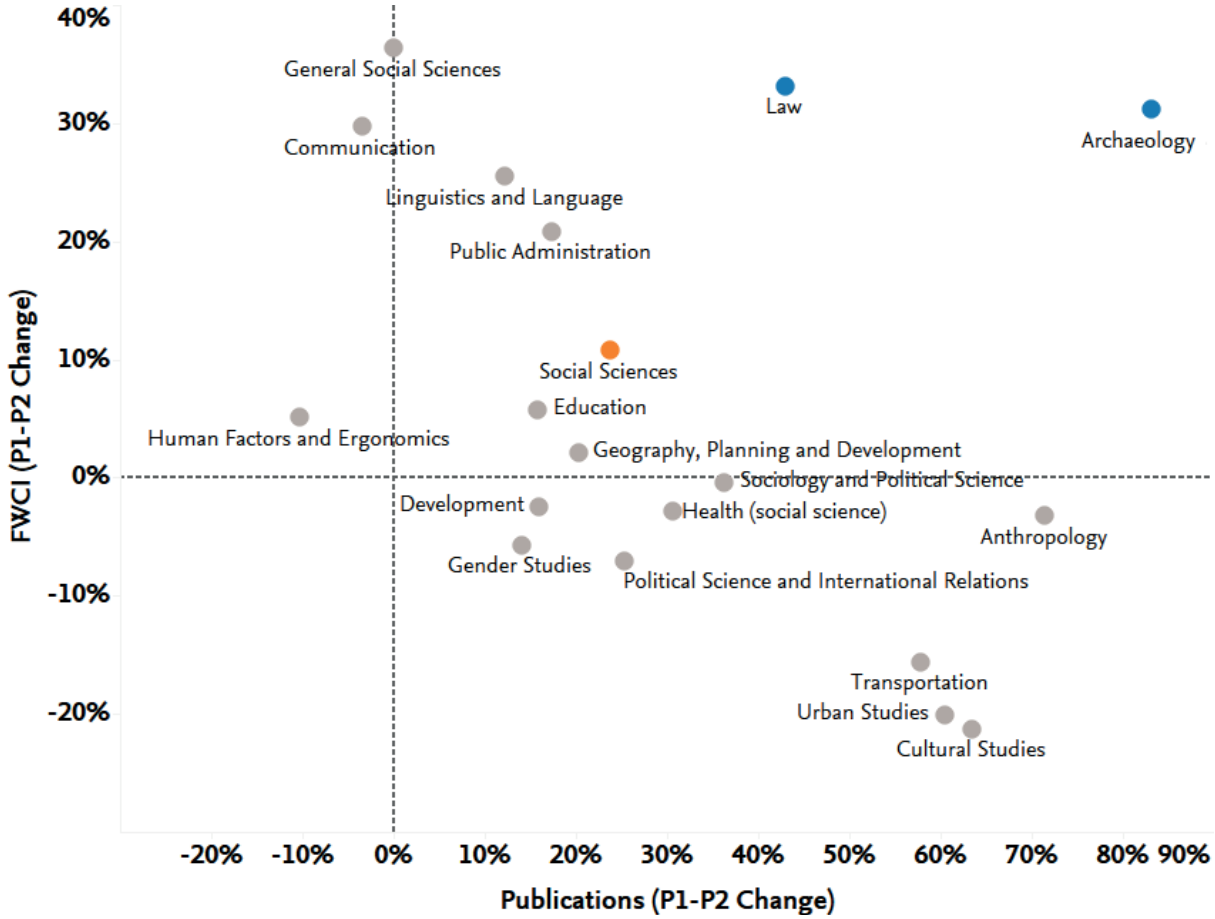
Social sciences is another field where outputs have increased for all countries, with Denmark (77%) and Sweden (64%) leading (Figure 5.19). Impact increases were more modest with many countries staying below 10%, with the exception of Scotland which had an 11% increase in impact.

Figure 5.19— *Publication output and impact change from P_1 to P_2 within Biological Sciences per country in Social Sciences. Size of the bars indicate publication output, color-coding reflects FWCI. Source: Scopus.*



Scottish publications in Social Sciences increased by 24% in volume and 11% in citation impact over the period (Figure 5.20). Publications in Law and Archaeology increased considerably in both volume and impact and no subfields saw a decline in both indicators. Cultural Studies and Transportation did experience quite large declines in FWCI.

Figure 5.20— *Output and impact change per ASJC 334 subject area from P_1 to P_2 within Social Sciences, with a minimum of 100 publications per period. Source: Scopus.*



Appendix A – Topics of Prominence

Topics of Prominence (ToP)[26] is a new analysis from Elsevier indicating the 'momentum' in a particular field through ranking of topics according to prominence. Prominence is an indicator of the momentum of a particular field and does not make a judgement call whether a topic is important or not. 95% of all articles in Scopus are clustered into roughly 96,000 global and unique research topics based on recent citations, views and CiteScore[27] values. By looking at citation patterns rather than journal categories, topics have the advantage of spanning across disciplines and being dynamic. Through topics of prominence (ToP) analyses, it is possible to identify emerging topics with high momentum and how these topics are related to a selected entity or group's research portfolio. Topics can be large or small, new or old, growing or declining. The granularity of topics allows for defining the problem-level structure of science. Due to the way it is structured, topics do not need field weighting to be coherent collections and topics in social science and humanities are just as valid as in STEM areas, although they may be smaller and less prominent.

Prominence combines three metrics to indicate the momentum of the topic:

- Citation Count in year n to papers published in n and n-1
- Scopus Views Count in year n to papers published in n and n-1
- Average CiteScore for year n

Topics of prominence methodology allows entities to identify research fields that they are active in and if they are leading in these fields. In this report it will identify the research fields where Scotland publishes most and if these are becoming important. If these most-published fields are also highly prominent, then it will indicate that Scotland is aligned with the global topics gaining momentum. If Scotland's most published topics are not very prominent, it does not necessarily mean that these are the 'wrong' topics, but perhaps topics that are of more local relevance.

Since the topics are pre-calculated using 95% of the publications in the Scopus database, hyper-collaborated papers are included in the analyses presented in this section, which is different from the rest of the report.

In the following section we look at the outputs of Scotland per subject field and the topics to which these publications belong. Each subject field table presents the top ten topics in which Scotland has produced the most output. In order to contextualise these publications the 'World Publication Share' indicator is presented to show Scotland's position globally for that topic. The FWCI values correspond to the citation impact of Scotland's publications in that topic. Finally, the last column shows the prominence percentile of that topic to show whether Scotland's top outputs are in prominent topics.

Topics can also be listed according to prominence, as in table 6.1, however, as the table also indicates, the publication numbers are quite often limited and can give a misleading idea on Scotland's unique strengths.

[26] https://www.elsevier.com/solutions/scival/releases/topic-prominence-in-science

[27] Launched in 2016, CiteScore using Scopus data to rank journals looking at the citations in the previous three years. For detailed information on CiteScore please refer to: https://journalmetrics.scopus.com/

General overview of Scotland from a topic's perspective

In this section we give the top ten topics listed by output to understand whether these topics are also fields that have high momentum.

Most of the topics where Scotland has the largest number of publications are in the top 1% most prominent topics and these are mainly concentrated in the Physical Sciences field. A topic that stands out is from Clinical Sciences is 'Women; Men; women's preferences' - where Scotland not only publishes 15% of the publications worldwide but also has a high FWCI, which is over the UK average as well.

CP violation; angle γ" Is another topic where Scotland accounts for 20% of the global output and has a large FWCI but none of the Scottish institutions are in the top 20 globally.

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Table 6.1— *Top ten topics for Scotland in all areas, sorted by scholarly output for 2012-16. Source: Scopus*

Topic	SCO Output	SCO World Publication Share	SCO FWCI	GBR World Publication Share	GBR FWCI	Prominence percentile
jets; production; parton shower	208	13.91%	2.76	34.4%	2.55	99.81
galaxies; dust; infrared galaxies	193	17.67%	2.17	51.2%	1.82	98.78
decay; CP violation; angle γ	184	20.93%	3.31	30.0%	2.63	97.70
Angular momentum; Vortex flow; carrying orbital	170	8.71%	2.66	13.1%	2.36	99.36
galaxies; mass; quiescent galaxies	150	11.66%	3.07	37.5%	2.58	99.50
Optical communication; Light emitting diodes; indoor optical	147	5.93%	4.84	13.0%	3.44	99.68
quantum chromodynamics; lattices; lattice spacings	147	17.21%	1.42	24.8%	1.45	93.53
planet; planets; planet candidates	127	6.23%	1.50	26.9%	2.26	99.74
Women; Men; women's preferences	119	14.93%	1.38	26.5%	1.28	96.47
quarks; production; top-quark mass	118	12.10%	2.17	25.0%	1.86	98.17

Topics across different subjects

In this section topics within different subject fields are presented, ranked by Scotland's scholarly output. Since the most prominent topics may have a very limited number of publications, the data can be accessed with the data supplement provided for this report.

Clinical Sciences

The topic with the largest output in clinical sciences was one of the top ten for Scotland overall, on human behavior (Women; Men; women's preferences). Of table 6.2, a few topics stand out particularly for Scotland. In the field of 'Intelligence; Life; educational attainment' Scotland accounts for more than 34% of global publications and is second among comparators in this report after Sweden (Karolinska Institute is the leading institution in this topic). University of Strathclyde is the second institution in the world by output. The second topic that particularly stands out is 'Trypanosomiasis, African; Trypanosoma brucei; trypanosomiasis HAT', commonly known as the 'sleeping sickness' common to sub-Saharan Africa.

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Table 6.2— *Top ten topics for Scotland in Clinical Sciences sorted by output, for 2012-2016. Source: Scopus*

Topic	SCO Output	SCO World Publication Share	SCO FWCI	GBR World Publication Share	GBR FWCI	Prominence percentile
Women; Men; women's preferences	119	14.93%	1.38	26.5%	1.28	96.47
Proteomics; Urine; urine proteome	90	26.09%	1.99	29.6%	1.90	95.01
learning; Cultural Evolution; cumulative	78	16.46%	2.47	37.6%	2.30	96.89
Intelligence; Life; educational attainment	78	34.06%	2.08	51.5%	1.75	91.42
Trypanosomiasis, African; Trypanosoma brucei brucei; trypanosomiasis HAT	68	26.05%	1.87	42.1%	1.85	90.15
Stroke; Thrombectomy; anterior circulation	67	2.96%	5.39	6.1%	5.84	99.89
Candida albicans; Hyphae; human fungal	63	9.01%	2.71	15.7%	2.10	98.21
Trypanosoma; Trypanosomiasis; evansi	61	11.89%	1.95	20.7%	1.83	92.72
Delirium; Patients; delirium prevention	56	4.07%	2.62	11.3%	1.93	99.12
Commerce; Health Expenditures; prescribing efficiency	56	30.77%	1.82	40.7%	1.67	81.71

Health & Medical Sciences

An analysis of Scotland's most published topics in the field of Health & Medical Sciences shows that the there is a growing focus on veterinary research. 'Anthelmintic; Sheep; anthelmintic drugs' is the topic with the highest output among Scotland's publications in Health & Medical Sciences. 'Empathy; Nursing; compassionate care' also stands out. It should however be noted that the field is quite small overall globally.

If the topics are listed by prominence, one topic stands out where University of Stirling is the 8th most published institution – 'Muscle Proteins; Proteins; protein ingestion' (prominence percentile 99.3).

Table 6.3— *Top ten topics for Scotland in Health& Medical Sciences sorted by output, for 2012-2016. Source: Scopus*

Topic	SCO Output	SCO World Publication	SCO FWCI	GBR World Publication	GBR FWCI	Prominence percentile
Anthelmintics; Sheep; anthelmintic drugs	52	9.67%	1.82	23.3%	1.66	96.02
Sheep; Haemonchus; count FEC	52	18.91%	1.27	18.0%	1.38	87.00
Motor Activity; Accelerometry; wear time	38	3.54%	2.44	13.6%	2.63	99.22
Theileria; Theileriasis; T parva	31	9.81%	1.15	55.1%	1.06	90.84
Empathy; Nursing; compassionate care	29	14.80%	1.45	14.1%	1.46	83.05
Muscle Proteins; Proteins; protein ingestion	27	3.88%	3.08	14.1%	2.13	99.32
Horses; Anthelmintics; S vulgaris	27	10.04%	1.91	8.0%	1.63	82.79
Stroke; Gait; treadmill training	26	2.82%	2.45	20.7%	1.56	98.13
Tuberculosis, Bovine; Mycobacterium bovis;	25	3.17%	1.48	8.1%	1.70	97.35
Paratuberculosis; Mycobacterium avium subsp. paratuberculosis; paratuberculosis	24	3.09%	1.33	21.9%	1.32	96.23
Horses; Tooth; cheek teeth	24	9.72%	1.70		1.22	78.95

Biological Sciences

Almost all topics that Scotland publishes most in Biological Sciences are among top 5% most prominent topics in the world. The most prolific field 'Proteomics; Urine; urine proteome' is a specialisation for the country. Aquatic science is another area where Scotland demonstrates strength.

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Table 6.4— Top ten topics for Scotland in Biological Sciences sorted by output, for 2012-2016. Source: Scopus

Topic	SCO Output	SCO World Publication	SCO FWCI	GBR World Publication	GBR FWCI	Prominence percentile
Proteomics; Urine; urine proteome	90	26.10%	1.99	29.6%	1.90	95.01
learning; Cultural Evolution; cumulative	78	16.50%	2.47	37.6%	2.30	96.89
porpoise; Phocoenidae; harbor porpoises	73	14.50%	1.98	23.1%	1.48	93.97
Trypanosomiasis, African; Trypanosoma brucei brucei; trypanosomiasis HAT	68	26.10%	1.87	42.1%	1.85	90.15
behavioral ecology; behavior; behavioural	65	8.70%	2.57	23.5%	2.50	98.95
charcoal; soil; biochar amendment	64	2.90%	4.39	5.9%	4.31	99.96
Candida albicans; Hyphae; human fungal	63	9.00%	2.71	15.7%	2.10	98.21
Trypanosoma; Trypanosomiasis; evansi	61	11.90%	1.95	20.7%	1.83	92.72
fish oils; fatty acid composition; dietary lipid	60	6.80%	2.35	7.7%	2.28	98.29
whale; whales; whale calls	59	10.90%	1.36	16.3%	1.19	94.52

Environmental Sciences

Environmental Sciences is another field in which Scotland's most published topics are highly prominent. In most of these topics England has more publications than Scotland so these topics could also reflect UK-wide strengths rather than unique Scottish strengths. The top topic on the other hand 'Catchments; hillslope; hydrograph separation' is a topic where Scotland publishes considerably more than the other UK nations.

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Table 6.5— *Top ten topics for Scotland in Environmental Sciences sorted by output, for 2012-2016. Source: Scopus*

Topic	SCO Output	SCO World Publication	SCO FWCI	GBR World Publication	GBR FWCI	Prominence percentile
Catchments; hillslope; hydrograph separation	67	15.60%	3.39	21.0%	2.98	97.97
charcoal; soil; biochar amendment	64	2.90%	4.39	5.9%	4.31	99.96
spatial planning; marine policy; marine governance	52	9.40%	1.71	32.8%	2.30	98.22
Storage (materials); Aquifers; saline aquifers	49	3.00%	1.23	11.2%	1.39	99.31
nitrous oxide; emissions; N2O emissions	43	4.50%	2.18	11.2%	2.20	99.11
Silver; Nanoparticles; CuO NPs	42	1.70%	2.42	8.7%	2.80	99.97
climate change; models; models SDMs	41	2.50%	3.45	15.6%	3.81	99.79
ecosystem service; ecosystem services; multiple ecosystem	40	3.00%	6.82	16.5%	5.16	99.91
seabirds; seabird; foraging trips	40	8.40%	1.58	36.2%	2.09	94.51
Nature; landscape; perceived restorativeness	38	3.50%	5.06	19.3%	3.03	99.51

Mathematics

Scotland's publications in Mathematics are relatively less prominent on average compared to other fields, although there are some exceptions. As a matter of fact, the most published topics for Scotland in Mathematics have 200-750 publications globally and are not among the most prominent topics, which is a valid observation for the UK as well.

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Table 6.6— Top ten topics for Scotland in Mathematics sorted by output, for 2012-2016. Source: Scopus

Topic	SCO Output	SCO World Publication Share	SCO FWCI	GBR World Publication Share	GBR FWCI	Prominence percentile
Model checking; Process algebra; rule-based	78	19.80%	1.33	29.9%	1.46	90.00
Stochastic models; Stochastic systems;	44	7.40%	1.60	19.4%	1.40	93.41
Stochastic differential equations; Differential equations; mean-square stability	39	7.70%	1.66	15.0%	1.52	82.58
Model checking; Markov processes;	37	5.10%	1.32	19.8%	2.12	90.91
Synchronization; synchronism; bursting	37	7.20%	2.12	12.3%	1.74	91.94
Parallel programming; Libraries; algorithmic	36	14.40%	1.26	24.0%	1.23	74.08
Query languages; Computability and decidability; finite satisfiability	29	12.50%	3.12	22.8%	2.67	73.01
Tumors; Neoplasms; tumour growth	28	5.30%	1.86	14.3%	1.31	94.64
Oscillators (electronic); oscillators; coupled	25	3.80%	1.75	11.4%	1.76	97.75
Communication; Network protocols; multiparty	25	6.90%	2.02	32.9%	2.69	88.15

Physical Sciences

Most of the most published topics in Physical Sciences for Scotland are highly prominent. 'Optical communication; Light emitting diodes; indoor optical' is a large topic with nearly 2,500 publications. Another topic in which a Scottish institution is the leading publisher is 'Angular momentum; Vortex flow; carrying orbital'.

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Table 6.7— *Top ten topics for Scotland in Physical Sciences sorted by output, for 2012-2016. Source: Scopus*

Topic	SCO Output	SCO World Publication Share	SCO FWCI	GBR World Publication Share	GBR FWCI	Prominence percentile
jets; production; parton shower	208	13.90%	2.76	34.4%	2.55	99.81
galaxies; dust; infrared galaxies	193	17.70%	2.17	51.2%	1.82	98.78
decay; CP violation; angle γ	184	20.90%	3.31	30.0%	2.63	97.70
Angular momentum; Vortex flow; carrying orbital	170	8.70%	2.66	13.1%	2.36	99.36
galaxies; mass; quiescent galaxies	150	11.70%	3.07	37.5%	2.58	99.50
Optical communication; Light emitting diodes; indoor optical	147	5.90%	4.84	13.0%	3.44	99.68
quantum chromodynamics; lattices; lattice	147	17.20%	1.42	24.8%	1.45	93.53
planet; planets; planet candidates	127	6.20%	1.50	26.9%	2.26	99.74
quarks; production; top-quark mass	118	12.10%	2.17	25.0%	1.86	98.17
Scale (deposits); Corrosion inhibitors; squeeze	97	20.50%	1.43	34.0%	1.26	87.88

Engineering

Scotland's most published topics in the field of Engineering have varied prominence levels. The top three topics are shared with the Physical Sciences field. Solar equipment; Solar radiation; spinning solar' is another topic where a Scottish Institute leads globally. Another topic is 'Wind turbines; Condition monitoring; turbine gearbox', which is among the top 2% most prominent topics in the world. Although China leads as a country in this topic, the top authors are mainly from European institutions. Scottish Universities lead another topic related to oil and gas – 'Petroleum reservoirs; Petroleum reservoir evaluation; filter EnKF'. This is again a strength unique to Scotland where contributions from other UK nations are very limited.

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Table 6.8— *Top ten topics for Scotland in Engineering sorted by output, for 2012-2016. Source: Scopus*

Topic	SCO Output	SCO World Publication Share	SCO FWCI	GBR World Publication Share	GBR FWCI	Prominence percentile
Angular momentum; Vortex flow; carrying orbital	170	8.71%	2.66	13.1%	2.36	99.36
Optical communication; Light emitting diodes; indoor optical	147	5.93%	4.84	13.0%	3.44	99.68
Scale (deposits); Corrosion inhibitors; squeeze treatment	97	20.46%	1.43	34.0%	1.26	87.88
Solar equipment; Solar radiation; spinning solar	94	29.01%	1.42	30.6%	1.43	83.05
Electric potential; Power converters; circulating currents	80	4.15%	3.39	9.2%	2.92	99.61
HVDC power transmission; DC power transmission; source converter	78	4.92%	2.57	14.8%	2.36	98.72
Wind turbines; Condition monitoring; turbine gearbox	76	7.26%	1.84	21.9%	1.74	98.69
Passive mode locking; Lasers; mode-locked semiconductor	76	17.88%	0.32	23.5%	0.34	83.85
Telegraph; MOSFET devices; statistical variability	74	12.11%	1.48	13.4%	1.39	87.35
Petroleum reservoirs; Petroleum reservoir evaluation; filter EnKF	69	8.98%	1.41	14.2%	1.28	92.39

Social Sciences

Most of Scotland's most published topics in Social Sciences are prominent topics with overall global publication numbers ranging between 113-1102. In most topics listed below, English institutions publish more although the impact varies. An interesting topic is Great Britain; decentralization; policy copying', where the top five most-published universities are from devolved nations. Although Scotland publishes most in the listed topics, it does not lead these topics in most cases. One exception is ''farmer; farm; agricultural policy'.

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Table 6.9— Top ten topics for Scotland in Social Sciences sorted by output, for 2012-2016. Source: Scopus

Topic	SCO Output	SCO World Publication Share	SCO FWCI	GBR World Publication	GBR FWCI	Prominence percentile
spatial planning; marine policy; marine governance	52	9.40%	1.71	32.8%	2.30	98.22
Iceland; Norse; soil erosion	44	32.80%	2.11	47.0%	1.92	80.07
Education; Students; digital game-based	38	3.80%	4.48	10.6%	2.35	97.67
Great Britain; decentralization; policy copying	36	31.90%	1.47	67.3%	0.95	76.99
Structural priming; Syntactic priming; Language production	35	14.80%	8.20	29.5%	4.94	84.91
geography; cultural geography; art	34	4.20%	2.46	37.0%	1.86	93.87
child; people; children's agency	34	5.50%	1.36	38.4%	1.32	92.72
course; Education; discussion forums	31	2.80%	5.27	9.1%	4.43	99.43
Containers; Freight transportation; dry ports	30	2.80%	1.61	8.1%	1.18	95.97
Sports; event; sport mega-events	28	3.20%	1.49	23.0%	1.79	96.63
farmer; farm; agricultural policy	28	6.60%	1.79	25.5%	1.84	95.91

Business

Similar to Social Sciences, it is difficult to find a topic in Business where Scotland leads globally. A Scottish institute leads in the topic of 'Six Sigma; Work simplification; define measure' although this topic's global impact is limited. In this field there seems to be no institutional leads but certain researchers stand out across topics.

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Table 6.10— *Top ten topics for Scotland in Business sorted by output, for 2012-2016. Source: Scopus*

Topic	SCO Output	SCO World Publication Share	SCO FWCI	GBR World Publication Share	GBR FWCI	Prominence percentile
Consumption; Consumers; consumption practices	38	4.30%	1.04	21.8%	1.17	97.70
Six Sigma; Work simplification; define measure	37	4.70%	2.90	10.2%	2.06	95.55
Corporate social responsibility; Disclosure; environmental disclosure	35	3.40%	3.04	12.4%	2.79	99.20
Entrepreneurship; Entrepreneurial; enterprise education	32	2.20%	3.28	13.5%	2.62	99.50
Algorithms; Agents; hedonic games	31	4.80%	1.06	11.7%	1.41	88.82
Public-private partnerships; Risks; concession period	28	2.70%	0.80	11.0%	1.04	97.68
Sports; event; sport mega-events	28	3.20%	1.49	23.0%	1.79	96.63
Monetary policy; Inflation; policy rule	24	1.90%	0.42	14.4%	0.95	95.73
Internationalization; SMEs; born global	24	3.10%	1.84	12.3%	1.87	98.06
Corporate governance; Boards; non-executive directors	21	1.50%	2.42	8.5%	1.71	98.17

Humanities

In Humanities, Scotland has leading institutions in some of the topic areas, although it should be added that the prominence of these topics is more limited than in other fields. Where Scotland publishes more and with more impact than England is the topic of 'Epistemic; Knowledge; pragmatic encroachment', strongly suggesting that this is a strong area for Scotland more broadly. 'Structural priming; Syntactic priming; Language production' is another topic where Scotland has very high citation impact.

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Table 6.11— Top ten topics for Scotland in Humanities sorted by output, for 2012-2-16. Source: Scopus

Topic	SCO output	SCO World Publication Share	SCO FWCI	GBR World Publication Share	GBR FWCI	Prominence percentile
Epistemic; Knowledge; pragmatic encroachment	89	9.80%	2.55	18.9%	2.05	80.36
Iceland; Norse; soil erosion	44	32.80%	2.11	47.0%	1.92	80.07
Truth; Logic; consequence relations	37	8.50%	1.57	22.7%	1.35	61.48
Younger Dryas; Scotland; Glen Roy	36	46.80%	1.93	88.3%	1.57	77.60
Structural priming; Syntactic priming; Language production	35	14.80%	8.20	29.5%	4.94	84.91
Computational linguistics; Computer aided language translation; hierarchical phrase-based	29	2.00%	1.40	7.8%	1.00	91.66
Great Britain; Scottish; independence referendum	27	22.10%	0.63	65.6%	0.97	66.16
Bilingual; Bilingualism; language control	24	3.10%	4.62	15.5%	3.29	99.04
Computational linguistics; Syntactics; dependency parsers	24	2.00%	1.57	4.5%	2.01	94.50
Tephra; tephrochronology; tephra layers	22	15.20%	2.52	60.7%	3.14	89.68

Appendix B

Subject Area Mapping

In Scopus titles are classified under one of the 27 all science journal classifications (ASJC) which are further divided into 334 subcategories. In this report we have used the same classification which was used in the 2016 BEIS report "International Comparative Performance of the UK Research Base", where the 26 subjects are clustered into ten areas. Multidisciplinary field was not mapped to any of the BEIS subject and remains separate. The table below shows the mapping of the ASJC subject areas to the ten areas used in the report. Journals may belong to more than one subject area.

Scopus Subject Classification	BEIS subject field
Agricultural and Biological Sciences	Biological Sciences
Arts and Humanities	Humanities
Biochemistry, Genetics and Molecular Biology	Biological Sciences
Business, Management and Accounting	Business
Chemical Engineering	Engineering
Chemistry	Physical Sciences
Computer Science	Physical Sciences
Decision Sciences	Business
Dentistry	Health & Medical Sciences
Earth and Planetary Sciences	Physical Sciences
Economics, Econometrics and Finance	Business
Energy	Engineering
Engineering	Engineering
Environmental Science	Environmental Sciences
Health Professions	Health & Medical Sciences
Immunology and Microbiology	Biological Sciences
Materials Science	Physical Sciences
Mathematics	Mathematics
Medicine	Clinical Sciences
Multidisciplinary (journals like Nature and Science)	Multidisciplinary
Neuroscience	Clinical Sciences
Nursing	Health & Medical Sciences
Pharmacology, Toxicology and Pharmaceutics	Biological Sciences
Physics and Astronomy	Physical Sciences
Psychology	Clinical Sciences
Social Sciences	Social Sciences
Veterinary	Health & Medical Sciences

Subject Field	Subject Area
Biological Sciences	Ageing
Biological Sciences	Agricultural and Biological Sciences (miscellaneous)
Biological Sciences	Agronomy and Crop Science
Biological Sciences	Animal Science and Zoology
Biological Sciences	Applied Microbiology and Biotechnology
Biological Sciences	Aquatic Science
Biological Sciences	Biochemistry
Biological Sciences	Biochemistry, Genetics and Molecular Biology
Biological sciences	Biological sciences
Biological Sciences	Biophysics
Biological Sciences	Biotechnology
Biological Sciences	Cancer Research
Biological Sciences	Cell Biology
Biological Sciences	Clinical Biochemistry
Biological Sciences	Developmental Biology
Biological Sciences	Drug Discovery
Biological Sciences	Ecology, Evolution, Behavior and Systematics
Biological Sciences	Endocrinology
Biological Sciences	Food Science
Biological Sciences	Forestry
Biological Sciences	General Agricultural and Biological Sciences
Biological Sciences	General Biochemistry Genetics and Molecular Biology
Biological Sciences	General Immunology and Microbiology
Biological Sciences	General Pharmacology, Toxicology and Pharmaceutics
Biological Sciences	Genetics
Biological Sciences	Horticulture
Biological Sciences	Immunology
Biological Sciences	Immunology and Microbiology (miscellaneous)
Biological Sciences	Insect Science
Biological Sciences	Microbiology
Biological Sciences	Molecular Biology
Biological Sciences	Molecular Medicine
Biological Sciences	Parasitology
Biological Sciences	Pharmaceutical Science
Biological Sciences	Pharmacology
Biological Sciences	Pharmacology, Toxicology and Pharmaceutics
Biological Sciences	Physiology
Biological Sciences	Plant Science
Biological Sciences	Soil Science
Biological Sciences	Structural Biology

Biological Sciences	Toxicology
Biological Sciences	Virology
Business	Accounting
Business	Business
Business	Business and International Management
Business	Business, Management and Accounting (miscellaneous)
Business	Decision Sciences (miscellaneous)
Business	Economics and Econometrics
Business	Economics, Econometrics and Finance (miscellaneous)
Business	Finance
Business	General Business, Management and Accounting
Business	General Decision Sciences
Business	General Economics, Econometrics and Finance
Business	Industrial Relations
Business	Information Systems and Management
Business	Management Information Systems
Business	Management of Technology and Innovation
Business	Management Science and Operations Research
Business	Marketing
Business	Organisational Behaviour and Human Resource
Business	Statistics, Probability and Uncertainty
Business	Strategy and Management
Business	Tourism, Leisure and Hospitality Management
Clinical Sciences	Anatomy
Clinical Sciences	Anesthesiology and Pain Medicine
Clinical Sciences	Applied Psychology
Clinical Sciences	Behavioral Neuroscience
Clinical Sciences	Biochemistry (medical)
Clinical Sciences	Biological Psychiatry
Clinical Sciences	Cardiology and Cardiovascular Medicine
Clinical Sciences	Cellular and Molecular Neuroscience
Clinical Sciences	Clinical Psychology
Clinical Sciences	Clinical Sciences
Clinical Sciences	Cognitive Neuroscience
Clinical Sciences	Complementary and Alternative Medicine
Clinical Sciences	Critical Care and Intensive Care Medicine
Clinical Sciences	Dermatology
Clinical Sciences	Developmental and Educational Psychology
Clinical Sciences	Developmental Neuroscience
Clinical Sciences	Drug Guides
Clinical Sciences	Embryology

Clinical Sciences	Emergency Medicine
Clinical Sciences	Endocrine and Autonomic Systems
Clinical Sciences	Endocrinology, Diabetes and Metabolism
Clinical Sciences	Epidemiology
Clinical Sciences	Experimental and Cognitive Psychology
Clinical Sciences	Family Practice
Clinical Sciences	Gastroenterology
Clinical Sciences	General Medicine
Clinical Sciences	General Neuroscience
Clinical Sciences	General Psychology
Clinical Sciences	Genetics (clinical)
Clinical Sciences	Geriatrics and Gerontology
Clinical Sciences	Health Informatics
Clinical Sciences	Health Policy
Clinical Sciences	Hematology
Clinical Sciences	Hepatology
Clinical Sciences	Histology
Clinical Sciences	Immunology and Allergy
Clinical Sciences	Infectious Diseases
Clinical Sciences	Internal Medicine
Clinical Sciences	Medicine (miscellaneous)
Clinical Sciences	Microbiology (medical)
Clinical Sciences	Nephrology
Clinical Sciences	Neurology
Clinical Sciences	Neurology (clinical)
Clinical Sciences	Neuropsychology and Physiological Psychology
Clinical Sciences	Neuroscience (miscellaneous)
Clinical Sciences	Obstetrics and Gynecology
Clinical Sciences	Oncology
Clinical Sciences	Ophthalmology
Clinical Sciences	Orthopedics and Sports Medicine
Clinical Sciences	Otorhinolaryngology
Clinical Sciences	Pathology and Forensic Medicine
Clinical Sciences	Pediatrics, Perinatology and Child Health
Clinical Sciences	Pharmacology (medical)
Clinical Sciences	Physiology (medical)
Clinical Sciences	Psychiatry and Mental Health
Clinical Sciences	Psychology (miscellaneous)
Clinical Sciences	Public Health, Environmental and Occupational Health
Clinical Sciences	Pulmonary and Respiratory Medicine
Clinical Sciences	Radiology, Nuclear Medicine and Imaging

Clinical Sciences	Rehabilitation
Clinical Sciences	Reproductive Medicine
Clinical Sciences	Reviews and References (medical)
Clinical Sciences	Rheumatology
Clinical Sciences	Sensory Systems
Clinical Sciences	Social Psychology
Clinical Sciences	Surgery
Clinical Sciences	Transplantation
Clinical Sciences	Urology
Engineering	Aerospace Engineering
Engineering	Architecture
Engineering	Automotive Engineering
Engineering	Bioengineering
Engineering	Biomedical Engineering
Engineering	Building and Construction
Engineering	Catalysis
Engineering	Chemical Engineering (miscellaneous)
Engineering	Chemical Health and Safety
Engineering	Civil and Structural Engineering
Engineering	Colloid and Surface Chemistry
Engineering	Computational Mechanics
Engineering	Control and Systems Engineering
Engineering	Electrical and Electronic Engineering
Engineering	Energy (miscellaneous)
Engineering	Energy Engineering and Power Technology
Engineering	Engineering
Engineering	Engineering (miscellaneous)
Engineering	Filtration and Separation
Engineering	Fluid Flow and Transfer Processes
Engineering	Fuel Technology
Engineering	General Chemical Engineering
Engineering	General Energy
Engineering	General Engineering
Engineering	Industrial and Manufacturing Engineering
Engineering	Mechanical Engineering
Engineering	Mechanics of Materials
Engineering	Media Technology
Engineering	Nuclear Energy and Engineering
Engineering	Ocean Engineering
Engineering	Process Chemistry and Technology
Engineering	Renewable Energy, Sustainability and the Environment

Engineering	Safety, Risk, Reliability and Quality
Environmental Science	Ecological Modeling
Environmental Science	Ecology
Environmental Science	Environmental Chemistry
Environmental Science	Environmental Engineering
Environmental Science	Environmental Science
Environmental Science	Environmental Science (miscellaneous)
Environmental Science	General Environmental Science
Environmental Science	Global and Planetary Change
Environmental Science	Health, Toxicology and Mutagenesis
Environmental Science	Management, Monitoring, Policy and Law
Environmental Science	Nature and Landscape Conservation
Environmental Science	Pollution
Environmental Science	Waste Management and Disposal
Environmental Science	Water Science and Technology
Health & Medical Sciences	Advanced and Specialized Nursing
Health & Medical Sciences	Assessment and Diagnosis
Health & Medical Sciences	Care Planning
Health & Medical Sciences	Chiropractics
Health & Medical Sciences	Community and Home Care
Health & Medical Sciences	Complementary and Manual Therapy
Health & Medical Sciences	Critical Care Nursing
Health & Medical Sciences	Dentistry (miscellaneous)
Health & Medical Sciences	Emergency Medical Services
Health & Medical Sciences	Emergency Nursing
Health & Medical Sciences	Equine
Health & Medical Sciences	Food Animals
Health & Medical Sciences	Fundamentals and Skills
Health & Medical Sciences	General Dentistry
Health & Medical Sciences	General Health Professions
Health & Medical Sciences	General Nursing
Health & Medical Sciences	General Veterinary
Health & Medical Sciences	Gerontology
Health & Medical sciences	Health & Medical sciences
Health & Medical Sciences	Health Information Management
Health & Medical Sciences	Health Professions (miscellaneous)
Health & Medical Sciences	Issues, Ethics and Legal Aspects
Health & Medical Sciences	Leadership and Management
Health & Medical Sciences	LPN and LVN
Health & Medical Sciences	Maternity and Midwifery
Health & Medical Sciences	Medical and Surgical Nursing

Health & Medical Sciences	Medical Laboratory Technology
Health & Medical Sciences	Nursing (miscellaneous)
Health & Medical Sciences	Nutrition and Dietetics
Health & Medical Sciences	Occupational Therapy
Health & Medical Sciences	Oncology (nursing)
Health & Medical Sciences	Optometry
Health & Medical Sciences	Oral Surgery
Health & Medical Sciences	Orthodontics
Health & Medical Sciences	Pediatrics
Health & Medical Sciences	Periodontics
Health & Medical Sciences	Pharmacology (nursing)
Health & Medical Sciences	Pharmacy
Health & Medical Sciences	Physical Therapy, Sports Therapy and Rehabilitation
Health & Medical Sciences	Podiatry
Health & Medical Sciences	Psychiatric Mental Health
Health & Medical Sciences	Radiological and Ultrasound Technology
Health & Medical Sciences	Research and Theory
Health & Medical Sciences	Respiratory Care
Health & Medical Sciences	Review and Exam Preparation
Health & Medical Sciences	Small Animals
Health & Medical Sciences	Speech and Hearing
Health & Medical Sciences	Veterinary (miscellaneous)
Humanities	Archaeology (arts and humanities)
Humanities	Arts and Humanities (miscellaneous)
Humanities	Classics
Humanities	Conservation
Humanities	General Arts and Humanities
Humanities	History
Humanities	History and Philosophy of Science
Humanities	Humanities
Humanities	Language and Linguistics
Humanities	Literature and Literary Theory
Humanities	Museology
Humanities	Music
Humanities	Philosophy
Humanities	Religious Studies
Humanities	Visual Arts and Performing Arts
Mathematics	Algebra and Number Theory
Mathematics	Analysis
Mathematics	Applied Mathematics
Mathematics	Computational Mathematics

Mathematics	Control and Optimization
Mathematics	Discrete Mathematics and Combinatorics
Mathematics	General Mathematics
Mathematics	Geometry and Topology
Mathematics	Logic
Mathematics	Mathematical Physics
Mathematics	Mathematics
Mathematics	Mathematics (miscellaneous)
Mathematics	Modelling and Simulation
Mathematics	Numerical Analysis
Mathematics	Statistics and Probability
Mathematics	Theoretical Computer Science
Multidisciplinary	Multidisciplinary
Physical Sciences	Acoustics and Ultrasonics
Physical Sciences	Analytical Chemistry
Physical Sciences	Artificial Intelligence
Physical Sciences	Astronomy and Astrophysics
Physical Sciences	Atmospheric Science
Physical Sciences	Atomic and Molecular Physics, and Optics
Physical Sciences	Biomaterials
Physical Sciences	Ceramics and Composites
Physical Sciences	Chemistry (miscellaneous)
Physical Sciences	Computational Theory and Mathematics
Physical Sciences	Computer Graphics and Computer-Aided Design
Physical Sciences	Computer Networks and Communications
Physical Sciences	Computer Science (miscellaneous)
Physical Sciences	Computer Science Applications
Physical Sciences	Computer Vision and Pattern Recognition
Physical Sciences	Computers in Earth Sciences
Physical Sciences	Condensed Matter Physics
Physical Sciences	Earth and Planetary Sciences (miscellaneous)
Physical Sciences	Earth-Surface Processes
Physical Sciences	Economic Geology
Physical Sciences	Electrochemistry
Physical Sciences	Electronic, Optical and Magnetic Materials
Physical Sciences	General Chemistry
Physical Sciences	General Computer Science
Physical Sciences	General Earth and Planetary Sciences
Physical Sciences	General Materials Science
Physical Sciences	General Physics and Astronomy
Physical Sciences	Geochemistry and Petrology

Physical Sciences	Geology
Physical Sciences	Geophysics
Physical Sciences	Geotechnical Engineering and Engineering Geology
Physical Sciences	Hardware and Architecture
Physical Sciences	Human-Computer Interaction
Physical Sciences	Information Systems
Physical Sciences	Inorganic Chemistry
Physical Sciences	Instrumentation
Physical Sciences	Materials Chemistry
Physical Sciences	Materials Science (miscellaneous)
Physical Sciences	Metals and Alloys
Physical Sciences	Nuclear and High Energy Physics
Physical Sciences	Oceanography
Physical Sciences	Organic Chemistry
Physical Sciences	Paleontology
Physical Sciences	Physical and Theoretical Chemistry
Physical Sciences	Physical Sciences
Physical Sciences	Physics and Astronomy (miscellaneous)
Physical Sciences	Polymers and Plastics
Physical Sciences	Radiation
Physical Sciences	Signal Processing
Physical Sciences	Software
Physical Sciences	Space and Planetary Science
Physical Sciences	Spectroscopy
Physical Sciences	Statistical and Nonlinear Physics
Physical Sciences	Stratigraphy
Physical Sciences	Surfaces and Interfaces
Physical Sciences	Surfaces, Coatings and Films
Social Sciences	Anthropology
Social Sciences	Archeology
Social Sciences	Communication
Social Sciences	Cultural Studies
Social Sciences	Demography
Social Sciences	Development
Social Sciences	Education
Social Sciences	Gender Studies
Social Sciences	General Social Sciences
Social Sciences	Geography, Planning and Development
Social Sciences	Health (social science)
Social Sciences	Human Factors and Ergonomics
Social Sciences	Law

Social Sciences	Library and Information Sciences
Social Sciences	Life-span and Life-course Studies
Social Sciences	Linguistics and Language
Social Sciences	Political Science and International Relations
Social Sciences	Public Administration
Social Sciences	Safety Research
Social Sciences	Social Sciences
Social Sciences	Social Sciences (miscellaneous)
Social Sciences	Sociology and Political Science
Social Sciences	Transportation
Social Sciences	Urban Studies

Appendix C

Methodology and Rationale

Our methodology 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. The *Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems* (Moed, Glänzel and Schmoch, 2004)[28] gives a good overview of this field and is based on the pioneering work of Derek de Solla Price (1978),[29] Eugene Garfield (1979)[30] and Francis Narin (1976)[31] in the US, and Christopher Freeman, Ben Martin and John Irvine in the UK (1981, 1987)[32], and in several European institutions including the Centre for Science and Technology Studies at Leiden University, the Netherlands, and the Library of the Academy of Sciences in Budapest, Hungary.

The analyses of bibliometric data in this report are based upon recognised advanced indicators (e.g. the concept of relative citation impact rates). 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 the past decade, the field of indicators research has developed best practices which state how indicator results should be interpreted and which influencing factors should be considered. Our methodology builds on these practices.

Counting

All analyses make use of whole counting rather than fractional counting. For example, if a paper has been co-authored by one author from Scotland and one author from Germany, then that paper counts towards both the publication count of Scotland, as well as the publication count of Germany. Total counts for each institution are the unique count of publications.

[28] Moed H., Glänzel W., & Schmoch U. (2004). Handbook of Quantitative Science and Technology Research, Kluwer: Dordrecht.
[29] de Solla Price, D.J. (1977–1978). "Foreword," Essays of an Information Scientist, Vol. 3, v–ix.
[30] Garfield, E. (1979). Is citation analysis a legitimate evaluation tool? Scientometrics, 1 (4), 359-375.
[31] Pinski, G., & Narin, F. (1976). Citation influence for journal aggregates of scientific publications: Theory with application to literature of physics. Information Processing & Management 12 (5): 297–312.
[32] Irvine, J., Martin, B. R., Abraham, J. & Peacock, T. (1987). Assessing basic research: Reappraisal and update of an evaluation of four radio astronomy observatories. Research Policy, 16(2-4), 213-227.

Collaboration

Research collaboration is indicated by articles with at least two different entities listed in the authorship by-line.

Collaborations in this report can be classified as:

- Institutional: all authors are from the same institution.
- National: authors are affiliated with at least two institutions within a country.
- International: at least one author is from an institution outside of the country.

Single-authored publications are used as a benchmark in this report.

Data Sources

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

Scopus coverage is multi-lingual and global: 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 covers approximately 6,400 titles from North-America, 11,800 from Europe and 2,500 from Asia-Pacific and 1,500 from Latin-America and Africa. The geographical breadth of Scopus ensures comprehensive coverage of research outputs and impact of regionally-collaborated research.

Scopus coverage is also inclusive across all major research fields, with 7,500 titles in the Physical Sciences, 6,800 in the Health Sciences, 4,500 in the Life Sciences, and 8,100 in the Social Sciences (the latter including some 2,800 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, and currently covers more than 121,000 books.

For this report, a static version of the Scopus database covering the period 2007-2016 inclusive was aggregated by institution, country, region, and subject. Subjects were defined by ASJC subject areas (see **Appendix A** for more details). When aggregating article and citation counts, an integer counting method was employed where, for example, a paper with two authors from a United States address and one from a United Kingdom address would be counted as one article for each country (i.e. 1 United States and 1 United Kingdom). This method was favoured over fractional counting, in which the above paper would count as 0.67 for the United States and 0.33 for the United Kingdom, to maintain consistency with other reports (both public and private) we have conducted on the topic.

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 article comprise most research outputs.

Appendix D

Glossary of Terms

Article/Publication types (unless otherwise indicated) denotes the main types of peer reviewed documents published in journals: articles, reviews, and conference papers.

Article/Publication output for an institute or country is the count of articles with at least one author from that institution or country respectively (according to the affiliation listed in the authorship by-line). 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 by-line) is counted once each for every institution listed.

Compound Annual Growth Rate (CAGR) is defined as the year-over-year constant growth rate over a specified period of time. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series.

$$\mathrm{CAGR}(t_0, t_n) = (V(t_n)/V(t_0))^{\frac{1}{t_n - t_0}} - 1$$

$V(t_0)$: start value

$V(t_n)$: finish value

$t_n - t_0$: number of years.

Citation is a formal reference 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 importance of the reported research.

Field-weighted citation impact (FWCI) 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. When an 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, an un-weighted 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, 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 two years on either side, so weightings are readjusted across the remaining available values.

Highly-cited articles are those in the top cited X% of all articles published and cited in a given period. An institution's number or share of highly-cited articles is treated as indicative of the excellence of their research. In this report, we present data on the top 10% cited articles.

International collaboration (i.e., research collaboration) in this report is indicated by articles with at least two different countries listed in the authorship by-line.

Institutional collaboration (i.e., research collaboration) in this report is indicated by articles with a single institute listed in the authorship by-line.

Journal is a peer-reviewed periodical in which scholarship relating to a 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.

National collaboration (i.e., research collaboration) in this report is indicated by articles with at least two different institutes from the same country listed in the authorship by-line.

Relative Activity Index (RAI) is defined as an institution's share of its total article output across a subject area relative to the global share of articles in the same subject area. A RAI of 1.0 indicates that a country's research activity in a subject area corresponds exactly with the amount of global activity in that field; higher than 1.0 implies a greater emphasis, while lower than 1.0 suggests a lesser focus in this area of research.

Authors and About

Authors

This study was commissioned by the Scottish Science Advisory Council (SSAC) and funded by the SSAC, the Scottish Funding Council, Universities Scotland and the Royal Society of Edinburgh. It was conducted and written by Dr.Başak Candemir and data used in the report was extracted by Eleonora Palmaro.

Extensive feedback was provided primarily by SSAC Chair Professor.Paul Boyle, CBE, FRSE, FBA and also by other members of the project steering committee and Dr.Jorg Hellwig.

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Project Funders

The Scottish Science Advisory Council which commissioned this report would like to thank The Scottish Funding Council, Universities Scotland, and the Royal Society of Edinburgh, for both their funding contribution to the project.

Project Steering Group

The SSAC would like to thank The Scottish Funding Council, Universities Scotland, Royal Society of Edinburgh, Scottish Enterprise, and Highlands and Islands Enterprise, for their time on the project steering group and contributions to shaping the project.

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