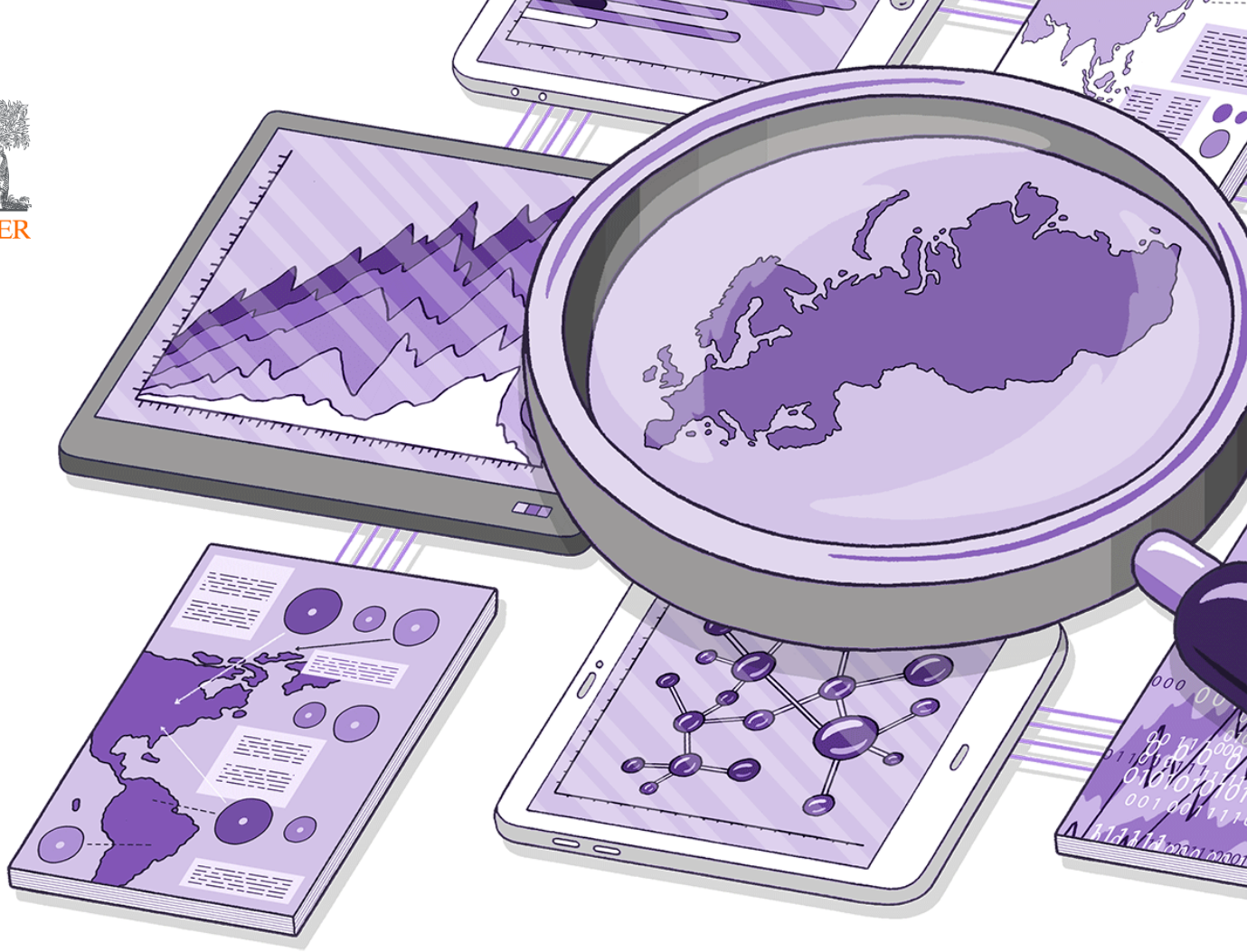


A performance-based assessment of the Welsh Research base (2010-2018)

Analytical Services

Foreword by Professor Peter Halligan, Chief Scientific Advisor to the Welsh Government

Research and innovation are well recognised drivers of economic productivity. Over the past 20 years, Wales has grown the volume, quality, and international reach of its research base to become one of the most efficient nations converting relatively small levels of funding into highly regarded and innovative research.

Given that Wales receives only 2% of overall UK R&D funding, EU structural funds allocated by the Welsh Government have, over the past 20 years contributed to growing Wales research and innovation base and wider international collaboration. Brexit will bring an end to these EU Structural funds and unless replaced will have a significant and disproportionate impact on the future research and innovation.

With a view to profiling current performance and updating previous Elsevier reports, I asked Elsevier to produce an evidenced based analysis of Wales's research base covering the period 2010-2018 and compare it to other UK nations and a number of international countries including EU and World averages.

This report shows that the quality and international reach of Wales's research outputs continues to remain impressive. In terms of research output per expenditure, Wales has the largest output per €m spent on R&D, making it the most efficient of all UK nations well above other international comparators.

Wales also continues to contribute strongly to the quality of UK research base, producing an average Field Weighted Citation Impact (FWCI) of 1.8 in 2018, that is 80% more citations than the global average and the second highest of all UK nations. This has not always been the case. For much of the early 1990s, Wales' research performance was below the world average but by the mid-1990s Wales' citation impact began to equal and exceed the world average. From 2000 onwards, Wales' research impact grew steadily, exceeding the World, EU and UK average and in the process overtook several well-performing similar-sized countries.

The quality of Wales's performance remains particularly striking when one considers that, from 2003 onwards and with productivity and citation impact growing rapidly, the size of the Welsh academic researcher base remained relatively unchanged. Growing the research base will be a critical factor in determining Wales' future capacity to conduct excellent research at scale.

Over the past decade, a key contributor to Wales' impressive research performance, has been growing its level of international collaborative networking. International collaboration not only accounts for a growing number of the Welsh published articles, but also results in their high field-weighted citation impact.

Between 2010 and 2018, Wales grew its share of internationally co-authored publications by more than 15%, rising to almost 60%. Wales research publications remain impressively international with half of its research publications having international co-authors. International collaboration produces an average citation impact more than twice the global average (FWCI = 2.4) -the highest of the UK nations.

EU programmes has helped foster and strengthen this scientific collaboration with Wales main collaborating countries over the past decade (after the US) including Germany, Spain, France, Italy, Netherlands, Belgium, Sweden, and Ireland.

As a small research nation, Wales has also benefited greatly from research mobility and exchange with other EU countries. Welsh researchers are highly mobile, and the Welsh researcher base is the most mobile among all UK nations. Mobile researchers migrating to and from the EU show the highest productivity and FWCI for all groups. A decline in researcher mobility associated with Brexit will clearly pose risks for Wales' future research performance.

In 2010, most R&D expenditure came from the higher education sector, however in the period (2010-2018) expenditure from the business sector (BERD) grew from 47% in to 62%. Business to academic collaboration (knowledge transfer) although small saw growth with these collaborations for Wales achieving an average FWCI of 4.7, the highest of all UK nations.

In this report, Elsevier have applied a new analysis on Topics of prominence designed to capture the current visibility and public momentum of research questions at a more granular level. Based on citation links and clusters of publication, this analysis has the potential to identify new emerging research trends. In Wales's case, the analysis found 20 topic areas of prominence where the average FWCI was greater than global and UK averages, suggesting that these topics clusters many be emerging areas of research strengths.

While this report shows unequivocal evidence that Welsh research is highly impactful and hugely efficient, the lack of an adequate research base means that Wales does not have the scale of capacity needed to deliver its full potential. Ensuring that Wales has greater future research capacity to win greater competitive funding to build a stronger and sustainable research and innovation base will require significant long-term investment.

Executive summary

Wales' research is highly productive, collaborative, and deeply embedded in the UK research system. Its researchers are the most efficient and mobile of all UK nations' researchers.

Wales accounts for 0.05% of the world's R&D funding, and 0.1% of the world's researchers[1] but provides almost 0.3% of the world's research articles, 0.5% of global citations and 0.5% of the most highly cited articles.

The purpose of this performance-based analysis of Wales' science and research base is to provide an up-to-date, comprehensive bibliometric analysis that profiles the strengths of the Welsh research and innovation base, building upon and updating previous Elsevier reports from 2013 and 2016. The report supports the Welsh Government's strategic agenda committed to growing and evaluating Wales' research performance with a view to demonstrating and improving Welsh research effectiveness and economic productivity.

Although small, Wales' research system is characterised by high productivity—measured as scholarly output per researcher and per expenditure. Wales' population accounts for 5% of the UK population, whereas its researcher base only accounts for 3.4% of all UK researchers. Wales had the lowest growth of researcher numbers among the UK nations (1.7% annually between 2010 and 2017) but had the second-highest publication output per researcher (0.84) of all global comparators, outperformed only by Scotland. The UK average output per researcher was 0.72.

Wales also had the highest productivity in terms of output per gross domestic expenditure on research and development (GERD[2]) of all global comparators. However, to put this in perspective, the share of GERD as a percentage of gross domestic product (GDP) was only around 1%, less than any other UK nation, which puts Wales at risk in the long run. The increase in overall expenditure was mainly driven by an increasing share of expenditure from the business enterprise (BERD[3]). This is in line with the observations for other UK nations.

[1] Data calculated using data from UNESCO Institute for Statistics (http://data.uis.unesco.org) and Eurostat (https://ec.europa.eu/eurostat/web/science-technology-innovation/data/database)

[2] Gross domestic expenditure on R&D (GERD): Total intramural expenditure on R&D performed on the national territory during a given period.

[3] Business enterprise expenditure on R&D (BERD)

Between 2010 and 2018 Wales' research output grew by 3.0% annually, comprising 59,391 publications in total as indexed in Scopus—accounting for 4% of all UK publications. The annual growth rate was lower than those of most of the global comparators and almost the lowest of all UK nations.

The scholarly output from Wales, however, is highly impactful, with an average Field-Weighted Citation Impact (FWCI) of 1.8 between 2010 and 2018, accruing 80% more citations than the global average. This impact growth between the two periods was the highest among all UK nations and only bettered by Estonia and China among the benchmarked countries. Wales, therefore, contributes strongly to the performance of the UK research system. This finding is also supported by the fact that the share of top 5% most highly cited publications among Wales' publication outputs was almost twice the global average, with strong growth between 2010 and 2017 but a decline in the most recent year of this analysis, 2018.

One of the main drivers behind Wales's strong research performance has been international collaboration. Between 2010 and 2018, Wales increased its share of internationally (outside UK) co-authored publications by more than 15%, rising to almost 60%, with the impact of these publications being the highest of all UK nations. The average FWCI of internationally co-authored publications was 2.4. The share of academic–corporate co-authored publications increased from 6% in 2010 to 7% in 2018, and had an average FWCI of 4.7, which undoubtedly contributed to the overall high research impact of Wales.

Wales is deeply embedded within the UK research system. More than one fifth of Wales' publications were published in co-authorship with other UK nations without other international collaborators. This is twice the share of Northern Ireland and Scotland and 10 times England's share. Within-UK collaboration came at the expense of within country collaboration (only between Welsh institutions without partners outside the nation), which was the lowest of all UK nations.

Wales' researchers remain highly mobile; almost 60% of the researcher base is transitory, being abroad (or moving into Wales) for less than two years. Wales has a very low share of non-mobile researchers (less than 10%), making the Welsh researcher base the most mobile among all UK nations.

Across all migration regions, transitory researchers are the most productive and impactful. For the group of researchers migrating to and from EU countries, relative productivity and the FWCI are the highest of all groups, although the share of researchers is the lowest for this group.

As a small research nation, Wales benefits greatly from mobility and exchange with EU countries. In this context, a decline in researcher mobility associated with Brexit poses serious risks for Wales' research performance.

NATURAL SCIENCE and MEDICAL AND HEALTH SCIENCE are the most prolific subject areas for Wales' research, accounting for 54% and 39% of all research output respectively. Publications in these subject areas were also the most impactful, with MEDICAL AND HEALTH SCIENCE publications showing an average FWCI of 2.0, accumulating twice the average citations as the global average in this subject area.

Topics and topic clusters allow for a more granular view, to better understand those areas where Wales' research output is focused and makes a significant contribution to the wider UK research base. Wales' share of UK publications is higher in several of these clusters than its overall average share of 4%, suggesting areas of existing

and or emerging strengths for Wales and the United Kingdom.

Research clusters where Wales displays high shares of output and high impact compared to both the UK and global averages include the following:

- CATALYSTS; ZEOLITES; HYDROGENATION: Wales' output accounts for more than 15% of the United Kingdom's output, and the FWCI is on par with the UK average.
- MEMBRANES; DESALINATION; ULTRAFILTRATION: Wales has a share of 16% of the United Kingdom's output and an FWCI of 2.1.
- GLACIERS; HOLOCENE; GLACIAL GEOLOGY: Here Wales accounts for nearly 2% of global research output and more than 11% of the UK output. On average, publications from Wales had an FWCI of 2.3, which is higher than the UK (1.9) and global (1.3) averages.
- LEACHING; ORES; BIOLEACHING: Here Wales accounts for 1.2% of the global output and almost 40% of UK output.

Key findings

Total publications account for 4% of all UK publications

- Welsh researchers produced 59,391 publications between 2010 and 2018, accounting for 4% of all UK publications and 0.3% of global scholarly output
- More than 50% of Welsh publications came from the Natural Sciences
- Given the small researcher base, the total number of publications from Wales only grew by 3.0% annually, the lowest growth rates for global comparators

Researcher base is efficient, but shows the lowest growth in the UK

- From 2010 to 2017, the number of Welsh researchers grew by 1.7%, the lowest growth among UK nations explaining the low annual growth in number of publications.
- Despite a small researcher base that accounts for just 3.4% of all UK researchers, Wales achieved the second-highest publication output per researcher of all global comparators.

Welsh research funding is low, but its researchers remain highly productive

- Wales' spend on R&D accounts for only 1% of its GDP which is lower than all other UK nations.
- In 2010, most R&D expenditure came from the higher education sector (49%); however, this dropped to 35% by 2018. In the same period (2010-2018), expenditure from the business sector (BERD) grew from 47% to 62%.
- In terms of output per expenditure, Wales showed the largest output per €m spent on R&D, making it the most efficient of all UK nations.
- On a global scale, Wales is also well above other comparators for the number of publications per research expenditure, being the only nation with more than 8.5 publications per €m spent.

Wales's research is highly impactful

- Wales continues to contribute strongly to the quality of the UK research base.
- Rising from an FWCI of 1.5 in 2010, Wales achieved an FWCI of 1.8 by 2018 (80% more citations than global average), the second highest of all UK nations.
- Between 2010 and 2018, Wales' FWCI grew by 0.3 points, the highest FWCI growth of all UK nations.
- Wales' publication share of the top 5% most highly cited publications is twice that of the global average.

Subject areas show a well-rounded research landscape

- Wales demonstrates a well-rounded coverage of subject areas–which contributes to the strong performance of Welsh research publications .
- Wales has a high share of the most highly cited publications across all subject areas and above the global average and UK average.
- NATURAL SCIENCE and MEDICAL AND HEALTH SCIENCE are the most prolific subject areas accounting for 54% and 39% of all research output.
- Publications from these subject areas were also most impactful: MEDICAL AND HEALTH SCIENCE publications showed an average FWCI of 2.0, accumulating twice the average citations as the global average.
- ENGINEERING AND TECHNOLOGY is the fastest growing subject area in Wales.
- Wales also has a strong showing in SOCIAL SCIENCE compared to other UK nations.

Wales is a global research collaborator

- Between 2010 and 2018, Wales increased its share of internationally co-authored publications by more than 15%, rising to almost 60%.
- AGRICULTURAL SCIENCE, NATURAL SCIENCE, and ENGINEERING AND TECHNOLOGY have more than 50% of their scholarly output published with international collaborators.
- International collaboration publications continue to be the most highly cited.
- International collaboration produced an average citation impact that is more than twice the global average (Field Weighted Citation Impact =2.4) and the highest of the UK nations.

Academic–corporate collaboration is highly impactful

- Although small, academic–corporate collaborations are a good indicator of knowledge transfer
- The share of academic–corporate co-authored publications increased from 6% in 2010 to 7% in 2018
- These publications achieved an average FWCI of 4.7, the highest of all UK nations.
- NATURAL SCIENCE, MEDICAL AND HEALTH SCIENCE, and ENGINEERING AND TECHNOLOGY were the most prolific subject areas.

Within-UK collaboration shows high contribution to wider UK research system

- Wales' research is deeply embedded in the wider UK research system.
- Some 20% of Wales' publications were produced in collaboration with other UK nations, but not with other international partners. This is twice the share of Northern Ireland and Scotland and 10 times England's share.

Wales' researchers are highly mobile

- Welsh researchers are highly mobile.
- More than 90% of all active researchers have published outside Wales.
- Almost 60% of the researcher base is transitory making the Welsh researcher base the most mobile among all UK nations.
- Mobile researchers migrating to and from Wales within the EU show the highest productivity and FWCI for all groups.

Emerging high performing topic clusters indicate research strengths

- Based on citation links, paper views, and clusters of publications, Topics of prominence was developed by Elsevier as a way to capture the current visibility and public momentum of "research challenges" or topics.
- This analysis was used to identify new emerging research trends across different countries.
- In the case of Wales, the Elsevier analysis identified some 20 topic areas of prominence for which the average FWCI was greater than both global and UK averages (p71), suggesting that these topics clusters are potential research strengths.
- Research challenges or topics during 2014-2018 where Wales showed almost double or higher than Wales share of UK publications outputs (>4%) and higher than average and UK global citation impact (FWCI) included:
    - Bioleaching (39% of UK outputs)
    - Rumen Fermentation / Dairy Cows (24% of UK outputs)
    - Mangroves / Seagrass (19% of UK outputs)
    - Membranes and ultrafiltration (16% of UK output)
    - Catalysts (15% of UK outputs)
    - Gallium nitride -high electron mobility transistors (13% of UK outputs)
    - Glaciers and Glacial geology (12% of UK output)
    - Vibration Analysis/ Functionally graded materials (>10% of UK outputs)
    - Intellectual Disability (>10% of UK outputs)
    - Depression / Serotonin (>10% of UK Outputs)
    - Rivers/ Sediment Transport (>10% of UK outputs)
    - Computer graphics (>10% of UK outputs)
    - Paleoceanography (>9% of UK output)
    - Cardiopulmonary Resuscitation (>9% of UK outputs)
    - Thyroid Neoplasms (>9% UK outputs)
    - Semiconductors Quantum Wells (8% of UK outputs)

Contents

Introduction

The Welsh Government Office for Science commissioned Elsevier to provide a bibliometric analysis of the performance of the Welsh research base to provide ministers and interested stakeholders with an evidenced overview.

This study is the third report in a series of reports on Wales, the first of which was published in 2013, followed by an update in 2016.[4] The previous reports analysed bibliometric data until 2014, and this report provides an update and key analyses with data until 2018.

The report tracks the performance of Wales' scientific research base over nine years (2010–2018), analysing a number of key indicators relating to the scholarly output of Wales and selected comparators. Only articles, reviews, and conference proceedings indexed in the Scopus database are taken into account.

The subject areas used in this report are based on definitions of research and development (R&D) provided by the Frascati Manual, as used by the Organisation for Economic Co-operation and Development (OECD).[5]

While research publication outputs comprise only one of the many outputs of a research system, they nevertheless provide quantitative systematic data that allows for inter-country comparisons. Even though these indicators are useful to assess research performance, we recognise they also have their limitations.

First, citation analysis requires large data samples. Infrequent outlier values can skew indicator values for small samples (such as a single subject field within a single institution). The number of publications for Wales and comparator countries, however, is large enough to provide a robust meaningful analysis.

Second, citation analysis provides a useful assessment of scientific performance for those fields where research publications and citations sufficiently reflect the state and dynamics of research. Throughout this report, normalisation procedures are used to take into account subject-specific differences in citation behaviour.

Third, in order to show a more reliable picture, we present different indicators to show the comparative performance of the Welsh research base.

[4] https://www.hefcw.ac.uk/policy_areas/research/research_highlights.aspx

[5] OECD. (2015). *Frascati Manual 2015: Guidelines for collecting and reporting data on research and experimental development*. OECD Publishing. https://doi.org/10.1787/9789264239012-en.

In summary, while bibliometric analyses can provide a data-driven base to support decision-making, it is crucial to evaluate the findings in this process carefully.

Throughout the report, Wales' research performance has been benchmarked against a number of comparators:

- UK constituents (Scotland, England, and Northern Ireland) as well as the United Kingdom overall
- European countries (Austria, Denmark, Estonia, France, Germany, and Ireland)
- International research nations outside Europe (United States, China, Japan, New Zealand, and South Africa)
- Collective international benchmarks (world, EU, and OECD averages), where appropriate

For trend analyses, indicator values are presented per year, and for snapshots, two 5-year blocks are used (2010–2014 as period 1 and 2014–2018 as period 2).

By exploring these different aspects of research performance, this report provides a comprehensive picture of Wales' research base and demonstrates how this base contributes to the wider UK research system.

Data sources and methodology

Data sources

Most of the data presented in this report are derived from UNESCO (R&D expenditure and human capital for global comparators), Eurostat (R&D expenditure and human capital on European and UK nations level), and Scopus (articles and citations). All data sources aggregate information from a large number of disparate primary sources and, as a result, missing values and discrepancies in the data are to be expected. For R&D expenditure per sector and 'sanity checks' on other data sources, data from the Office for National Statistics (ONS) have been used.

More information on data sources used in this report can be found in ***Appendix B: Data Sources***, and full methodological details are discussed in ***Appendix C: 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, 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's or nation's research base.

Comparators

Comparator countries are defined consistently across all data sources: unless otherwise indicated, the European Union (EU-27), the OECD members, and the world are used as benchmarks. Standard ISO 3-character country codes are used throughout for visual clarity where required (except the United Kingdom).

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. Calculating the score within disciplines accounts for field-dependent citation differences. FWCI is a widely accepted normalised metric that enables comparisons across countries.

Measuring change

Most of the analyses in this report cover the 2010–2018 period. Throughout the report, this period is divided into two sub-periods—Period 1 (P1) from 2010–2014 and Period 2 (P2) from 2014–2018—to help track changes between them. In some analysis, we use the compound annual growth rate (CAGR), which is the year-on-year constant growth rate over a specified period.

Subject classifications

The subject areas used in this report are based on the OECD classification, described in the Frascati Manual 2015. The six subject areas, together with their short names used and the academic disciplines included are listed in TABLE 1-1, below.

Subject area	Short name	Discipline
Agricultural and veterinary science	Agricultural science	Agriculture, forestry, and fishery
		Animal and dairy science
		Veterinary science
		Agricultural biotechnology
Engineering and technology	Engineering & Technology	Civil engineering
		Electrical engineering, electronic engineering, information engineering
		Mechanical engineering
		Chemical engineering
		Materials engineering
		Medical engineering
		Environmental engineering
		Environmental biotechnology
		Industrial biotechnology
		Nanotechnology
Humanities and the arts	Humanities & arts	History and archaeology
		Languages and literature
		Philosophy, ethics and religion
		Arts (arts, history of arts, performing arts, music)
Medical and health science	Medical science	Basic medicine
		Clinical medicine
		Health sciences
		Medical biotechnology
Natural science	Natural science	Mathematics
		Computer and information sciences
		Physical sciences
		Chemical sciences
		Earth and related environmental sciences
		Biological sciences
Social science	Social science	Psychology and cognitive sciences
		Economics and business
		Education
		Sociology
		Law
		Political science
		Social and economic geography
		Media and communications

TABLE 1-1
OECD subject areas, short names, and academic disciplines used throughout the report

Chapter 1

Research performance and productivity

1.1 Human capital

While the number of researchers in Wales is below its population share and only grew by 1.7% annually over the 9-year period, the Welsh output per researcher is the second highest of all UK nations and global comparators.

One of the crucial resources of any country's research base is its researchers, and Wales' contribution to the advancement of knowledge, nationally and globally, remains—among other factors—dependent on the contributions of the researchers within its research infrastructure. This report uses UNESCO and Eurostat data on researcher numbers, which include not only staff working in universities and research institutes but also staff in civil and military research in government, hospitals, and the business sector.

Wales' researcher base grew from 2010 to 2018 from below 9,000 to more than 10,100 researchers. It accounted for 3.4% of the United Kingdom's total researchers in 2017 (FIGURE 1-1), which is below its population share of 5%. Previous reports in this series[6] have indicated that Wales has a relatively low proportion of researchers in the population, and the numbers above point in the same direction.

The growth in number of researchers corresponds to a CAGR of 1.7%, which is the lowest of all UK nations. England's researcher base grew by 2%, Scotland's by 2.1%, and Northern Ireland increased its researcher base by 2.6%, although starting from a lower level.

The number of researchers is a critical factor in determining Wales' capacity to conduct excellent research; therefore, not growing the researcher base may pose problems for the future. Developing world-class research requires a stimulating environment and that includes a growing pipeline of research talent as well as many highly skilled researchers.

[6] See *International comparative performance of the Welsh research base 2013*.

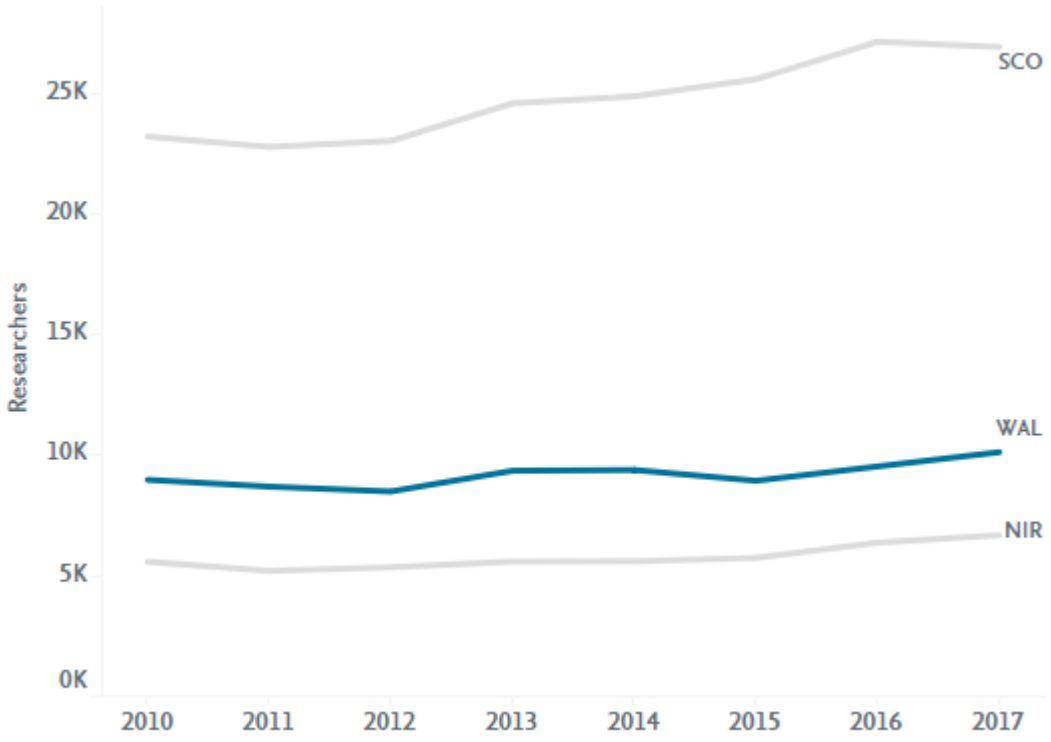


FIGURE 1-1
Research personnel as full-time equivalents (FTE) for Wales and UK nations, 2010–2017; England excluded for visual reasons.
Source: Eurostat, extracted on 27 May 2020

Analysis of journal articles, reviews, and conference papers provides useful insights into the comparative performance of a country's research base—though journal article and citation-based indicators capture the research performance better in some fields than in others. However, using only the absolute numbers of publications would naturally rank countries by their size. Normalising national scholarly output by the number of researchers (in full-time equivalents (FTE)) introduces a measure of productivity and gives some indication of the efficiency of a research base.

Despite having a lower number of researchers, Wales had the second-largest output per FTE (0.84) among UK nations, following Scotland (FIGURE 1-2). The output-per-researcher ratio changed little during the analysis period, except for the 2012–2013 period, which corresponds with a peak in publications.

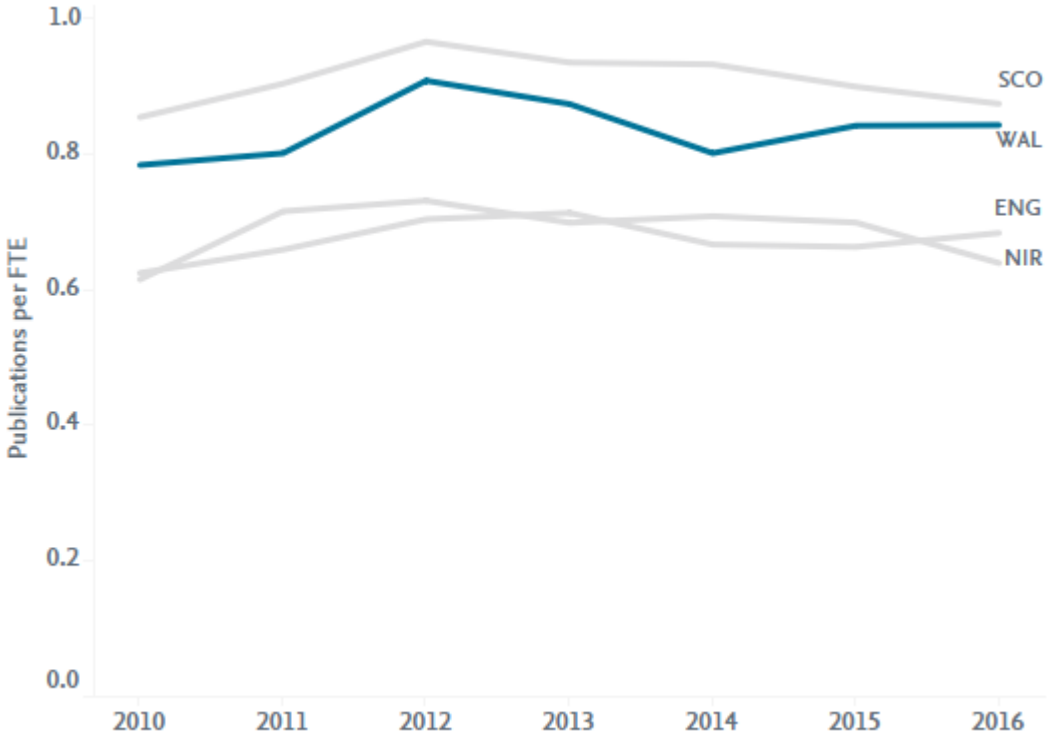


FIGURE 1-2
Productivity: Publications per year per researcher for Wales and UK nations, 2010–2017.
Source: Scopus and Eurostat

The data on the number of researchers (in FTE) have been taken from Eurostat for European countries and UK nations, while global comparators are retrieved from UNESCO. Both data sources have been checked for comparability, and the data between Eurostat and UNESCO vary by a maximum of five percentage points.

Scotland and Wales are the leading UK nations and globally are the most productive of all comparators. Previous reports[7] have confirmed the high productivity per researcher of the UK research system. Indeed, among the international comparators, together with New Zealand and South Africa, the United Kingdom is leading the way—with Scotland and Wales making a significant contribution.

China, which is one of the global drivers of scholarly output, is leveraging its large researcher base.

[7] https://www.elsevier.com/research-intelligence/research-initiatives/beis2016

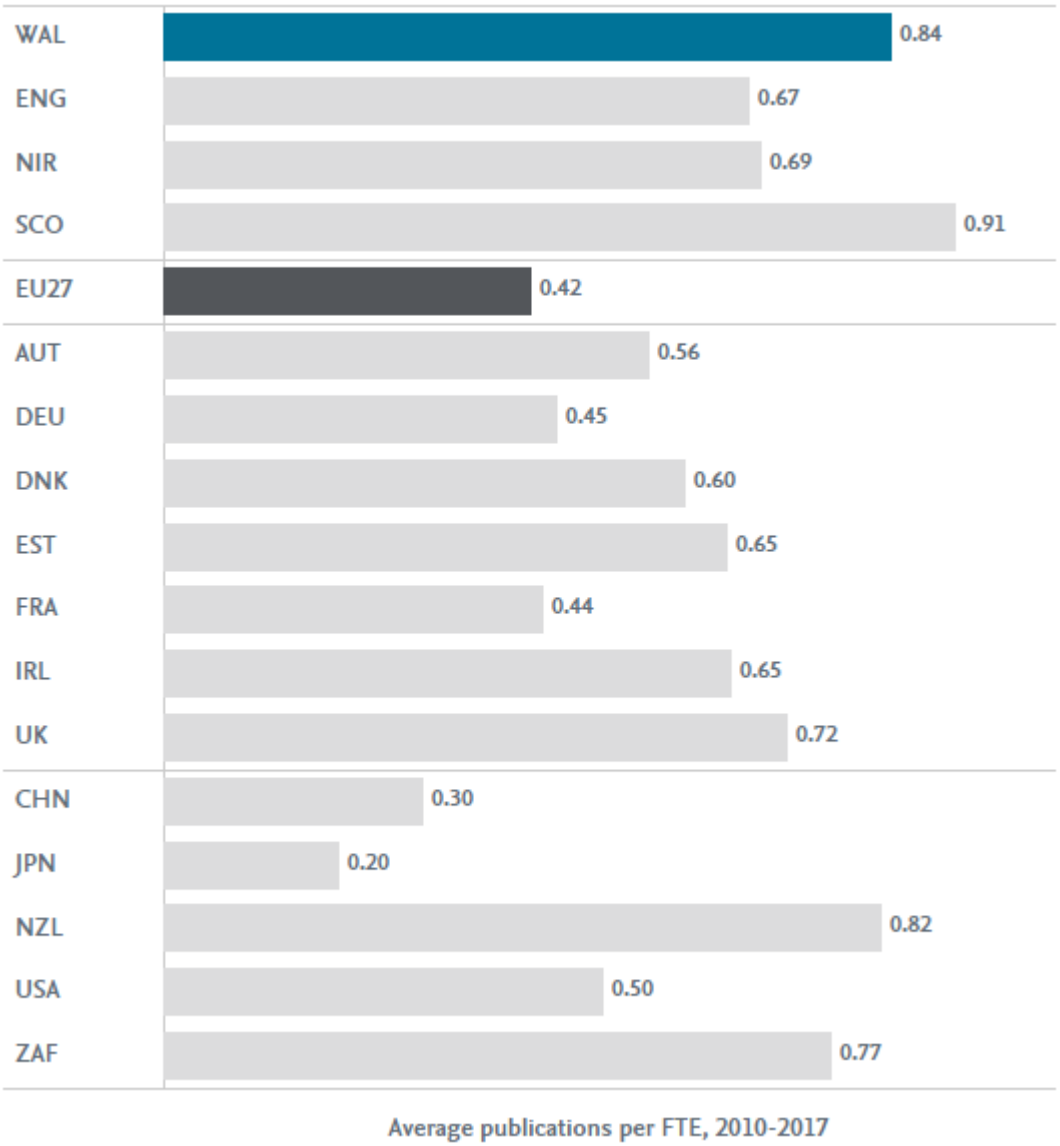


FIGURE 1-3
Average publications per researcher for Wales, UK nations, and global comparators, 2010–2017.
Source: Scopus, Eurostat, UNESCO

1.2 Research expenditure

Welsh researchers published, on average, more than 8 publications per €m expenditure, placing Wales at the top of all global comparators in terms of efficiency and productivity.

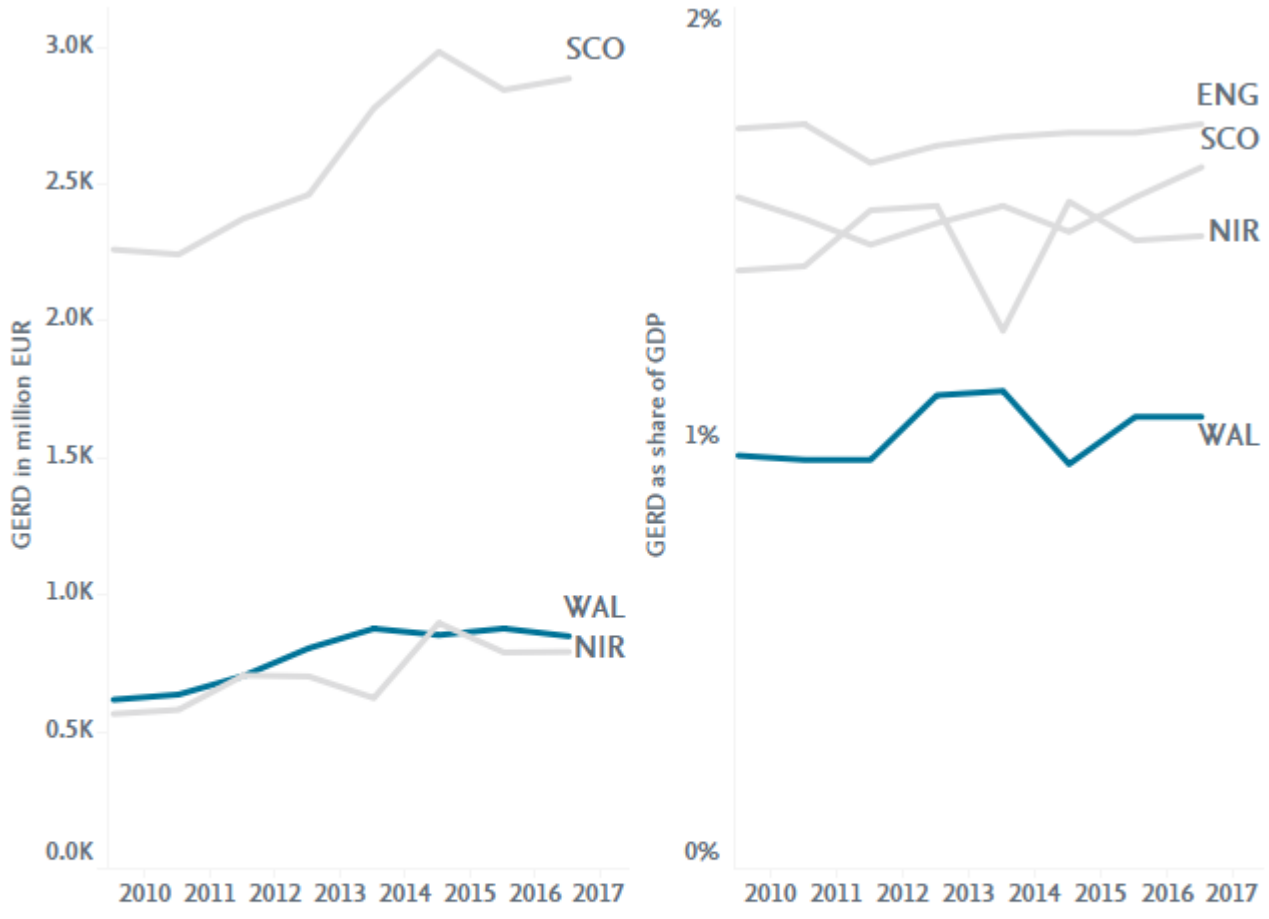
Two interrelated components pivotal to excellent research are people and funding. There is a widely acknowledged relationship between the development and maintenance of national research capabilities and a country's underlying economic growth.

A country's expenditure on R&D supports research not only by paying skilled researchers and providing the necessary infrastructure to support them in their work but also by generating supply and demand for services and products across many industries.

Gross domestic expenditure on R&D (GERD) represents the total expenditure on R&D within a country, regardless of the sector of performance or funding; it includes domestically conducted R&D financed from overseas but excludes R&D funding that is paid abroad (for example, to international agencies). GERD, measured as a share of the country's gross domestic product (GDP), is also known as research intensity.[8]

In parallel with the size of economies, England had the largest expenditure on R&D, followed by Scotland. Wales and Northern Ireland had similar amounts of expenditure (FIGURE 1-4, left panel), with growth rates of 4.7% and 4.9% respectively. These growth rates are higher than those of England (3.7%) and Scotland (3.5%). While an increase in R&D investment is a positive development, Wales' expenditure on R&D still accounts for around only 1% of its GDP, which is lower than the other UK nations (FIGURE 1-4, right panel) and also well below the EU 27 average (2%).

[8] OECD. (2015). *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development*. OECD Publishing. https://doi.org/10.1787/9789264239012-en.



	Average GERD, 2010-2017	CAGR GERD, 2010-2017
WAL	777	4.7%
ENG	32,318	3.7%
NIR	707	4.9%
SCO	2,604	3.5%

FIGURE 1-4
R&D intensity/GERD in €m (excluding England for visual clarity) (left panel) and GERD as a share of GDP (right panel) for Wales and UK nations, 2010–2017. The bottom table displays GERD average and CAGR, 2010–2017.
Source: Eurostat, extracted on 27 May 2020

Breaking down the different sectors of expenditure shows a shift in funding streams. In 2010, most R&D expenditure for Wales and Scotland came through the higher education sector (HERD, FIGURE 1-5, upper panel), which decreased to 35% in 2017. In the same period, expenditure from the business sector (BERD, FIGURE 1-5, bottom panel) increased from around 47% in 2010 to 62% in 2017. A similar trend can be observed for Scotland, whereas for England and Northern Ireland HERD remained the same and BERD increased.

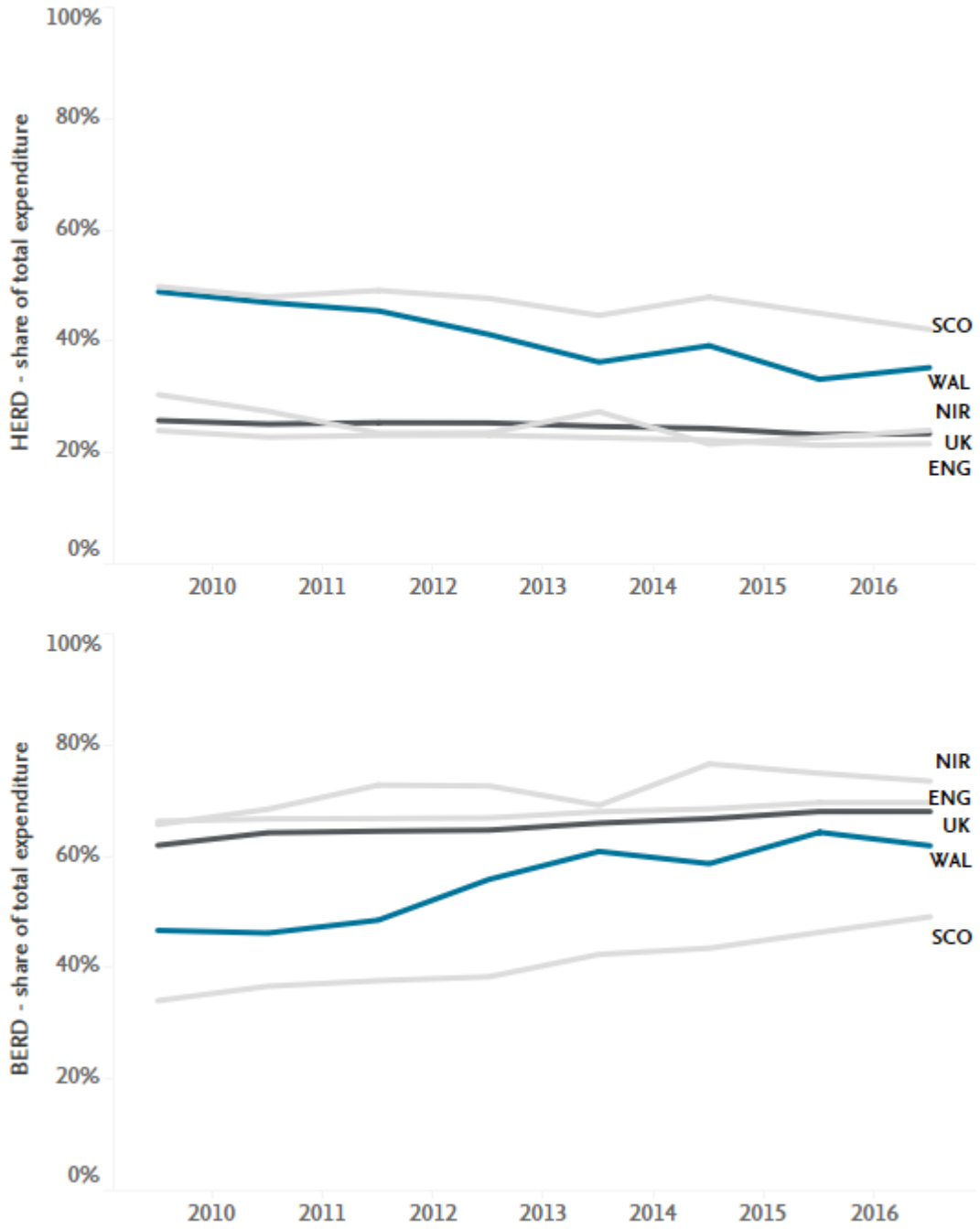


FIGURE 1-5
HERD (upper panel) and BERD (bottom panel) as a share of total GERD for Wales and UK nations, 2010–2017.
Source: ONS data, gross domestic expenditure on research and development, by region, UK; retrieved on 22 June 2020

Welsh researchers published, on average, more than 8 publications per €m expenditure

In terms of output per expenditure, Wales had the largest output per €m spent on R&D, ahead of all UK nations (FIGURE 1-6). However, it also showed the largest decline among the UK comparators, a fact that may be explained by several contributory factors. Overall, the average annual growth rate of Welsh publications was less than the average annual growth rate in research expenditure. There was a steep increase in funding, starting in 2011 with Wales' GERD increasing from EUR 700 million to EUR 800 million and reaching a peak in 2014 with EUR 875 million, as seen in FIGURE 1-4. As there is a time gap between funding of research and publication, the years that saw increased funding are likely to show a lower 'productivity'. However, we are already observing a small increasing trend in productivity from 2014 onwards, which suggests a positive effect of increased funding.

The funding of Northern Ireland displays a similar trend, with a jump from 2014 to 2015. In contrast, England and Scotland display similar growth rates in output and expenditure, resulting in a more stable productivity trend.

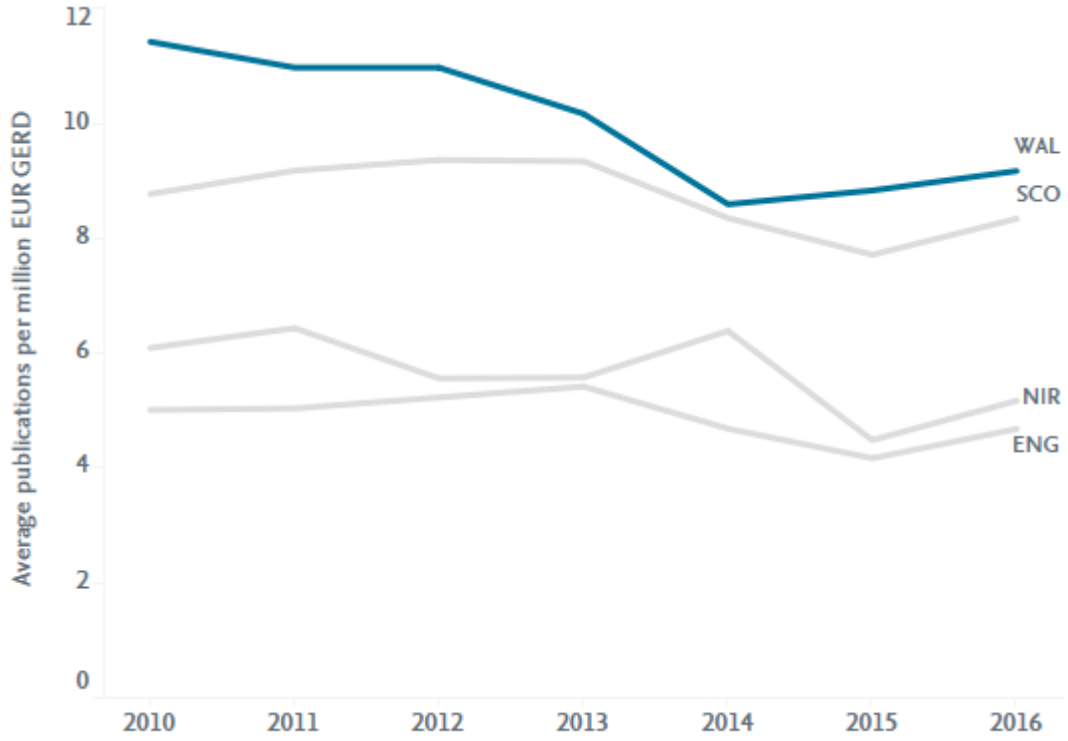


FIGURE 1-6
Publications per €m GERD for Wales and UK nations, 2010–2017.
Source: Scopus, Eurostat

Globally, Welsh researchers are the most efficient in publication output per €m

On a global scale, Wales is well above all other comparators for the number of publications per research expenditure. With the exception of Estonia, the countries that are driving growth in publication output, such as China, are less efficient—showing less publication output per expenditure.

In order to compare Wales with other countries, we combined data from Eurostat and UNESCO. UNESCO states expenditures in USD million (purchasing power parity USD, PPP$), whereas Eurostat uses EUR million. We used UK data as a conversion factor between PPP$ and EUR and calculated the expenditure for UK nations based on these conversion rates. While this data may not be exact, the trends and general observations provide clear indications on the efficiency of UK nations and Wales in particular.

The UK nations are, on average, more productive than the global comparators, except for New Zealand. However, Wales takes the leading position, being the only nation with more than 8.5 publications per €m spent.

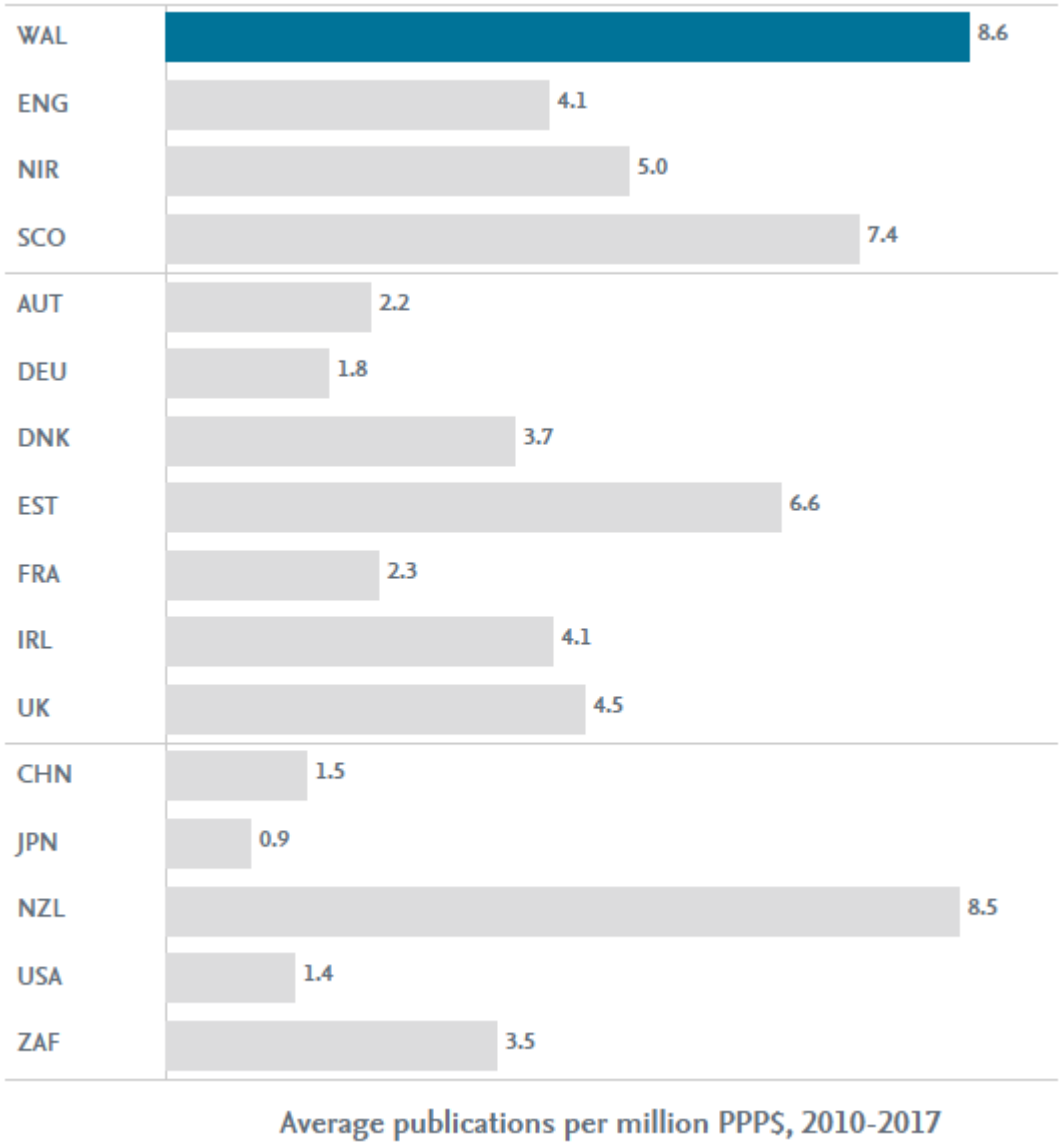


FIGURE 1-7
Average publications per USD million (PPP$) for Wales and comparators, 2010–2017.
Source: Scopus, Eurostat, UNESCO

1.3 Scholarly output

Welsh research output between 2010 and 2018 amounted to more than 59,000 publications, with almost half of this coming from the NATURAL SCIENCE subject area.

Analysis of journal articles, reviews, and conference papers provides useful insights into the comparative performance of a country's research base, although journal article and citation-based indicators capture the research performance better in some fields than in others. This chapter examines the scholarly output, growth, impact, and excellence of the Welsh research base, when benchmarked with other UK nations and global comparators.

Welsh published research output grew by 3% annually over the period

Despite showing the lowest increase in the number of researchers of all UK nations, the scholarly output of Welsh researchers showed a steady growing trend between 2010 and 2018, increasing from 6,000 publications annually in 2010 to more than 7,600 publications in 2018 (FIGURE 1-8). This increase equates to a CAGR of 3%.

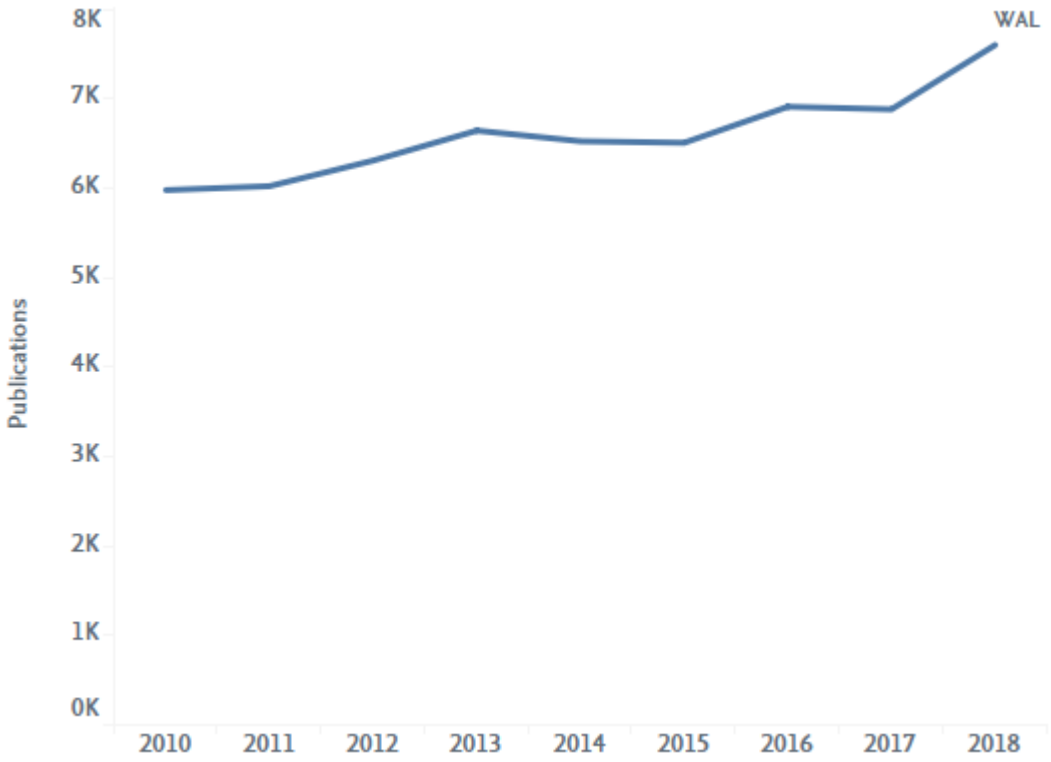


FIGURE 1-8
Publication output of Wales, 2010–2018.
Source: Scopus

This research output shows a similar pattern to the other UK nations, especially England: both countries had a peak of publication in 2013 (FIGURE 1-9). As the scholarly output of the UK nations is very diverse, with England publishing 20 times the output of Wales, the lower panel of FIGURE 1-9 displays the annual output for UK nations excluding England.

England is the largest contributor, accounting for over 80% of UK publications, followed by Scotland (over 11%); Northern Ireland contributes 2%. Wales is the third largest contributor to the overall UK output at 4%. This trend mirrors the population and economic size of the UK nations.

In terms of annual trends, Wales has a very similar output trend to that of England, with a peak of publications in 2013, whereas Scotland and Northern Ireland display more stable patterns.

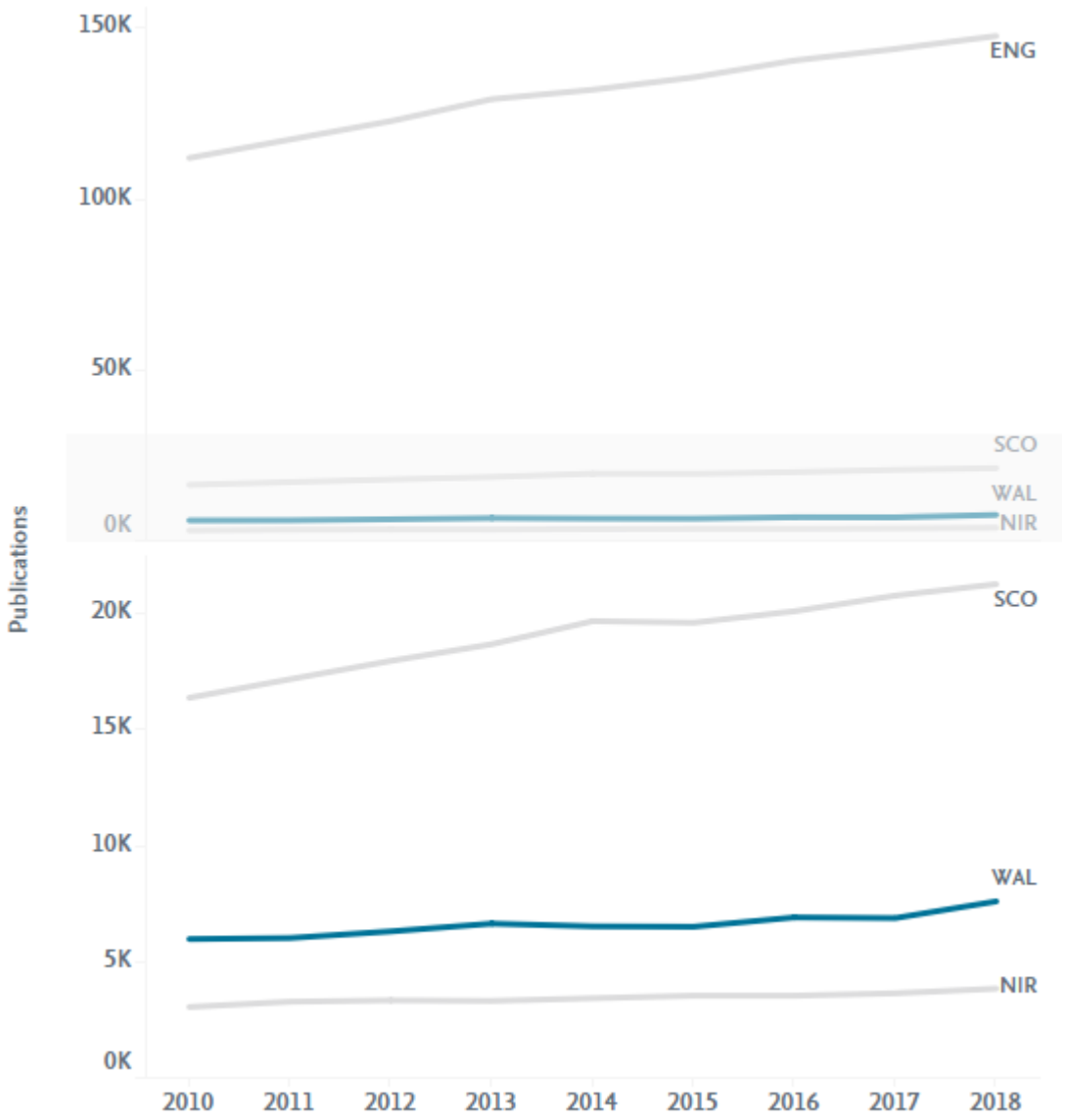


FIGURE 1-9
Publication output of Wales and UK nations, 2010–2018. The lower panel expands the grey area of the upper panel to show trends.
Source: Scopus

Compared to other UK nations, Wales' research output shows the lowest growth in research publications

To contextualise the research growth trends better, we compare Wales against selected countries. FIGURE 1-10 shows the publication increase between the two periods (2010–2014 and 2014–2018) and the CAGR across the whole period.

Levelling out individual years, the left panel of FIGURE 1-10 shows the growth between the first time period, P1 (2010–2014), and the second time period, P2 (2014–2018). The scholarly output of Welsh researchers grew from 31,485 publications in P1 to 34,432 in P2, which indicates an increase of 9.4% from P1 to P2. Compared with the United Kingdom and global comparators, however, this growth is markedly less. On average, the publication output from P1 to P2 increased by 10% for Europe and the OECD countries, while the global output grew by almost 12%. The larger increase in global output is likely driven by China. Smaller research nations such as South Africa (40.7%), Denmark (24.9%), and Estonia (22.8%) lead in terms of increase from P1 to P2, but it is mainly China pulling up the global numbers. Publishing almost 20% of the worldwide output and growing by more than 22% from P1 to P2, China has very substantial effects on global growth. Japan is the only research nation with a decline in publication output. France and the United States are growing less than Wales. This pattern is reflected as well in the annual growth rates, indicated by CAGR. South Africa, Denmark, Estonia, and China are leading other countries by a notable margin.

In summary, amongst the UK nations, Wales and Northern Ireland show the lowest growth rate between the two time periods and in terms of annual growth rates. This can be explained by the low growth rate of the researcher base, as seen in the previous chapter.

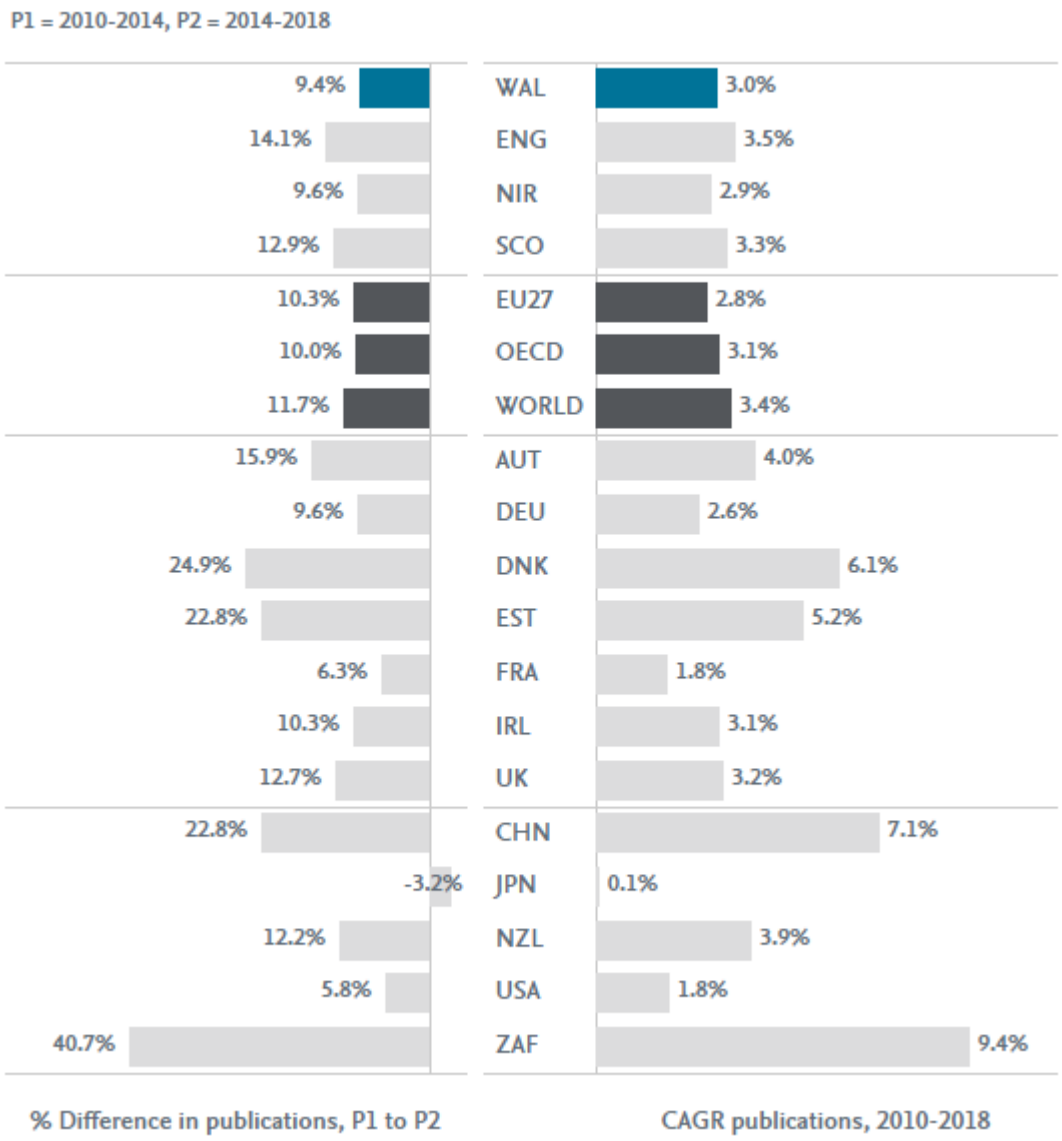
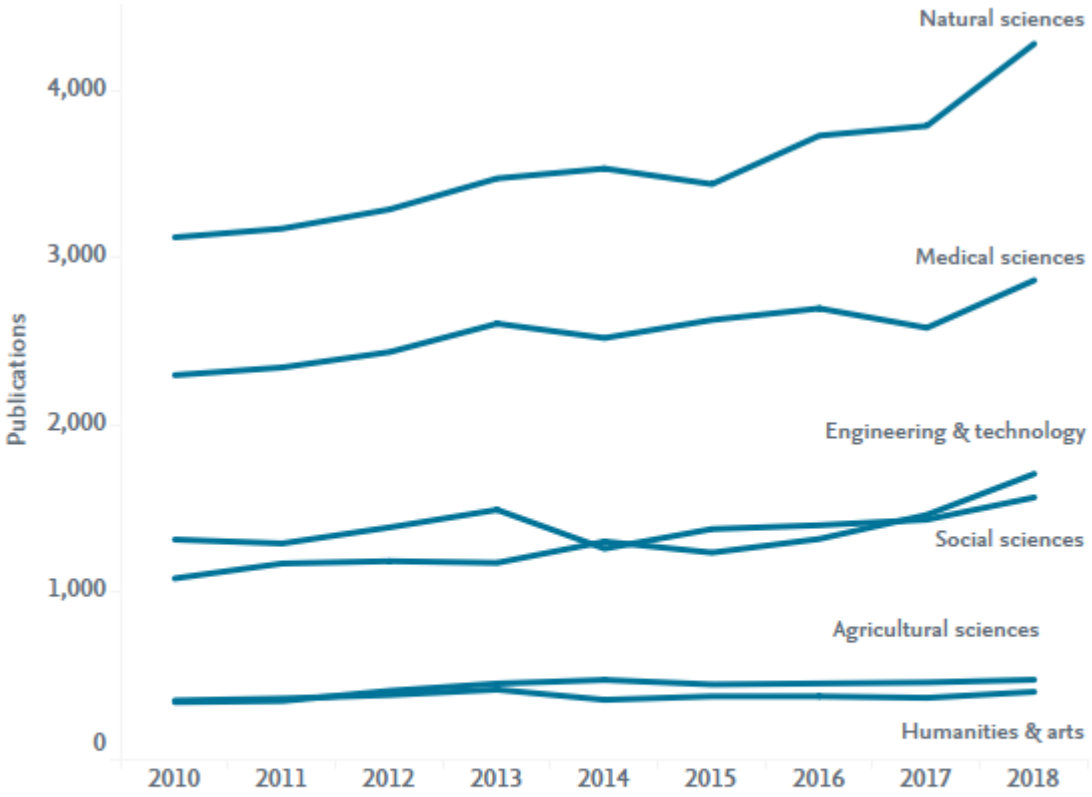


FIGURE 1-10
Difference in publication output for Wales and comparators, P1 = 2010–2014, P2 = 2014–2018 (left panel) and compound annual growth rate (CAGR) for publication output 2010–2018 (right panel).
Source: Scopus

ENGINEERING & TECHNOLOGY is the fastest-growing subject area in Wales

The most prolific subject areas in terms of Welsh research output are NATURAL SCIENCE, MEDICAL AND HEALTH SCIENCE, and SOCIAL SCIENCE. While scholarly output grew across all subject areas, the trend was most marked in NATURAL SCIENCE, AGRICULTURAL SCIENCE, and ENGINEERING & TECHNOLOGY, which grew by 4.0%, 4.2%, and 5.9% respectively. ENGINEERING & TECHNOLOGY is has now surpassed SOCIAL SCIENCE for

total output. FIGURE 1-11 shows the annual trend for scholarly output per subject area and the CAGR for the period 2010–2018.



	Natural sciences	Medical sciences	Engineering & technology	Social sciences	Agricultural sciences	Humanities & arts
CAGR	4.0%	2.8%	5.9%	2.2%	4.2%	1.7%

FIGURE 1-11
Publication output and CAGR per subject area for Wales, 2010–2018.
Source: Scopus

Aside from the total output per subject area, we examined subject area publications' share of the total output for Wales with other comparators. FIGURE 1-12 shows that all comparators show the highest share of publications within NATURAL SCIENCE, but with significant differences in the other subject areas. While the UK nations have slightly more than half of their publications within NATURAL SCIENCE, followed by MEDICAL AND HEALTH SCIENCE and SOCIAL SCIENCE, most of the comparators seem to focus on NATURAL SCIENCE, with more or less equal focus on MEDICAL AND HEALTH SCIENCE and ENGINEERING & TECHNOLOGY. One possible reason for this could be a language bias in capturing SOCIAL SCIENCE-related content since all English-speaking countries show a similar pattern—especially New Zealand and South Africa.

China, as one of the main drivers of global output, shows a strong presence in NATURAL SCIENCE and ENGINEERING & TECHNOLOGY, whereas its share of MEDICAL AND HEALTH SCIENCE is only 19%.

Although the differences between the UK nations are not large, Wales has a stronger footprint in SOCIAL SCIENCE, especially compared to Scotland, which focuses more on NATURAL SCIENCE. SOCIAL SCIENCE is recognised as a focus area for the United Kingdom, and Wales is a strong contributor to this strength.

	Agricultural sciences	Engineering & technology	Humanities & arts	Medical sciences	Natural sciences	Social sciences
ENG	6%	20%	6%	37%	54%	19%
NIR	7%	21%	5%	38%	55%	18%
SCO	9%	19%	6%	33%	61%	17%
WAL	7%	20%	6%	39%	54%	21%
EU27	7%	27%	4%	32%	62%	13%
OECD	6%	32%	4%	31%	61%	12%
WORLD	7%	31%	4%	31%	60%	13%
AUT	7%	24%	3%	32%	66%	11%
DEU	6%	27%	3%	31%	66%	11%
DNK	9%	20%	3%	41%	59%	13%
EST	10%	25%	9%	20%	64%	18%
FRA	6%	27%	4%	29%	67%	10%
IRL	8%	22%	5%	37%	57%	16%
UK	6%	20%	6%	37%	54%	19%
CHN	5%	50%	1%	19%	71%	4%
JPN	6%	34%	1%	34%	67%	4%
NZL	14%	16%	5%	34%	54%	21%
USA	6%	23%	4%	38%	56%	16%
ZAF	12%	19%	9%	28%	55%	23%

All publication share
0% 70%

FIGURE 1-12
Share of publications per subject for Wales and comparators, 2010–2018.
Source: Scopus

1.4 Scholarly impact

The Field Weighted Citation Impact (FWCI) of Welsh publications grew by 0.3 points from 2010 to 2018, accruing 80% more citations than the global average.

The number of citations received by published research articles from subsequent published articles is used as an indicator of the quality or impact of the cited research. However, the total number of citations can be affected by the type of publication (e.g., reviews receive more citations than conference proceedings or articles), the subject area, and the year of publication. Therefore, most bibliometric analyses use the FWCI, which normalises the citation impact for publication type, subject area, and year of publication.

As shown in FIGURE 1-13, the scholarly impact of Wales has grown steadily throughout the decade, with a first peak in 2012 and a second in 2016. This is likely to be related to several factors, including increased participation by Welsh researchers in large-scale studies such as the Global Burden of Disease Study or those in physics. 'Hypercollaborated' publications often have large numbers of co-authors (>100 minimum) and accordingly receive disproportionately large numbers of citations.

To minimise the effect of outliers such as the hypercollaborated papers, we calculated a rolling year FWCI (average FWCI of the year in question and the two previous years) and a linear trendline of FWCI across all years (FIGURE 1-13). Both trendline and rolling year FWCI confirm the steady growth of Wales' scholarly impact.

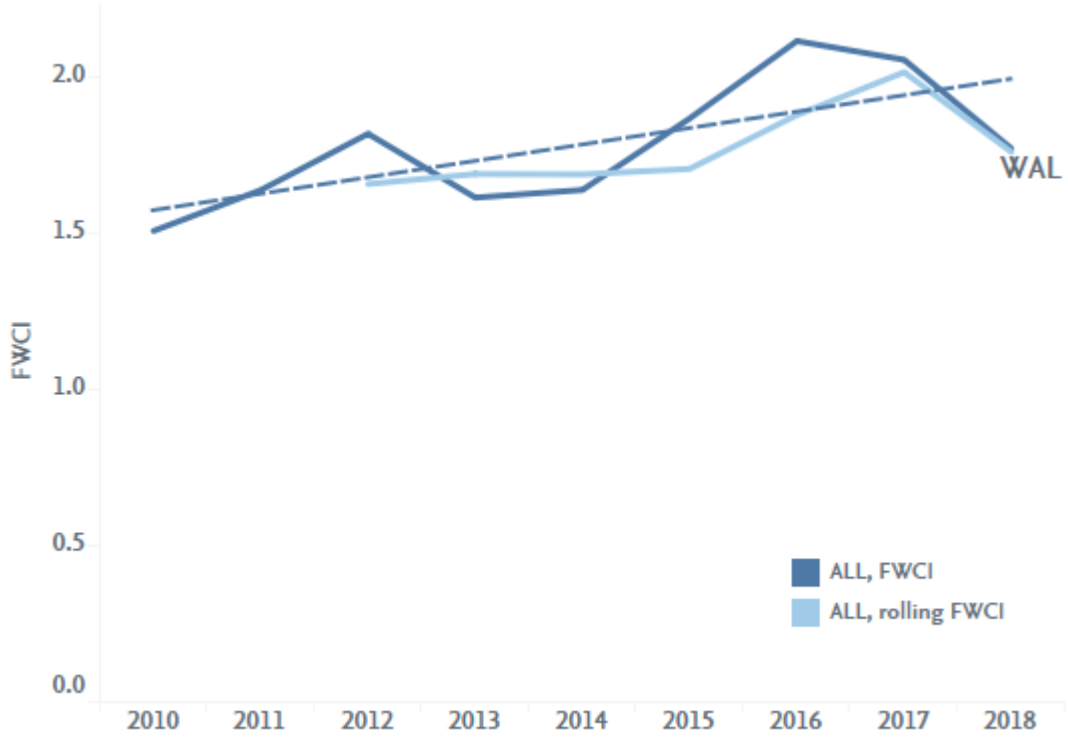


FIGURE 1-13
Field-weighted citation impact (FWCI) as rolling year average (rolling year FWCI) and trendline for Wales, 2010–2018.
Source: Scopus

The rolling year FWCI shows an overall increasing trend for the scholarly impact of Welsh publications, rising from 1.5 in 2010 (50% above the global average) to over 1.8 in 2018 (80% above the global average). Looking at the growth between P1 and P2, it can be seen that Wales' impact grew by 0.2 points. Except for the strong drivers of global growth such as China and Estonia, Wales shows the highest growth of all global comparators (FIGURE 1-14) for its citations. Again, Estonia (FWCI in 2010 = 1.4) started from a lower level than Wales, which makes it easier for it to demonstrate significant growth—especially by participation in hypercollaborative networks.

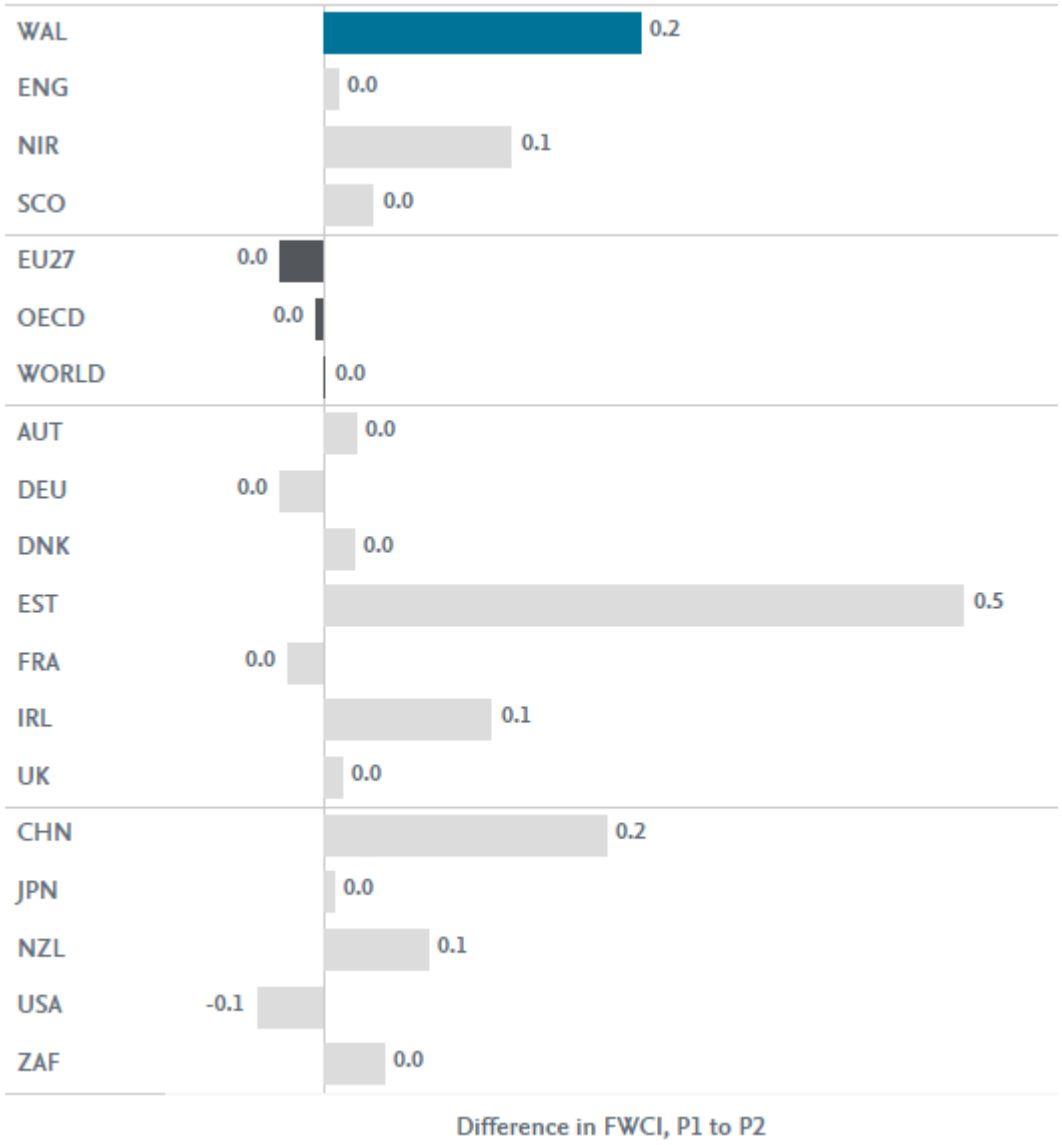


FIGURE 1-14
Difference in FCWI for Wales and comparators over 2 time periods; P1 = 2010–2014, P2 = 2014–2018.
Source: Scopus

There is a trend for growth rates to correlate with the size and the history of research nations. Except for China, the established research nations remain more or less stable for FWCI, while the smaller or growing countries are able to make rather significant steps.

Among the UK nations, England, with its high scholarly output, accounts for 5.2% of the global scholarly output, whereas Scotland published around 0.8% of the global output and Wales 0.3%. By FWCI, however, Scotland and Wales are the leading UK nations between 2010 and 2018 (FIGURE 1-15).

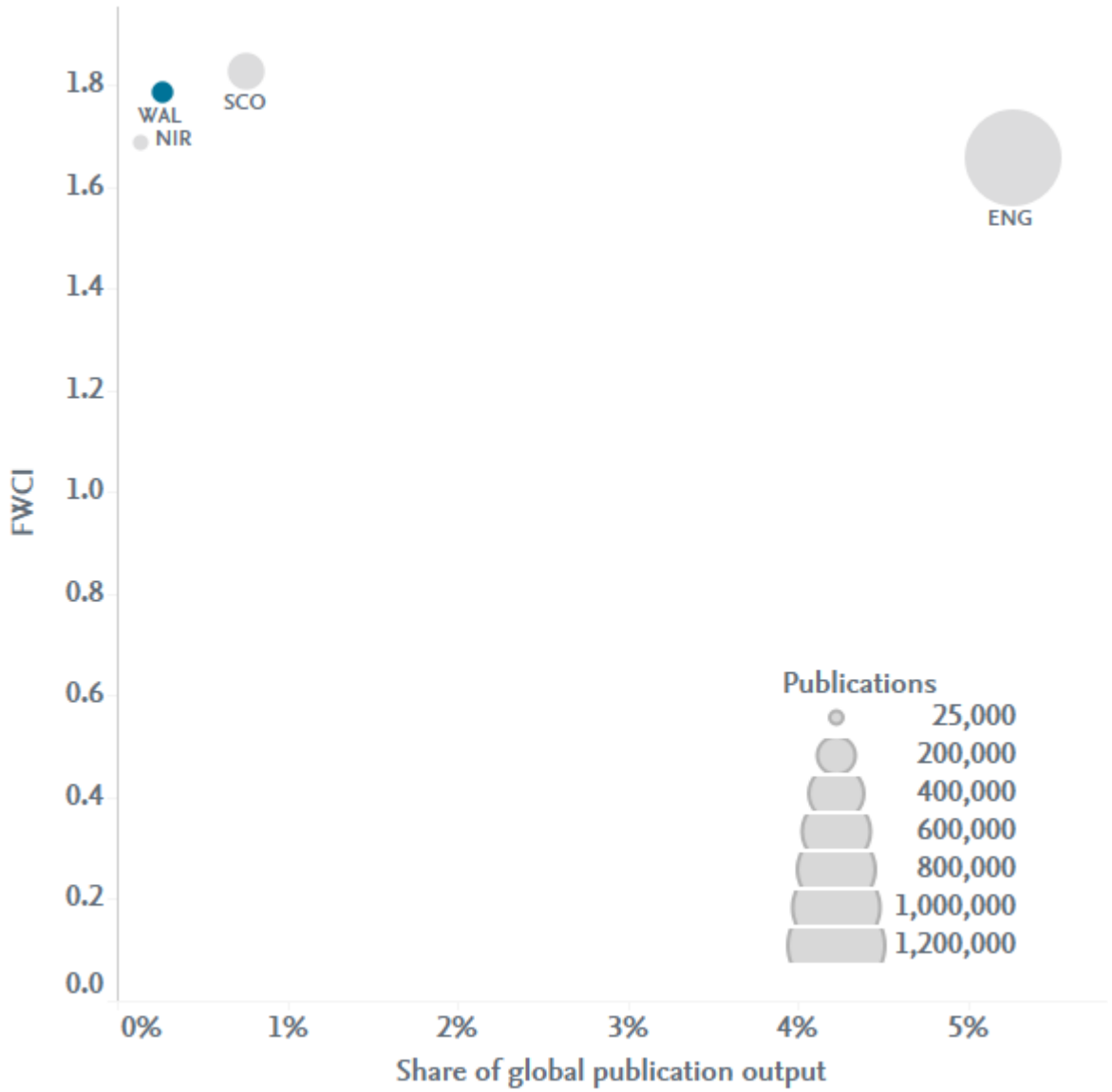


FIGURE 1-15
FWCI and share of global publication output for UK nations, 2010–2018. Size of nodes indicates total publication output.
Source: Scopus

MEDICAL AND HEALTH SCIENCE shows the highest scholarly impact for Wales

While the Welsh research output across all subjects areas accrued 80% more citations than the global average (FWCI = 1.8 for 2010–2018), the individual impact per subject area is more diverse (FIGURE 1-16). The two most prolific subject areas, MEDICAL AND HEALTH SCIENCE and NATURAL SCIENCE, are also the most impactful. MEDICAL AND HEALTH SCIENCE is close to an FWCI of 2.0, accumulating twice the number of citations as the global average.

Except for SOCIAL SCIENCE and HUMANITIES AND THE ARTS, Wales' output in all subject areas is close to or above the UK average, indicated by the dashed line in the figure.

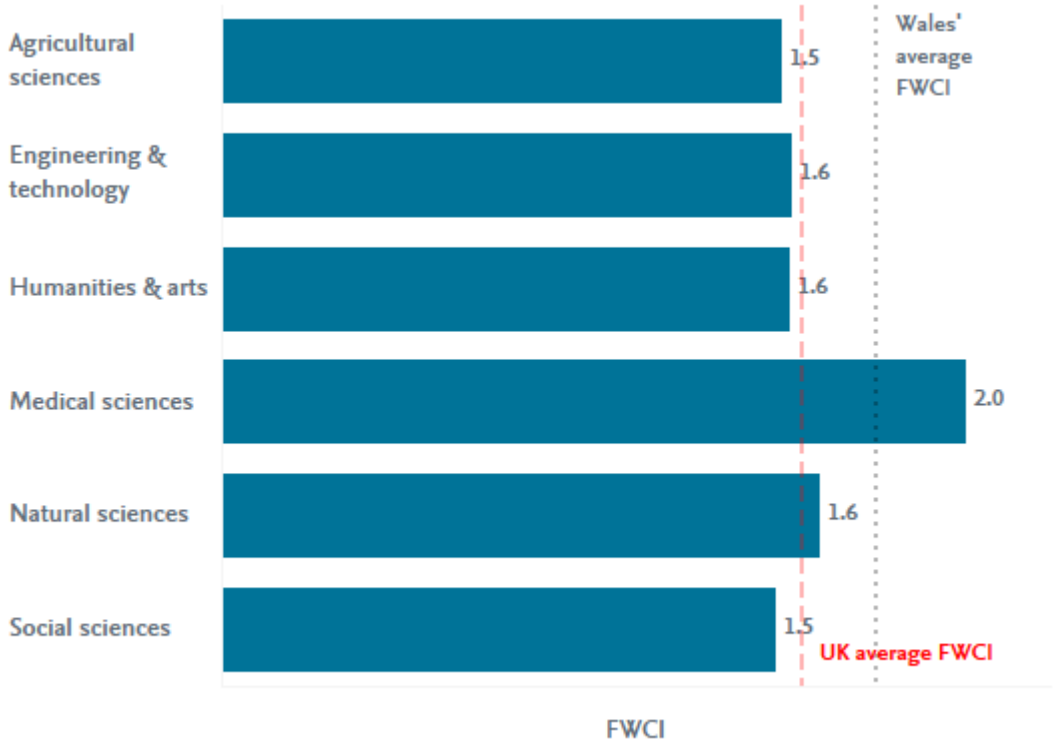


FIGURE 1-16
FWCI per subject area for Wales, 2010–2018. Dotted red line indicates UK average FWCI across all subjects and dotted grey line indicates Wales' average FWCI across all subjects.
Source: Scopus

FIGURE 1-17 delineates the FWCI per subject area together with the overall for Wales and comparators. For most comparators, MEDICAL AND HEALTH SCIENCE shows the greatest impact. There are, however, some notable differences:

- All UK nations show an FWCI above global average in all subjects.
- The FWCI of Wales' research output in all subjects is only bettered by Scotland - driven mainly by publications in MEDICAL AND HEALTH SCIENCE.
- Wales shows a well-rounded picture with all subject areas, showing an FWCI above 1.5. All subject areas contribute to the strong performance of Wales' research.
- England is similarly strong in all subject areas, but generally its impact is lower than Wales'.
- Japan is the only research nation with an FWCI below the global average in every subject.

- China displays an impact at world average only in its two smallest subject areas, HUMANITIES AND THE ARTS and SOCIAL SCIENCE.
- The main driver for the high FWCI for Scotland is MEDICAL SCIENCE.

	Agricultural sciences	Engineering & technology	Humanities & arts	Medical sciences	Natural sciences	Social sciences	ALL
ENG	1.5	1.5	1.6	1.8	1.6	1.5	1.7
NIR	1.4	1.5	1.7	2.0	1.5	1.3	1.7
SCO	1.6	1.4	1.7	2.3	1.6	1.5	1.8
WAL	1.5	1.6	1.6	2.0	1.6	1.5	1.8
EU27	1.1	1.2	0.9	1.2	1.2	1.1	1.2
OECD	1.0	1.1	1.1	1.1	1.1	1.1	1.1
WORLD	0.9	1.0	1.0	1.0	1.0	1.0	1.0
AUT	1.3	1.3	1.3	1.8	1.5	1.5	1.6
BEL	1.4	1.5	1.2	2.0	1.5	1.5	1.7
DEU	1.3	1.3	1.2	1.5	1.4	1.3	1.4
DNK	1.5	1.7	1.7	2.0	1.7	1.6	1.8
EST	1.2	1.3	0.9	3.6	1.6	1.1	1.9
FRA	1.3	1.2	0.8	1.6	1.3	1.0	1.3
IRL	1.5	1.5	1.2	1.9	1.5	1.3	1.6
UK	1.4	1.5	1.5	1.7	1.5	1.5	1.6
CHN	0.9	0.9	1.0	0.9	1.0	1.0	0.9
JPN	0.8	1.0	0.9	0.9	1.0	0.8	0.9
NZL	1.3	1.3	1.5	1.8	1.4	1.2	1.5
USA	1.2	1.5	1.4	1.5	1.5	1.3	1.5
ZAF	1.0	1.1	1.1	1.7	1.1	0.9	1.2

FIGURE 1-17
FWCI per subject area and overall for Wales and comparators, 2010–2018.
Source: Scopus

Breadth of Excellence: Wales' share of top 5% most highly cited publications is almost twice the global average

By its very nature, citation distribution across articles is heavily skewed: a small proportion of all published articles receive most of the citations, a larger proportion receive some citations, and a significant proportion of all articles never receive a single citation.[9] One approach to research assessment is to examine the small proportion of the most highly cited articles. Research suggests that this method can yield insights not possible from looking at aggregate measures that include the entirety of research outputs.

While the FWCI can be affected by some extreme outliers—especially with smaller numbers—the share of publications in the top most highly cited citation percentiles can be used as an indicator of breadth in excellence. With some fluctuations, Wales increased its share in this percentile to almost 10% from 2010 to 2018. A linear trendline was added to FIGURE 1-18 to highlight the growth pattern. In other words, Wales' share of publications in the top 5% most highly cited publications is twice that that of the global average, confirming the strong and increasing FWCI trend of Wales. For 2018, we observe a dip in the share, which should be observed in the future to assess whether it is a trend or an outlier. Scotland displays a similar dip for the most recent year in publications within the top 5% most highly cited, while England and Northern Ireland had already dipped in previous years.

[9] While there is no comprehensive, exact overview, research suggests 10%–20% of all articles are never cited. See van Noorden, R. (2017).

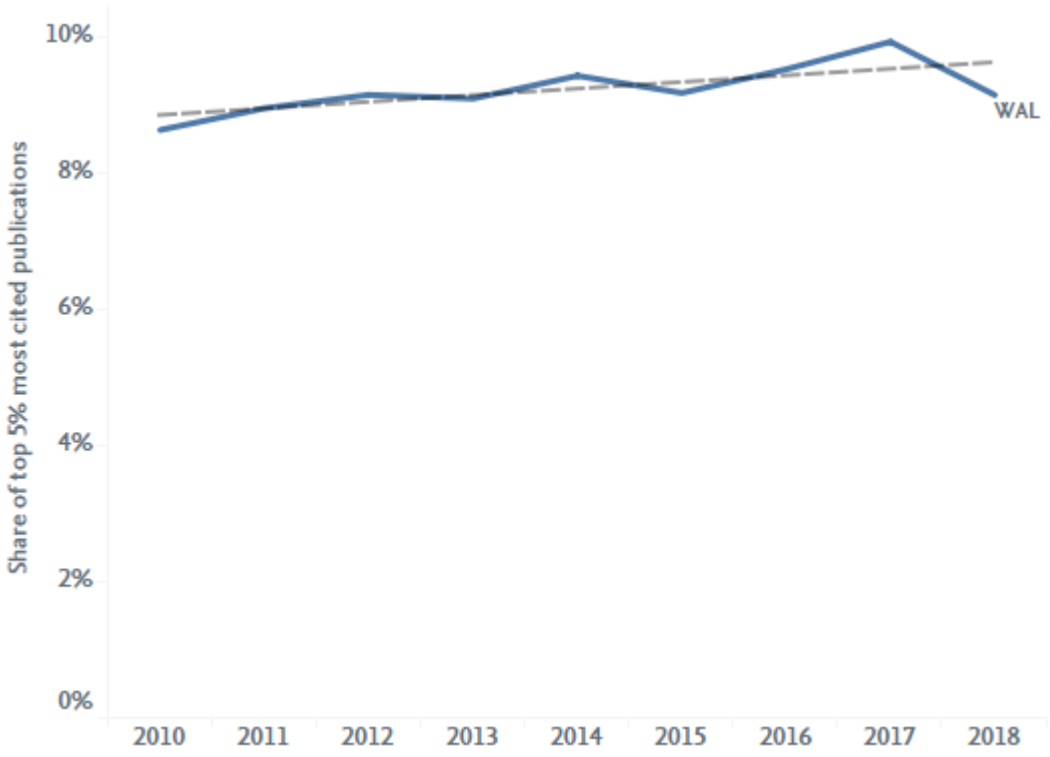


FIGURE 1-18
Share of publications among the top 5% most cited global publications for Wales, 2010–2018.
Source: Scopus

Wales grew its share of these highly cited publications by almost 0.5 percentage points between P1 and P2, but is topped by Northern Ireland and Scotland within the United Kingdom. FIGURE 1-19 displays the growth from P1 to P2 for all comparators. Although the correlation with the size of the country is not as clear as for the FWCI, the trend remains similar. In general, it is much easier for smaller countries with a relatively low historical share of high-impact publications to grow their share. The exception is China.

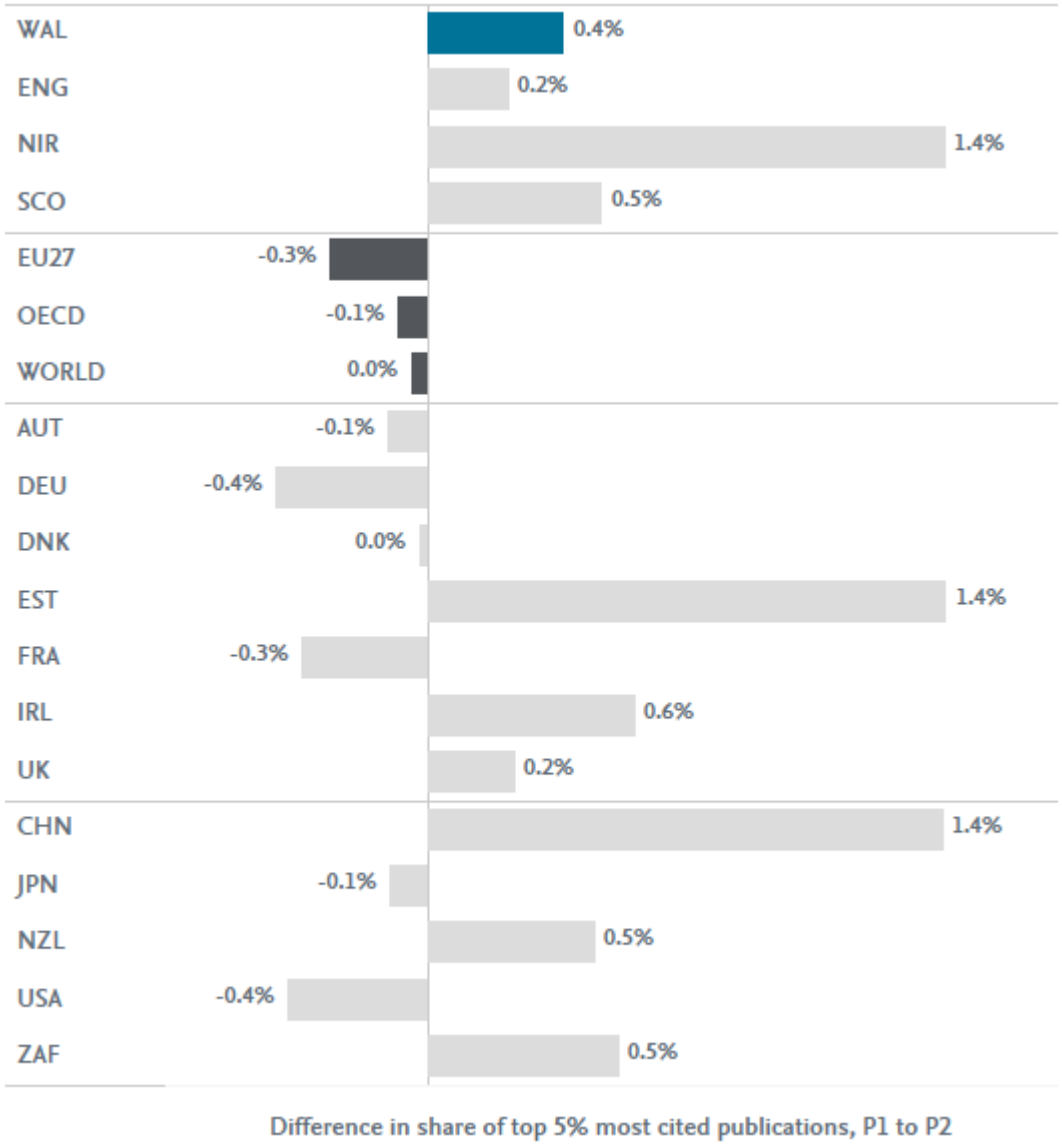


FIGURE 1-19
Difference in share of top 5% most cited publications over 2 time periods; P1 = 2010–2014, P2 = 2014–2018.
Source: Scopus

Welsh research excellence is well rounded across all subject areas

The growth rates indicate only the difference between the two periods, but they do not show the total share of highly cited publications. Although Northern Ireland has the highest growth across all subjects, it has the lowest overall share of all UK nations (FIGURE 1-20). In general, looking into the individual subjects reveals a similar picture to the FWCI. Wales has a high share of the most highly

cited publications across all subject areas; only AGRICULTURAL AND VETERINARY SCIENCE has a share below 9%—still far above the global average and slightly above the UK average.

	Agricultural sciences	Engineering & technology	Humanities & arts	Medical sciences	Natural sciences	Social sciences	ALL
WAL	7.6%	9.4%	10.6%	9.0%	9.0%	9.1%	9.2%
ENG	7.6%	9.1%	11.2%	9.6%	8.8%	9.5%	9.4%
NIR	7.5%	8.9%	8.6%	9.2%	7.6%	7.0%	8.4%
SCO	8.1%	8.5%	11.0%	11.4%	9.3%	8.4%	10.0%
EU27	4.6%	6.8%	5.6%	5.5%	5.9%	6.1%	5.9%
OECD	3.9%	5.7%	7.0%	4.9%	5.3%	6.0%	5.3%
WORLD	3.4%	5.3%	5.8%	4.3%	4.9%	5.3%	4.8%
AUT	6.3%	7.3%	8.3%	9.3%	8.0%	8.6%	8.5%
DEU	5.6%	7.8%	7.4%	7.4%	7.4%	7.2%	7.5%
DNK	7.5%	10.7%	11.9%	10.1%	9.6%	10.3%	10.3%
EST	5.2%	6.7%	5.3%	12.6%	9.2%	5.9%	8.9%
FRA	5.6%	6.4%	4.1%	7.4%	6.4%	5.0%	6.6%
IRL	8.0%	8.5%	7.1%	8.9%	8.3%	6.8%	8.4%
UK	7.2%	8.7%	10.5%	9.0%	8.4%	8.9%	8.9%
CHN	3.4%	4.5%	6.0%	3.3%	4.8%	5.6%	4.1%
JPN	2.3%	4.7%	4.4%	3.2%	4.2%	3.3%	4.0%
NZL	5.6%	6.9%	9.5%	7.7%	6.7%	6.4%	7.2%
USA	5.3%	9.1%	9.2%	7.6%	8.3%	7.6%	8.2%
ZAF	3.7%	5.7%	6.3%	6.6%	5.4%	4.0%	5.6%

Share of TCP
0.0% 15.0%

FIGURE 1-20
Share of the top 5% most cited publications percentile per subject and for ALL subjects for Wales and comparators, 2010–2018; blue shading indicates a share above 5%, and beige shading indicates a share below 5%.
Source: Scopus

Chapter 2

Collaboration

2.1 Collaboration output

Half of Wales' published research involved international collaboration, and the Welsh research base is deeply embedded in the UK research landscape.

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

The extent and spatial distribution of published collaboration can be assessed from publications generated, as co-authors list their affiliations which provide information on the geographical extent of the collaboration. While co-authorship is not the only form of collaboration, particularly in fields such as SOCIAL SCIENCE and HUMANITIES AND THE ARTS, it can be quantified with reasonable robustness and is the basis for the indicators discussed in this chapter. Single-author articles are slowly becoming less common in the face of the inexorable rise of international collaboration, the latter being measured by the proportion of articles with at least two different countries listed in the authorship by-line. Internationally co-authored articles are, on average, associated with a higher FWCI than those co-authored institutionally or nationally.

For this study, we adopted a more granular approach to collaboration, distinguishing between the following collaboration types:

- Institutional collaboration: All authors are from the same institution.
- National collaboration: A national collaboration in the context of Wales would be a publication with a minimum of two authors from different institutions in Wales.
- Within-UK collaboration: All authors are from the United Kingdom, with at least two UK nations represented and no authors affiliated to a non-UK institution.
- International collaboration: These are publications with at least two authors affiliated to two different countries. In the case of UK nations, this would mean at least one author affiliated to an institution in England, Northern Ireland, Scotland, or Wales and one author affiliated to a non-UK institution in another country.

To better illustrate these collaboration types, please see the examples in the table below.

	Welsh university 1	Welsh university 2	Scottish university	German university	Collaboration type
Publication A	X X				Institutional
Publication B	X	X			National
Publication C	X	X	X		Within UK
Publication D	X		X	X	International

TABLE 2-1
Fictional examples of publications depicting collaboration types. X refers to an author.

These collaboration types are exclusive. Therefore, a publication by a Welsh, an English, and a European author will only be regarded as an international collaboration. These definitions are keeping with definitions used in previous reports for the Welsh Government although the actual data may be different due to a changed and updated list of institutions which are used to aggregate into the UK nations.

International collaboration is growing

International collaboration publications account for the largest group of publications for Wales in both periods, growing from an average of over 46% during 2010–2014 to nearly 544% in 2014–2018 (FIGURE 2-1). This comes at the expense of institutional collaboration and single authorship, while collaboration with other UK nations and within Wales remained at the same level. The trend for Wales mimics the global trend of an increasing share of international collaboration in scholarly output.

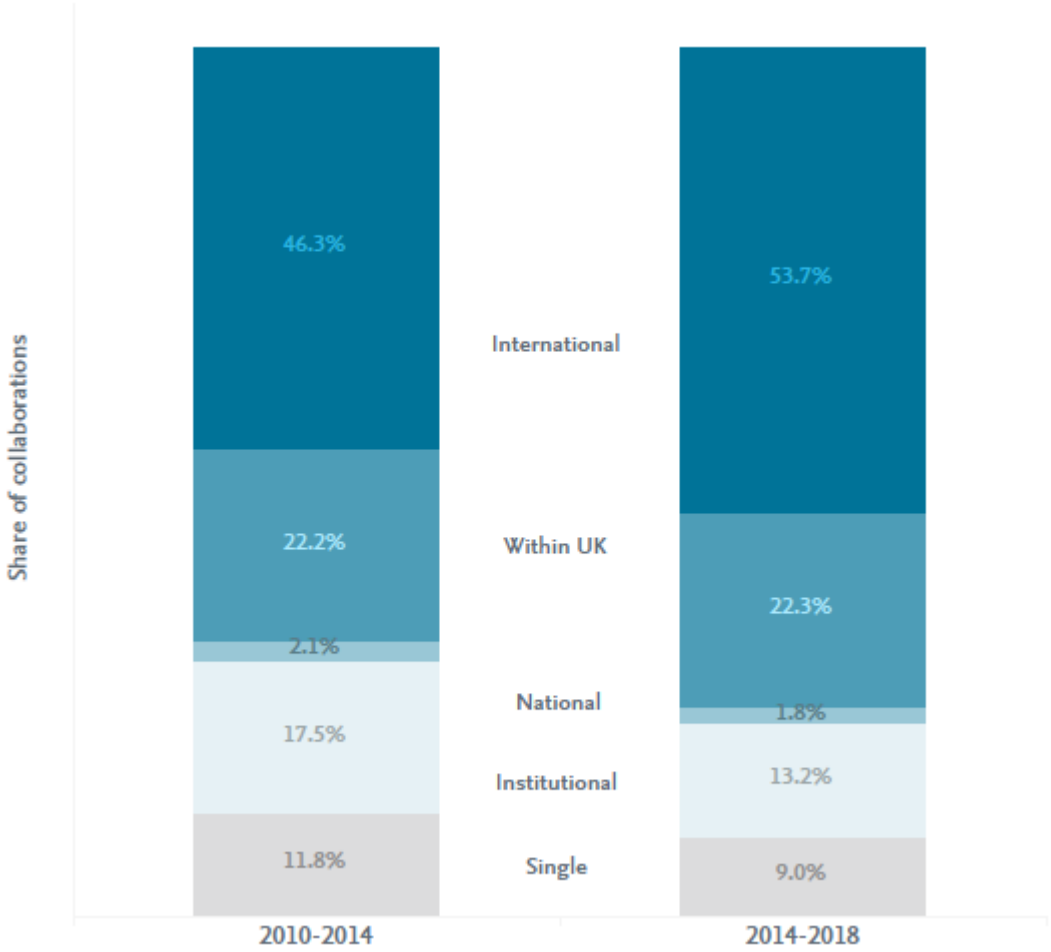


FIGURE 2-1
Share of publications per collaboration type of total output for Wales, P1 = 2010–2014, P2 = 2014–2018.
Source: Scopus

When the share of international collaboration is compared with the other UK nations, Wales has a slightly lower share (FIGURE 2-2). Northern Ireland has the highest share of international collaboration, with the Republic of Ireland being the second most prolific international partner behind the United States. All UK nations grew their international collaborations annually between 3% (Scotland) and 5% (Northern Ireland); Wales had a CAGR of 4%.

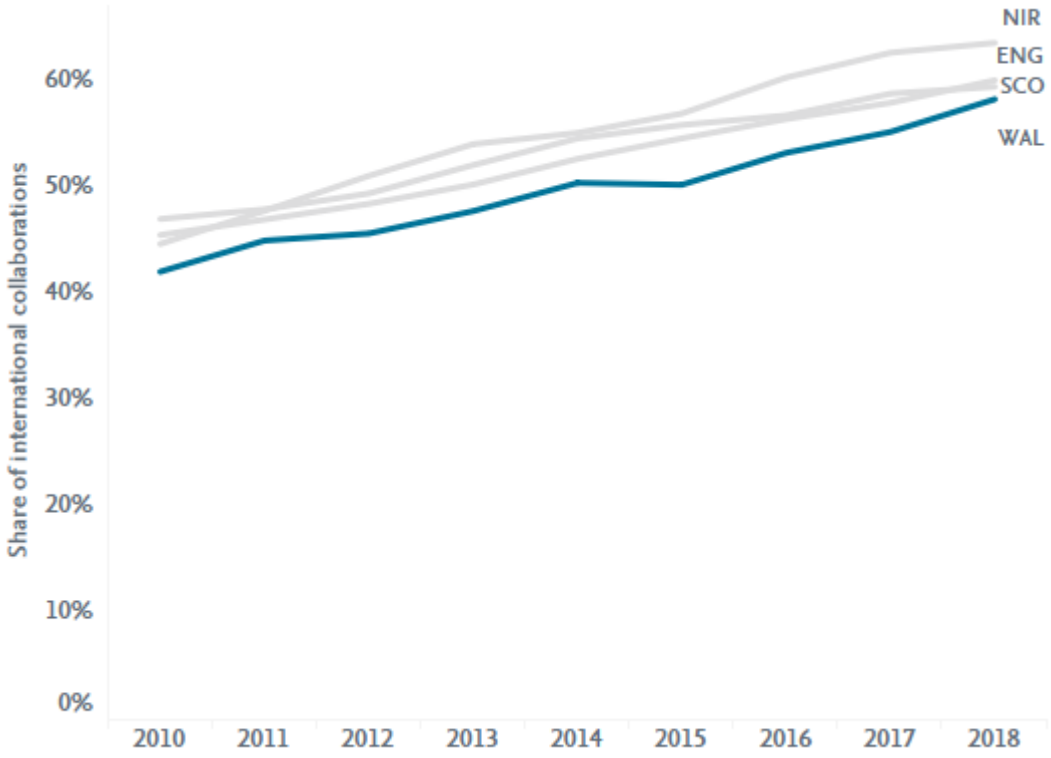


FIGURE 2-2
Share of publications in international collaboration for Wales and UK nations, 2010–2018.
Source: Scopus

Welsh research is deeply embedded in UK research

Wales displays the highest share of within-UK collaboration—that is, publications with at least one author from Wales and one or more authors from another UK nation. This has remained stable throughout the analysis period at over 22%, which is considerably higher than any other UK nation and shows the degree to which Wales is embedded in the UK research ecosystem (see FIGURE 2-3).

The low share of within-UK collaboration for England may be based on the size of England's researcher base and the high number of institutions. On the other hand, Wales has nearly twice the share of within-UK collaboration of Scotland or Northern Ireland.

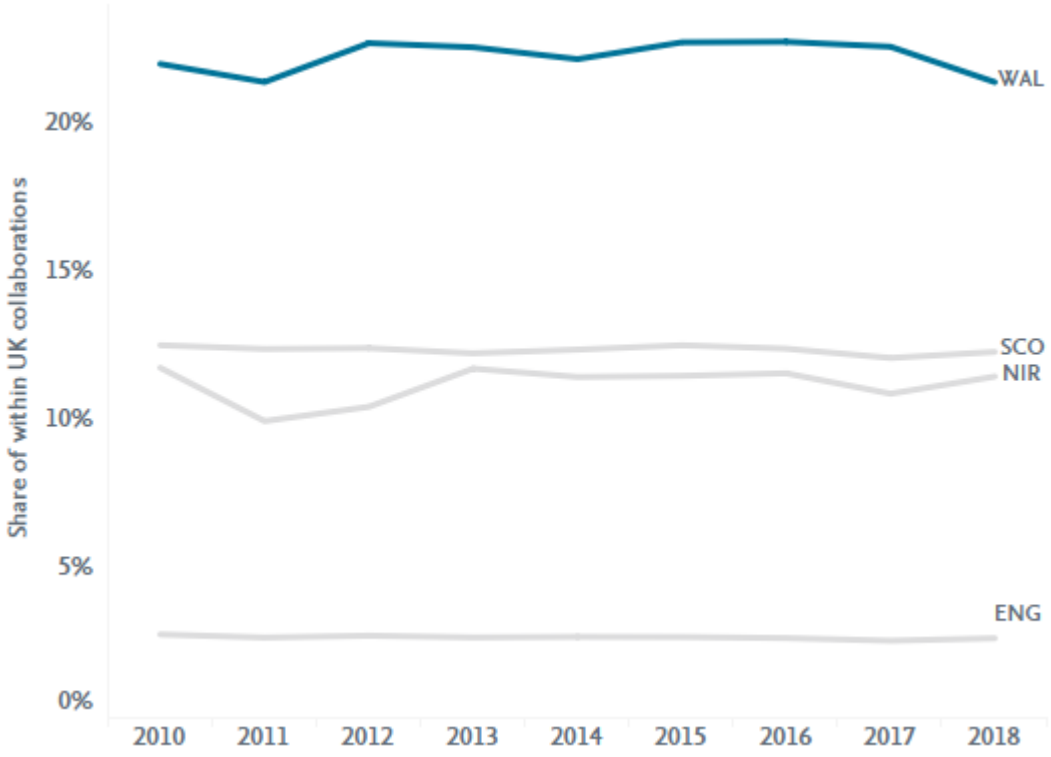


FIGURE 2-3
Share of publications in within-UK collaboration for Wales and UK nations, 2010–2018.
Source: Scopus

2% of all Welsh publications stem from national collaboration

The high share of within-UK collaborations for Wales comes at the expense of national collaboration, which shows the lowest share among the collaboration types and is the lowest among all UK nations. On average, only 2% of all Welsh output is published in national collaboration—meaning collaboration between only Welsh institutions. This share is considerably lower than the shares for Scotland (8%) and Northern Ireland (7%). Welsh research institutions collaborate with institutions in other UK nations much more than Wales' national comparators and much more than within Wales.

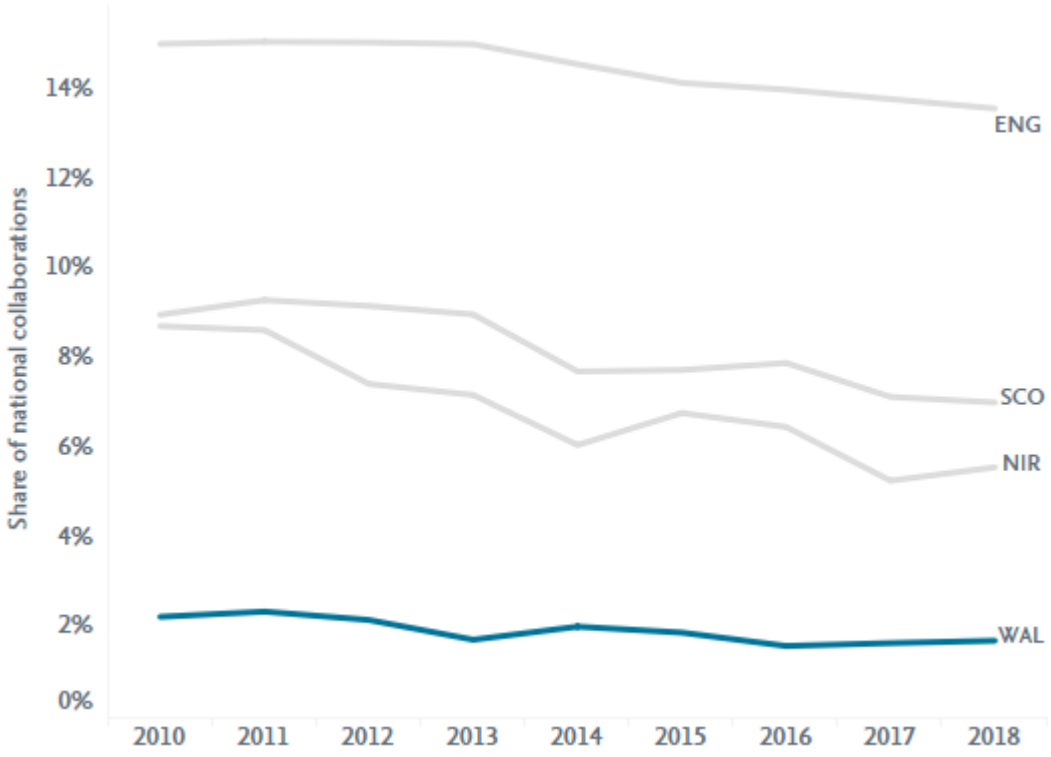


FIGURE 2-4
Share of publications with national collaboration for Wales and UK nations, 2010–2018.
Source: Scopus

Shares of institutional collaboration and single authorship dropped by almost 10% for Wales

The shares of institutional collaborations and publications involving single authors have been decreasing for all UK nations; for Wales, these collaboration types decreased from close to 20% to 11% and from 13% to 8%, respectively.

Single authorship decreased for all UK nations.

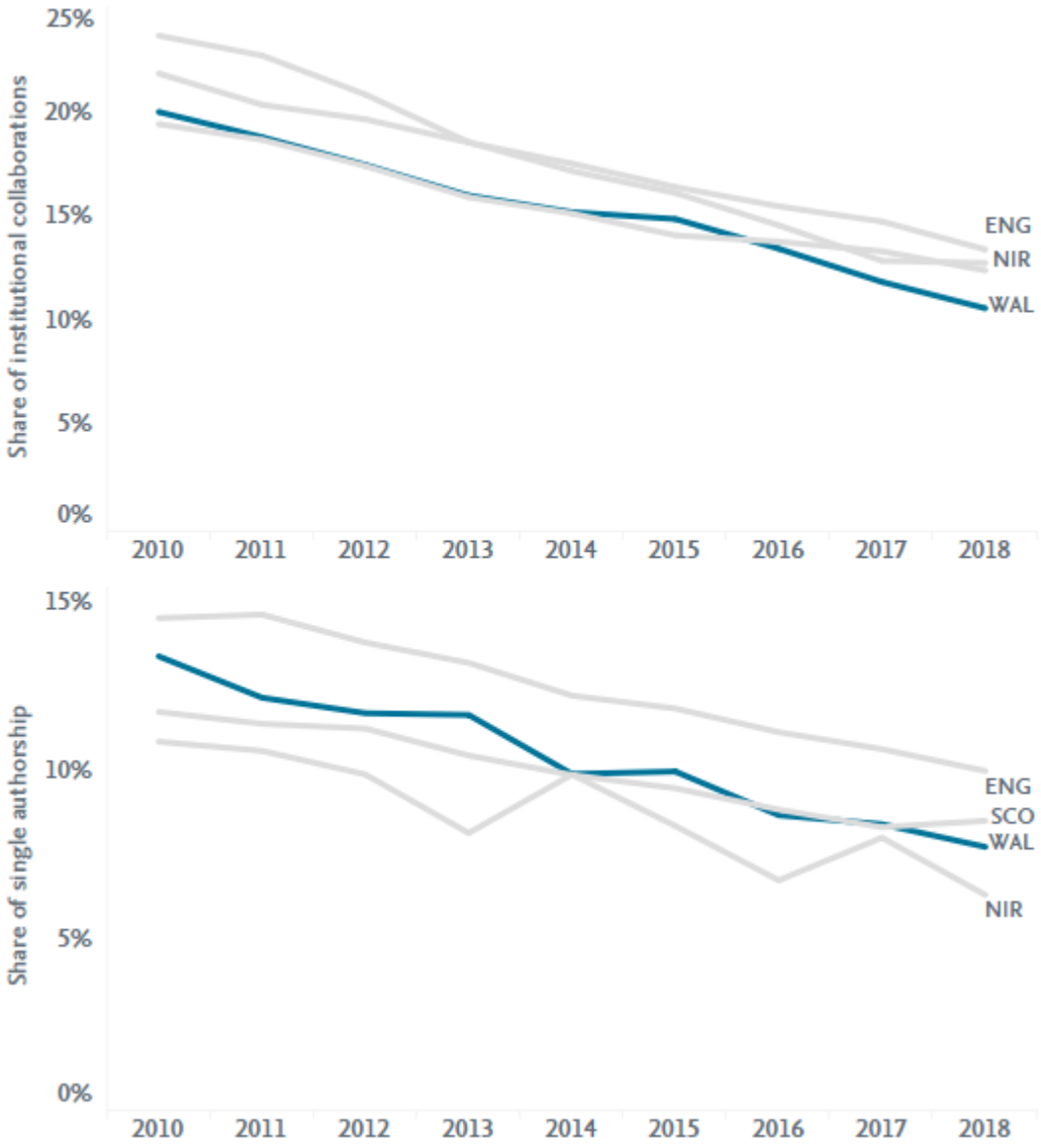


FIGURE 2-5
Share of publications in institutional collaboration (upper panel) and single authorship (bottom panel) for Wales and UK nations, 2010–2018.
Source: Scopus

Most subject area publications show a high share of international collaboration, except for SOCIAL SCIENCE and HUMANITIES AND THE ARTS

Exploring the distribution of collaboration types per subject area, it becomes clear that different subject areas follow different patterns of collaboration (FIGURE 2-6). AGRICULTURAL SCIENCE, NATURAL SCIENCE, and ENGINEERING & TECHNOLOGY have more than 50% of their scholarly output published with international collaboration. In contrast, single-authored publications are the most dominant publication type in HUMANITIES AND THE ARTS, in keeping with the global trend. In MEDICAL SCIENCE, the collaboration pattern is more balanced and distributed, although still with international collaboration having the highest share (41%).

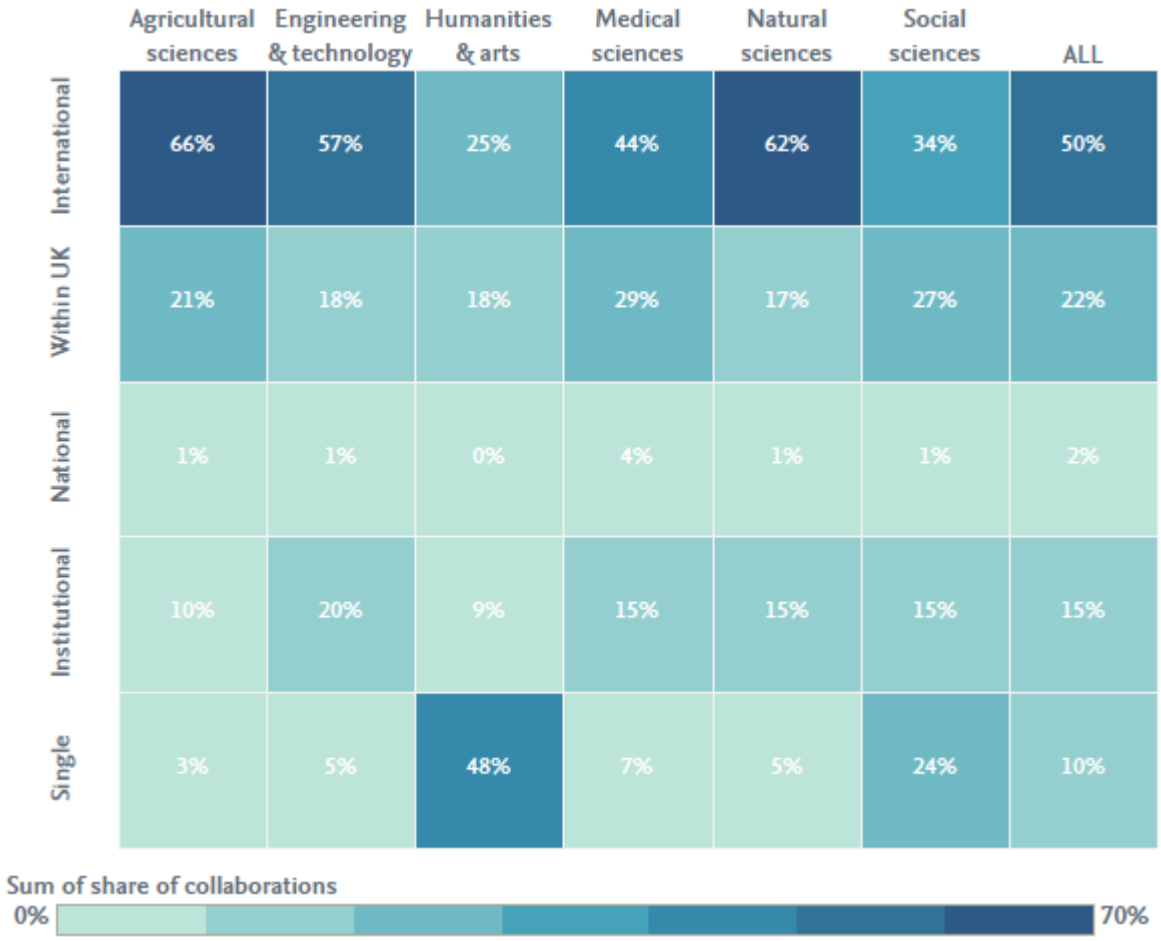


FIGURE 2-6
Distribution of collaboration types per subject area and for ALL subjects for Wales, 2010–2018.
Source: Scopus

2.2 Collaboration impact

International collaboration is the most impactful collaboration type for Welsh scholarly output, followed by within-UK collaboration.

The high degree of collaboration with international and UK researchers results in high impact for Wales-based researchers, as indicated by the FWCI. Globally, we observe that international collaboration is associated with high scholarly impact, and this is also the case for Wales (FIGURE 2-7). The main drivers of the high impact of Welsh research are international collaboration (an average FWCI of 2.4 for 2010–2018) and collaboration within the United Kingdom (average FWCI of 1.4 for 2010–2018).

National collaborations within Wales produced an average FWCI of 0.7 for 2010–2018, which is below the global average, and a similarly low FWCI of 0.9 can be seen for single-author publications. This does not indicate that this research is less important but that the findings and outcomes reported secured less impact in the form of citations by other peer-reviewed literature.

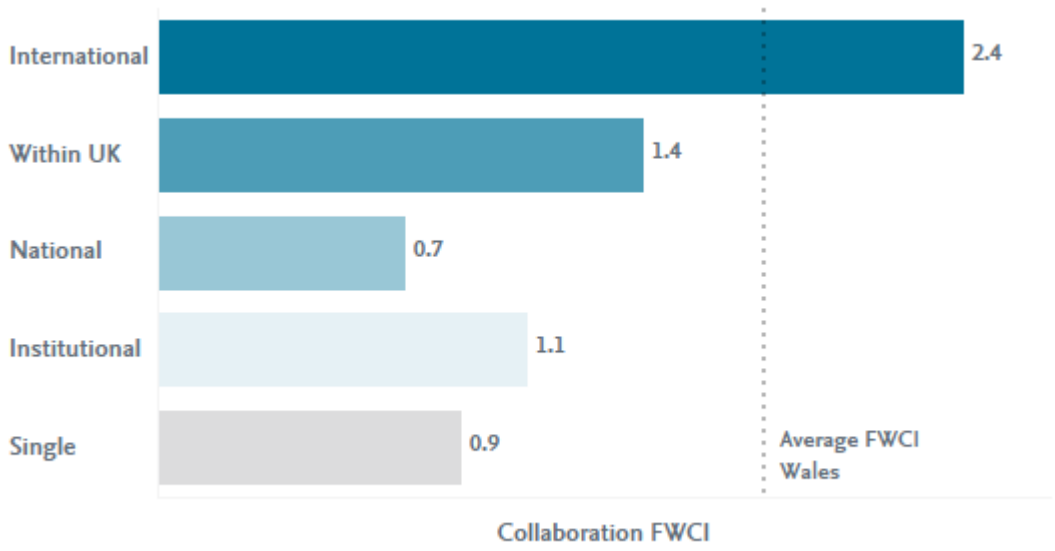


FIGURE 2-7
Average FWCI of publications per collaboration type for Wales, 2010–2018.
Source: Scopus

While the overall pattern of high FWCI for internationally collaborated publications holds true for all UK nations (FIGURE 2-8), Wales and Scotland are benefiting most from this collaboration type. For Wales, the difference between the FWCI of international collaborations and those of other collaboration types is the largest of all UK nations. Given that the share of international collaborations increased to more than 50% of all Welsh publications in 2018, this collaboration type is a significant contributor to the published impact of Welsh researchers.

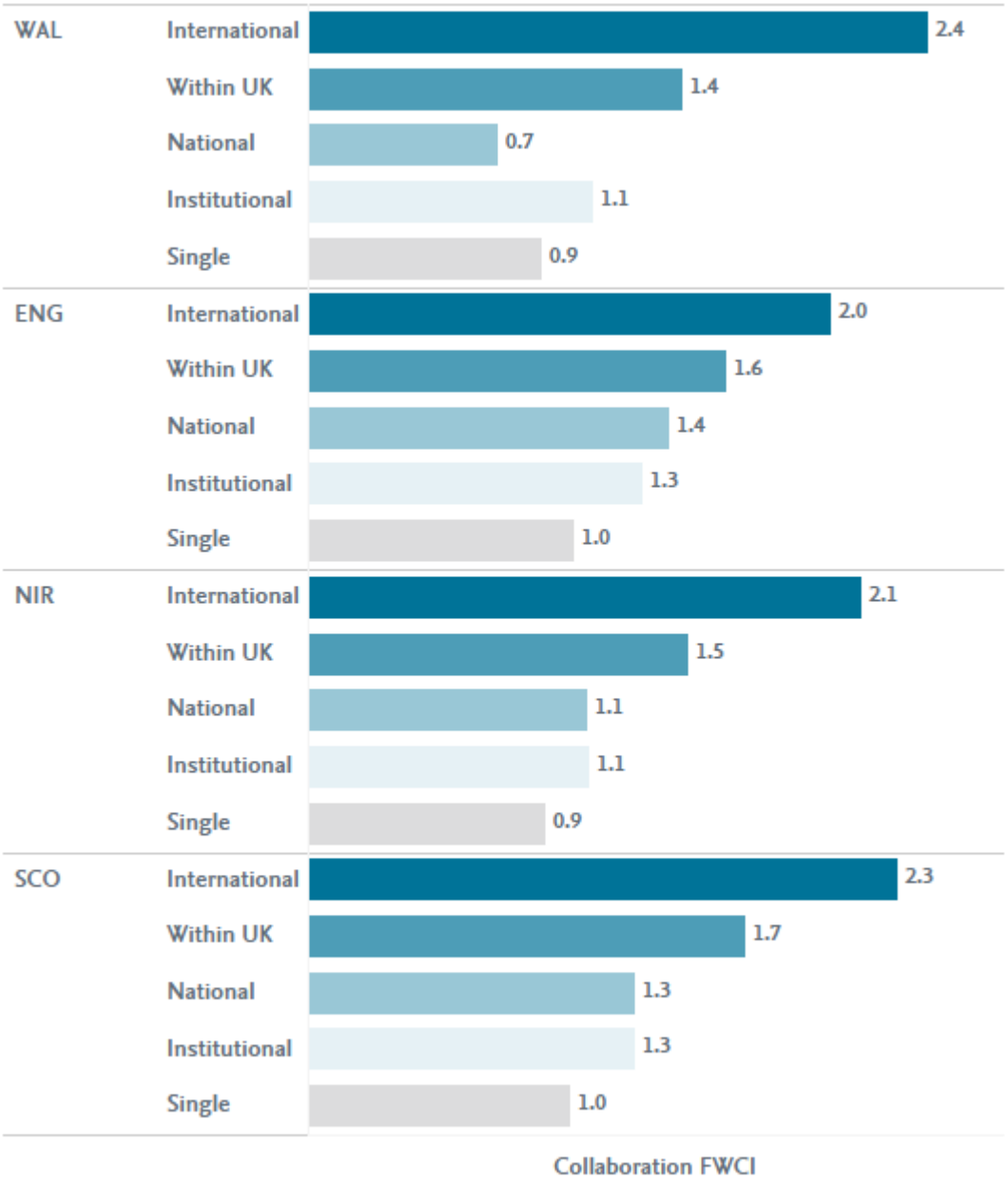


FIGURE 2-8
Average FWCI of publications per collaboration type for Wales and UK nations, 2010–2018.
Source: Scopus

For all Welsh subject areas, international collaboration is typically associated with the highest FWCI, showing the highest overall FWCI of 3.2 for MEDICAL SCIENCE. This high FWCI may be related to participation in hypercollaborated publications—publications with more than 100 authors—which are often seen in Medicine and Physics. Examples of this are the Global Burden of Disease Study, to which Welsh researchers contributed. Publications with single authorship show an FWCI at the global average only in SOCIAL SCIENCE, AGRICULTURAL SCIENCE, AND HUMANITIES. National collaboration, which has a very low share of overall publications, displays a high FWCI only for HUMANITIES AND THE ARTS.

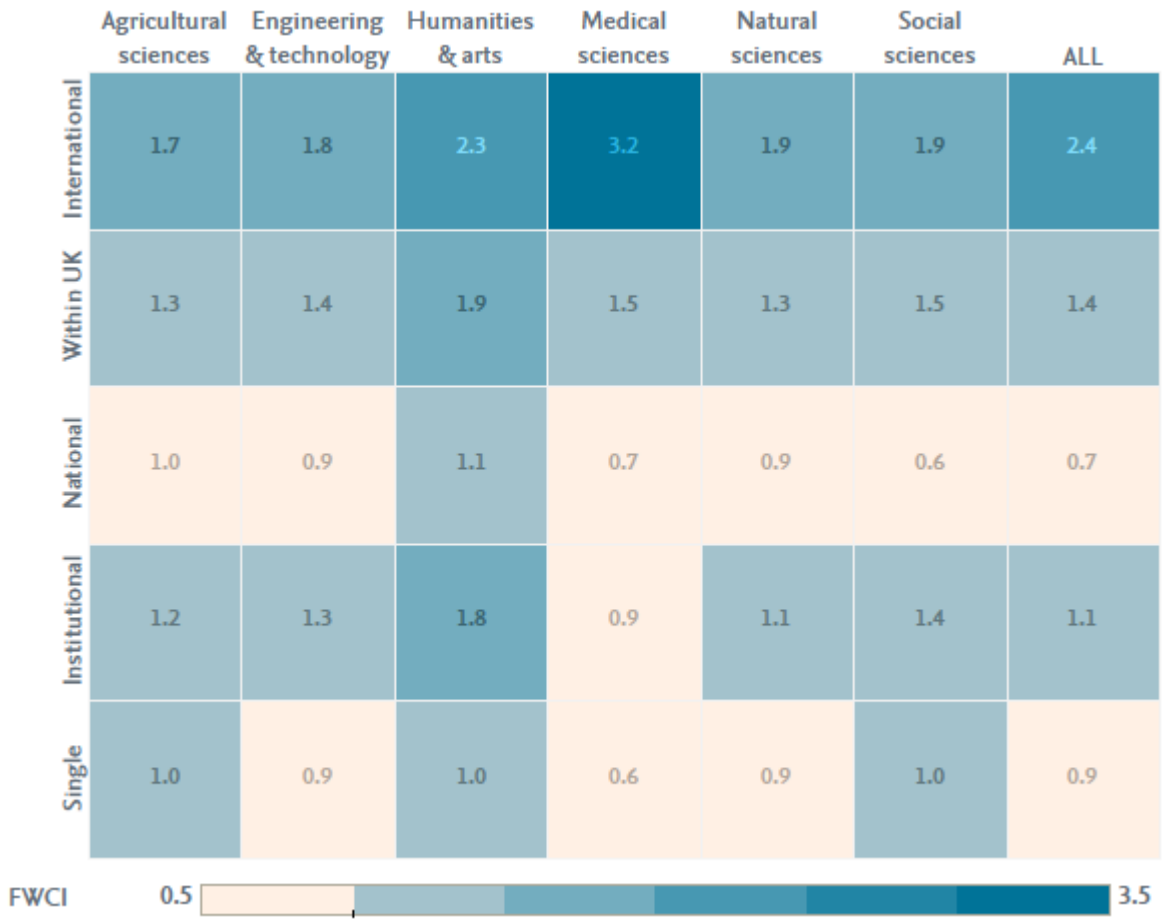


FIGURE 2-9
FWCI per collaboration type per subject area and for ALL subjects for Wales, 2010–2018.
Source: Scopus

2.3 Academic–corporate collaboration

Wales' share of academic–corporate collaboration grew to almost 7% of research output, with the citation impact of these publications remaining the highest across all UK nations.

Cross-sector collaboration provides interaction opportunities between research practices and areas that are often quite different, with varying priorities and access to resources. Academic–corporate collaborations are regarded as a good example of knowledge transfer in the research world, with innovation, expertise, and practice co-mingling, somewhat providing the best of both worlds: academia's blue-sky, fundamental research freedom with the corporate world's focus on applicability and best practices. In this report, academic–corporate collaboration is defined as publications that have at least one author from an academic institution and at least one author from the corporate sector in the affiliation by-line. While we acknowledge that there are many different forms of collaboration, this type of co-authorship serves as a useful proxy for demonstrating collaboration and knowledge transfer. Academic–corporate collaborations often accumulate high citation counts, as indicated by usually high FWCI values.

During 2010–2018, around 2.6% of global publications were published with academic–corporate collaboration, with these securing an average FWCI of 1.8. The United Kingdom (with an average share of 6% from 2010–2018) and the UK nations returned a higher share of academic–corporate publications than the global average, ranging between 5% and 8% between 2010 and 2018, and displaying a growing trend (FIGURE 2-10). Among the UK nations, England had the highest share of academic–corporate collaboration, growing from 7% to 8%. Scotland and Wales both had a similar share of academic–corporate collaboration in 2010, close to 6%. While both countries showed fluctuating trends, Scotland's share—being larger—increased more than Wales' and reached almost 8%, closer to England's figure.

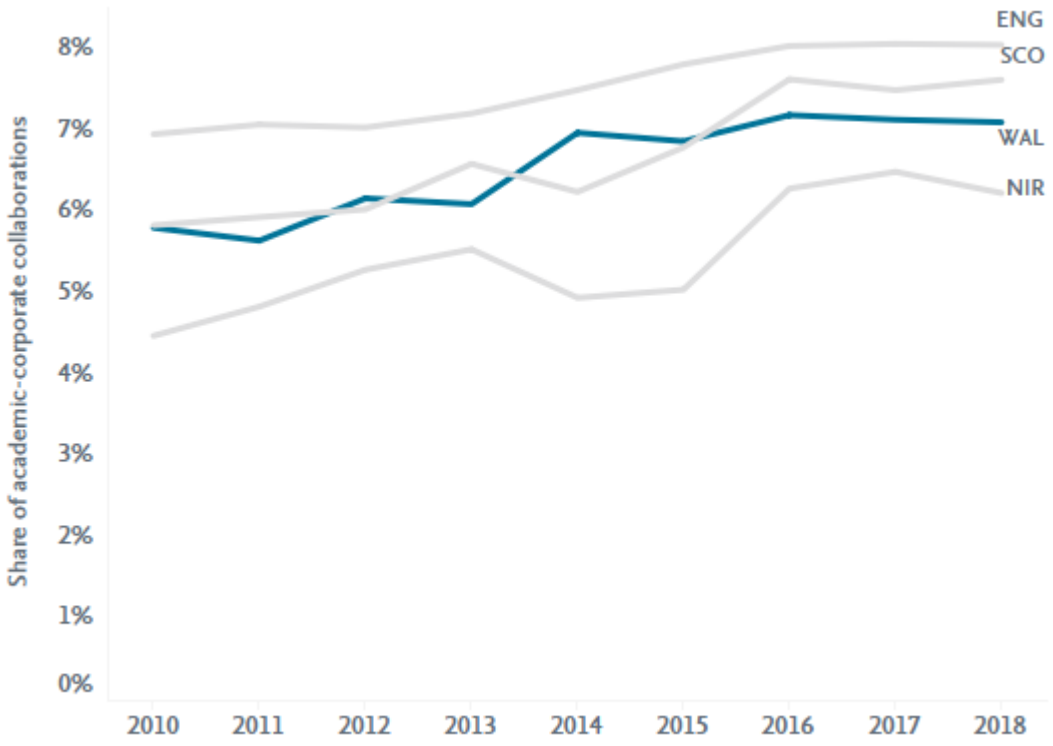


FIGURE 2-10
Share of publications in academic–corporate collaboration for Wales and UK nations, 2010–2018.
Source: Scopus

Since the total number of academic–corporate publications is relatively small—compared to the overall output—outliers may have significant effects, and therefore annual numbers for the FWCI show sharp fluctuations. However, the average FWCI of academic–corporate collaborations for Wales for the analysis period (2010-2018) was 4.7, surpassing other nations of the United Kingdom in 2015—a position that it has maintained.

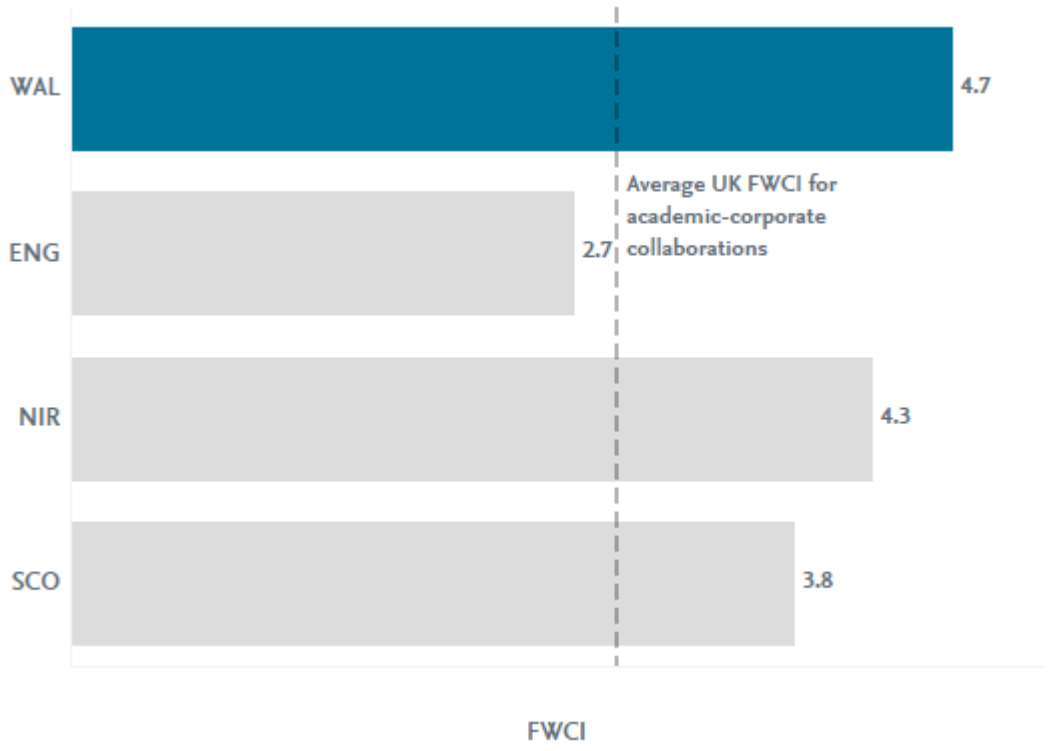


FIGURE 2-11
Impact of publications in academic–corporate collaboration for Wales and UK nations, 2010–2018. Dotted line indicates average UK FWCI for academic–corporate collaborations.
Source: Scopus

FIGURE 2-12 below provides a summary of the impact of academic–corporate collaborations. For all UK nations, academic–corporate collaborations return the highest FWCI. It needs to be stated, however, that the effect on the overall FWCI across all collaboration types is due to the limited numbers of collaborated publications, but it becomes clear that these cross-sector collaborations are a major source of research excellence.

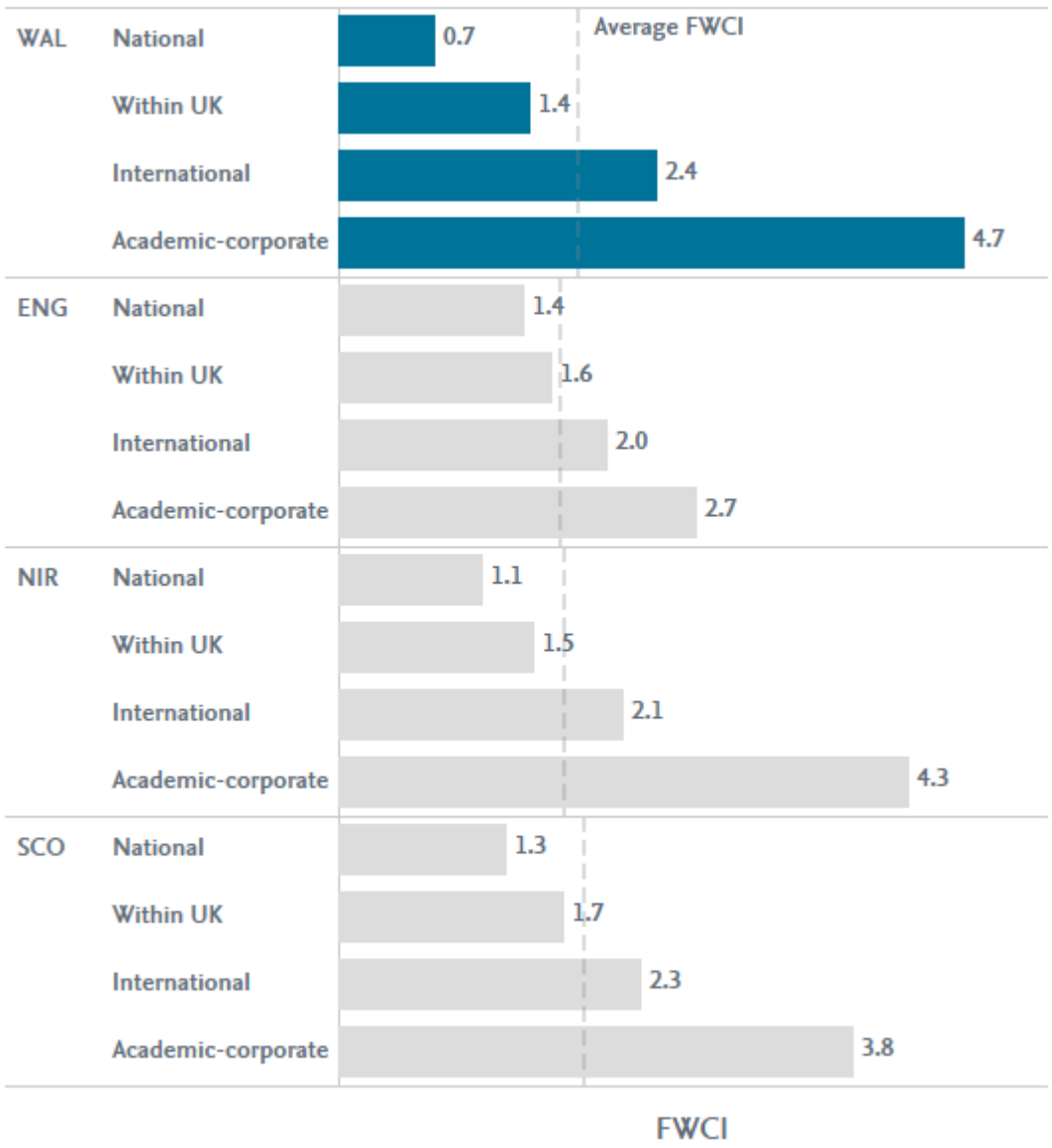


FIGURE 2-12
Average FWCI of publications per collaboration type for Wales and UK nations, 2010–2018. Dotted lines indicate average FWCI for all publications per UK nation.
Source: Scopus

NATURAL SCIENCE, MEDICAL AND HEALTH SCIENCE, and ENGINEERING AND TECHNOLOGY are the most prolific subject areas for Welsh researchers in academic–corporate collaborations, and this follows global patterns. As with global trends, within HUMANITIES AND THE ARTS the shares of academic–corporate collaborations are lower, with Welsh academic researchers only publishing 24 publications jointly with corporate researchers.

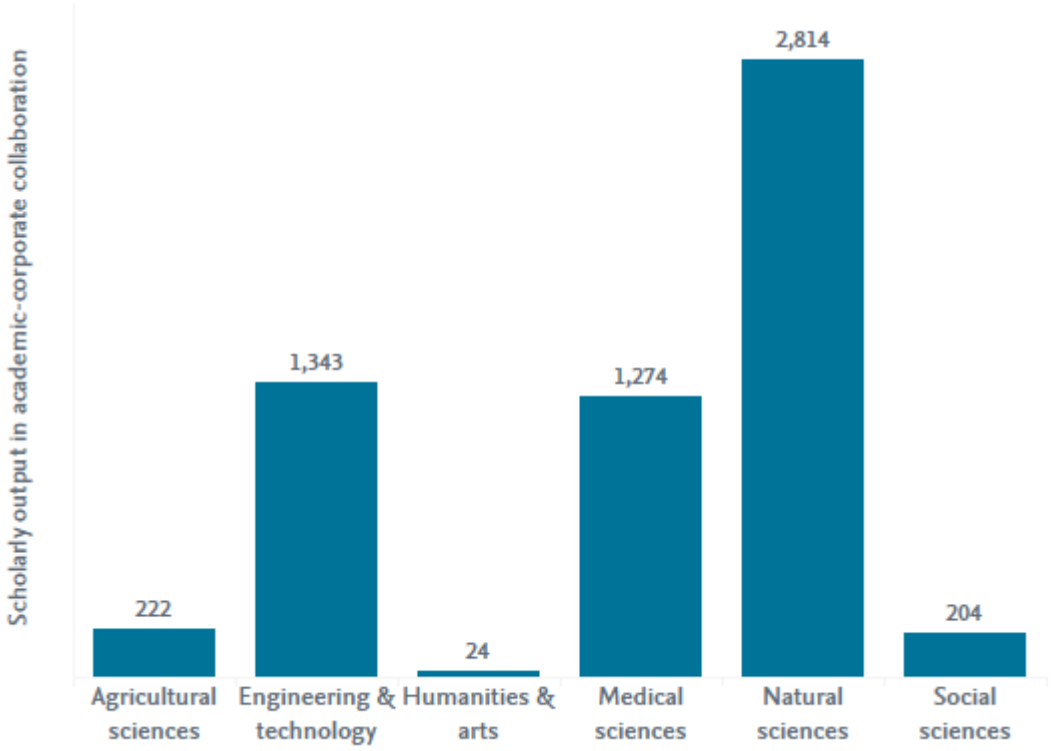


FIGURE 2-13
Number of academic–corporate collaborations per subject area for Wales, 2010–2018.
Source: Scopus

The distribution of publications in academic–corporate collaborations is reflected in the list of the top 10 most collaborated corporations in TABLE 2-2. Seven of the top 10 corporates are from the United Kingdom and all of them are active within NATURAL SCIENCE, MEDICAL SCIENCE, or ENGINEERING & TECHNOLOGY. With the exceptions of Rolls-Royce and Tata Steel Europe Ltd., all collaborated publications show an impact well above the global average.

Corporate	Country	Academic–corporate collaborated output	FWCI
IQE plc	UK	174	2.5
GlaxoSmithKline	UK	132	4.7
Motor Design Ltd	UK	132	2.8
Tata Steel Europe Ltd.	UK	90	0.8
AstraZeneca	UK	88	4.8
Rolls-Royce	UK	87	1.0
IBM	USA	85	2.3
VTT Technical Research Centre of Finland Ltd.	FIN	74	7.6
Micro Materials Limited	UK	71	1.2
Pfizer	USA	71	8.3
Novo Nordisk A/S	NOR	59	10.1
Phytoquest Ltd	UK	50	1.1
Health Economics and Outcomes Research Ltd	UK	47	1.6
Airbus Group	FRA	46	2.7
deCODE Genetics	ISL	46	14.3

TABLE 2-2
Top 15 collaborating corporates 2010–2018, by number of co-authored scholarly outputs.
Source: Scopus

Chapter 3

Mobility

3.1 Introduction to mobility

The movement of people across national borders is an important mechanism for research collaboration and knowledge exchange. By tracking an authors publication affiliations, it is possible to analyse researcher mobility between countries.

Mobility classes

International researcher mobility is a topic of high interest for many stakeholders. Of particular importance is a country's or nation's ability to attract or maintain high-level researchers, while simultaneously fostering the international flow of researchers and subsequent knowledge exchange.

Mobility, however, poses some difficulties when teasing out long-term mobility from short-term mobility (such as doctoral research visits, sabbaticals, secondments), which might reflect a form of collaboration instead. In this study, researchers who stayed outside Wales for **two years or more** were considered '**migratory**' and were further subdivided into groups of those who remained abroad and those who subsequently returned to Wales. Researchers staying **less than two years** abroad were deemed **'transitory'**.

For example, a researcher who left Wales for three years, published abroad, and then came back is considered as migratory 'outflow, long leave'. If a researcher left Wales and did not come back at all, this is considered as **migratory 'outflow, permanent leave'**. On the other hand, a researcher starting his or her career in a European country such as France, moving to Wales for at least two years, and then returning to France (or moving to another country such as Germany) is categorised as **migratory 'inflow, long stay'**. A researcher staying in Wales or moving abroad for less than two years is considered to be **'transitory'**.

Similar to the approach for mobility, we assessed the different places of migration by tracking the affiliations in the affiliation by-line. For a researcher moving from a Welsh institution to a university in Scotland, Northern Ireland, or England, the region was deemed to be 'UK'. If the destination was an institution in a European country, then the region was considered to be 'Europe'; everything else was called 'International'.

It should be noted that researchers may have multiple, different mobility events—a Welsh researcher may first move to elsewhere in the United Kingdom, come back to Wales after more than two years, and then subsequently move to the United States without coming back. Such a researcher would be counted within 'outflow, long leave' towards the United Kingdom, and the same researcher would be counted towards the group of 'outflow, permanent leave—international'. However, since the overall numbers for Welsh researchers (without region of migration) count researchers and not mobility events, in the aggregated view this researcher would be counted only as 'outflow, permanent leave'.

Since article or author data do not capture nationality, 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 not accurately reflect the real situation. Errors in assigning migratory patterns, however, are assumed to be evenly distributed across the groups, and the overall pattern remains valid. Researchers without any apparent mobility based on their published affiliations were considered 'non-migratory'.

This mobility analysis tracks a mixed cohort of researchers as it analyses each author's output for the period 1996–2019. Some researchers may publish articles during the entire period, others have become active only relatively recently, and yet others may have stopped publishing. The possible inclusion of PhD students, who usually do not move at this point of their career, may lead to an underrepresentation of the relative mobility of researchers with a short publication history.

Also, although their activities might not always have resulted in a peer-reviewed article with an affiliation to a non-Welsh institution, researchers classified as non-migratory may have travelled and collaborated internationally in this period.

Mobility indicators

The following three aggregate indicators for the mobility groups defined above represent the impact of publications, productivity, and the seniority of the researchers they include.

- FWCI is calculated for all articles in each mobility class.
- Relative productivity represents a measure of the articles per year since the first appearance of each researcher as an author during the period 1996–2019, relative to all Welsh researchers in the same period.
- Relative seniority represents the number of years since the first appearance of each researcher as an author during the period 1996–2019, relative to all Welsh researchers in the same period.

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

3.2 Mobility of the Welsh researcher base

The Welsh research base is highly mobile. More than 90% of all active researchers have published outside Wales, being more productive and impactful than sedentary researchers.

In this chapter, we analyse Welsh researcher mobility using Scopus author profile data. Publications include author affiliations and tracking these data makes it possible to construct a history of Welsh author affiliations. Authors are assigned to mobility classes, defined by the type and duration of observed moves. In SOCIAL SCIENCE and HUMANITIES AND THE ARTS, researchers tend to publish more in the form of books, monographs, and non-textual data, which this report does not capture; therefore, the affiliation history may be less reliable in these subjects.

From 1996 onwards, the pool of Welsh author profiles included a total of 56,726 researchers, of which 19,716 are considered active. Author profiles with relatively few articles throughout the period 1996 to 2019 likely represent individuals who left the research system, and the 'active researcher' filter excludes these researchers. The filter restricts the analysis to (1) those authors with at least one article in the latest 5-year period (2015–2019) and at least 10 articles in the entire author-history period (1996–2019), or (2) those authors with fewer than 10 articles in 1996–2019 but at least four articles in 2015–2019. We acknowledge that the filter may exclude researchers at a very early stage of their career, with fewer than four publications in total.

FIGURE 3-1 displays the mobility pattern of Welsh researchers. Welsh researchers are highly mobile, with more than 90% of all active researchers having published at least one publication outside a Welsh affiliation (total of Inflow, Outflow, and Transitory categories). Welsh researchers are more mobile than overall UK researchers. The 2016 BEIS report stated that only 72% of all UK researchers were mobile, with the same approach as used in this report. The BEIS report assessed data until 2015 and for Wales found that 89% of all active researchers were mobile. With that, Wales had the lowest share of non-mobile researchers of all UK nations and the numbers were confirmed by the updated data used in this report until 2019.

Transitory researchers, being abroad (or moving into Wales) for less than two years, are by far the biggest mobility group, comprising almost two thirds of the active research base. They are the most productive as well—publishing, on average, four times the output of non-mobile researchers and 1.5 times more than migratory researchers (having stays longer than two years). As expected, based on the methodological considerations, the non-mobile group is the most junior (relative seniority 0.56), with the lowest productivity (relative productivity 0.33) and FWCI (1.93).

Inflow and Outflow group are similar in relative seniority and relative productivity. Overall, consistent with other reports, the Welsh research base displays a net outflow of researchers.

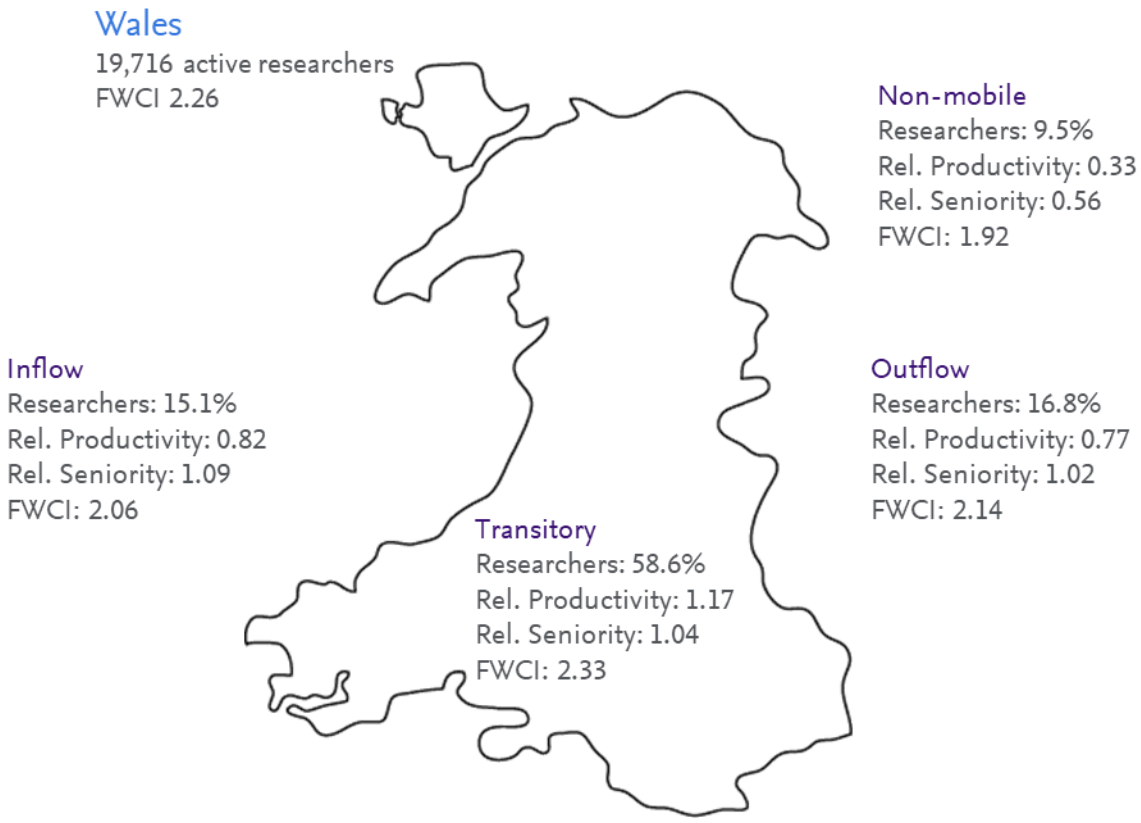


FIGURE 3-1
International mobility of Welsh researchers, 1996–2019.
Source: Scopus

Exploring mobility in more detail, we stratified the pattern by destination (or provenance). TABLE 3-1 below shows the share of researchers and the mobility indicators for within the United Kingdom, within EU countries, and internationally.

Across all migration regions, transitory researchers are the most productive and impactful. For the group of researchers migrating to and from Wales but within the EU, relative productivity and FWCI are the highest of all groups, although the share of researchers is the lowest for this group. While it may not be surprising to see the majority of mobile researchers migrating to or from the United

Kingdom, the shares for internationally mobile researchers are consistently higher than for mobility within the EU. Especially for the group of transitory researchers, who are associated with the highest productivity and the highest citation impact, the differences are quite large—35% are transitory within the United Kingdom, 33% are transitory international, and only 22% are transitory within the EU.

Wales, as a small research nation, benefits highly from mobility and exchange with EU countries. In this context, Brexit may pose significant issues for Wales' research performance.

		Inflow	Transitory	Outflow
Wales	Researchers	15.1%	58.6%	16.8%
	Relative productivity	0.82	1.17	0.77
	Relative seniority	1.09	1.04	1.02
	FWCI	2.06	2.33	2.14
UK	Researchers	10.7%	38.8%	8.5%
	Relative productivity	0.83	1.22	0.72
	Relative seniority	1.13	1.06	1.04
	FWCI	1.94	2.48	2.04
EU	Researchers	2.4%	22.4%	2.0%
	Relative productivity	0.87	1.71	0.83
	Relative seniority	1.05	1.15	0.97
	FWCI	2.26	2.61	2.50
International	Researchers	3.5%	32.9%	3.4%
	Relative productivity	0.94	1.51	0.78
	Relative seniority	1.05	1.12	0.94
	FWCI	2.33	2.49	1.98

TABLE 3-1
International mobility of Welsh researchers, by region of migration, 1996–2019.
Source: Scopus

Chapter 4

Topics of prominence

4.1 Introduction to topics of prominence

Topics of prominence are a new granular approach to research publications that can identify high-performing research clusters.

While analyses at subject area level (Chapters 1–2) is an established way to codify research topics, these remain highly dependent on a journal-level analysis, given that publications are traditionally assigned to subject areas based on the journal published in. The journal-level approach works well for publications where the journal coverage is highly specific, but less so for the increasing number of multidisciplinary journals, which lack the same specificity. Complementary to this would be a more granular approach on the publications level. Based on citation links between individual publications, clusters of publications addressing the same research area can be calculated and represented. This approach has been taken using **topics of prominence** and **topic clusters**.

Topics of prominence

Of all articles in Scopus, 95% can be clustered into roughly 96,000 global and unique research topics based on direct citation analysis. Topics are meant to be aligned to the research-question level, created by clustering articles with strong citation linkages. Topic (as opposed to subject) names are derived from the keywords used in the abstracts of the articles constituting the topic. The relationship between potential topics can be identified by looking at where the citation links are weak. Weak links enable clusters to be split into separate topics.

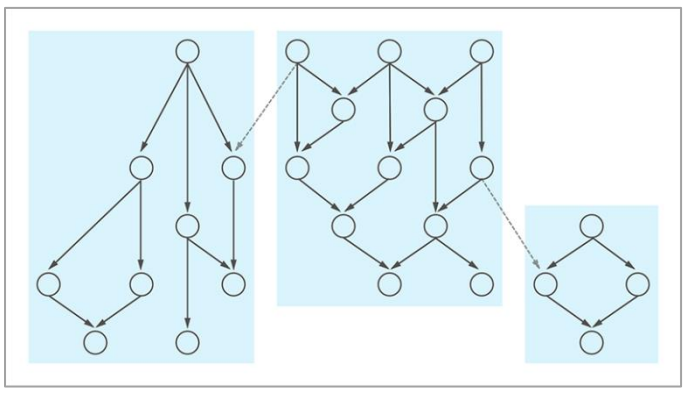


FIGURE 4-1
Depiction of publications being clustered into topics.
Source: SciVal website

Topic clusters are formed by aggregating individual topics with similar research interest together to form a broader, higher-level area of research. Topic clusters are formed using the same direct citation algorithm that creates the topics. When the strength of the citation links between different topics reaches a threshold, a topic cluster is formed. Each of the 96,000 topics can be classified within 1,500 topic clusters.

Topics and topic prominence analysis builds on the academic research conducted by Richard Klavans and Kevin W. Boyack.[10] Topics of prominence indicate the **momentum** in a particular field through ranking of topics according to prominence.

Topic prominence

Calculating a topic's 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

Prominence was developed as an indicator that would capture the momentum of topics and therefore has the potential to predict whether a topic will grow or decline in the near future, regardless of whether the topic is considered to be emergent or not. In the context of the current report, momentum therefore provides an indication where a research topic is more visible in terms of the attention it has received from the academic peers group. Prominence, however, should not be equated with importance, innovativeness, or newness.

[10] For further information regarding the methodology and calculation of prominence, please see the following publications:

- Small, H., Klavans, R., & Boyack, K. W. (2014). Identifying emerging topics in science and technology. *Research Policy, 43 (8),* 1450–1467.
- Klavans, R., & Boyack, K. W. (2017). Research portfolio analysis and topic prominence. *Journal of Informetrics, 11 (4),* 1158–1174.

4.2 Top topic clusters for Wales

Wales' top 20 topic clusters contribute to the United Kingdom's performance with high publication shares and impact.

To describe the research publications of Wales using topic clusters, we took a closer look at the recent period of 2014–2018. FIGURE 4-1 shows the general distribution of Welsh publications across various topic clusters, with a minimum of 50 publications during 2014–2018. It can be seen that most Welsh publications are located in highly prominent topic clusters with average scholarly impact values above the global average, and with only a few topic clusters showing an FWCI below the global average (red colour coding). The largest topic cluster GALAXIES; STARS; PLANETS, with almost 700 publications from Wales, was excluded from this view for visual reasons. Almost two thirds of the publications in this cluster resulted from hypercollaboration—that is, publications by more than 100 authors.

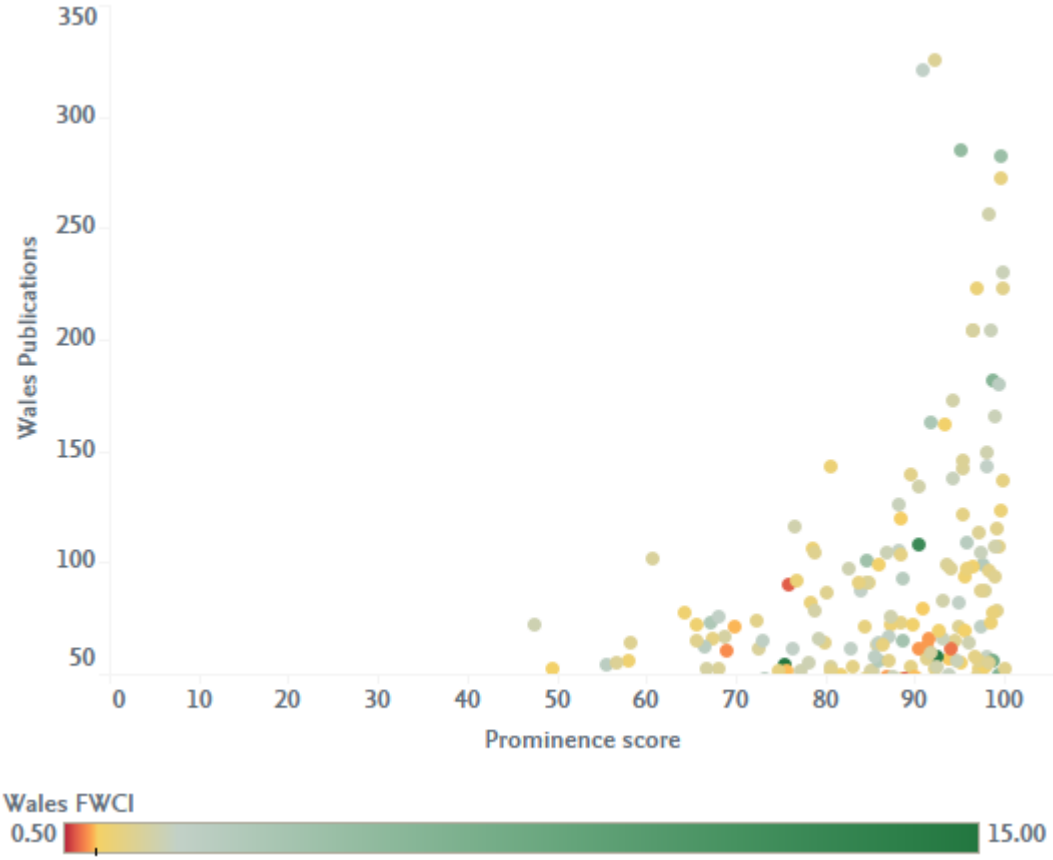


FIGURE 4-2
Distribution of Welsh publications across different topic clusters for 2014–2018. There is a minimum threshold of 50 publications for the period. The topic cluster GALAXIES; STARS; PLANETS has been excluded for visual purposes. Colour of the dots indicates the average FWCI of Wales in that topic cluster; red = below global average of 1.
Source: Scopus

All the top 20 topic clusters for Wales by output have a prominence score of 90 or above, indicating they are within the top decile of most prominent clusters globally. Some of these follow global trends—GALAXIES; STARS; PLANETS, T-LYMPHOCYTES; NEOPLASMS; IMMUNOTHERAPY, INDUSTRY; INNOVATION; ENTREPRENEURSHIP, ALGORITHMS; COMPUTER VISION; MODELS, and OBESITY; MOTOR ACTIVITY; CHILD are also among the top 20 topic clusters globally. To understand the topic clusters where Wales has unique strengths, and their relative contribution to the United Kingdom and globally we charted the global prominence topic clusters.

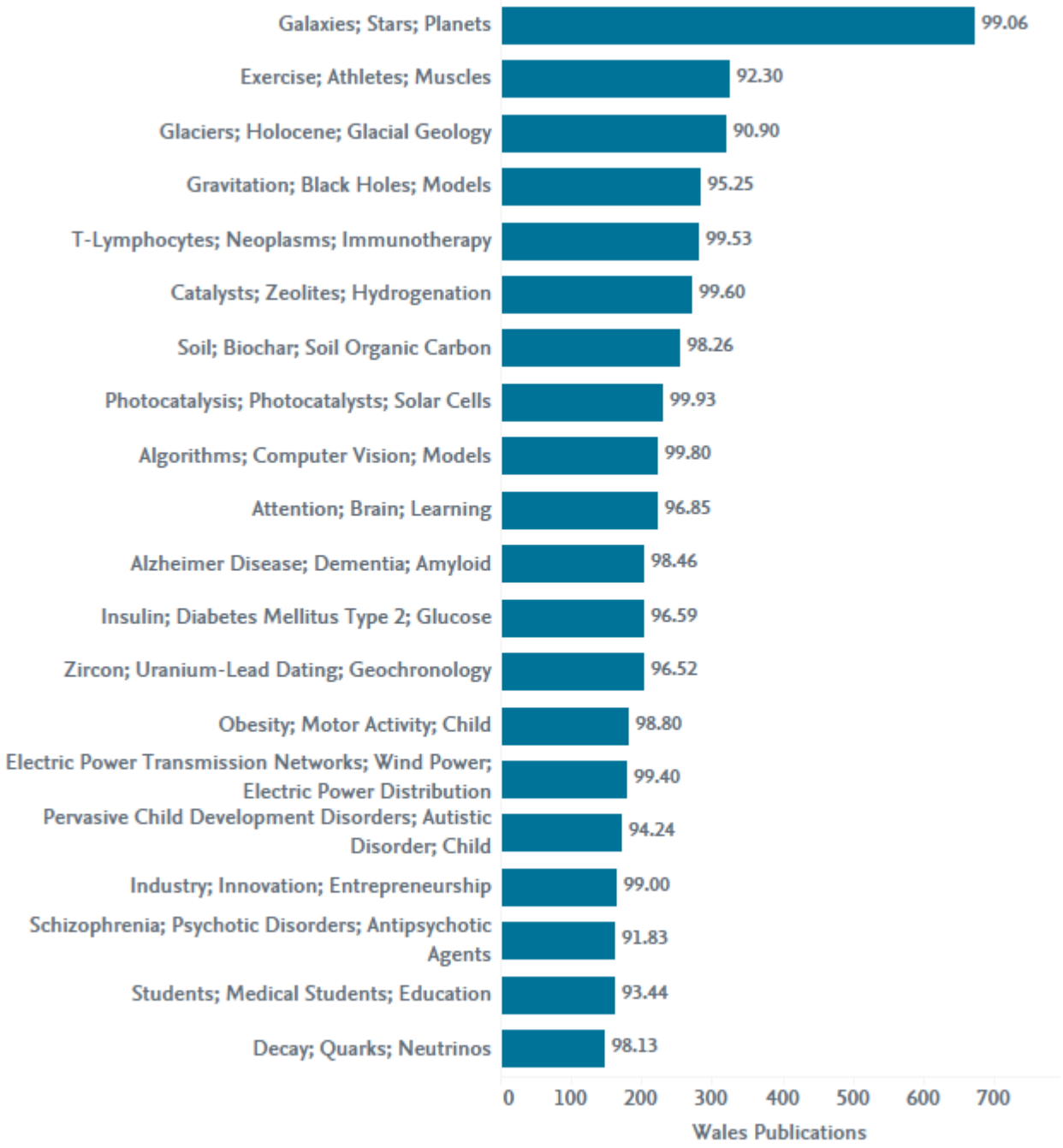


FIGURE 4-3
Wales' top 20 research topic clusters by output, 2014–2018. Number outside the bars indicates the global prominence score of that topic cluster for 2019.
Source: Scopus

FIGURE 4-4 shows the top 20 topic clusters where Wales has the largest global output share and where the average FWCI is greater than both the global average and the UK average. The colour coding of

the topics indicates the ratio of Wales' FWCI divided by global FWCI in this cluster—the darker the colour, the higher Wales' FWCI is compared to the global FWCI. A full list of these topic clusters is provided in Appendix D. The first topic cluster is GLACIERS; HOLOCENE; GLACIAL GEOLOGY, and here Wales accounts for nearly 2% of global research output and more than 11% of the UK output. Geography departments at Aberystwyth and Swansea Universities were among the top contributors within Welsh institutions. On average, publications from Wales showed an FWCI of 2.3, which is higher than the UK (1.9) and global (1.3) averages. A second topic cluster is LEACHING; ORES; BIOLEACHING, where Wales accounts for 1.2% of the global output and over 35% of the UK output. Bangor University is among the most published institutions globally in this cluster.

FIGURE 4-5 is similar to FIGURE 4-4 but this time is sorted according to Wales' share in the United Kingdom and where Wales' average FWCI was greater than the global average and the UK average. It can be seen that, although the order of the topic clusters differ, there is a close overlap between the topic clusters—the topic clusters in which Wales accounts for a large share of the UK output are also the ones where it has a large share of global publications.

All topic clusters in this selection display a share of UK publications higher than 4%—the average share of Welsh publications within the United Kingdom (please see chapter 1 for detailed numbers)—suggesting that these clusters can be considered as **research strengths** of Wales. They contribute with an above-average share of publications and with a higher FWCI than the United Kingdom's performance globally.

Some other clusters that are not among the top 20 by global output share but are still highly prominent and do well are also worth mentioning. CATALYSTS; ZEOLITES; HYDROGENATION is a topic cluster highly dominated by Chinese and Russian institutions. However, Cardiff University (through its Chemistry Department) was the most published UK university, accounting for over 15% of the UK output in this cluster, and 0.5% of the global output. One of the Cardiff professors is among the most published authors globally in this topic.

Through its Centre for Water Advanced Technologies and Environmental Research (CWATER), Swansea University was one of the top institutions in Europe in the topic cluster of MEMBRANES; DESALINATION; ULTRAFILTRATION. Wales accounts for over 0.5% of global and over 16% of UK output in this cluster, with average scholarly impact higher than both the United Kingdom and the world. Researchers from Swansea University's School of Medicine have contributed significantly to Wales' output in INSULIN; TYPE 2 DIABETES MELLITUS; GLUCOSE. The average FWCI of Wales in this cluster is 1.8, which is considerably higher than the global FWCI of 1.3. Wales accounted for over 6% of UK publications in this cluster during 2014–2018.

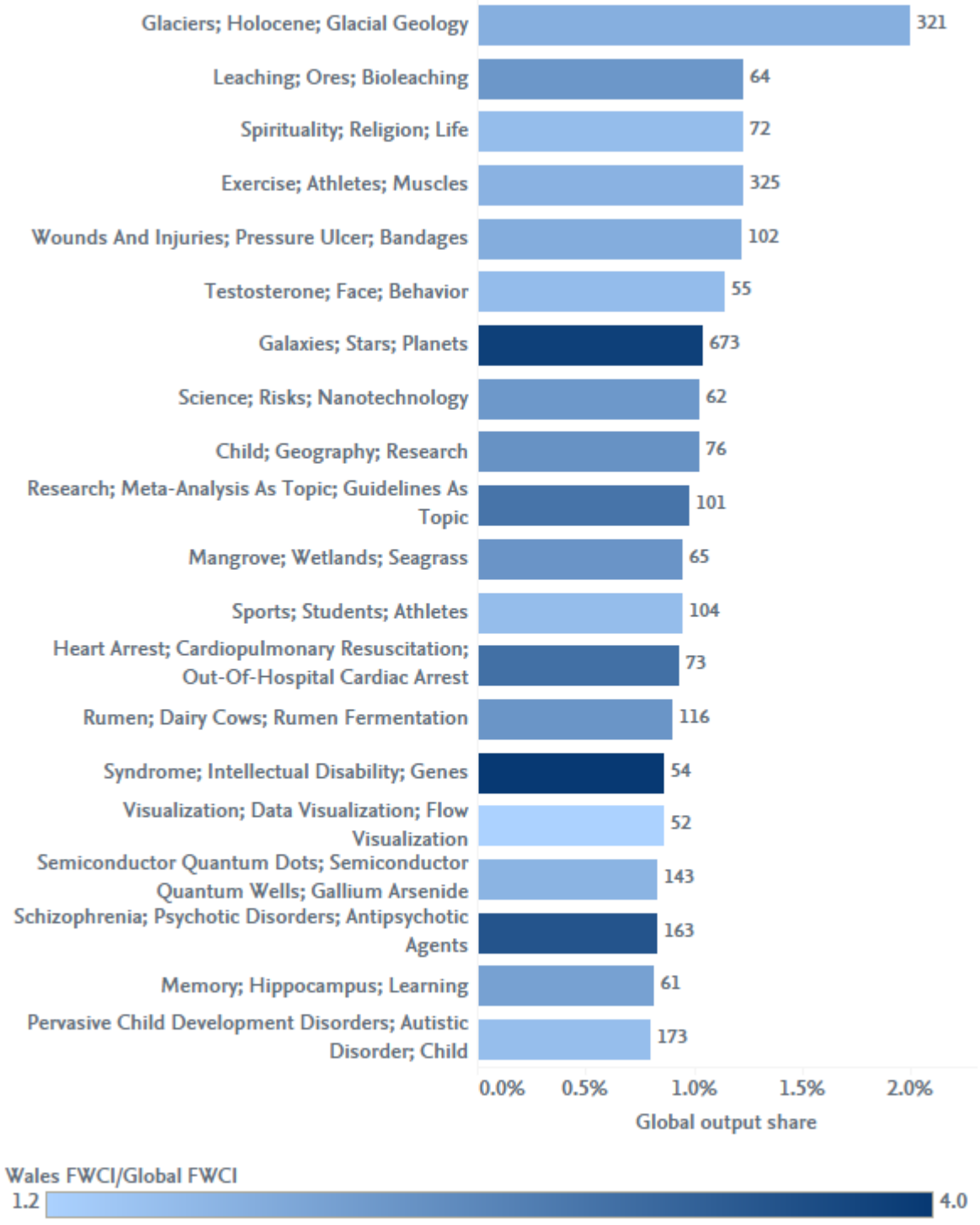


FIGURE 4-4
Wales' top 20 topic research clusters by global share, 2014–2018, where the Welsh FWCI was higher than both the global and UK FWCI. Number outside the bars indicates the Welsh output in that cluster between 2014–2018, and the colour indicates how much higher the Welsh FWCI is compared to the global FWCI in that topic.
Source: Scopus

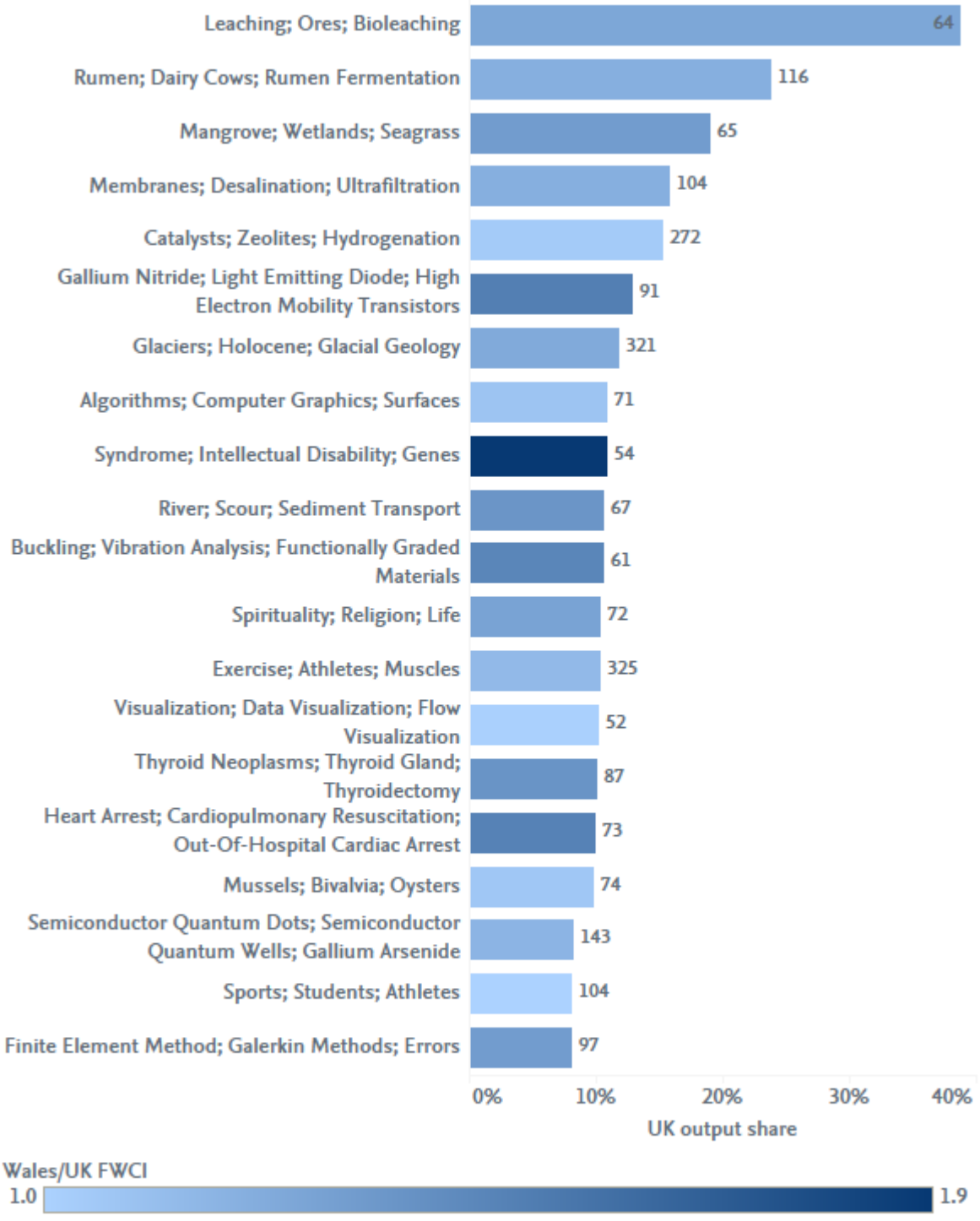


FIGURE 4-5
Wales' top 20 research topic clusters by UK share, 2014–2018, where the Welsh FWCI was higher than both the global and UK FWCIs. Number outside the bars indicates the Welsh output in that cluster between 2014–2018, and the colour indicates how much higher the Welsh FWCI is compared to the global FWCI in that topic.
Source: Scopus

Conclusion

Wales' research publications are of high quality, making the best of its small research base and scarce resources. Future investment in the research base will be essential to grow the capacity to ensure the future competitiveness of Welsh' research.

The purpose of the 'performance-based analysis of Wales' science and research base' was to provide an up-to-date, robust, comprehensive bibliometric analysis of research publications that profiles the strengths of the Welsh research and innovation base. This analysis builds upon and updates previous Elsevier reports from 2013 and 2016. It supports the Welsh Government's Science for Wales' strategic agenda, which is committed to evaluating Wales' research performance to improve Welsh research effectiveness. The analysis adds further support to the arguments presented in 'Wales: Protecting research and innovation after EU exit',[11] particularly with regard to the risk associated with the loss of EU funding and the consequential impact that this poses. The data in this update report provides evidence that can be used to leverage greater investment from Welsh and UK Governments but particularly UKRI and BEIS as part of the UK Governments commitment to 'levelling up' place in addition to greater contributions from industry.

Wales' research is highly productive, but its growth of publication output is lowest of all UK nations

Wales' GERD as a share of total GDP is the lowest of all UK nations, and its researcher base is the second smallest. Despite limited input in terms of researchers and expenditure, Wales' productivity per expenditure and per researcher outranks most, if not all of, the UK and global comparators. However, its growth in publication output remains amongst the lowest of all comparators, which has the potential to affect the leading position of Wales' efficiency and productivity in the longer term if sustained.

Quality of Wales' research is high

The scholarly impact of Wales has grown from an FWCI of 1.5 in 2010 to 1.8 in 2018, and its share of the global top 5% most highly cited publications is almost twice that of the global average. Amongst other factors, collaboration is likely to be one of the key success factors for strong research quality.

Almost three quarters of Wales' research output is based on international and within-UK collaboration

The FWCI of Wales' international co-authored publications (2.4) is the highest of all UK nations, and Wales is deeply embedded in the UK research system. Its

[11] https://gov.wales/wales-protecting-research-and-innovation-after-eu-exit

share of within-UK collaborations is more than twice those of Scotland and Northern Ireland, showing the external focus of its research.

Academic–corporate ties are strong but need to be strengthened to remain competitive

A growing share of Wales' R&D expenditure comes from the business enterprise. Wales' share of academic–corporate co-authorship publications is more than twice the global average but less than the share for other UK nations. However, the impact of these publications is the highest for all UK nations.

Wales' researchers are highly mobile and have their highest productivity and impact when the EU is their destination

Wales, as a small research nation, benefits greatly from mobility and exchange with EU countries. In this context, Brexit may pose significant issues for Wales' research performance.

Appendix A

Glossary of terms

Academic–corporate collaboration is defined as a publication in which at least one author is affiliated with a corporation and at least one author is affiliated with an academic institution.

Author refers to any individual listed in the author by-line of a Scopus-indexed publication.

Citation is a formal reference to earlier work made in an article or patent, frequently to journal publications. A citation is used to credit the originator of an idea or finding. The number of citations received by a publication or patent from subsequently published articles is a proxy for the influence or impact of the publication. In this report, 'citations' refer to citations by any Scopus-indexed publications, whereas citations made by other types of documents (e.g., patents, clinical guidelines) specifically reference the type of document that the citation was made in (e.g., as 'patent citations' or citations in clinical guidelines).

Collaboration (i.e., research collaboration) is defined as publications resulting from the efforts of two or more authors. Collaboration can be further categorised into the following types:

- International collaboration—affiliations listed by authors include institutions from two or more countries
- National collaboration—affiliations listed by authors include least two different institutions and all institutions are from the same country
- Institutional collaboration—all authors are affiliated with the same institution

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.

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

where:

$V(t_0)$: start value

$V(t_n)$: finish value

$t_n - t_0$: number of years

Field-Weighted Citation Impact (FWCI) is an indicator of the citation impact of a publication. It is calculated by comparing the number of citations actually received by a publication with the number of citations expected for a publication of the same document type, publication year, and subject. An FWCI of more than 1.00 indicates that the entity's publications have been cited more than would be expected based on the global average for similar publications; for example, 2.11 means 111% more than the world average. An FWCI of less than 1.00 indicates that the entity's publications have been cited less than would be expected based on the global average for similar publications; for example, 0.87 means 13% less than the world average.

In general, the FWCI is defined as:

$$FWCI = \frac{C_i}{E_i}$$

with

C_i= citations received by publication i

E_i= expected number of citations received by all similar publications in the publication year plus following 3 years

When a similar publication is allocated to more than one subject, the harmonic mean is used to calculate E_i.

To calculate mean FWCI for the publication set, we use the following formula:

$$\overline{FWCI} = \frac{1}{N}\sum_{i=1}^{N}\frac{C_i}{E_i}$$

Where N = the number of Scopus-indexed publications in the publication set.

The FWCI is 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 ages (e.g., older documents are expected to have accrued more citations than more recently published documents), document types (e.g., reviews typically attract more citations than research articles), as

well as subjects (e.g., publications in Medicine accrue citations more quickly than publications in Mathematics. The FWCI is one of the most sophisticated indicators in the modern bibliometric toolkit.[12]

The FWCI uses an un-weighted variable 5-year window. The mean FWCI value for 2012 publications, for example, is calculated for documents published in 2012 using their citations in 2012–2017. For recent output with less than five years since publication, all citations available at the date of data extraction are used in the calculation. For instance, if an article was published in 2016, and the data were extracted in 2018, the article's FWCI is calculated using the article's 2016–2018 citations.

Full-time equivalent (FTE) is a unit that indicates the workload of a person (based on number of hours worked per week) in a way that makes workloads comparable across various contexts. FTE of R&D personnel is defined as the ratio of working hours actually spent on R&D during a specific reference period (usually a calendar year) divided by the total number of hours conventionally worked in the same period by an individual or by a group. In other words, one FTE may be thought of as one person-year. Thus, a person who normally spends 30% of his or her time on R&D and the rest on other activities (such as teaching, university administration, and student counselling) should be considered as 0.3 FTE. Similarly, if a full-time R&D worker is employed at an R&D unit for only six months, this results in an FTE of 0.5. Therefore, FTE is measured by combining two variables: actual involvement in R&D activities and formal engagement on the basis of normative/statutory working hours. FTE is considered to be a true measure of the volume of R&D and also the main R&D personnel statistic for international comparisons.[13]

Gross domestic expenditure on research and development (GERD) is the total intramural expenditure on R&D performed in the national territory during a given period. GERD is calculated as the total domestic intramural expenditure on R&D during a given year divided by the GDP (i.e., the sum of gross value added by all resident producers in the economy, including distributive trades and transport, plus any product taxes and minus any subsidies not included in the value of the products) and multiplied by 100. GERD can be split further into BERD (Expenditure on R&D in the business enterprise sector), HERD (Expenditure on R&D in the higher education sector) and GOVERD (Government intramural expenditure on R&D).

Gross domestic product (GDP) is an aggregate measure of production equal to the sum of the gross values added of all resident institutional units engaged in production (plus any taxes, and minus any subsidies, on products not included in the value of their outputs). The sum of the final uses of goods and services (all uses except intermediate consumption) measured in purchasers' prices, less the value

[12] Purkayastha, A., Palmaro, E., Falk-Krzesinski, H.J., and Baas, J. (2019). Comparison of two article-level, field-independent citation metrics: Field-Weighted Citation Impact (FWCI) and Relative Citation Ratio (RCR). *Journal of Informetrics, 13*(2), 635–642, https://doi.org/10.1016/j.joi.2019.03.012.

[13] Source of Definition: OECD. (2015). Frascati manual 2015: Guidelines for collecting and reporting data on research and experimental development.

of imports of goods and services, or the sum of primary incomes distributed by resident producer units.

Hypercollaboration: While no consensus definition exists on the number of co-authors required to constitute 'hypercollaborative' co-authorship, numbers in the hundreds or thousands seem worthy of the term. The publication with the highest number of authors reported results from the Reduction of Atherothrombosis for Continued Health (REACH) Registry and was published in 2016 with 5,567 authors.[14] As an indication of the frequency of such hypercollaborative publications, it is noteworthy that while the number of publications with more than 3,000 authors was 76 in 2012 and 52 in 2011, these were outlier years, and in all other years from 2008 to 2017, the number of publications with more than 3,000 authors never exceeded 5. Hypercollaborative co-authorship may be a consequence of the rise of so-called 'Big Science'—a term used to describe research that requires major capital investment.[15]

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

International collaboration: (i.e., research collaboration)—see Collaboration.

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

Purchasing power parity (PPP) is the rates of currency conversion that equalise the purchasing power of different currencies by eliminating the difference in price levels between countries.

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

Research & development (R&D) is any systematic creative activity undertaken in order to increase the stock of knowledge, including knowledge of humanity, culture, and society, and the use of this knowledge to devise new applications. R&D includes fundamental research, applied research in such fields as agriculture, medicine, and industrial chemistry, and experimental development work leading to new devices, products, or processes.

Top 5% percentile publications are those among the top 5% based on FWCI of all articles published and cited in a given period. An institution's number or share of highly cited articles is treated as

[14] Eisen, A. et al. (2016). Angina and future cardiovascular events in stable patients with coronary artery disease: Insights from the Reduction of Atherothrombosis for Continued Health (REACH) Registry. *Journal of American Heart Association, 5* (10), e004080.

[15] Weinberg, A.M. (1961). Impact of large-scale science on the United States. *Science, 134*(3473), 161–164.

indicative of the excellence of their research. In this report, we present data on the top 5% cited articles.

Appendix B

Data sources and abbreviations

The **Organisation for Economic Co-operation and Development (OECD)** is an international economic organisation founded in 1961 and representing 34 member countries.[16] The OECD collects internationally comparable data on R&D, and the data are available in the Main Science and Technology Indicators database.[17] A useful history of the development of the OECD's R&D statistics is available.[18] Data are presented for the most recent five years for which data are available, though some countries may lack data for certain years. Where applicable, missing values were estimated using established statistical methods. Financial data are given in constant USD at current prices and corrected for purchasing power parity (PPP), allowing comparability over time and between countries. Full-time equivalent (FTE) counts are used for all human capital data in this report. The OECD's Main Science and Technology Indicators is a biannual publication that provides a set of indicators that reflect the level and structure of the efforts undertaken by OECD Member countries and nine non-member economies in the field of science and technology. The indicators cover the resources devoted to research and development, patent families, technology balance of payments, and international trade in R&D-intensive industries.

Scopus is Elsevier's abstract and citation database of peer-reviewed literature, covering 77.3 million documents published in over 39,000 journals, book series, and conference proceedings by some 5,000 publishers.

Scopus coverage is multi-lingual and global: approximately 46% of titles in Scopus are published in languages other than English (or published in both English and another language). In addition, more than half of Scopus content originates from outside North America, representing many countries in Europe, Latin America, Africa, and the Asia-Pacific region.

Scopus coverage is also inclusive across all major research fields, with 13,300 titles in PHYSICAL SCIENCE, 14,500 in HEALTH SCIENCE, 7,300 in LIFE SCIENCE, and 12,500 in SOCIAL SCIENCE (the latter including some 4,000 HUMANITIES AND THE ARTS titles). Titles that are covered are predominantly serial publications (journals, trade journals, book series, and conference material), but considerable numbers of

[16] OECD; www.oecd.org

[17] MSTI 2013/1; www.oecd.org/sti/msti

[18] Godin, B. (2008). The culture of numbers: Origins and development of statistics on science, technology and innovation. Project on the History and Sociology of S&T Statistics, Working Paper No. 40, Canadian Science and Innovation Indicators Consortium.

conference papers are also covered from stand-alone proceedings volumes (a major dissemination mechanism, particularly in COMPUTER AND INFORMATION SCIENCES).

For this report, a static version of the Scopus database covering the period 1996–2019 inclusive was aggregated.

The **Office for National Statistics (ONS)** is the national statistical institute for the United Kingdom. It is responsible for collecting and publishing statistics related to the economy, population, and society at national, regional, and local levels, and conducts the census in England and Wales every 10 years. The ONS collects data on UK GERD and related indicators and the data are available in the Datasets and Reference Tables database (www.ons.gov.uk/ons/datasets-and-tables/index.html).

United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics (UIS) is the United Nations depository for cross-nationally comparable statistics on education, science and technology, culture, and communication. The UIS database[19] provides country profiles, indicators, and data series in UNESCO's fields of competence, tools to build statistical tables, related documentation, and metadata.

Abbreviations used for countries in this report

Standard ISO 3-character country codes are used throughout for visual clarity where required (except the United Kingdom). EU-27 refers to all 27 current EU Member States.

ISO 3	Country name	Region
WAL	Wales	United Kingdom
NIR	England	United Kingdom
ENG	Northern Ireland	United Kingdom
SCO	Scotland	United Kingdom
AUT	Austria	Europe
DEU	Germany	Europe
DNK	Denmark	Europe
EST	Estonia	Europe
FRA	France	Europe
IRL	Ireland	Europe

[19] http://data.uis.unesco.org/

UK	United Kingdom	
CHN	China	World
JPN	Japan	World
NZL	New Zealand	World
USA	United States	World
ZAF	South Africa	World

TABLE 6-1
ISO 3 codes used throughout the report.
Source: United Nations Statistics Division, https://unstats.un.org/unsd/methodology/m49/

Appendix C

Methodology

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[20] gives a good overview of this field. It is based on the pioneering work of Derek de Solla Price (1978),[21] Eugene Garfield (1979),[22] and Francis Narin (1976)[23] in the USA; Christopher Freeman, Ben Martin, and John Irvine in the United Kingdom (1981, 1987);[24] and researchers 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 that 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 Cardiff University and one author from Swansea University, then that paper counts as one publication towards both the publication count of Cardiff University and the publication count of Swansea University. Total counts for each institution or country are the unique count of publications. Hyper-authored publications, defined as publications with more than 100 authors were included in the analysis.

[20] Moed H., Glänzel W., & Schmoch U. (2004). *Handbook of quantitative science and technology research*. Kluwer.

[21] de Solla Price, D.J. (1977–1978). Foreword. In *Essays of an Information Scientist* (Vol. 3, pp. v–ix).

[22] Garfield, E. (1979). Is citation analysis a legitimate evaluation tool? *Scientometrics, 1*(4), 359–375.

[23] 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.

[24] Irvine, J., Martin, B. R., Abraham, J. & Peacock, T. (1987). Assessing basic research: Reappraisal and update of an evaluation of fourradio astronomy observatories. *Research Policy, 16*(2-4), 213–227.

Measuring collaboration

Publications with two or more authors can be viewed as collaborations. Collaboration resulting in research publications can be a useful measure to understand with whom researchers are working to generate publications. Collaboration is assessed by analysing the author affiliations associated with each publication and categorising publications based on who has contributed as an author and what each author's affiliation is. We assess collaboration based on geography and sector. Geographic collaborations categorise publications into groups based on the location of author affiliations. For example, institutional collaboration is ascribed to publications where all the authors are affiliated with the same institution; national collaboration is ascribed to publications where authors are affiliated with at least two different institutions and all affiliations are within the same country; international collaboration is ascribed to publications where authors are affiliated with at least two different countries. Cross-sector collaborations categorise publications into groups based on the sector of author affiliations and categorises publications according to which sectors are represented among the author affiliations.

Measuring author mobility

The approach presented here uses Scopus author profile data to derive a history of active Welsh authors. Based on the affiliations recorded in each author's published articles over time, authors are assigned to a mobility class defined by the type and duration of observed moves.

How are individual researchers unambiguously identified in Scopus?

Scopus uses a sophisticated author-matching algorithm to precisely identify articles by the same author. The Scopus Author Identifier gives each author a unique ID and groups together all the documents published by that author, matching alternate spellings and variations of the author's last name and distinguishing between authors with the same surname by differentiating on data elements associated with the article (such as affiliation, subject area, co-authors, and so on). This is enriched with manual, author-supplied feedback, both directly through Scopus and via Scopus' direct links with ORCID (Open Researcher & Contributor ID).[25]

Who is a 'Welsh author'?

To define the Welsh population for study, Welsh authors are identified as those that have listed a Welsh affiliation on at least one publication (as defined in the section 'Publication types used in the analysis') published across the sources included in Scopus during the period 1996–2019.

Who is an 'actively publishing author'?

[25] https://orcid.org/

An actively publishing author is defined as a Welsh author as defined above, who has published either

- 10 or more papers from 1996 onwards and at least 1 paper in 2014–2018, or
- those who produced 4 or more papers in 2014–2018.

This 'productivity filter' is implemented because the 56,726 Welsh authors identified include a large proportion with relatively few articles over the entire 9-year period of analysis. Applying the productivity filter enables the removal of these authors with relatively few articles, who are not likely to represent career researchers but rather individuals who have left the research system. After applying the productivity filter, a set of 19,716 actively publishing Welsh authors was defined and formed the basis of further analysis.

How are mobility classes defined and measured?

The measurement of international researcher mobility by co-authorship in the published literature is complicated by the difficulties involved in teasing out long-term mobility (resulting from attainment of faculty positions, for example) from short-term mobility (such as doctoral research visits, sabbaticals, secondments), which might be deemed instead to reflect a form of collaboration. In this study, active researchers are broadly divided into two groups:

▸ Non-mobile: actively publishing Welsh authors whose Scopus author data for the period 1996–2019 indicate that they have not published outside Wales

▸ Mobile: actively publishing Welsh authors whose Scopus author data for the period 1996–2019 indicate that they have published outside Wales

Mobile researchers are further subdivided based on the length of their stay (permanent, long stay, short stay) and the direction of their migration (inflow, outflow).

▸ Inflow researchers: refers to those researchers whose publication history indicates that the author first published outside Wales and then published in Wales. Inflow researchers are further categorised according to length of stay within Wales:

- Permanent stay—authors who first published outside Wales and then published in Wales for at least 2 years and further remained in Wales
- Long stay—authors who first published outside Wales, then published in Wales, and then at least 2 years after the first publication in Wales, published outside Wales
- Short stay—authors who first published outside Wales, then published in Wales, and then, at less than 2 years after the first publication in Wales, published outside Wales again

▸ Outflow researchers: refers to those researchers whose publication history indicates that the author first published in Wales and then published outside Wales. Outgoing researchers are further categorised according to length of stay outside of Wales:

- Permanent leave—authors who first published in Wales and then published outside Wales for at least 2 years and remained outside Wales
- Long leave—authors who first published in Wales, then published outside Wales, and then at least 2 years after the first publication outside Wales, published in Wales again
- Short leave—authors who first published in Wales, then published outside Wales, and then at less than 2 years after the first publication outside Wales, published in Wales again

How do we characterise the mobility groups?

To better understand each mobility group, three aggregate indicators are calculated for each group to provide insight with regard to the group's scholarly productivity, impact, and relative seniority. Respectively, these indicators are

- the average relative productivity of authors in the group,
- the average FWCI of the publications by authors in the group, and
- the average relative seniority of authors in the group.

All mobility indicators are calculated based on active researchers only. Relative productivity is the average number of articles per year since the first appearance of each researcher as an author during the period <start date>–<end date>, relative to all Welsh researchers in the same period. The FWCI is a measure of publication impact based on citations and normalised against the average for publications of a similar age, type, and subject. We use the count of years since the first appearance of each researcher as an author during the period 1996–2019 to calculate a proxy of seniority. The average seniority is the average number of years since the first publication for all researchers for the country. Relative seniority compares the average seniority of authors in a group (e.g., the sedentary group) relative to all Welsh researchers in the same period. For example, if relative seniority for a group is 1.2, this indicates the group's average seniority is 0.2 times greater than the average for the country (i.e., the group is more senior on average). All three indicators are calculated for each author's entire output in the period (i.e., not just those articles listing a Welsh address for that author).

Scopus author profiles

Scopus uses a sophisticated author-matching algorithm to precisely identify articles by the same author. The Scopus Author Identifier gives each author a unique ID and groups together all the documents published by that author, matching alternate spellings and variations of the author's last name and distinguishing between authors with the same surname by differentiating on data elements

associated with the article (such as affiliation, subject area, co-authors, and so on). This is enriched with manual, author-supplied feedback, both directly through Scopus and via Scopus' direct links with ORCID (Open Researcher & Contributor ID). Gender is not captured in Scopus author profiles.

Appendix D

List of topic clusters where the Welsh FWCI is greater than the UK and world FWCIs during 2014–2018

Topic clusters ranked by Prominence Score. Wales output refers to the total number of publications by Welsh authors in the topic cluster, Wales FWCI refers to the FWCI these publications account for. UK (Global) output share displays the share of Wales' publication within the UK (global) output in this topic cluster. Wales/UK (Global) FWCI normalized the FWCI of Welsh publications in this topic cluster by dividing it by UK (global) FWCI in this cluster. Only topic clusters with an FWCI greater than UK and world are s shown. FWCI values may be influenced by small publication output.

Topic Custer Name	2019 Prominence Score	Wales output	Wales FWCI	UK output share	Wales/UK FWCI	Global output share
Zeolite; Catalyst; Cerium Oxide	99.60	272	1.35	15.3%	1.06	0.5%
Immunotherapy; T Lymphocyte; Checkpoint	99.53	282	4.72	8.0%	1.31	0.6%
Microrna; Long Noncoding RNA; Exosome	99.46	50	6.27	3.4%	1.99	0.1%
Smart Grid; Electric Vehicle; Microgrid	99.40	180	2.75	5.7%	1.48	0.3%
Galaxy; Planet; Black Hole	99.06	673	4.77	5.0%	2.46	1.0%
Entrepreneurship; Innovation; Firm	99.00	165	2.08	3.2%	1.01	0.4%
Bioenergy; Sewage; Anerobic Digestion	98.86	94	1.56	7.6%	1.06	0.3%
Exercise; Sedentary Lifestyle; Childhood Obesity	98.80	182	6.11	3.1%	2.59	0.4%
Intestine Flora; Microbial Community; Probiotic Agent	98.73	56	7.50	4.8%	1.98	0.2%
Wireless Sensor Network; Internet of Thing; Routing Protocol	98.06	58	2.22	2.7%	1.13	0.1%
Antibiotic Resistance; Methicillin Resistant Staphylococcus Aureus; Urinary Tract Infection	97.99	143	2.28	5.0%	1.23	0.4%

Sliding Mode Control; Nonlinear System; Model Predictive Control	97.66	99	3.16	4.8%	1.83	0.2%
Austenite; Steel; Alloy	97.46	87	1.53	4.9%	1.04	0.2%
Desalination; Membrane; Distillation	97.39	104	2.12	15.9%	1.22	0.5%
Hyperspectral Imagery; Lidar; Hyperspectral	97.32	71	2.52	5.2%	1.1	0.2%
Ruthenium; Ligand; Carbon Monoxide	97.05	52	1.33	5.4%	1.04	0.3%
Drug Delivery System; Tablet; Chitosan	96.79	34	1.95	2.0%	1.13	0.1%
Mesenchymal Stem Cell; Stem Cell; Induced Pluripotent Stem Cell	96.32	35	2.31	2.0%	1.34	0.1%
Cloud Computing; Cloud; Virtual Machine	96.12	64	1.98	3.2%	1.03	0.2%
Building; Thermal Comfort; Air Conditioning	95.92	97	1.27	5.2%	1.08	0.4%
Rankine Cycle; Exergy; Ejector	95.85	20	1.44	1.9%	1.03	0.1%
Biodiversity; Trait; Savanna	95.78	109	2.88	4.7%	1.25	0.5%
Bullying; Parenting; School	95.38	146	1.64	6.6%	1.05	0.6%
Black Hole; Gravitation; Space-time	95.25	285	5.28	6.7%	2.77	0.7%
Chromatin; Nucleosome; Epigenetic	95.05	24	2.04	1.6%	1.05	0.1%
Parkinson Disease; Brain Depth Stimulation; Alpha Synuclein	94.98	82	2.35	3.6%	1.19	0.4%
Sequencing; RNA Sequence Analyse; Genomic	94.91	39	12.61	3.1%	3.14	0.3%
Slow Wave Sleep; Obstructive Sleep Apnea; Sleep Initiation and Maintenance Disorder	94.85	71	1.61	4.1%	1.07	0.3%
Malware; Attack; Computer Security	94.65	56	2.07	3.2%	1.17	0.2%
Zika Virus; Dengue; Zika Virus Infection	94.51	15	3.26	0.8%	1.26	0.1%
Palliative Care; Childhood Cancer Survivor; Intensive Care Unit	94.31	138	2.13	4.5%	1.44	0.5%

Autism; Autistic Disorder; Mental Deficiency	94.24	173	1.87	5.8%	1.19	0.8%
Dental Prosthesis; Tooth; Dentine	94.04	97	1.63	5.2%	1.34	0.2%
Molecular Dynamic; Intrinsically Disordered Protein; Protein Folding	93.78	50	2.17	3.2%	1.07	0.3%
Microfluidic; Lab-on-A-chip Device; Droplet	93.71	27	1.65	2.8%	1.3	0.1%
Extreme Learning Machine; Support Vector Machine; Feature Selection	93.37	42	2.07	3.1%	1.05	0.2%
Salmonella; Listeria Monocytogene; Campylobacter	93.24	83	1.90	4.2%	1.31	0.3%
Notch; Sonic Hedgehog Protein; Catenin	93.17	34	1.56	2.0%	1.18	0.2%
Connectivity; Magnetic Resonance Imaging; Connectome	93.11	66	2.09	3.2%	1.07	0.3%
Air Quality; Particulate Matter; Air Pollutant	92.84	17	10.58	1.8%	3.5	0.2%
Antenna; Microstrip Antenna; Antenna Array	92.64	69	1.10	3.6%	1.02	0.2%
Atrial Fibrillation; Implantable Cardioverter Defibrillator; Catheter Ablation	92.57	53	1.93	1.7%	1.07	0.2%
Scoliosis; Low Back Pain; Spine	92.50	58	14.59	2.9%	9.01	0.2%
Solid Phase Extraction; Solid Phase Microextraction; Liquid Phase Microextraction	92.44	2	5.58	0.9%	3.96	0.0%
Starch; Bread; Rice	92.37	12	1.73	2.6%	1.24	0.1%
Strength Training; Soccer; Player	92.30	325	1.62	10.4%	1.16	1.2%
Reinforced Concrete; Column; Concrete	92.03	13	1.95	1.0%	1.96	0.0%
Community Detection; Online Social Network; Complex Network	91.97	21	2.10	1.5%	1.12	0.1%
Schizophrenia; Psychotic Disorder; Neuroleptic Agent	91.83	163	3.69	5.3%	2.16	0.8%
Autophagy; Phosphatidylinositol 3-kinase; Rapamycin	91.70	25	4.81	3.2%	2.25	0.2%
Hydroxymethylglutaryl-CoA Reductase Inhibitor; Cholesterol; Familial Hypercholesterolemia	91.50	43	6.67	2.7%	1.84	0.2%

Protein Protein Interaction; Gene Regulatory Network; Synthetic Biology	91.43	43	1.82	2.7%	1.1	0.3%
Human Influenza; Orthomyxovirida; Influenza A Virus	91.10	36	1.79	1.9%	1.06	0.2%
Ice Cover; Permafrost; Antarctica	90.90	321	2.35	11.8%	1.25	2.0%
Oil Well Flooding; Hydraulic Fracturing; Oil and Gas Field	90.56	29	1.71	2.4%	1.14	0.1%
Prostatic Neoplasm; Prostate; Prostatectomy	90.43	108	12.26	7.0%	3.58	0.6%
Colorectal Neoplasm; Rectum Tumor; Colon Tumor	90.36	134	1.90	6.5%	1.08	0.6%
Leptin; Adiponectin; Ghrelin	90.29	17	1.89	2.1%	1.09	0.1%
Quorum Sensing; Biofilm; Pseudomona Aeruginosa	90.09	13	1.47	1.0%	1.06	0.1%
Atopic Dermatitis; Food Allergy; Allergen	89.36	47	2.51	3.1%	1.15	0.3%
Thermoelectric; Thermoelectricity; Thermoelectric Equipment	88.89	34	1.56	10.7%	1.11	0.3%
Acute Myeloid Leukemia; Acute Lymphoblastic Leukemia; Chronic Myeloid Leukemia	88.76	65	4.13	5.4%	1.69	0.4%
Rheumatoid Arthritis; Pustulosis Palmoplantari; Psoriatic Arthritis	88.69	93	2.88	4.5%	1.25	0.5%
Venous Thromboembolism; Anticoagulant Agent; Lung Embolism	88.29	105	2.26	5.1%	1.22	0.4%
Glaucoma; Eye; Phakic Intraocular Lens	88.15	126	2.13	5.9%	1.35	0.4%
Pancreatic Neoplasm; Pancreatitis; Bile Duct Carcinoma	87.68	48	3.41	4.2%	1.68	0.2%
Neuralgia; Fibromyalgia; Pain	87.55	49	2.06	2.9%	1.24	0.3%
News; Journalism; Social Medium	87.15	67	2.44	4.0%	1.29	0.4%
Permanent Magnet; Induction Motor; Permanent Magnet Synchronous Motor	86.95	104	2.05	6.6%	1.26	0.3%
Photonic Crystal; Silicon Photonic; Waveguide	86.68	33	1.58	2.9%	1.59	0.2%
Endometriosis; Ovarian Neoplasm; Endometrial Neoplasm	86.48	44	2.62	3.1%	1.53	0.2%

Bird; Songbird; Seabird	86.35	63	1.33	2.6%	1.05	0.3%
Asphalt; Pavement; Asphalt Pavement	86.28	3	1.77	0.6%	1.49	0.0%
Genome-wide Association Study; Single nucleotide Polymorphism; Non Insulin Dependent Diabete Mellitu	86.21	45	8.03	3.7%	2.68	0.5%
Candida; Candida Albican; Aspergillosis	86.08	64	2.49	6.3%	1.2	0.4%
Intimate Partner Violence; Domestic Violence; Child Abuse	85.94	56	3.35	4.8%	2.08	0.5%
Bipolar Disorder; Involutional Depression; Antidepressant	85.54	58	2.62	4.6%	1.48	0.5%
Posttraumatic Stress Disorder; Refugee; Veteran	85.14	51	1.78	3.8%	1.35	0.4%
Wind Turbine; Asynchronous Generator; Turbine	84.94	91	1.46	6.6%	1.08	0.5%
Frailty; Sarcopenium; Frail Elderly	84.87	25	3.31	2.6%	1.34	0.3%
Systematic Review; Evidence-based Practice; Meta-analyse	84.67	101	4.49	4.4%	1.35	1.0%
Willingness to Pay; Contingent Valuation; Discrete Choice Experiment	84.61	35	3.15	4.4%	1.23	0.5%
Aluminum Gallium Nitride; Light Emitting Diode; Gallium Nitride	84.54	91	1.67	12.9%	1.5	0.5%
Metabolomic; Metabolome; Metabolite	84.20	19	2.23	3.1%	1.06	0.3%
Essential Oil; Thymoquinone; Nigellum Sativa	84.07	4	1.79	2.3%	1.23	0.0%
Thyroid Neoplasm; Thyroid Gland; Thyroid Papillary Carcinoma	84.00	87	2.33	10.2%	1.38	0.4%
Systemic Lupus Erythematosus; Systemic Sclerodermum; Antiphospholipid Syndrome	83.87	25	2.91	2.1%	1.5	0.2%
Cannabis; Alcohol Consumption; Substance Abuse	83.80	91	1.35	5.7%	1.04	0.6%
Galectin 3; Polysaccharide; Glycosylation	83.47	3	1.65	0.6%	1.13	0.0%
Narcotic Analgesic Agent; Opiate Addiction; Buprenorphine	83.33	18	1.83	3.2%	1.37	0.2%
Plasma Jet; Atmospheric Pressure; Discharge	83.00	5	1.56	1.1%	1.04	0.0%

Buckling; Functionally Graded Material; Free Vibration	82.93	61	2.39	10.7%	1.46	0.4%
Discontinuous Galerkin Method; Isogeometric Analyse; Discontinuous Galerkin	82.60	97	1.98	8.1%	1.33	0.5%
Plant Growth-promoting Rhizobacterium; Solubilization; Microbial Community	82.20	6	2.51	2.1%	1.26	0.1%
Biodiesel; Bioenergy; Panicum	81.99	46	1.70	10.7%	1.11	0.6%
Helicobacter Pylorus; Gastroesophageal Reflux; Proton Pump Inhibitor	81.79	34	1.99	3.6%	1.1	0.2%
Russia; Kazakhstan; Education	80.99	2	2.31	3.2%	1.63	0.0%
Foam; Energy Absorption; Aluminum Foam	80.92	19	2.13	3.4%	1.28	0.2%
Photoacoustic Effect; Near-infrared Spectroscopy; Optical Coherence Tomography	80.86	7	3.86	0.8%	2.69	0.1%
Pharmacist; Adverse Drug Reaction; Prescription	80.66	53	1.72	3.6%	1.26	0.4%
Fish; Salmon; Salmonidae	80.59	51	1.50	4.9%	1.02	0.4%
Quantum Dot; Gallium Arsenide; Indium Arsenide	80.52	143	1.21	8.3%	1.19	0.8%
AMP-activated Protein Kinase; Peroxisome Proliferator-activated Receptor; Lipid Droplet	80.39	6	2.56	1.3%	1.54	0.1%
Smart City; Electronic Government; Open Government	80.25	16	2.63	2.5%	1.33	0.2%
Polysaccharide; Agaricales; Ganodermum Lucida	80.19	16	1.53	11.9%	1.09	0.2%
Wolf; Elephant; Carnivore	79.99	64	1.49	4.5%	1.09	0.5%
Fabry Disease; Sphingolipid; Gaucher Disease	79.85	10	1.81	1.4%	1.12	0.1%
Internal Wave; Eddy; Estuary	79.38	66	2.02	5.2%	1.35	0.6%
Prenatal Care; Maternal Welfare; Health Auxiliary	79.18	32	18.62	1.7%	8.29	0.3%
Landslide; Debris Flow; Rockfall	79.05	14	1.73	2.8%	1.09	0.2%
Pneumonia; Streptococcus Pneumonia; Pneumococcal Vaccine	78.92	78	1.84	5.3%	1.14	0.6%

Physical Education; Sport; Mentoring	78.85	104	1.54	8.2%	1.02	1.0%
Anthozoa; Coral Reef; Porifera	78.51	44	2.12	7.1%	1.15	0.6%
Potential Energy Surface; Quantum Chemistry; Potential Energy	78.45	30	1.90	6.6%	1.12	0.5%
Drosophila Suzukii; Drosophila; Drosophila Melanogaster	77.84	15	1.71	1.6%	1.03	0.2%
Ferrite; Magnetic Property; Cobalt Ferrite	77.71	9	1.32	5.1%	1.14	0.1%
Hydraulic Fracturing; Natural Gas; Cement	77.24	14	1.81	1.6%	1.48	0.1%
Organic Food; Farmer; Urban Agriculture	77.18	51	1.96	6.7%	1.17	0.6%
Liquid Crystal; Nematic Liquid Crystal; Nematic	77.04	2	1.72	0.4%	1.36	0.0%
Fault Diagnose; Rolling Bearing; Bearing	76.84	7	2.05	2.0%	1.63	0.1%
Rumen; Silage; Rumen Fermentation	76.57	116	1.93	23.9%	1.22	0.9%
Microcystin; Cyanobacterium; Diatom	76.44	18	2.95	4.2%	2.02	0.2%
Extinction; Fear; Memory	76.31	61	2.31	6.9%	1.68	0.8%
Curcumin; Ginger; Curcumum	75.97	5	2.10	4.1%	1.23	0.1%
Angular Momentum; Optical Tweezer; Beam	75.70	19	2.57	2.3%	1.88	0.2%
Carborane; Boron; Hydrogen Generation	75.57	28	1.60	8.4%	1.27	0.6%
Seaweed; Fucoidan; Red Alga	75.50	29	1.93	10.7%	1.04	0.4%
Natural Fiber; Biocomposite; Jute Fiber	75.44	5	3.85	3.1%	2.26	0.1%
Technology Assessment; Cost-benefit Analyse; Rare Disease	75.37	54	26.79	3.8%	9.56	0.7%
Adsorption; Adsorbent; Zeolite	75.10	11	1.52	4.3%	1.13	0.2%
Bose-einstein Condensate; Condensation (phase transition); Statistical Mechanic	74.90	6	3.01	0.6%	1.6	0.1%

Head and Neck Neoplasm; Mouth Neoplasm; Nasopharynx Carcinoma	74.70	31	1.29	4.2%	1.11	0.3%
Oncorhynchus Mykis; Oreochromi Niloticu; Carp	74.30	7	3.20	1.8%	1.95	0.1%
Pelvic Organ Prolapse; Overactive Bladder; Prostate Hypertrophy	74.10	45	2.25	2.9%	1.78	0.3%
Genome; Draft; Genus	73.63	24	1.53	5.8%	1.16	0.2%
Health Literacy; Social Medium; Health Information	73.29	48	2.79	5.3%	1.65	0.6%
Anura; Lizard; Turtle	73.23	46	1.84	5.7%	1.55	0.4%
Mangrove; Wetland; Salt Marsh	72.96	65	2.51	19.1%	1.33	1.0%
Optogenetic; Microelectrode; Retinal Implant	72.89	3	2.57	0.7%	1.65	0.0%
Harvester; Energy Harvesting; Piezoelectricity	72.56	27	1.57	7.3%	1.07	0.4%
Omega 3 Fatty Acid; Docosahexaenoic Acid; Icosapentaenoic Acid	72.49	7	2.25	1.6%	1.13	0.1%
Bivalvia; Crassostrea; Oyster	72.42	74	1.47	9.9%	1.08	0.8%
Coating; Magnetra Sputtering; Nitriding	71.55	12	1.59	5.0%	1.64	0.1%
G-protein-coupled Receptor; Guanine nucleotide Binding Protein; Rhodopsin	71.08	4	1.90	0.9%	1.17	0.1%
Hydrate; Gas Hydrate; Methane	70.62	7	1.87	3.0%	1.46	0.1%
Mitochondrial Genome; Chloroplast Genome; Phylogeny	70.48	20	2.75	3.5%	1.16	0.3%
Point Cloud; Rendering; Computer Graphic	69.95	71	0.94	11.0%	1.1	0.5%
Antibody Conjugate; Single-domain Antibody; Bispecific Antibody	69.81	5	1.83	1.5%	1.29	0.1%
Social Capital; Self-rated Health; Social Class	69.28	22	5.06	2.2%	3.02	0.3%
Personality Disorder; Narcissism; Personality	69.21	33	2.87	4.8%	1.93	0.6%
Nitric Oxide; N(g),N(g) dimethylargiNiNe; Arginase	69.14	24	2.05	5.7%	1.47	0.4%

Segmentation; Deep Learning; Neural Network	69.01	19	2.82	5.1%	1.33	0.3%
Forensic Science; Microsatellite Repeat; Dermatoglyphic	68.81	8	2.90	1.1%	1.68	0.1%
River; Bedload; Flood	68.74	67	1.79	10.7%	1.37	0.8%
Migraine Disorder; Headache; Cluster Headache	68.61	5	62.08	0.9%	23.76	0.1%
Adult Respiratory Distress Syndrome; Artificial Ventilation; Noninvasive Ventilation	68.41	15	2.60	2.9%	1.27	0.2%
Radon; Radioisotope; Urania	68.34	4	0.92	0.6%	1.13	0.0%
Geography; Border; Feminism	68.14	76	2.35	4.6%	1.52	1.0%
Transfusion; Tranexamic Acid; Blood Transfusion	68.01	52	1.67	6.0%	1.04	0.5%
Carotenoid; Crocus; Retinol	67.74	6	2.32	3.1%	1.39	0.1%
Cardiopulmonary Resuscitation; Heart Arrest; Out of Hospital Cardiac Arrest	67.27	73	3.51	10.1%	1.48	0.9%
Schiff Base; Coordination Compound; Crystal Structure	67.20	6	0.83	2.7%	1.09	0.1%
Astrocyte; Glutamic Acid; Neuroglia	67.07	4	4.05	1.5%	1.97	0.1%
Folic Acid; Homocysteine; Cyanocobalamin	67.00	17	2.73	4.2%	1.93	0.2%
Harmonic Generation; Ionization; Laser Pulse	66.73	17	2.11	3.3%	2.17	0.2%
Unmanned Aerial Vehicle; Photogrammetry; Cultural Heritage	66.60	13	2.05	4.4%	1.01	0.2%
Anthropocene; Environmental Engineering; Nanotechnology	66.53	62	2.78	6.9%	1.46	1.0%
Replication; Reproducibility; Periodical	66.47	31	3.77	5.7%	1.32	0.8%
Urbanization; Land Use; Land Use Change	66.33	5	3.91	3.1%	2.53	0.1%
Fetal Alcohol Spectrum Disorder; Alcohol Consumption; Ethanol	66.27	9	9.25	2.7%	3.99	0.2%
Paraganglioma; Pheochromocytoma; Primary Hyperaldosteronism	65.73	26	2.63	3.5%	1.81	0.3%

Ankle; Diabetic Foot; Foot	65.66	65	1.53	5.4%	1.39	0.6%
Meshfree Method; Hydrodynamic; Material Point Method	64.99	18	2.51	5.4%	1.4	0.3%
DNA Barcoding; Barcoding; Genetically Modified	64.93	32	3.15	11.4%	1.34	0.7%
Fibroin; Silk; Elastin	64.86	1	2.20	0.5%	1.58	0.0%
Port; Container; Container Terminal	64.66	12	1.99	3.7%	1.65	0.2%
Crack; Stress Intensity Factor; Pipeline	64.59	36	1.97	5.6%	2.3	0.3%
Electric Fault Location; Power Line; Protection	64.32	17	0.88	5.9%	1.04	0.1%
Vortex-induced Vibration; Cable; Riser	62.92	7	1.21	1.1%	1.25	0.1%
Psychedelic Agent; Serotonin; Serotonin Transporter	62.65	33	2.35	8.1%	1.26	0.6%
Congenital Heart Disease; Congenital Heart Malformation; Patent Foramen Ovale	62.52	16	1.14	2.2%	1.03	0.1%
Dielectric Elastomer; Flapping; Wing	62.45	20	1.68	5.5%	1.3	0.3%
Breast Feeding; Necrotizing Enterocolitis; Human Milk	62.32	32	2.62	6.4%	1.48	0.5%
Epoxide Hydrolase; Acetylsalicylic Acid; Cyclooxygenase 2	62.18	16	1.79	5.3%	1.09	0.3%
Abdominal Aortic Aneurysm; Dissecting Aneurysm; Aneurysm	62.05	31	2.50	3.6%	1.75	0.3%
Stigma; Mental Health; Mental Patient	61.78	18	1.67	1.7%	1.02	0.3%
Nanopore; Nanofluidic; Translocation	61.71	12	3.32	5.2%	1.48	0.5%
Macroinvertebrate; Chironomidae; Diatom	61.45	7	1.87	2.6%	1.15	0.1%
Azobenzene; Diarylethene; Photochromism	61.31	2	3.13	2.1%	2.71	0.1%
Invasive Species; Biological Invasion; Introduced Species	61.18	14	2.54	3.8%	1.02	0.3%
Programming; Education Computing; Computer Science	61.11	27	1.98	5.5%	1.38	0.3%

Celiac Disease; Gluten; Gluten-free Diet	60.98	31	2.45	7.4%	1.32	0.7%
Vacuum Assisted Closure; Bandage; Wound and Injury	60.78	102	1.71	7.8%	1.33	1.2%
Attention Deficit Hyperactivity Disorder; Methylphenidate; Atomoxetine	60.58	27	1.89	4.4%	1.15	0.5%
Arterial Stiffness; Pulse Wave Analyse; Photoplethysmography	59.71	35	3.57	6.9%	2.46	0.5%
Hydrogen Sulphide; Fluorescent Dye; Sodium Bisulphide	59.57	4	2.07	2.7%	1.04	0.1%
Bile Acid and Salt; Sclerosing Cholangiti; Autoimmune Hepatitis	59.10	9	2.24	2.2%	1.35	0.2%
Savanna; Rangeland; Grazing	58.90	17	2.14	7.1%	1.14	0.4%
N Methyl Dextro Aspartic Acid Receptor; Synapse; AMPA Receptor	58.70	9	2.61	2.7%	2.14	0.2%
Vertigo; Benign Paroxysmal Positional Vertigo; Dizziness	58.63	18	1.29	4.1%	1.04	0.3%
Aerogel; Silica; Insulation	58.30	2	4.59	2.3%	2.78	0.1%
Industry 4.0; Cybe Physical System; Automation	58.23	11	11.60	5.8%	4.48	0.2%
Leaching; Bioleaching; Ore	58.17	64	1.57	38.8%	1.27	1.2%
Topology Optimization; Shape Optimization; Trusse	57.83	17	3.28	9.6%	2.08	0.4%
Thymosin; Involutional Depression; Depression	57.63	9	3.76	3.8%	1.19	0.3%
Peptide; Peptoid; Peptidylprolyl Isomerase	57.30	3	1.74	1.0%	1.4	0.1%
Weed; Herbicide; Weed Control	56.83	4	2.18	2.7%	1.57	0.1%
Attractiveness; Testosterone; Kinship	56.76	55	1.63	6.9%	1.19	1.1%
Terahertz; Terahertz Wave; Terahertz Spectroscopy	56.36	24	0.92	4.3%	1.14	0.3%
B Lymphocyte; Repertoire; Germinal Center	56.16	13	1.97	4.6%	1.39	0.4%
Turner Syndrome; Digeorge Syndrome; Copy number Variation	55.56	54	2.74	10.9%	1.91	0.9%

Postnatal Depression; Postpartum Period; Depression	55.42	40	2.23	9.1%	1.26	1.0%
Venom; Snake Bite; Snake Venom	55.35	31	1.45	14.2%	1.03	0.6%
Fullerene; Fullerene c60; Corannulene	55.15	5	0.85	4.8%	1.09	0.1%
Antitrust; Platform; Merger	54.75	3	1.43	0.5%	1.25	0.1%
Pigment; Painting; Glaze	54.42	6	1.92	1.4%	1.12	0.1%
White Spot Syndrome Virus; Shrimp; Litopenaeu Vannamei	54.28	13	2.39	7.3%	1.35	0.4%
Podocyte; Nephrotic Syndrome; Membranous Glomerulonephritis	54.22	11	2.20	3.0%	1.39	0.2%
Electroplating; Composite Coating; Coating	53.88	7	1.07	3.4%	1.28	0.1%
Parity; Symmetric; Time Symmetry	53.55	2	3.11	1.1%	1.91	0.1%
GRACE; Geodesy; Gravitation	53.28	25	1.82	11.7%	1.25	0.5%
Uric Acid; Gout; Hyperuricemia	53.21	6	2.00	2.0%	1.17	0.1%
Fractional Differential Equation; Boundary Value Problem; Positive Solution	53.01	1	1.24	1.9%	2.14	0.0%
Dyeing; Cotton Fabric; Textile	52.68	2	1.26	1.7%	1.55	0.0%
Public Administration; Governance; Co-production	52.28	36	2.00	4.9%	1.21	0.7%
Cryptosporidium; Giardium Intestinali; Cryptosporidiosis	51.81	36	1.43	15.2%	1.05	0.8%
Acne Vulgari; Hidradeniti Suppurativa; Rosacea	51.41	26	3.02	16.1%	1.47	0.8%
Mesothelioma; Asbestos; Silicosis	50.87	16	3.43	5.7%	2.4	0.4%
Hepatolenticular Degeneration; Zinc; Metallothionein	50.80	11	1.57	4.6%	1.21	0.3%
Helicene; Azulene; Chirality	50.47	4	3.27	4.0%	3.45	0.2%
Skin; Skin Aging; Ichthyosis	50.20	5	1.48	1.8%	1.37	0.1%

Library; Information Literacy; Librarian	50.07	12	0.97	2.6%	1.34	0.1%
Visualization; Data Visualization; Visual Analytic	49.53	52	1.03	10.2%	1.03	0.9%
Homogenization; Homogenization Method; Effective Property	48.86	29	1.49	22.7%	1.35	0.8%
Pemphigus; Bullous Pemphigoid; Lichen Planu	48.73	8	1.74	2.9%	1.47	0.2%
Oligochaeta; Collembolum; Vermicompost	48.53	8	1.56	5.8%	1.27	0.2%
Spirituality; Religion; Religiosity	47.59	72	2.00	10.4%	1.29	1.2%
Transposon; Retroelement; Endogenous Retrovirus	47.05	1	1.52	0.4%	1.06	0.0%
Lichen (disease); Lichen (organism); Bryophyte	46.99	4	1.17	2.7%	1.26	0.1%
Burn; Keloid; Cicatrix	46.52	33	1.08	9.1%	1.3	0.6%
Radar; Ultra-wideband (UWB); Microwave	46.45	11	1.16	5.0%	1.04	0.2%
Refugee; Asylum; Border	45.45	19	2.67	2.8%	1.42	0.5%
Global Health; Medical Mission; Internship and Residency	45.18	23	32.84	3.4%	13.24	0.6%
Isotope Fractionation; Isotope; Stable Isotope	44.91	13	2.11	6.1%	1.09	0.6%
New Mineral; Crystal Structure; Mineral	44.31	9	1.22	4.6%	1.71	0.3%
International Law; Human Right; Armed Conflict	44.24	17	1.07	1.2%	1.16	0.2%
Colletotrichum; Anthracnose; Fungus	43.44	5	8.21	3.7%	2.61	0.1%
Gear; Spur Gear; Transmission System	43.24	2	5.03	1.8%	5.07	0.0%
Thermography; Infrared Photography; Thermal Diffusivity	43.11	2	1.41	1.0%	1.02	0.1%
Baculovirida; Beauverium; Entomopathogenic Nematode	42.90	21	1.41	12.5%	1.09	0.5%
Plagiarism; Whistleblowing; Ethic	42.84	13	1.34	4.7%	1.01	0.4%

India; Social Class; Politic	41.97	11	1.62	1.2%	1.35	0.2%
Location Problem; Facility Location; Set Covering Problem	40.23	5	2.21	3.3%	1.86	0.2%
Garcinia Mangostanum; Xanthone Derivative; Mangiferin	39.69	2	1.06	5.4%	1.15	0.1%
Steven-johnson Syndrome; DRESS Syndrome; Drug Hypersensitivity	39.16	8	1.55	4.2%	1.48	0.2%
Explosive; Forensic Science; Picric Acid	37.82	5	2.31	3.3%	2.37	0.2%
Testosterone Congener; Clenbuterol; Doping	37.62	10	2.60	4.9%	1.99	0.4%
Pneumothorax; Pleura Effusion; Thoracoscopy	36.95	13	2.45	3.5%	2.27	0.3%
Prenatal Diagnose; Gastroschisis; Down Syndrome	34.00	17	2.12	5.1%	1.22	0.5%
Endocarditi; Bacterial Endocarditi; Aortic Sinus	30.52	22	1.56	10.9%	1.31	0.7%
Conflict of Interest; Drug Industry; Payment	29.18	4	0.98	1.6%	1.04	0.2%
Kynurenine; Kynurenine Pathway; Kynurenic Acid	21.29	7	2.41	7.8%	1.6	0.7%
Leptospirosis; Leptospira; Leptospira Interrogan	19.61	1	1.53	1.2%	1.1	0.1%

TABLE 6-2
List of Wales' topics with a higher FWCI than world and UK levels. Colour coding indicates the share of UK publications and thick row border indicate prominence percentiles.
Source: Scopus

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Authors

This study was conducted and written by Dr. Basak Candemir and Dr. Jörg Hellwig, and data extraction was done by Celina Sprague.

Dr. Basak Candemir is Head of Analytical Services Europe & Emergia with Elsevier's Research Management division. Basak has extensive experience in the analysis of university–industry relations and commercialisation through an innovation systems approach. Her particular experience is in combined quantitative/qualitative analysis and reporting, for both academic clients and government. She has experience in analysing large amounts of publication, citation, macroeconomic, and patent data from various sources. She was Science & Innovation Officer for 2.5 years as part of the UK Science and Innovation Network. Prior to that, Basak was a researcher in a number of EU projects such as AQUAMETH (Advanced Quantitative Methods for the Evaluation of the performance of public sector research) and PROKNOW (Production of Knowledge Revisited). Basak holds a DPhil on Science & Technology Policies from SPRU, University of Sussex.

Dr. Jörg Hellwig is an Analytical Product Manager at Elsevier's Research Management division. He focuses on analysing the research performance and trends for public agencies and academic institutes. Prior to this role, he worked as a Customer Consultant for Elsevier's Research Intelligence in Germany, the Netherlands, South Africa, and the United Kingdom, responsible for supporting the adoption and use of SciVal, Scopus, and various analytical tools and solutions for research performance and planning. This role implied a thorough knowledge of the higher education sector in various countries. Dr. Hellwig holds a PhD in Chemistry from Georg August University of Göttingen in Germany, with a subsidiary subject Communication Theory and Publicism. After receiving his PhD, he worked in pharmaceutical companies for almost 10 years before joining Elsevier in 2008.

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