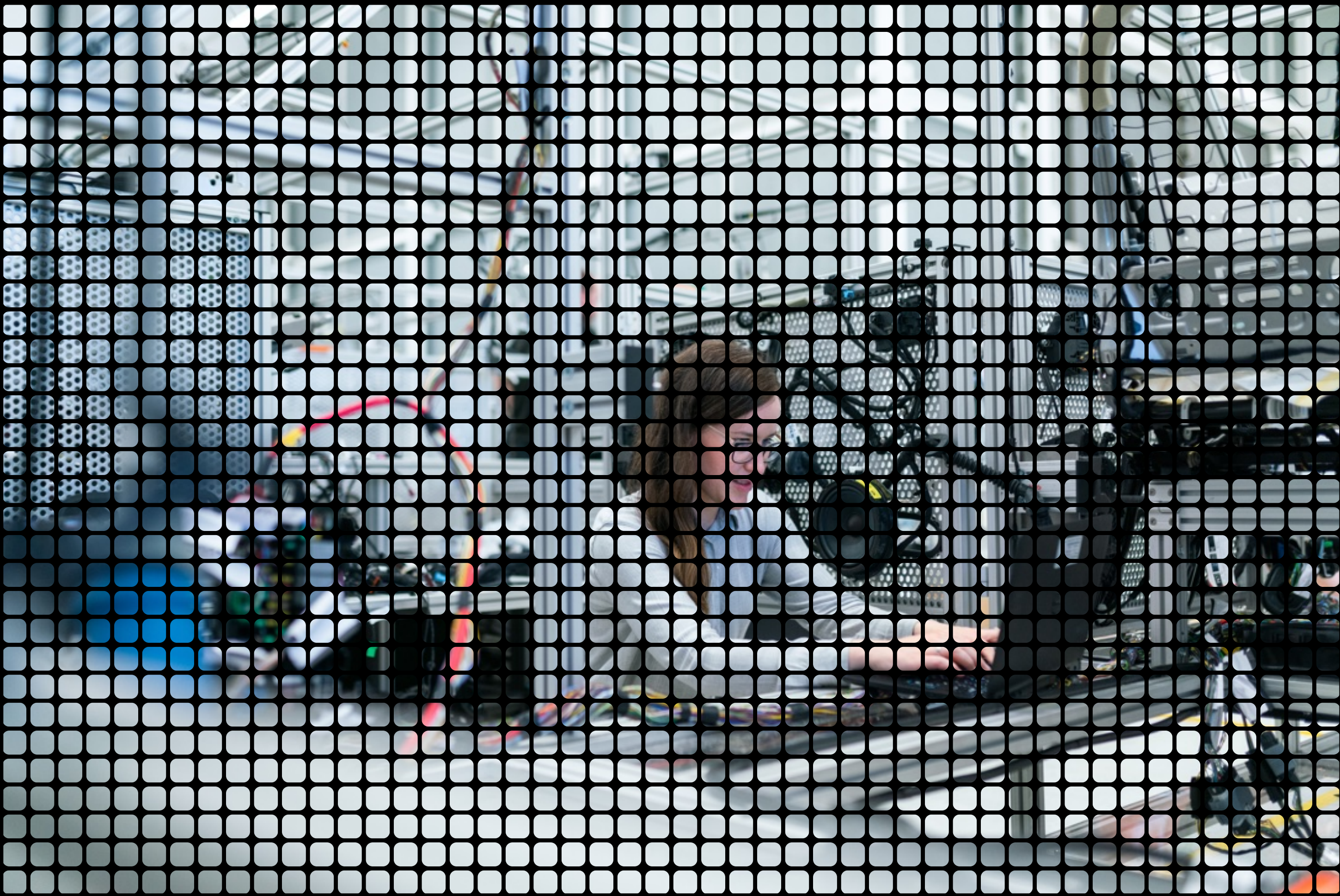

Executive Summary

Trends in Engineering Research

a quantitative analysis of engineering research publications in the UK

Hélène Draux, Cristina Rosemberg, Briony Fane, and Juergen Wastl

OCTOBER 28, 2024

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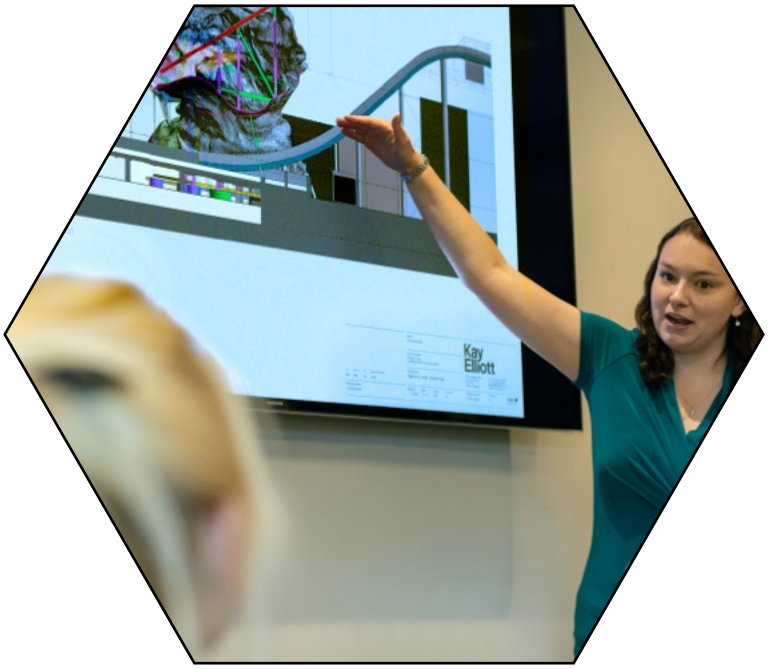
Foreword



We are pleased to present *Trends in Engineering Research*, a bibliometric analysis of the UK engineering research output. Sponsored by the Royal Academy of Engineering, it provides insights into the strengths, quality, and impact of UK engineering research from 2007 to 2021.

As a funder, the Academy runs an extensive programme of grants and prizes for engineers at every career stage in the UK to support and celebrate the pursuit of engineering activities and to enable closer contact between academia and industry. Through support, training, mentorship, and funding, the Academy cultivates outstanding and diverse engineering researchers, and we bolster engineering and technology research outputs with high potential for commercialisation and societal benefits. The research we have supported covers all engineering, from developing advanced technological solutions to relieve overstretched health services and advancing the digital security of nuclear facilities and critical national infrastructures, to improving the sustainability of food production and the energy efficiency of computing systems[1].

[1] Annual Report and Accounts 2022—2023, Royal Academy of Engineering, 2023.

As the UK national academy for engineering and technology, we provide progressive leadership for engineering and technology and see monitoring the health of the UK engineering research output as part of that role. The results of the Research Excellence Framework (REF) 2021 and the Engineering and Physical Sciences Research Council (EPSRC) report on Tomorrow's Engineering Research Challenges (TERC)[2] have made significant contributions to analysing engineering research in the UK. Our Trends in Engineering Research analysis adds a complementary bibliometric quantitative assessment.

[2] Tomorrow's Engineering Research Challenges (TERC), UKRI, 2022.

Engineers are drivers of economic opportunity, positive social impact, and advances in technology innovation. This comes from leveraging advances in research to develop and deliver new products, services, and enterprises that generate jobs and benefit society. Engineering traverses the modern economy and engineers are involved in almost every economic sector, from 'engineering sectors', such as advanced manufacturing and software, to non-engineering industries like financial services and the media. This diversity and scale emphasise the national economic importance and influence of engineering, which underpins a range of activities from machinery-based to computing and research. Engineering is a pivotal topic in the emerging economy of the UK[3]. Arguably, it is now more important than ever that the UK harnesses its engineering talent to address the challenges that impact the UK and the world, by creating disruptive technologies, providing sustainable solutions and ensuring a resilient future[4].

[3] Engineering Economy and Place, Royal Academy of Engineering, 2023.

[4] TERC, UKRI, 2022.

There is wide agreement across the globe that harnessing science, engineering, and technology is the route to prosperity and progress. In 2023, the UK government identified five critical technologies to build strategic advantage – AI, engineering biology, future telecommunications, semiconductors, and quantum technologies – all of which engineering is fundamental to. If the UK wishes to keep pace and continue to develop global competitive advantage, a resilient, responsive, and productive engineering research base will need to underpin this.

The analysis in this report presents a well-evidenced understanding of the UK strengths, gaps, and trends in engineering research based on bibliometric data. It provides insights to better inform discussions about engineering research priorities, the health of the engineering research sector, and its contribution to a safer and more resilient UK. It sets out how UK engineering research compares to global comparators and captures our international partners. It tracks trends in industry engagement. It provides insights into how UK engineering research performance aligns with current and future challenges, such as those outlined in TERC.

Much has happened in the time period covered by the analysis; in non-exhaustive reverse order, the last five years include the COVID pandemic, the UK departure from the EU, the creation of UK Research and Innovation (UKRI), Industrial Strategy and the creation of the eight great technologies. Looking ahead, we are seeing a focus on national security, both with the UK keen to secure strategic advantage and to protect our research from security threats; revitalising international relationships with EU countries now that the association to Horizon Europe is confirmed; the global economic downturn and its implications for private investment in R&D; and major global investments in engineering. The insights gleaned from this report should be considered with all this context in mind.

What does this extensive analysis show and what does it mean for UK engineering research? Although the Executive Summary and Evidence Report go into much more detail, here we capture the headlines. In summary, while the UK is a global leader in terms of the quality of its engineering research, this status is not guaranteed. There are signs that action may be needed to shore up this status, and we are keen to continue this conversation.

This analysis shows that there is a positive story to be told about engineering research in the UK that has a strong global reputation with excellent high-quality performance in all areas. When analysing quality, the UK secures the second position behind the US when analysing the percentage of publications in the top 1% of the most cited engineering publications globally. When applying the Field Citation Ratio[5] however, the UK has the highest score of all countries included[6]. Machine learning is a clear UK success story, performing significantly better than global comparators, signalling that the UK has an excellent foundation in a transformative engineering discipline. On the other hand, areas of historic strength of the UK, such as aerospace and biomedical engineering, show a decline in quality. This may signal a shift away from these areas to an increased focus on digital and emerging technologies.

The UK remains a partner of choice, increasing its collaboration with other countries both bilaterally and multilaterally[7]. It has a global reputation, with Italy, China, the US, and France as the UK top collaborators. Bilateral collaboration is the most frequent form of collaboration and this could be reflective of the UK effort to strengthen bilateral international partnerships to enhance technical capability.

The Research Excellence Framework (REF) found that a high number of engineering outputs were highly interdisciplinary and internationally collaborative[8]. Engineering is inherently interdisciplinary and through demonstrating this, these outputs showed the potential to be impactful for the UK and beyond. As stated in the TERC, addressing the technological challenges require integration and inclusive input from many disciplines. Our research shows strong links between UK engineering research and disciplines outside of engineering; however, greater funding could be geared toward collaboration with social sciences[9]. The analysis paints a positive picture when mapping engineering research to the TERC technological challenges. Quality is notable for ‘Space research’ and ‘responsible engineering’ and is shown to outperform other countries, with an increasing trend in ‘Robotics and AI’. The interdisciplinary nature of the TERC presented difficulties when trying to classify the data; therefore, there are limitations to this analysis.

Despite the favourable position of the UK in terms of the quality of its

[5] Field Citation Ratio is calculated by dividing the number of citations a paper has received by the average number received by documents published in the same year in the same category. It is a robust quality assessment, as it accounts for differences in citation patterns in a given field and different specialisms across countries.

[6] United States, Canada, Germany, France, Italy, South Korea, China, India, Japan

[7] Bilateral represents collaboration with one other country; multilateral represents collaboration with two or countries.

[8] Overview Report by Main Panel B and Sub-panels 7-12, Research Excellence Framework 2021, 2022.

[9] TERC, UKRI, 2022.

research output, its status is not guaranteed. There has been a sharp increase in the quality of engineering research in other countries such as South Korea and China. The definition of engineering in much of this report includes computer science[10]. However, it is important to acknowledge that, when looked at in isolation, computer sciences outperform engineering. Globally, the quality of computer science research brings the UK third behind the US and China in terms of the global top 1% cited publications.

[10] For the purposes of this report, engineering publications have been extended to include Information and Computing Sciences (46) based on its crossover with Engineering (40). Unless stated otherwise, engineering research refers to both Engineering (40) and Information and Computing Sciences (46).

There is a heavy reliance on funding from EPSRC, with two-thirds of UK engineering research publications (based on the publications with credited funders in the acknowledgements) crediting EPSRC as a funder. This confirms how critical EPSRC is to UK engineering research.

Worryingly, both industry funding and collaborations with industry partners has declined in the majority of subdisciplines. This may have consequences for business R&D in the UK and the impact of engineering research. It could also increase competition in the UK public funding landscape, result in less access to resources and facilities, and furthermore, difficulty in the ability to scale up research. It is noted that not all industrially funded research will be published, as it may be commercially sensitive. The decline could be due to a number of reasons. It may be reflective of economic uncertainty across the industrial funding landscape that has slowed investment and, therefore, limited R&D levels - this warrants further investigation[11]. Additionally, there has been a decline in manufacturing activity in the UK and changes in the nature of technological innovation. For example, automotive engineering, another of the UK former key areas of strength, has observed a drop in industrial involvement. This could be ascribed to the end of almost all combustion engine research and the increase in alternative fuels through the ongoing transition to net zero. Organisations have called for interventions to ensure that the automotive industry can thrive through this transition[12]. The UK should focus efforts to reverse the decline of industry involvement in research and research funding and improving this would be hugely beneficial for UK society and the business landscape.

[11] UK tech funding steepest drop in Europe, UKTN, 2023.

[12] UK Automotive Sector: Surviving the Net Zero Transition, Institution of Mechanical Engineers, 2023.

Engineering research plays a crucial role in our economy and it is essential that we recognise our strengths and areas for improvements to ensure that engineering continues to bring benefits to society. We hope that this report provides evidence to help further focus UK efforts to provide engineering solutions for the UK and beyond.

Professor Máire O'Neill FREng FIAE MRIA
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Regius Professor in Electronics and Computer Engineering
Director, UK Research Institute in Secure Hardware and Embedded Systems (RISE)
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Introduction

2.1 This report

This report presents a bibliometric analysis of the UK engineering research output. It provides insights into the strengths, quality, and impact of UK engineering research over the past 15 years - from 2007 to 2021, unless indicated otherwise. To provide a broader context, the analysis includes a comparative assessment of the performance of the UK against nine countries (selected in collaboration with the Academy) considered the main contributors to engineering research.

The key findings of the report are presented in this Executive Summary, with additional and accompanying data available in the supporting Evidence Report.

Analyses carried out rely entirely on bibliometric data, which has recognised strengths and anticipated limitations. A key strength of the bibliometric approach is that it enables a systematic examination of more than 135 million research publications, providing a historical perspective through the application of well-established and validated bibliometric indicators.

This approach provides multifaceted insights into the current shape of engineering research activity in the UK across key dimensions including quality, collaboration, impact, integrity, and the funding landscape. These indicators then facilitate comparisons across engineering subdisciplines and provide national and international context.

However, it is important to note that bibliometric data alone cannot fully explain all the observed patterns and trends emerging from this analysis. A deeper dive into the data could help to elucidate how, for instance, shifts in funding landscapes, policy strategies, or other contextual factors play a role in these results.

As such, this report offers a perspective on the leading edges of contemporary engineering research in the UK and raises questions that merit further exploration going forward.

"This report presents a bibliometric analysis of the UK engineering research output. It provides insights into the strengths, quality and impact of UK engineering research over the past 15 years - from 2007 to 2021."

2.2 Defining engineering research using bibliometric data

The main source of information used in the analyses is the publication data contained in Dimensions. Dimensions is the world's largest linked research information database. It links information on publications with grants, clinical trials, patents, datasets, and policy documents.

Publications are classified using the Fields of Research (FoR). FoR offers a hierarchical classification that covers all areas of R&D. It includes 21 divisions (disciplines) and groups (fields or subdisciplines). More than 135 million research publications available in Dimensions are mapped against the FoR, by applying semantic analysis (via machine learning) to the title and abstract of articles. When an abstract is not available, this mapping is done at the level of the journal.

The report combines two disciplines from the FoR classification: Engineering (40) and Information and Computing Sciences (46), taking into

"This report combines two disciplines from this classification: Engineering and Information and Computing Sciences, taking into account their significant overlap and interdisciplinary connections."

account their significant overlap and interdisciplinary connections. The approach is supported by an examination of the research output submitted to the UK REF2021 for two Units of Assessment (UoA) - UoA12 (Engineering) and UoA11 (Computer Sciences) - that demonstrate a notable intersection and cross-submissions between the two fields.

The Dimensions publication data contain more than 600,000 publications in the 19 subdisciplines included in Engineering (40) and 12 subdisciplines included in Information and Computing Sciences (46), published between 2007 and 2021. The number of publications in each of the 31 subdisciplines ranges from 5,000 in Environmental Engineering (4011) to 52,000 in Materials Engineering (4016).

A more detailed methodological section can be found in the accompanying Evidence Report.

2.3 The big picture

The UK engineering research is well-regarded internationally, and the bibliometric analysis indicates continued areas of strength, especially in the emerging field of Machine Learning (4611) where the UK demonstrates high levels of production coupled with high quality (as measured by field-weighted citation ratios), significantly above the world baseline. As Machine Learning (4611) is poised to enable breakthroughs across many research and economic sectors, the UK has a solid foundation in a crucially important engineering discipline of the future. Attempts to consolidate and expand this leadership position would be strategic. Moving forward, fully leveraging this position, while also boosting output more broadly, will be key to ensuring that the UK engineering research ecosystem remains dynamic and impactful on the world stage.

"The UK engineering research is well-regarded internationally, and the bibliometric analysis indicates continued areas of strength, especially in the emerging discipline Machine Learning (4611)."

However, the bibliometric analysis and international comparisons reveal a widening gap in overall publication output and a shortening gap in terms of quality. Specifically, the UK is being outpaced by the rapid expansion of the volume of engineering research in the US and China across diverse subdisciplines. The volume of publications is in part driven by (research) population size, and the UK may never be in a position to compete with the US and China on this metric. The analysis also reveals a sharp increase in the quality of engineering research in China in the past decade as well as a steady increase in South Korea, while the US remains at the top in engineering research.

The bibliometric analysis also indicates that there has been a decline in funding from and collaboration with industry in UK engineering research. It is clear that trust markers in engineering are becoming more evident and, as this evolves, we might see an increase in this aspect of open research.

Maintaining the UK global standing in engineering will require strategies to bolster both the quantity and quality of research in an ever-evolving geopolitical landscape.

Targeted support may also be needed for further activity in research priority areas in engineering (such as those identified by the EPSRC).

Key areas of activity and strength

3.1 Activity

Overall

At the time of this report, the bibliometric analysis identified 605,358 publications in engineering research produced by UK-based authors between 2007 and 2021, which included research articles, books, book chapters, preprints and conference proceedings. This represents 17.4% of all UK research publications during this period, second only to the field of Biomedical and Clinical Sciences (32), which accounts for 961,296 publications.

The publications of engineering research in the UK constituted 3.9% of the global output in the field. For perspective, the UK represents 2.3% of world GDP and represents 3.4% of total global R&D investment. Thus, the UK has a significant position in international engineering research, broadly on a par with its economic and R&D global standing.

"The UK holds a sizeable position in international engineering research, broadly on a par with its economic and R&D global standing."

The subdiscipline view

Based on the volume of publications, the top three most productive engineering research subdisciplines in the UK are Materials Engineering (4016), Data Management and Data Science (4605), and Civil Engineering (4005).

The areas of highest growth according to the volume of publications are in Machine Learning (4611) with an 11.4% Compound Annual Growth Rate (CAGR), followed by Geomatic Engineering (4013) with a CAGR of 9.5%, and Cybersecurity and Privacy (4604) with a CAGR of 7.9%. See Figure 1 for a visual presentation of the trends.

Taking a closer look at individual subdisciplines reveals that:

- **Strong and growing**: There are three areas where the UK is strongest based on volume and where growth has been highest over the past 15 years: Materials Engineering (4016), Data Management and Data Science (4605), and Civil Engineering (4005).
- **Up and coming**: Environmental Engineering and Geomatic Engineering (4013) were in the bottom five for volume of publications but have one of the highest growth areas across the period. Growth in Geomatic Engineering (4013) [13] may be explained by growth in space infrastructures (such as satellites) in which the UK has invested heavily in the past 10 years.
- **Potential decline**: In contrast, the last five years (2017-2021) saw a decrease in the volume of publications in Software Engineering (-7.1% CAGR), Theory of Computation (-1.8% CAGR), Communications Engineering (-1.3% CAGR) and Nanotechnology (-1.2% CAGR), as outlined in Table 1.

[13] Science, engineering and modelling of measurements and data relating to Earth and its environment.

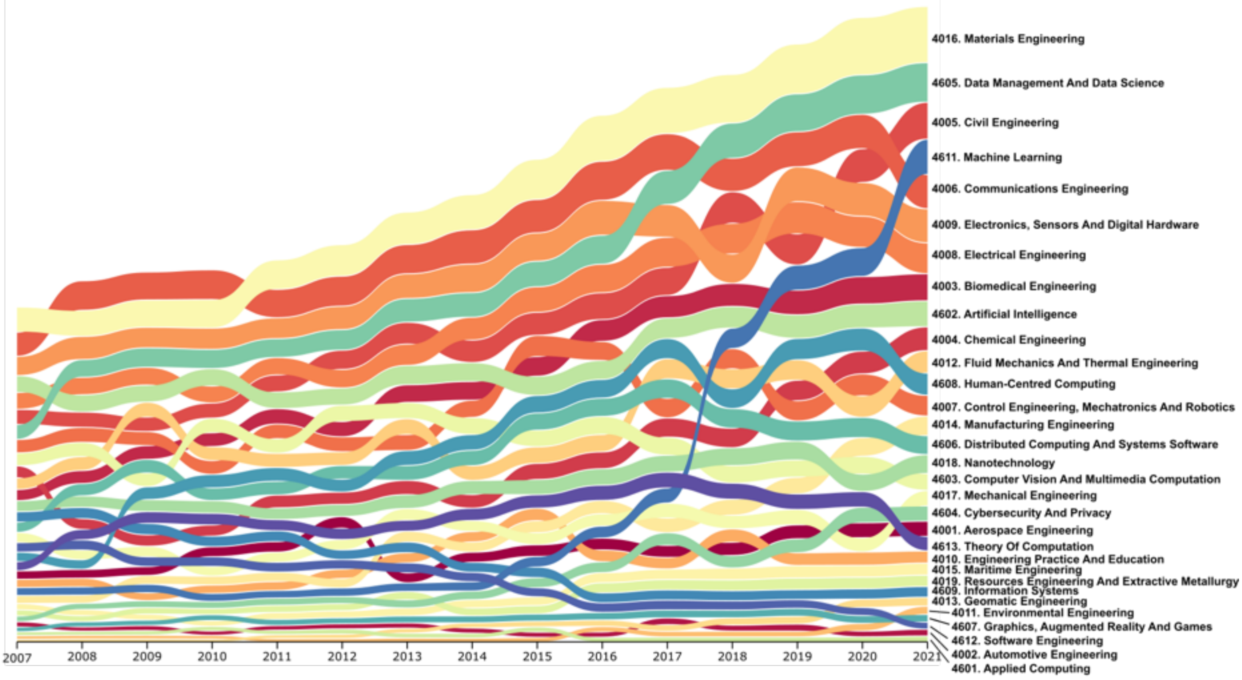

Figure 1: Rank and volume trend for engineering research in the UK, 2007 to 2021.

Table 1: Number of publications in the Engineering subdisciplines in the UK. Sorted in descending order by CAGR 2007 to 2021. 'All' represents the total volume of publications (deduplicated) and average CAGRs.

Field of Research	Total 2007-21	CAGR 2007-12	CAGR 2012-17	CAGR 2017-21	CAGR 2007-21
4611. Machine Learning	18,197	1.3	14.0	19.6	11.4
4013. Geomatic Engineering	6,098	11.7	9.6	7.3	9.5
4604. Cybersecurity And Privacy	12,096	6.1	13.6	4.3	7.9
4011. Environmental Engineering	5,370	0.8	11.8	9.4	7.2
4605. Data Management And Data Science	35,361	7.0	11.2	3.2	7.1
4014. Manufacturing Engineering	15,407	3.9	10.4	6.5	6.9
4003. Biomedical Engineering	24,760	7.0	8.5	4.3	6.6
4005. Civil Engineering	31,001	5.3	8.4	6.0	6.6
4608. Human-Centred Computing	21,105	7.2	10.1	2.0	6.4
4016. Materials Engineering	52,024	4.8	8.3	4.1	5.7
4015. Maritime Engineering	10,553	2.5	9.9	3.2	5.2
4004. Chemical Engineering	20,331	0.8	10.0	4.8	5.1
All	605,358	3.9	7.5	3.0	4.8
4012. Fluid Mechanics And Thermal Engineering	21,607	3.5	8.6	2.5	4.8
4019. Resources Engineering And Extractive Metallurgy	10,349	3.3	8.8	2.2	4.7
4601. Applied Computing	5,324	8.2	1.4	4.5	4.7
4606. Distributed Computing And Systems Software	20,645	6.4	8.2	-0.5	4.6
4001. Aerospace Engineering	14,261	7.3	0.9	5.2	4.4
4008. Electrical Engineering	31,495	2.1	10.7	0.7	4.4
4603. Computer Vision And Multimedia Computation	18,763	2.2	7.4	2.4	4.0
4009. Electronics, Sensors And Digital Hardware	36,233	4.2	7.2	0.9	4.0
4607. Graphics, Augmented Reality And Games	7,744	5.8	6.8	-0.7	3.9
4613. Theory Of Computation	16,450	4.9	7.4	-1.8	3.4
4007. Control Engineering, Mechatronics And Robotics	22,615	2.3	5.8	1.5	3.2
4602. Artificial Intelligence	25,612	0.4	4.0	4.9	3.1
4017. Mechanical Engineering	15,115	0.2	8.6	0.8	3.1
4010. Engineering Practice And Education	13,157	2.9	4.8	1.4	3.0
4006. Communications Engineering	42,723	4.7	4.2	-1.3	2.5
4002. Automotive Engineering	6,008	-0.3	7.3	-0.2	2.2
4018. Nanotechnology	20,744	5.4	2.1	-1.2	2.1
4609. Information Systems	12,892	-1.5	1.2	1.1	0.3
4612. Software Engineering	11,318	0.2	0.7	-7.1	-2.2

3.2 Quality

Overall

UK engineering research enjoys a global reputation, underscored by its robust collaboration with other countries, and by the substantial number of citations it accrues.

The UK REF2021 exercise has already highlighted the quality of engineering research in the UK (notwithstanding the fact that the exercise generates the incentives to submit the most outstanding research outputs). 91% of the outputs submitted to REF Sub-panel 12 (Engineering) and 87% of outputs submitted to REF Sub-panel 11 (Computer Science and Informatics) were assessed for originality, significance, and rigour as being of at least 'internationally excellent' quality.

In line with the REF2021 assessment, the bibliometric data analysed in this study reveal that the UK is second in all engineering research for the highest cited publications, only behind the US.

The analysis in Table 2 shows that 0.92% of the UK engineering publications are in the top 1% most cited engineering publications globally, while the US has 1% in the top 1%.

We also find that the UK accounts for 3.3% of the top 1% of highly cited work across engineering research globally (but naturally countries with a larger volume of publications, such as the US, will exhibit a larger share).

"UK engineering research enjoys a global reputation, underscored by its robust collaboration with other countries, and by the substantial number of citations garnered."

"3.3% of UK publications related to engineering research are in the top 1% (based on citations of those publications globally)."

Table 2: Top 1% publications in Engineering across all countries, from 2007 to 2021.

Countries	Number of publications in the top 1%	Number of publications	Percentage publications in the top 1%
United States	18,188	1,813,859	1.0
United Kingdom	4,532	491,624	0.92
Canada	2,454	328,289	0.75
Germany	3,491	573,816	0.61
France	2,230	414,169	0.54
Italy	1,741	336,181	0.52
South Korea	1,635	386,227	0.42
China	10,738	2,622,724	0.41
India	1,568	687,767	0.23
Japan	1,437	657,572	0.22

The average Field Citation Ratio (FCR) offers a more robust quality assessment (than the simple count of top 1% based on citations), as it accounts for differences in citation patterns in a given field and different specialisms across countries[14].

Trend analysis of average FCR reveals that, overall, the UK has marginally increased its level of quality in engineering research over time, from 2.49 in 2007 to 2.6 in 2021. Figure 2 below shows the evolution of the average FCR for each country (in red) and compares this against the average for those countries (dotted line). Other countries, including the US, France, and Germany, show a decline in the quality of their engineering research.

In contrast, there has been a marked increase in the quality of engineer-

[14] The FCR is calculated by dividing the number of citations a paper has received by the average number received by documents published in the same year and in the same FoR category.

ing research in China over the past 10 years despite a drop in the average FCR in the last two years of the period (from 1.73 in 2007 to 2.23 in 2021). South Korea also reveals a steady increase (from 1.81 in 2007 to 2.4 in 2021).

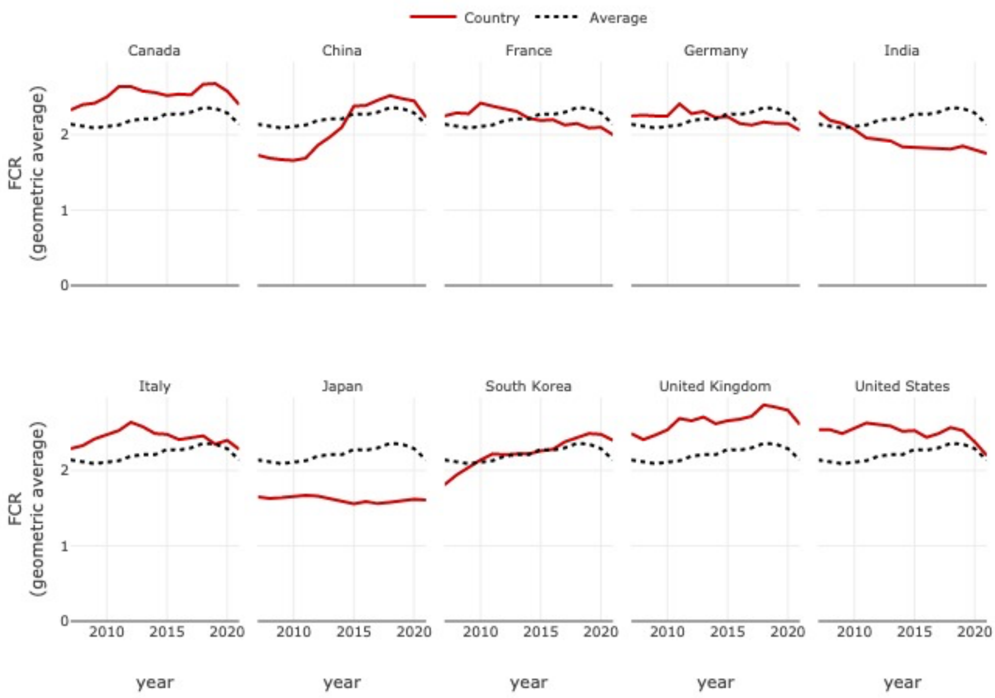

Figure 2: Field Citation Ratio trends for UK engineering research, 2007 to 2021 (average of the 31 subdisciplines making up Engineering).

The subdiscipline view

A more granular analysis reveals that the UK strongest subdisciplines in terms of quality (measured as average FCR) are:

- Machine Learning (3.3)
- Manufacturing Engineering (3.1)
- Applied Computing (3.0)
- Theory Of Computation (3.0)
- Human-Centred Computing (2.9)

UK publications in Machine Learning (4611) not only have the highest annual growth rate for volume of research publications but also the highest scientific impact (in comparison with UK publications across other Engineering subdisciplines), notwithstanding a drop in the average FCR in later years of the analysis. See Figure 3 below which shows the evolution of average FCR for each subdiscipline (in red) and compares this against the average for UK engineering research (dotted line).

"Machine Learning (4611) not only has highest UK annual growth rate for volume of research publications but also the highest scientific impact in the UK."

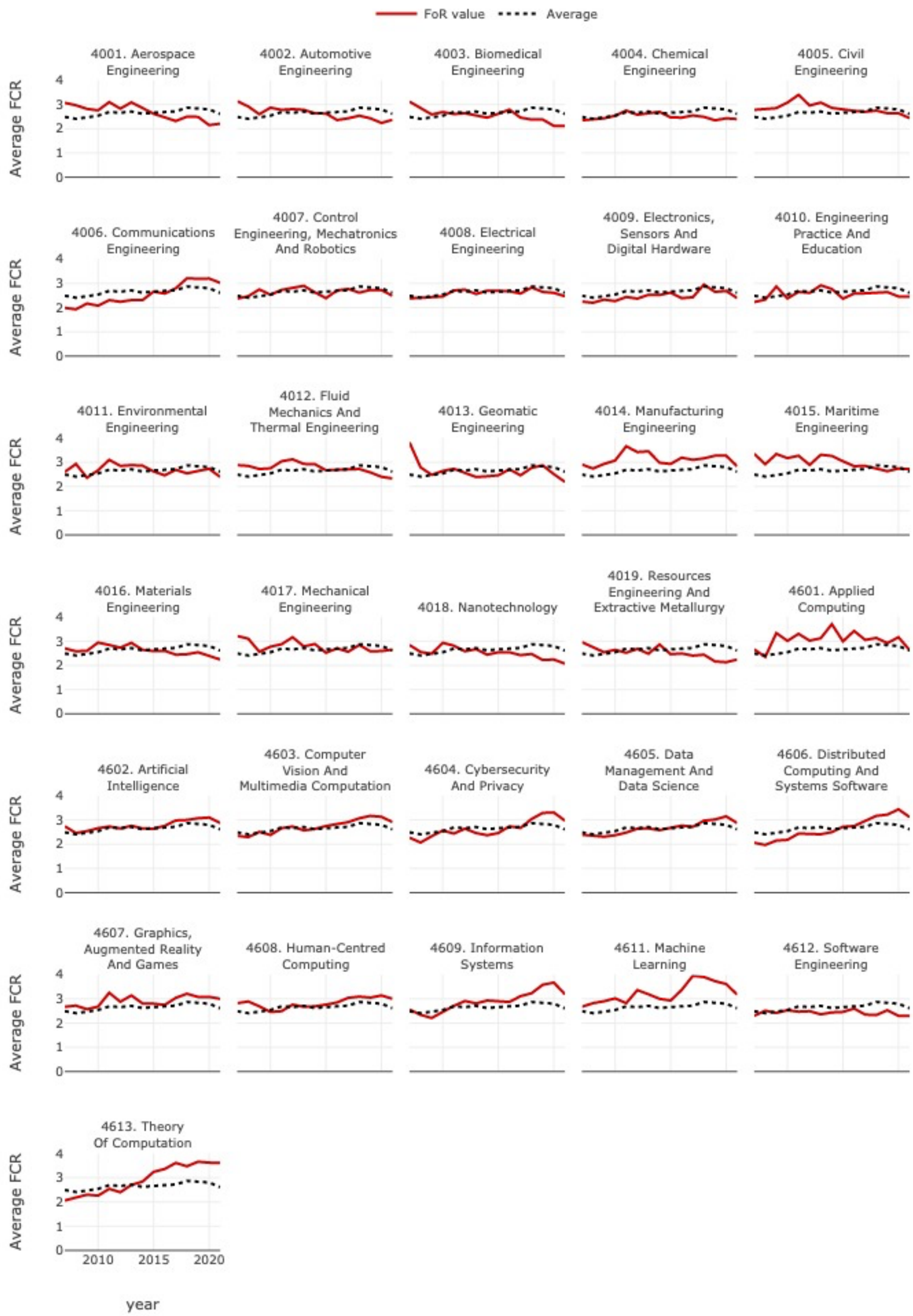

Figure 3: Field Citation Ratio trends for UK engineering research, 2007 to 2021 (average of the 31 subdisciplines making up Engineering).

Table 3 reveals that Applied Computing (4601) and Machine Learning (4611) have a relatively high percentage volume of publications in the top 1% (2.7% and 2.4% respectively), which is a more strict measure of quality (i.e. 2.4% of UK publications in the field of Machine Learning (4611) appear in the top 1% of publications based on citations globally). These results are likely to be driven by the presence of strong key players, including large corporations in the tech industry[15].

[15] https://jameswphillips.substack.com/p/s-and-t-is-the-uk-a-world-leader.

Table 3: Top 1% publications for each Field of Research in the UK, from 2007 to 2021.

Field of Research	Number of publications in the top 1%	Number of publications	Percentage of publications in the top 1%
4601. Applied Computing	145	5324	2.7
4611. Machine Learning	440	18197	2.4
4607. Graphics, Augmented Reality And Games	141	7744	1.8
4603. Computer Vision And Multimedia Computation	316	18763	1.7
4609. Information Systems	214	12892	1.7
4613. Theory Of Computation	241	16450	1.5
4602. Artificial Intelligence	336	25612	1.3
4014. Manufacturing Engineering	192	15407	1.2
4605. Data Management And Data Science	422	35361	1.2
4009. Electronics, Sensors And Digital Hardware	390	36233	1.1
4006. Communications Engineering	455	42723	1.1
4606. Distributed Computing And Systems Software	224	20645	1.1
4608. Human-Centred Computing	233	21105	1.1
4604. Cybersecurity And Privacy	126	12096	1.0
4612. Software Engineering	114	11318	1.0
4013. Geomatic Engineering	52	6098	0.9
4007. Control Engineering, Mechatronics And Robotics	180	22615	0.8
4008. Electrical Engineering	263	31495	0.8
4010. Engineering Practice And Education	87	13157	0.7
4018. Nanotechnology	142	20744	0.7
4016. Materials Engineering	292	52024	0.6
4005. Civil Engineering	176	31001	0.6
4011. Environmental Engineering	28	5370	0.5
4003. Biomedical Engineering	117	24760	0.5
4017. Mechanical Engineering	57	15115	0.4
4015. Maritime Engineering	47	10553	0.4
4001. Aerospace Engineering	52	14261	0.4
4019. Resources Engineering And Extractive Metallurgy	26	10349	0.3
4012. Fluid Mechanics And Thermal Engineering	61	21607	0.3
4004. Chemical Engineering	64	20331	0.3
4002. Automotive Engineering	14	6008	0.2

Table 3 above also reveals that subdisciplines traditionally perceived as areas of core research strengths in the UK, including Aerospace Engineering (4001) and Biomedical Engineering (4003), have shown a decline in quality over time. This is reflected in Figure 3 which shows the evolution of the average FCR for each subdiscipline (in red) and compares it with the average for engineering research in the UK (dotted line).

Furthermore, the percentage of publications positioned in the top 1% of publications for the period 2007 to 2021 is 0.4% and 0.5%, respectively (i.e. only 0.4% of publications in the subdiscipline Aerospace Engineering (4001) in the UK appear in the top 1% of publications based on citations globally). This is despite continued growth in volume (at 4.4% and 6.6% CAGR, respectively, in the same period).

Both Aerospace Engineering (4001) and Biomedical Engineering (4003) subdisciplines continue to exhibit strong performance in the UK compared to other countries. In fact, the UK ranks highest in Aerospace Engineering (4001) research (with a 2.6 average FCR, i.e., 2.6 times the global average of 1), ahead of both Italy and Canada (both with 2.5 average FCR), while for Biomedical Engineering (4003) the UK holds second place with Canada, South Korea and the US (all with a 2.5 average FCR) and only behind China (with 2.6 average FCR) as seen in Table 4.

However, the notable decline in quality over time in both Aerospace and Biomedical Engineering (4003) could be considered a cause for concern. This fall can likely be attributed to a number of factors, including changes in the industry landscape, such as a decline in manufacturing activity in the UK. Furthermore, changes in the nature of technological innovations in these subdisciplines may have played a role. Crucial advances in sectors like the Aerospace and Automotive industries might have transcended the traditional boundaries of research, with major technological breakthroughs occurring in advanced materials, recycling, autonomous systems, cybersecurity, among others. Consequently, high-performing research publications appear to be gravitating towards these 'new' areas, impacting the overall scientific influence of the field.

Finally, international comparisons also reveal good performance in a number of specific subdisciplines across countries, with China leading the way in Nanotechnology, Biomedical Engineering (4003), Materials Engineering (4016) and Chemical Engineering (4004). The US and the UK jointly lead the way in Machine Learning (4611) and in Graphics, Augmented Reality and Games (4607). Both countries also rank at the top of the league for publication volume in these subdisciplines. This is reflected in the heat map presented in Table 4 below, which assigns red to yellow shades, going from countries that exhibit the highest average FCR values, in the period 2007 to 2021, for each subdiscipline, to the lowest.

Table 4: Average FCR for Engineering subdisciplines - international comparisons.

Country Field of Research	Canada	China	France	Germany	India	Italy	Japan	South Korea	UK	US
4001. Aerospace Engineering	2.5	1.9	2.3	2.0	1.8	2.5	1.5	2.2	2.6	2.2
4002. Automotive Engineering	2.5	2.3	2.5	2.1	2.3	2.5	1.5	2.2	2.6	2.5
4003. Biomedical Engineering	2.5	2.6	2.1	2.3	2.2	2.3	1.8	2.5	2.5	2.5
4004. Chemical Engineering	2.4	2.6	2.4	1.8	2.4	2.6	1.8	2.4	2.5	2.5
4005. Civil Engineering	2.6	2.0	2.7	2.3	1.9	2.8	1.5	2.3	2.8	2.4
4006. Communications Engineering	2.4	1.9	2.1	2.0	1.6	2.2	1.6	2.0	2.5	2.2
4007. Control Engineering, Mechatronics And Robotics	2.6	2.0	2.2	2.2	1.8	2.5	1.5	2.2	2.6	2.5
4008. Electrical Engineering	2.4	1.9	2.0	2.1	1.7	2.5	1.6	2.0	2.6	2.4
4009. Electronics, Sensors And Digital Hardware	2.3	1.8	2.0	2.0	1.7	2.3	1.6	2.2	2.5	2.2
4010. Engineering Practice And Education	2.7	1.8	2.2	2.1	1.8	2.5	1.4	2.3	2.5	2.2
4011. Environmental Engineering	2.4	2.6	2.4	2.5	2.4	2.6	1.9	2.5	2.6	2.5
4012. Fluid Mechanics And Thermal Engineering	2.4	2.4	2.5	2.2	2.2	2.6	1.5	2.2	2.7	2.4
4013. Geomatic Engineering	2.3	2.0	2.2	2.4	1.7	2.4	1.6	2.1	2.6	2.5
4014. Manufacturing Engineering	3.0	2.0	2.5	2.1	2.4	2.9	1.5	2.2	3.1	2.6
4015. Maritime Engineering	2.5	2.0	2.6	2.4	1.9	2.9	1.5	2.1	2.9	2.4
4016. Materials Engineering	2.5	2.7	2.2	2.2	1.9	2.3	1.7	2.4	2.6	2.5
4017. Mechanical Engineering	2.6	2.5	2.0	2.2	2.3	2.7	1.5	2.2	2.8	2.5
4018. Nanotechnology	2.4	2.8	2.1	2.3	2.0	2.3	1.8	2.4	2.5	2.7
4019. Resources Engineering And Extractive Metallurgy	2.5	2.2	2.4	1.6	1.9	2.3	1.8	2.1	2.5	2.4
4601. Applied Computing	2.8	2.3	2.1	2.6	2.3	2.8	1.8	2.6	3.0	2.7
4602. Artificial Intelligence	2.7	2.0	2.2	2.4	2.0	2.5	1.5	2.2	2.8	2.7
4603. Computer Vision And Multimedia Computation	2.5	2.1	2.3	2.5	1.7	2.5	1.6	2.0	2.8	3.0
4604. Cybersecurity And Privacy	3.0	2.2	2.4	2.4	1.8	2.7	1.8	2.2	2.8	2.9
4605. Data Management And Data Science	2.6	2.0	2.0	2.1	1.8	2.4	1.5	2.1	2.7	2.6
4606. Distributed Computing And Systems Software	2.8	2.2	2.2	2.2	1.7	2.6	1.8	2.1	2.7	2.8
4607. Graphics, Augmented Reality And Games	2.7	2.2	2.5	2.9	1.7	2.4	1.5	2.0	2.9	3.2
4608. Human-Centred Computing	2.7	2.2	2.3	2.5	1.9	2.6	1.5	2.1	2.9	2.7
4609. Information Systems	2.7	1.9	2.3	2.3	1.9	2.6	1.4	2.4	2.9	2.8
4611. Machine Learning	3.1	2.7	2.6	2.9	2.1	2.8	1.8	3.1	3.3	3.3
4612. Software Engineering	2.6	1.6	2.1	2.2	1.7	2.5	1.6	1.8	2.4	2.4
4613. Theory Of Computation	2.8	2.2	2.4	2.4	1.6	2.5	1.7	2.2	3.0	2.9

International collaboration

The international standing of UK engineering research is further corroborated by (and benefits from) its high degree of international collaboration, both bilaterally and multilaterally (measured as the percentage of publications where these collaborations take place). In line with the upward trend in the proportion of UK engineering publications that include international collaboration, there is a simultaneous downward trend in the proportion of publications that include only UK authors/collaborations across all subdisciplines.

"The international standing of UK engineering research is further corroborated by (and benefits from) its high degree of international collaboration, both bilaterally and multilaterally."

Bilateral collaboration in UK engineering research (two authors, one in the UK and one in another country) is evident in nearly 40% of publications in the later years of the 2007 to 2021 time frame where the analyses reveal upward trends. Multilateral collaboration in UK engineering research (research collaboration across multiple countries), although a less frequent form of collaboration, also reveals upward trends across all the engineering subdisciplines. The data reveal that Italy, China, the US, and France are the main UK collaboration partners. They appear most frequently across Engineering subdisciplines and are in the top five countries across all 31 subdisciplines. The UK collaboration with France is also high in 30 of the 31 fields.

3.3 Research integrity

There is a growing interest in improving research integrity in the UK and worldwide. The 2023 report of the House of Commons Science and Technology Committee in the UK[16] recommended paying attention to research integrity issues. As such, 'trust markers' for research integrity have become increasingly important tools with which to assess the quality, reproducibility, and usability of data, from data and code availability to statements relating to ethical approvals and potential conflicts of interest.

[16] https://committees.parliament.uk/publications/39343/documents/194466/default/

The analysis of trust markers conducted as part of this study reveals that UK engineering research performs well and is in line with world standards in most subdisciplines. It also leads the way in making code available to enable research replication in Geomatic Engineering (4013), Applied Computing (4601), and Machine Learning (4611) as seen in Figure 4 below, which shows the percentage of research publications with code availability for each subdiscipline (in red) and compares this with the average for engineering research in the UK (shown as dotted lines). The UK also leads internationally in obtaining ethical approvals in Biomedical Engineering (4003).

"UK engineering leads the way in terms of code availability, to enable research replication in Geomatic Engineering (4013), Applied Computing (4601), and Machine Learning (4611)."

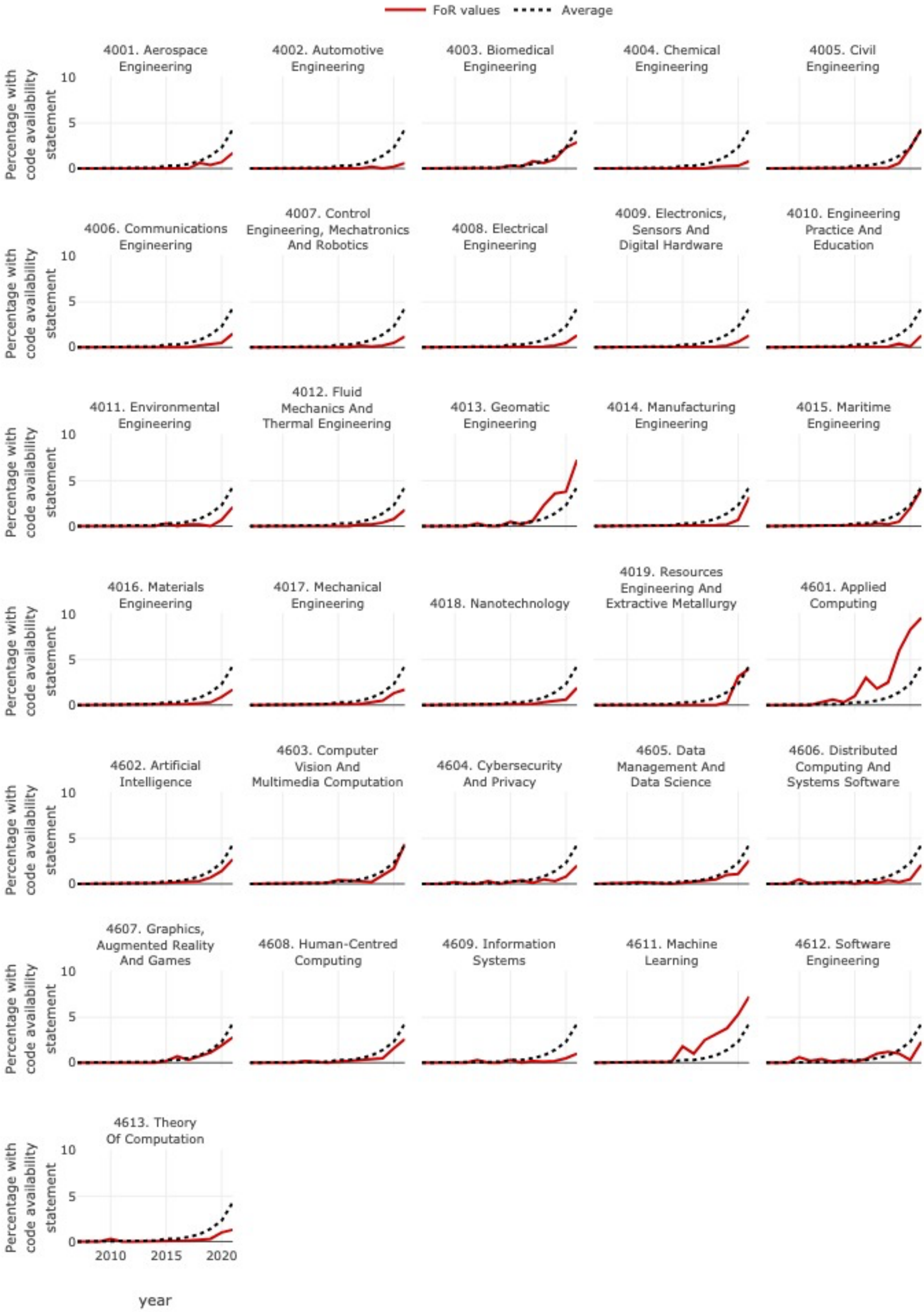

Figure 4: Percentage of research publications with a code availability statement for UK engineering research.

Addressing research priorities and contributions to societal challenges

4.1 Tomorrow's Engineering Research Challenges (TERC): Technological Challenges

The report 'Tomorrow's Engineering Research Challenges' (TERC), led by the EPSRC, aims to identify key challenges, inform future strategies in engineering, and identify the research needed to tackle them[17]. It identifies eight challenges:

[17] https://www.ukri.org/wp-content/uploads/2022/07/EPSRC-090822-TERCReport.pdf

- Ensure **space research** is sustainable, and design and develop technologies that will be used to explore and sustain life in space and on Earth.
- Develop sustainable, integrated, and equitable **transportation systems**.
- Accelerate environmentally sustainable and socially responsible creation and utilisation of **materials**.
- Improve whole-life **health and wellbeing** by developing sustainable, inclusive, and resilient healthcare systems and technologies resilient healthcare systems and technologies.
- Co-design and embed **robotics and AI** into engineering while ensuring ethical use with transparent and equitable decision making.
- Foster socially and environmentally **responsible approaches to engineering** guided by our understanding of human behaviours and needs.
- Unlock the full potential of **nature-based engineering**.
- Deliver **adaptable global engineering solutions** that are compatible with our understanding of the planet's ecosystem.

In this section, we explore the extent to which current engineering research aligns with the eight TERC Technological Challenges and its contribution to advance this agenda. To this end, we translated the definitions for each priority provided in TERC into a combination of Boolean searches and two classifications from Dimensions: Fields of Research (FoRs) and the United Nation's Sustainable Development Goals (SDGs). The complete methodology is described in the accompanying Evidence Report. This is a first attempt to operationalise this wide and complex area, and future research could arrive at more precise classifications (using, for instance, bottom-up approaches such as topic modelling).

Findings reveal that for the volume of publications, 'responsible engineering' is currently the UK strongest research area in the TERC Technological Challenges (based on the volume of research publications) with a notable increase throughout the decade 2010-2020 (see Figure 5). Other TERC Technological Challenges appear flat in the graph as a consequence of the substantial differences in overall volumes between 'responsible engineering' and the other Challenges, making smaller variations less visible in comparison. The operational definitions used to define the TERC Technological Challenges may be playing a role. In this report, 'responsible engineering' is defined as the intersection between engineering research and the environmental and social pillars of the SDGs, while 'robotics and AI' is defined as the intersection between autonomous systems, trust, ethics, and AI, and responsible AI, and the social pillar of the SDGs (see the Evidence Report for further methodological details).

"'Responsible engineering' is currently the UK strongest research area in the TERC Technological Challenges (based on the volume of research publications)."

In terms of international comparisons, although the UK lags behind China and the US across all the eight TERC Technological Challenges, the UK shows an increasing trend in 'robotics and AI'.

The quality (as measured by average FCRs) of UK engineering research is notable, particularly in 'space research' and 'responsible engineering', outperforming other countries included in the analysis. Research funders may have to consider directing more resources towards the TERC Technological Challenges to increase activity and overall international standing.

Note that Figure 5 uses shorthand to describe the TERC Technological Challenges listed above (e.g., 'Transportation' denotes "develop sustainable, integrated, and equitable transportation systems").

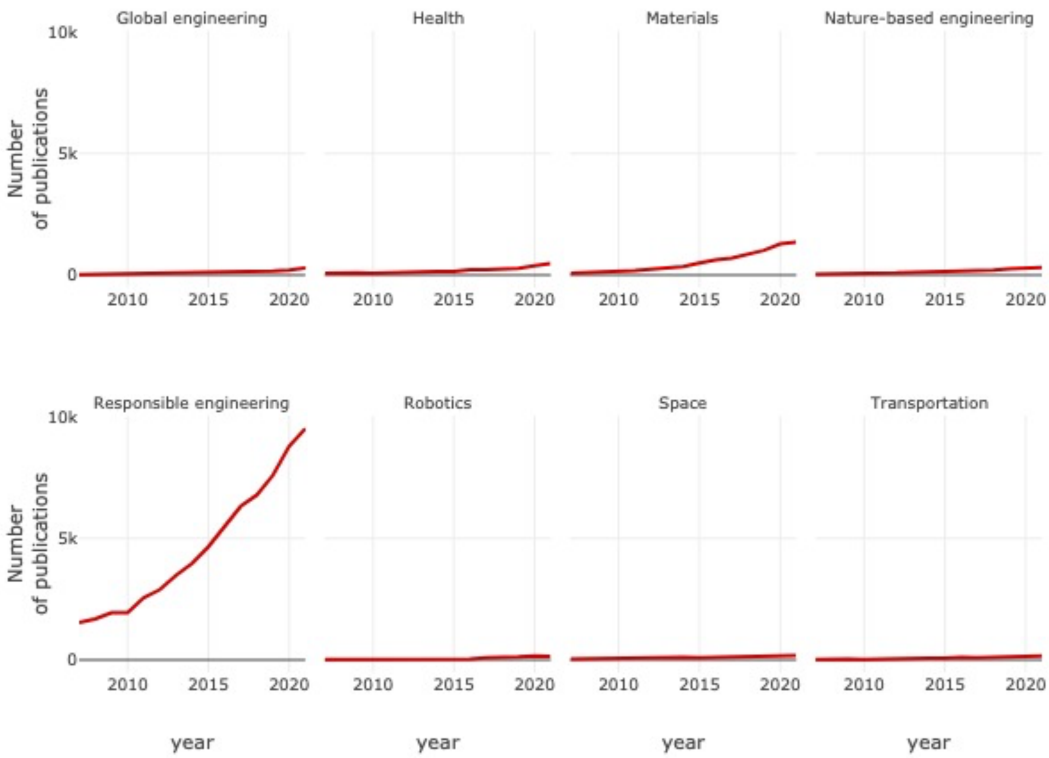

Figure 5: Time trends for UK engineering research publications across the TERC Technological Challenges.

4.2 Engineering's contribution to societal challenges

Engineering research in the UK demonstrates a significant contribution to research that addresses societal, environmental, and economic issues as defined by the SDGs. This is evidenced by the number of citations accrued by UK engineering research in publications related to the three dimensions of the SDGs. Significant attention is paid to areas including climate change, innovation (including in supply chains), and responsible consumption (based on the percentage of UK engineering publications cited in research that covers these areas).

There is also evidence that UK engineering research is highly cited in documents published by governments and nongovernmental institutions (e.g., WHO, World Bank, etc.), in particular, in the Machine Learning (4611) subdiscipline in later years (as shown in Figure 6 below, which shows the percentage of UK engineering publications with policy citations across each subdiscipline (in red) and compares this against the average for UK engineering research (shown as a dotted line)).

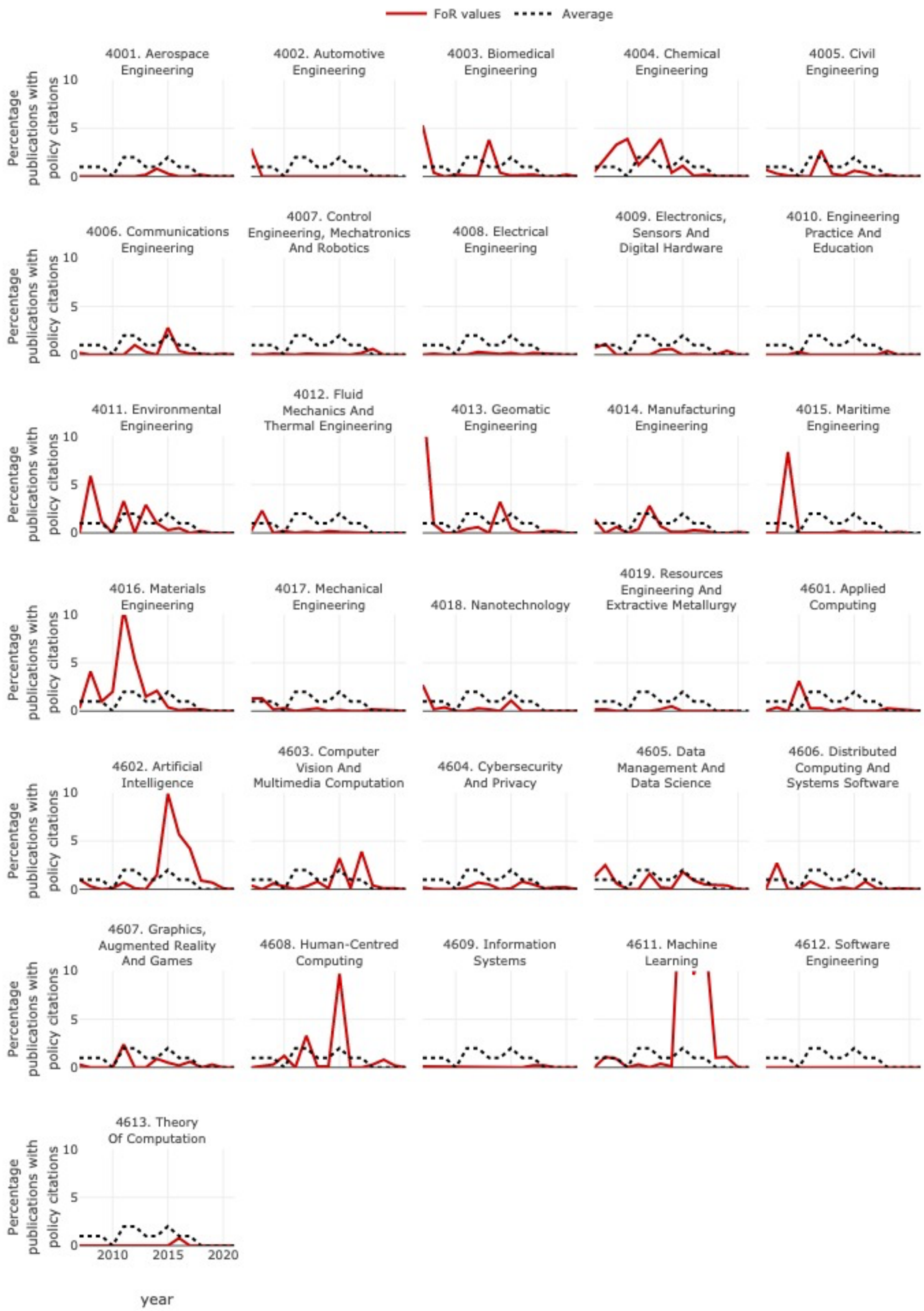

Figure 6: Percentage of UK engineering publications with policy citations from 2007 to 2021.

Main funders and industrial collaboration

Main funders

The findings outlined in Table 5 below indicate that a significant proportion of the funders acknowledged in UK engineering research is UK-based, with the EPSRC being the most prominent funder. More specifically, two-thirds of UK research publications in engineering credit the EPSRC as a funder in the acknowledgement sections. It is important to note here that this analysis is based on funders being credited in the acknowledgement sections rather than on value of funding, as not all publications in Dimensions have complete information on grants data; funders can also be acknowledged by co-authors.

"A significant proportion of the UK engineering research is funded domestically, with the EPSRC being a prominent funder."

Table 5: Number of Engineering publications funded by the top 10 funders in the UK, from 2007 to 2021.

Funder	Number of publications
Engineering and Physical Sciences Research Council (EPSRC)	151,486
Royal Society	15,664
Natural Environment Research Council (NERC)	8,134
Medical Research Council (MRC)	7,467
Biotechnology and Biological Sciences Research Council (BBSRC)	6,852
Wellcome Trust	5,749
Royal Academy of Engineering	5,731
Science and Technology Facilities Council (STFC)	5,416
Leverhulme Trust	5,297
Innovate UK	5,291

Internationally, both the EU and China are recognised as influential funders and co-funders of international collaborative engineering research (see Table 6). It is crucial to note that China's role in funding UK engineering research is not necessarily direct; rather, it operates through a model of co-funding alongside UK funders and further analysis of this dynamic is merited. It has been anticipated that future international funding for UK research in this field from these two entities, as well as their overall contribution to UK engineering research publications, may face challenges due to the impact of Brexit and ongoing geopolitical tensions. However, the recent association with Horizon Europe will likely help alleviate funding pressures.

"Internationally, both the EU and China are recognised as influential funders and co-funders of international collaborative engineering research."

Table 6: Number of UK Engineering publications funded by the top 10 global funders, from 2007 to 2021.

Funder	Country	Number of publications
European Commission	-	65913
National Natural Science Foundation of China	China	55396
European Research Council	-	16265
Ministry of Science and Technology of the People's Republic of China	China	15381
China Scholarship Council	China	10135
Ministry of Economy, Industry and Competitiveness	Spain	6050
Ministry of Education of the People's Republic of China	China	6018
Deutsche Forschungsgemeinschaft	Germany	4954
Australian Research Council	Australia	4069
Japan Society for the Promotion of Science	Japan	3879

Industry funding and collaboration

In industry, funding has declined in the majority of subdisciplines. This is particularly marked in Manufacturing Engineering (4014) and Mechanical Engineering (4017), which are medium sized in terms of their research volume (see Figure 7). Conversely, there is a more mixed trajectory in industry funding predominantly originating from the US (key funders including Google, Nvidia, and Microsoft) in the Computer Science disciplines including Graphics, Augmented Reality, and Games (4607) as well as Machine Learning (4611) and Applied Computing (4601), and in Engineering for the subdiscipline Engineering Practice and Education (4610). Given the growing significance of the digital domain in the world today, this development is perhaps not unexpected.

"Industry funding has declined. This is particularly marked in subdisciplines such as Manufacturing Engineering (4014) and Mechanical Engineering (4017)."

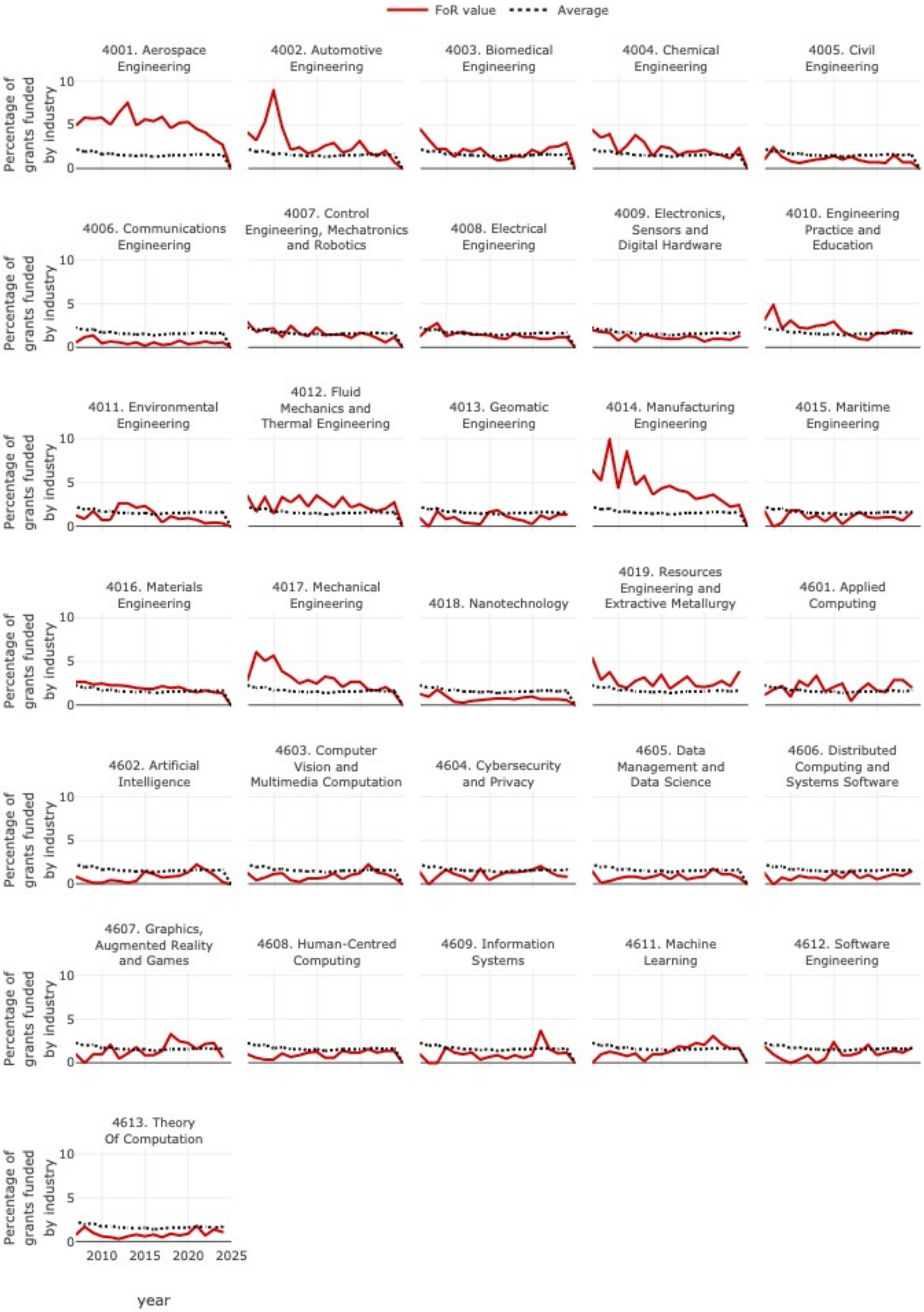

Figure 7: Time trends for percentage of UK engineering research grant funding by industry.

The data further shows that in the majority of engineering subdisciplines there is a decline in industrial collaboration (see Figure 8). In fact, industry collaboration appears in 5% or fewer of UK engineering publications across all subdisciplines, with the exception of Manufacturing Engineering (4014). It is unlikely that this pattern is being driven by changes in the way industry participation is recorded in publications (there is no evidence of this), which suggests that the figures do capture a potential decline in collaboration which is more pronounced in a number of specific subdisciplines. For example, Automotive Engineering (4002) reveals a decrease from 12% to 3%.

Only a few subdisciplines have maintained a consistent level of industry partnerships including Control Engineering, Mechatronics and Robotics (4007), Biomedical Engineering (4003), and Machine Learning (4611), just above or in line with the average. Trends of this nature are hard to explain; however, it is possible that funding constraints may in part account for this decline, leading to a decrease in corporate engagement or the academic focus of more academic collaboration in general, particularly in an international context.

Anecdotal evidence (shared by Academy Fellows and based on Technopolis' past evaluations for UKRI) also suggests an increased wariness of industry to fund external R&D and to collaborate with academics for fear of not being able to protect their IP and support the creation of potential competitors. This may be confounded with the fact that academics are incentivised to commercialise their technology, in the form of spin-outs.

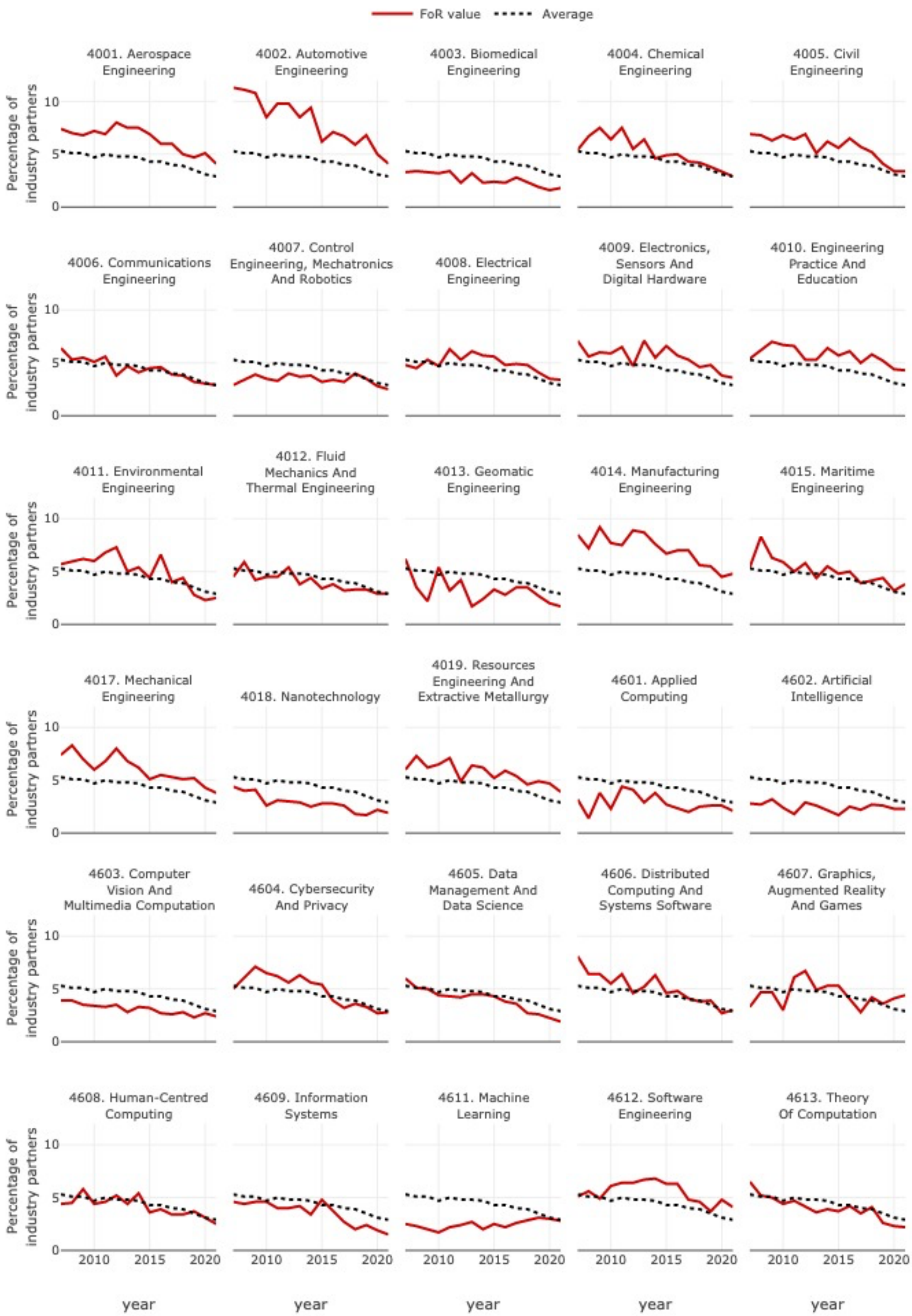

Figure 8: Percentage of industry partners in collaborative UK engineering publications.

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