A UNIVERSITY ALLIANCE *report*

Funding research excellence:

research group size, critical mass & performance

UNIVERSITY ALLIANCE

About University Alliance

University Alliance is a group of 23 major, business-engaged universities committed to delivering world-class research and a quality student experience around the UK.

Alliance universities have innovation and enterprise running through everything they do and deliver – the courses they offer; their leading graduate prospects; the impact of their research; how they work with business, the professions and the community; the leading role they play in building regional economies; right down to the way they are run.

They are universities without boundaries: delivering economic and social growth through close links with their research, students and staff and the world around them – locally, nationally and internationally. With representation right across the UK they educate over 25% of all UK students, with large proportions of international and post-graduate students.

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Foreword

University Alliance institutions are proud of the world-leading research that they undertake. They have proved their value through the RAE. The main findings of this research are compelling: that the UK should continue a policy of funding excellence wherever it exists.

For those that argue that first we must build a critical mass in research in order to be excellent, our report demonstrates conclusively that quality is a driver of scale and not vice-versa. Based on an analysis of RAE2008, it is clear that there are small and medium-sized units that perform as well as, and often better than, the largest units. It is also clear that growing these units would not necessarily show further improvement in quality.

Our report also demonstrates why there is no significant correlation between productivity and research unit size. The data provides clear evidence that funding should always follow excellence where it is found, as any metric based on scale would not improve productivity. Indeed it could have the effect of excluding some of the very best units.

There are high-stakes in any of these arguments because sustaining and building the UK research base must be a central tenet of any strategy for growth in the UK economy. Without a system that ensures we fund a healthy and excellent research base, universities will struggle to compete in an increasingly well-funded global sector. Alliance institutions also drive innovation because we know that research that creates real social and economic impact is critical to growth in local communities as well as regional and national economies.

As the higher education market at home diversifies, students are likely to recognise the value of joining universities that provide a research informed, academic and entrepreneurial learning environment. Therefore, any coherent vision for the future of the sector must include the role of research and a renewed commitment to funding on the basis of excellence alone. We must also recognise that postgraduate students will be the next generation of researchers and so it is imperative that we build environments that enable them to develop. We risk jeopardising the UK's future as a world-leader in research and innovation if we do not.

We are grateful to Dr Jonathan Adams and Dr Simon Thomson at *Evidence* for carrying out the research for this report. We hope you find it useful and informative.

Janet Beer
Chair, University Alliance

Libby Hackett
Director, University Alliance

1. Executive Summary

This report was commissioned by University Alliance from *Evidence*, a business of Thomson Reuters. It describes a study of the issues surrounding critical mass, selectivity and concentration.

The first part of our study (Section 3) analyses the relationship between the size of research units and their performance and productivity. Size is indicated by the number of full-time equivalent Category A Staff, performance by the outcomes of RAE2008 and citation impact, and productivity by the number of papers per full-time equivalent Category A Staff. The data show that:

- There is no continuous relationship between research unit size and performance in RAE2008. Among smaller research units there may be a significant positive correlation between size and performance but above a certain threshold no further improvement is evident. It is also apparent that there are small and median-sized units which perform as well as, and in some cases better than, the largest units. There is no evidence that funding on the basis of scale would improve overall performance.

- There is no significant correlation between productivity and research unit size. Small and median-sized research units tend to be at least as productive as large units. Also, peak productivity is not generally associated with the largest units, but is often found around the median. This is consistent with a study of US NIH data concluding that "middle sized labs do best" (**Study says middle sized labs do best** (2010), Wadman). From the data it would appear that funding on the basis of scale would not improve overall productivity but might eliminate some of the best units.

- There is also no significant correlation between normalised citation impact and research unit size. Again, small and median-sized units can perform as well as the largest units, and the best performing units are often not the largest.

- Consistent with this data, we propose a model of the relationship between scale and performance. We hypothesise that, rather than scale driving excellence; it is excellence that can enable small units to grow. Small research units can perform well or poorly. Those that perform well may attract additional resources and potentially grow into larger units. Large units that perform poorly are not viable and rapidly lose resources causing them to shrink or cease to exist. If funding was to be concentrated on the basis of scale, small excellent units would be lost. The effect of this would be to stifle the research base. In other words, quality is a driver of scale and not vice-versa.

The second part of our study (Section 4) uses Impact Profiles™ to assess the distribution of citation impact. Citation data are highly skewed with many papers receiving no citations and few receiving many citations. Impact Profiles™ allow such distributions of citations to a body of papers to be visualised. These show that:

- There is, for most of the Units of Assessment (UoAs) analysed, little difference in the profiles of the University Alliance institutions, the group of institutions with fewer than the median number of Category A Staff, and the UK as a whole. A similar percentage of the research papers published by each of these groups receive equivalent numbers of citations. Where there are differences in the profiles these can be explained by low volumes of papers being mapped to the relevant UoA, or because of the strategies by which institutions select papers for RAE submissions.

- Because the quality profile of each of the groups of institutions analysed is similar, there is no evidence that removing funding from any particular group would increase overall performance.

Finally we assessed the capacity for training of doctoral students (Section 5). In order to do this we investigated the proportion of UK PhD students that are trained in University Alliance institutions. The data shows that:

- University Alliance institutions contribute a substantial proportion of the UK's doctoral training capacity in the professional subjects – in some areas over a quarter of the UK's doctoral training capacity.

We conclude, as we have done previously, that there is insufficient evidence that further concentration of research resources would be the best way to improve UK research performance (**Funding research diversity** (2003), *Evidence*). Furthermore, the future resourcing of research in the UK Higher Education sector needs to sustain the diverse network of research activity across all levels and disciplines that contributes to the UK's competitiveness (**The future of research** (2010), *Evidence*). Concentrating resources on the basis of scale would eliminate the excellent small research units that form the dynamic core of the UK research base. The policy implication of this is that the best way to improve the performance of the UK research base is to continue to fund excellence wherever it occurs.

2. Introduction

University Alliance is a group of 23 business-engaged UK universities that educate over 25% of UK students. It was founded in 2009 to provide the member institutions with a unified voice on issues of mutual importance and to contribute to debates on Higher Education policy. Further to its own report published in 2009 (**Concentration and diversity: understanding the relationship between excellence, concentration and critical mass in UK research** (2009), Aston and Shutt), University Alliance has commissioned this study to investigate the relationship between research unit scale and performance.

It has been argued that large academic research groups perform better than small ones, in the same way that business and industry experience economies of scale. Furthermore, it has been suggested that those departments below a certain size (the critical mass) cannot make effective use of, and therefore should not receive, research funding. Such arguments are not new and there is a significant body of research into this area. The findings are, however, somewhat mixed. Our own studies ((**The Role of Selectivity and the Characteristics of Excellence** (2000), Adams, Cook, Law, Marshall, Mount, Smith, Wilkinson, Bayers, Pendlebury, Small and Stephenson), (**Funding research diversity** (2003), *Evidence*)) have shown that in many subjects, while there is a correlation between scale and performance, there is also evidence of a threshold above which performance stops increasing as rapidly or in some cases starts to decrease.

These findings have been confirmed by others ((**Cooperation structure, group-size and productivity in research groups** (1985), Kretschmer), (**A note on effective laboratory size** (1985), Noltingk), (**Effects of resource concentration on research performance** (1994), Johnston), (**The extensive nature of group quality** (2010), Kenna and Berche), (**Study says middle sized labs do best** (2010), Wadman), (**Critical mass and the dependency of research quality on group size** (2011), Kenna and Berche)). Other research has concluded that there is no evidence of a significant correlation between group scale and productivity ((**Are big universities better than small ones?** (1995), Kyvik), (**Scientific productivity and group size: A bibliometric analysis of Norwegian microbiological research** (2000), Seglen and Aksnes), (**Exploring size and agglomeration effects on public research productivity** (2005), Bonaccorsi and Daraio)). In the pharmaceutical industry, evidence has shown that scale is an important element driving research and development productivity (**Scale, scope, and spillovers: The determinants of research productivity in drug discovery** (1996), Henderson and Cockburn) but the sector differs from academia in several respects.

We have also suggested that the HE data may reflect a different causative relationship between size and outcome (**Funding research diversity** (2003), *Evidence*): small units that perform good research acquire resources to grow while large units that perform poorly lose resources and decline. In other words, quality is a driver of scale and not vice-versa.

These findings have implications for the allocation of research resources to Higher Education Institutions (HEIs). Some argue for an increasing concentration of resources in fewer institutions (**Top universities should get funding to stop 'mediocrity', says Russell Group head** (2009), Hough and Moore), while others argue that further concentration would damage the UK research base (**Does High Quality Research Require Critical Mass?** (2009), Harrison). It has also been proposed that resources are best focused on the “middle”, with an effort made to increase the size of smaller research groups to a point where they become viable (**The extensive nature of group quality** (2010), Kenna and Berche). Finally, some have argued that continuing the practise of funding excellence wherever it occurs is the best approach. Our own work led us to conclude that there is no evidence that further concentration would be the best way to address problems of research performance in the UK (**Funding research diversity** (2003), *Evidence*) and that future resourcing of research in the UK Higher Education sector needs to sustain the pervasive network of research activity that contributes to the UK’s competitiveness (**The future of research** (2010), *Evidence*).

In 2009 University Alliance published a policy report on the subject of concentration of resources and excellence (**Concentration and diversity: understanding the relationship between excellence, concentration and critical mass in UK research** (2009), Aston and Shutt). This report draws on a range of sources, and particularly our previous studies. The report notes that selectively funding based on quality, and not concentration, has driven up quality of the UK's research base.

Furthermore, volume alone does not determine excellent research and the diverse spread of excellence across the UK is important for the UK research base and Higher Education sector. The report concludes that the UK should continue to selectively fund excellent research wherever it exists.

This report describes the results of three studies related to these issues:

- A re-examination of the relationship between scale and research performance and productivity (Section 3).
- An investigation of the distribution of research quality within research units (Section 4).
- An analysis of the capacity to train new researchers that University Alliance institutions represent (Section 5).

3. The relationship between scale and performance

In this Section we analyse the relationship between the size of research units and the performance of those units in terms of quality (as indicated by peer-review in RAE2008), productivity, and citation impact.

3.1 Indicators

There are numerous ways in which research unit capacity or size can be evaluated. For example, the number of researchers, the number of principal investigators or the amount of research funding received could all be used as indicators of capacity. In this report we have used the number of full-time equivalent (FTE) Category A Staff submitted by each HEI to selected UoAs in RAE2008 as an index of research unit size.

- **RAE2008 Category A FTE Staff** – These are research-active staff that were in post and on the payroll of the submitting university on 31 October 2007. These staff are the principal investigators, rather than post-doctoral researchers. While researchers in a more general sense might initially seem to be a better indicator of research capacity, the principal investigators represent the core capacity for research within institutions. These are the staff who apply for grants, recruit staff and doctoral students, manage and direct projects, and are ultimately answerable to funding bodies. For these reasons we have selected them as the most appropriate indicator of research unit size.

Research performance is not something that can be measured directly and the research process has an extremely diverse range of outputs and outcomes. Various indicators of research performance can be used but each focuses on different aspects. Therefore, a basket of multiple indicators needs to be considered. To index performance in this report we have used three indicators – one relating to productivity and two relating to different perspectives on research quality:

- **RAE2008 grade point average** – Research submitted to RAE2008 was graded by a peer-review process on a scale of 4*, 3*, 2*, 1* and unclassified; 4* being the highest (defined as world-leading), unclassified being the lowest (defined as falling below the standard of nationally recognised work). The percentage of work classified at each level can therefore be used to calculate a grade point average for each RAE2008 submission. We have used this grade point average to indicate the overall quality of research as indicated by the RAE2008 peer-review process (Section 3.4).

- **Papers per RAE2008 Category A FTE Staff** – The number of papers produced by an individual is a useful index of research activity or productivity. If the administrative burden on a research unit is independent of the size of the unit (i.e. it is a fixed cost), then it would be expected that productivity would increase in larger research groups. We have mapped the papers in the 252 Thomson Reuters journal categories to the UoAs used in RAE2008. This mapping allows papers published in fields corresponding to the RAE2008 UoAs to be identified. We used the number of papers published over the period 2001 to 2007 per unit of Category A FTE Staff submitted to RAE2008 to investigate the extent to which economies of scale are a factor in conducting research (Section 3.5).

- **Normalised citation impact** – Research publications are a key output of the research process. Such publications in turn cite others which are of specific importance or relevance. Therefore, research publications that receive a greater number of citations are likely to be those that have a greater impact on the field of study. We have also shown that high citation rates are correlated with other measures of research excellence (**Maintaining Research Excellence and Volume: A**

report by *Evidence* Ltd to the Higher Education Funding Councils for England, Scotland and Wales and to Universities UK (2002), Adams, Jackson, Law, Mount, Reeve, Smith and Wilkinson). Because citations accumulate over time and citation behaviour differs between research fields, citation counts per paper do not allow for comparisons across publication years and subject areas. We therefore normalise citation counts per paper to the world average for the relevant publication year and Thomson Reuters journal category. This is known as the normalised citation impact or nci. We calculated the nci of papers submitted to RAE2008 as an indicator of research quality (Section 3.6). Bibliometrics and citation analysis are described more fully in Appendix A.

3.2 Subject coverage

In discussion with University Alliance we have selected eight representative RAE2008 units of assessment (UoAs) in which their institutions are active. These UoAs span a range of disciplines covering medical and health research, biological sciences, social sciences, and the arts and humanities[1]:

- **UoA12 – Allied Health Professions and Studies.** The UoA includes (but is not limited to): biomedical sciences; nutrition and dietetics; optometry and orthoptics; radiography; podiatry; occupational therapy; physiotherapy; speech and language therapy; arts therapies; health promotion; psychosocial and ethical aspects of health and healthcare; associated health services research (to include methodological work on quantitative or qualitative procedures).

- **UoA13 – Pharmacy.** The UoA includes research in pharmaceutical sciences, clinical pharmacy and pharmacy practice, including but not limited to pharmaceutics, drug delivery, medicinal chemistry and drug design, natural product chemistry, pharmaceutical biochemistry, xenobiotic metabolism and toxicology, pharmaceutical microbiology, receptor biology and modes of drug action, pharmacogenomics, radiopharmacy, pharmacokinetics, pharmacoepidemiology, pharmaceutical analysis, pharmacoeconomics, pharmaceutical technology, pharmaceutical materials science (as it relates to medical devices and medicinal products), sciences underpinning the discovery and development of medicines, health services and policy research (including health economics) applied to pharmacy and medicines, pharmaceutical public health, and pharmaceutical workforce and education.

- **UoA16 – Agriculture, Veterinary and Food Science.** The UoA includes all aspects of agricultural, veterinary and food science, including basic through to applied research, and interdisciplinary research with a significant content in any of these areas of science.

- **UoA23 – Computer Science and Informatics.** The UoA includes the study of methods for acquiring, storing, processing, communicating and reasoning about information, and the role of interactivity in natural and artificial systems, through the implementation, organisation and use of computer hardware, software and other resources. The subjects are characterised by the rigorous application of analysis, experimentation and design.

- **UoA25 – General Engineering and Mineral & Mining Engineering.** The UoA includes: any multidisciplinary and interdisciplinary engineering research; mineral and mining engineering; and submissions from departments or centres which include two or more of the main branches of engineering, i.e. chemical, civil, electrical and electronic, metallurgy and materials, mechanical, aero and manufacturing engineering. It also includes multidisciplinary areas such as offshore

[1] The UoA descriptors are taken from the RAE2008 website: http://www.rae.ac.uk/

technology, renewable energy/energy conversion, industrial studies, medical engineering, bioengineering and environmental engineering. It also includes pedagogic research in engineering.

- **UoA30 – Architecture and the Built Environment.** The UoA covers all forms of research that are relevant to the built environment, including research in architecture, building science and building engineering, construction, landscape, surveying, urbanism, and other research in which the built environment (including its operation and use) forms a major field for application or provides the context for research.

- **UoA35 – Accounting and Finance.** The UoA includes accounting and finance in all its forms. Research of all types, empirical or theoretical, strategic, applied, or policy-focused will be considered of equal standing. The research areas and sub-areas covered include, but are not confined to: accounting education, accounting history, accounting theory, auditing, accounting and computing; accounting and government, public sector and not-for-profit organisations; behavioural finance, computational finance, corporate finance, corporate governance; critical, social and environmental accounting; finance theory, financial accounting and reporting, financial econometrics, financial institutions, financial management, financial markets, financial mathematics, international accounting, international finance, management accounting, managerial finance, market-based accounting research, methodology and methods, studies of the accounting profession, taxation, treasury management; and other aspects of accounting and finance.

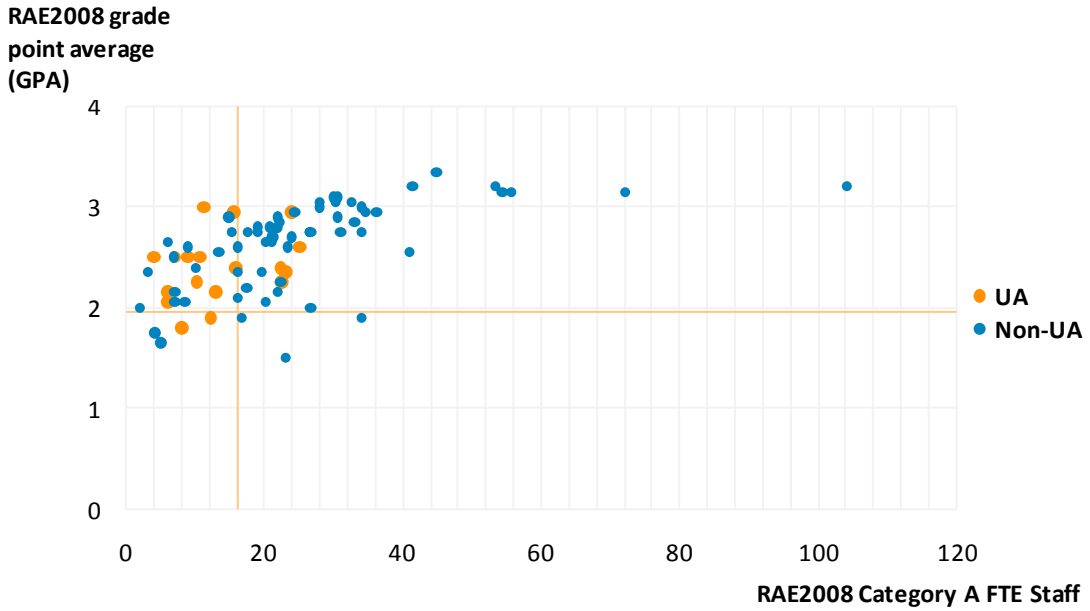
- **UoA63 - Art and Design.** The UoA encompasses all disciplines within art and design in which methods of making, representation, interrogation and interpretation are integral to their production. The UoA covers all areas of art and design, including but not limited to: fine arts, applied arts and crafts, design, spatial, two- and three-dimensional art and design, photography, time-based and digital media, critical, historical and cultural studies (where these relate to or inform art, media, design, production and practice), contributions to policy, management and entrepreneurship in the creative industries, arts and design, contributions to the construction of a scholarly infrastructure for arts and design through, for example, collections, archives, curation and pedagogy, curatorship, and appropriate pedagogic research in any of the areas identified above.

The subject focus of University Alliance institutions generally relates to the professions, and this is reflected in the selection of UoAs surveyed here. Research in these disciplines is often communicated using media other than scholarly journals and these areas tend to be less well covered by publication databases. These discipline factors are fully described in Appendix A.

3.3 Scatter plots

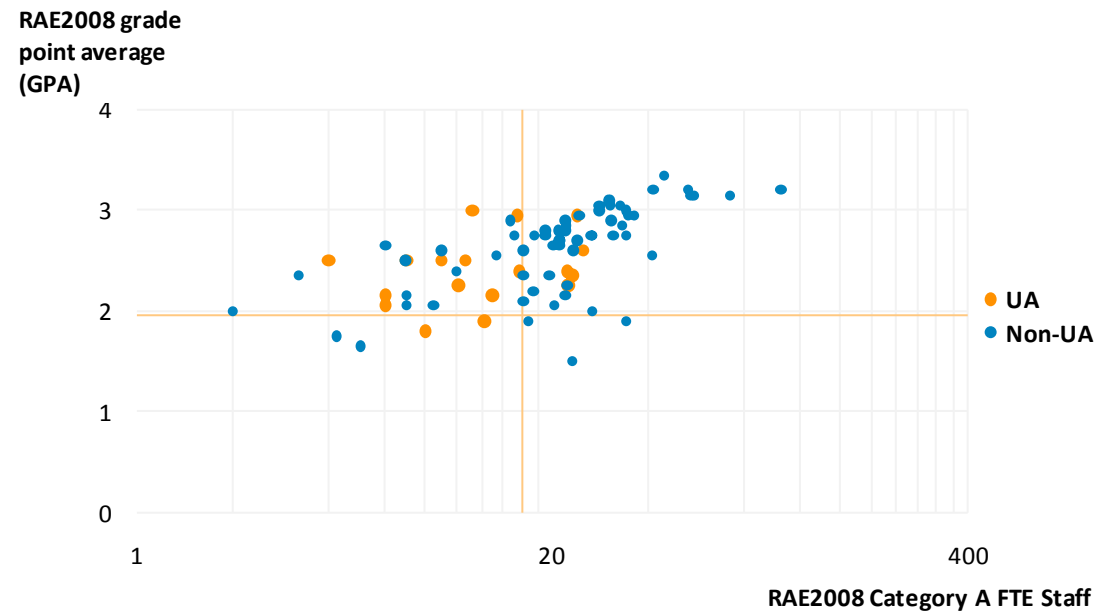
We have produced scatter plots to visualise the relationship between these indicators and unit size and examined dependencies across the data variables. All data on research activity are skewed, with many instances of low values and a small number of instances of exceptional values. Thus, data on numbers of RAE2008 Category A FTE Staff are skewed with many smaller research units and very few large units (Figure 3.3.1). Therefore, to allow the spread of the data to be visualised more easily, we have plotted the number of RAE2008 Category A FTE Staff on a logarithmic axis (Figure 3.3.2). The data for papers per RAE2008 Category A FTE Staff are also highly skewed with many low values and fewer high values, so we have also plotted these on a logarithmic axis (Figure 3.3.3). Where data are categorical (such as averages calculated from grade points) or are already indexed (such as normalised citation impact, nci), it is not appropriate to transform the axis.

Figure 3.3.1 RAE2008 grade point average plotted against RAE2008 Category A FTE Staff on a linear scale (UoA23)



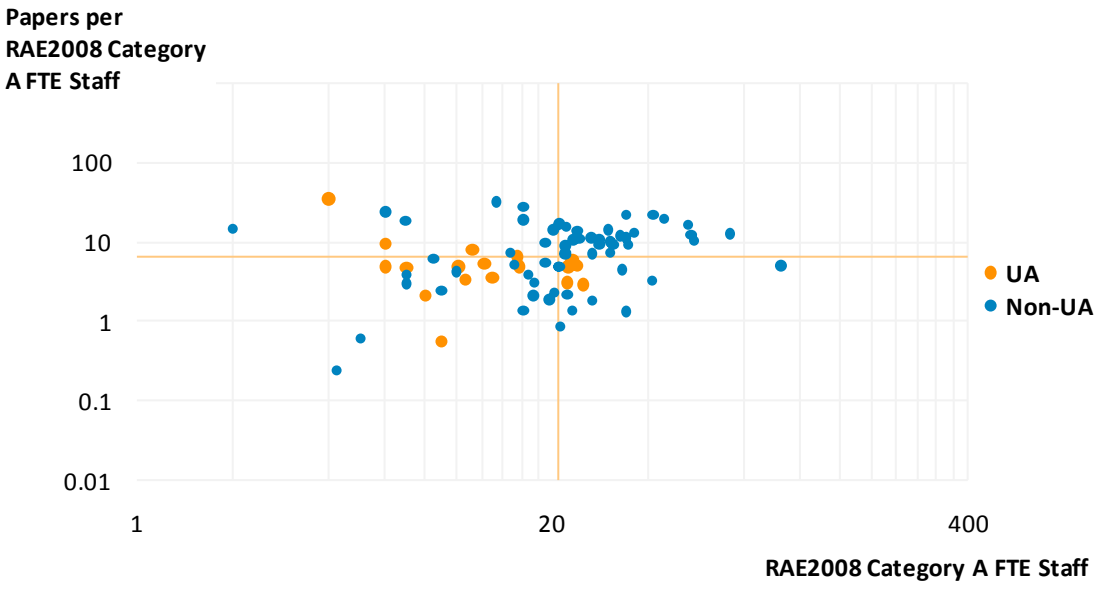
Data: HEFCE. Analysis: *Evidence*, Thomson Reuters

Figure 3.3.2 RAE2008 grade point average plotted against RAE2008 Category A FTE Staff on a logarithmic scale (UoA23)



Data: HEFCE. Analysis: *Evidence*, Thomson Reuters

Figure 3.3.3 Papers per RAE2008 Category A FTE Staff plotted against RAE2008 Category A FTE Staff on a logarithmic scale (UoA23)



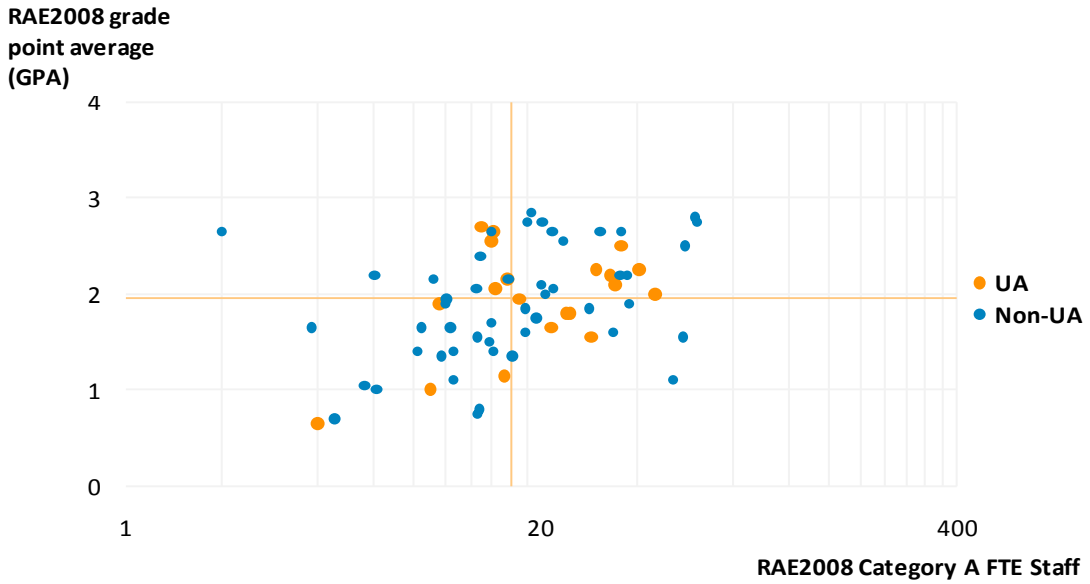
Data: HEFCE and Thomson Reuters. Analysis: *Evidence*, Thomson Reuters

3.4 Research unit size and RAE2008 grade point average

In this Section we analyse the relationship between research unit size and performance in RAE2008. Research unit size is indicated by RAE2008 Category A FTE Staff and performance in RAE2008 by grade point average (GPA). We analyse this relationship for each of the eight UoAs described above. We have illustrated the data in a series of scatter plots with University Alliance institutions highlighted in orange and the median number of RAE2008 Category A FTE Staff and median grade point average indicated by vertical and horizontal lines, respectively. As described above, we have presented the x-axis for RAE2008 Category A FTE Staff logarithmically to better visualise the distribution of the data given that they are often heavily skewed with a greater number of smaller research units than larger research units.

Figure 3.4.1 is a scatter plot showing the relationship between RAE2008 grade point average and RAE2008 Category A FTE Staff for UoA12 (Allied Health Professions and Studies). A statistical analysis of these data would indicate a significant positive correlation. This is because research units with more than the median number of RAE2008 Category A FTE Staff tend to achieve a higher grade point average than those with fewer than the median. The relationship, however, is not linear. There are units with fewer than the median number of RAE2008 Category A FTE Staff that perform as well as the best performing larger units. The key to this correlation is the relative scarcity of very poorly performing larger units. This is because larger units are generally only viable if they are also high performing.

Figure 3.4.1 – The relationship between research unit size and RAE2008 grade point average – UoA12

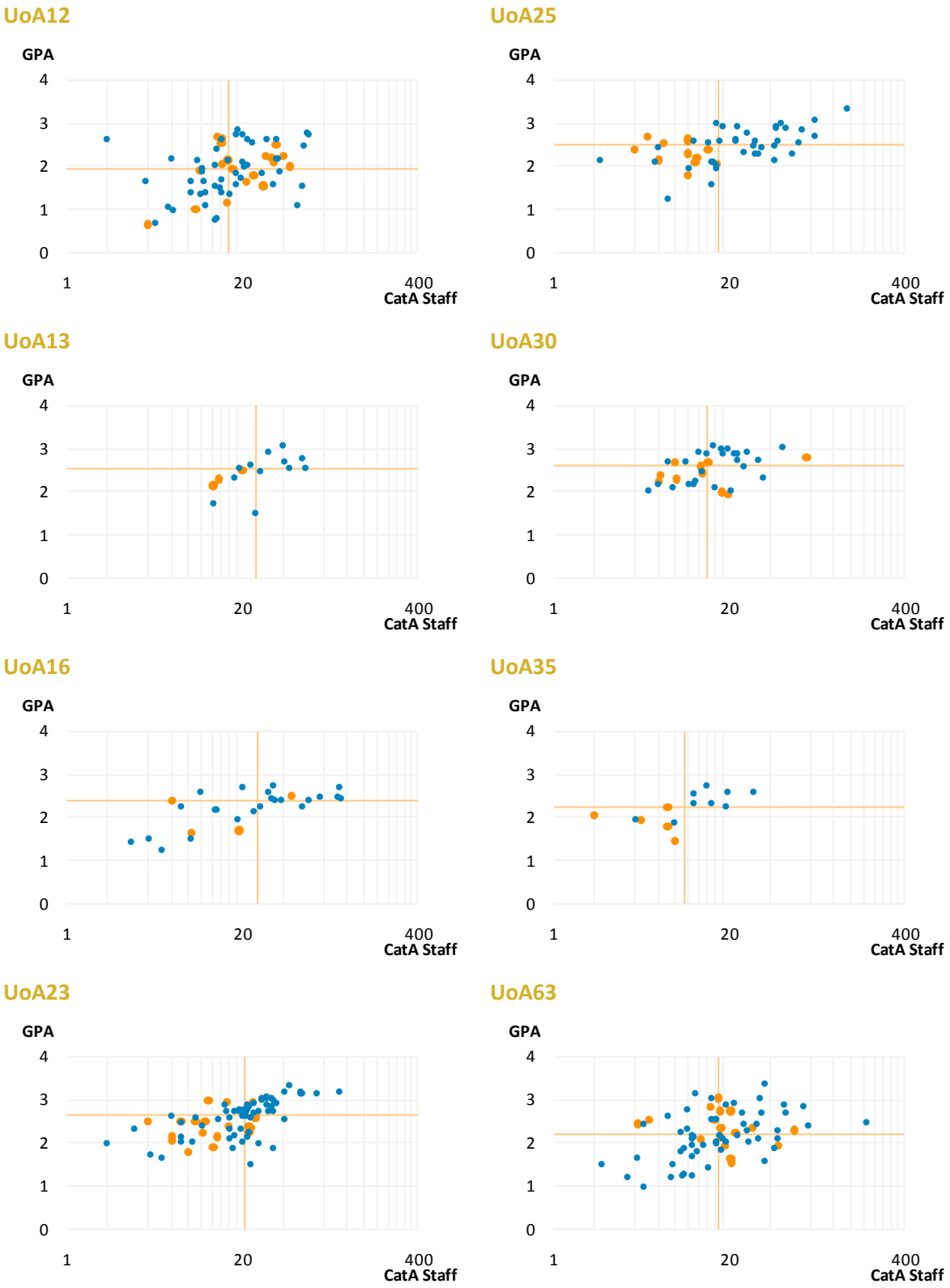


Data: HEFCE Analysis: *Evidence*, Thomson Reuters

Figure 3.4.2 comprises a series of scatter plots for different UoAs showing that there is a common pattern as exemplified by UoA12, above. There is a significant positive correlation between research unit size and grade point average, but this is not a continuous linear relationship. There are units of below median-size that perform as well as the best performing units (in the upper left quadrant) while there are relatively few poorly performing large research units (in the lower right quadrant). In other words, the performance of small research units ranges from poor to strong but large research units tend to perform well. This suggests that size does not drive performance. An alternative hypothesis is that small research units may perform well or poorly. Those that perform well can potentially attract resources and become large units. Poorly performing large units would be unsustainable and lose resources rapidly (Figure 3.4.3). Concentration of resources into larger

research units would withdraw support from all small research units regardless of performance. This would eliminate those small but excellent units that have the potential to grow into larger potentially higher-performing units.

Figure 3.4.2 The relationship between research unit size and RAE2008 grade point average – All UoAs



Data: HEFCE. Analysis: *Evidence*, Thomson Reuters

Figure 3.4.3 Charts showing the dynamic of the relationship between research units size and performance

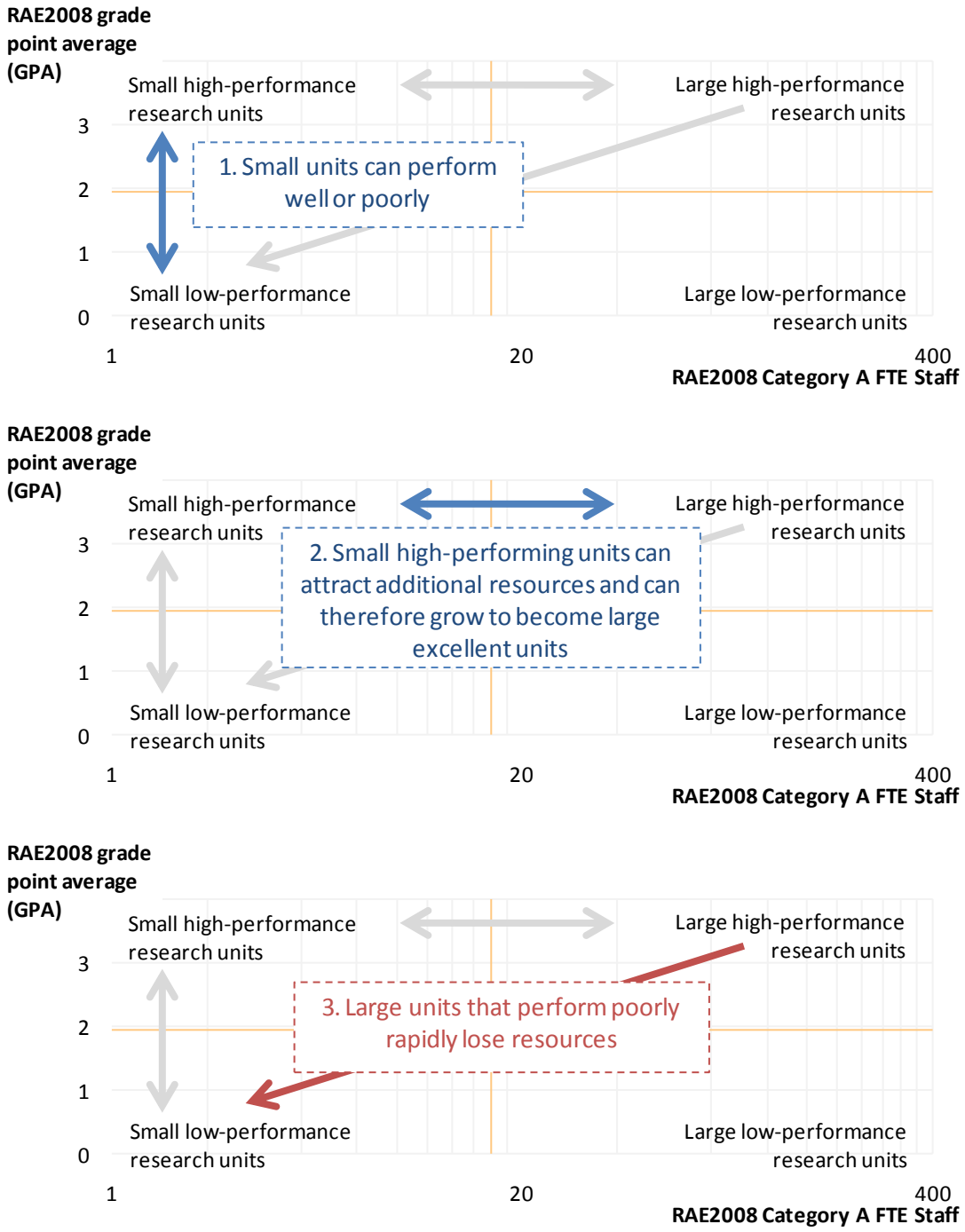
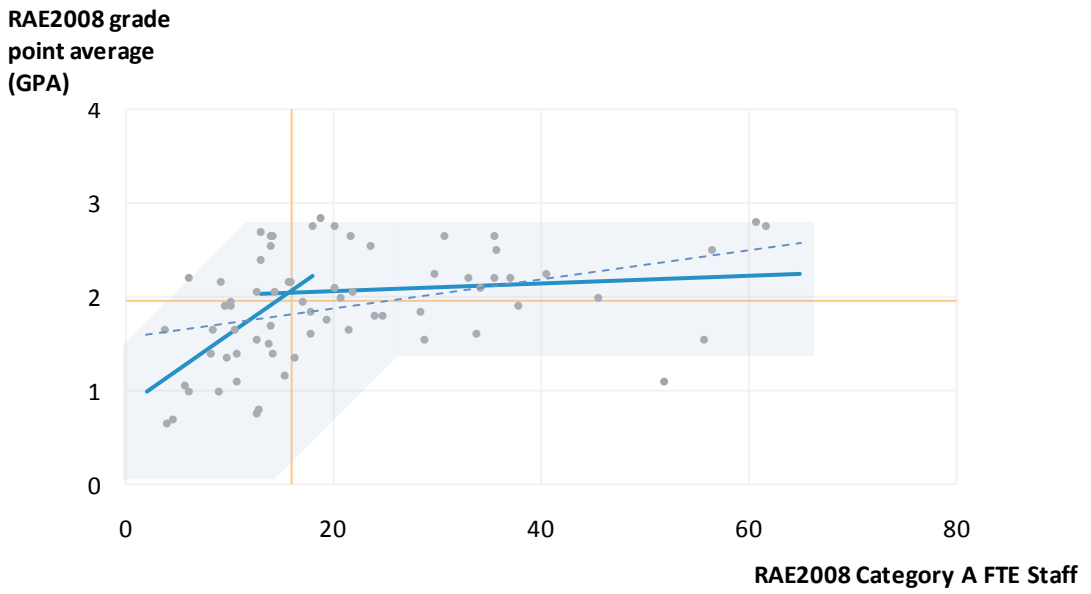


Figure 3.4.4 shows that the positive correlation between size and performance may be strongest for smaller research units, and that above a certain threshold no significant improvement is observed. This Figure also uses a dashed line to show how the relationship between size and performance would appear if it were continuous and linear. The data may, therefore, indicate the existence of a true critical mass below which units are not viable. This is likely to be relatively small and to differ between subjects. Nevertheless, there is no evidence that concentrating resources in the largest units would substantially improve overall performance.

Figure 3.4.4 Indicative changes in the linear relationship between RAE2008 grade point average and research unit size, (UoA12 excluding identified outliers)



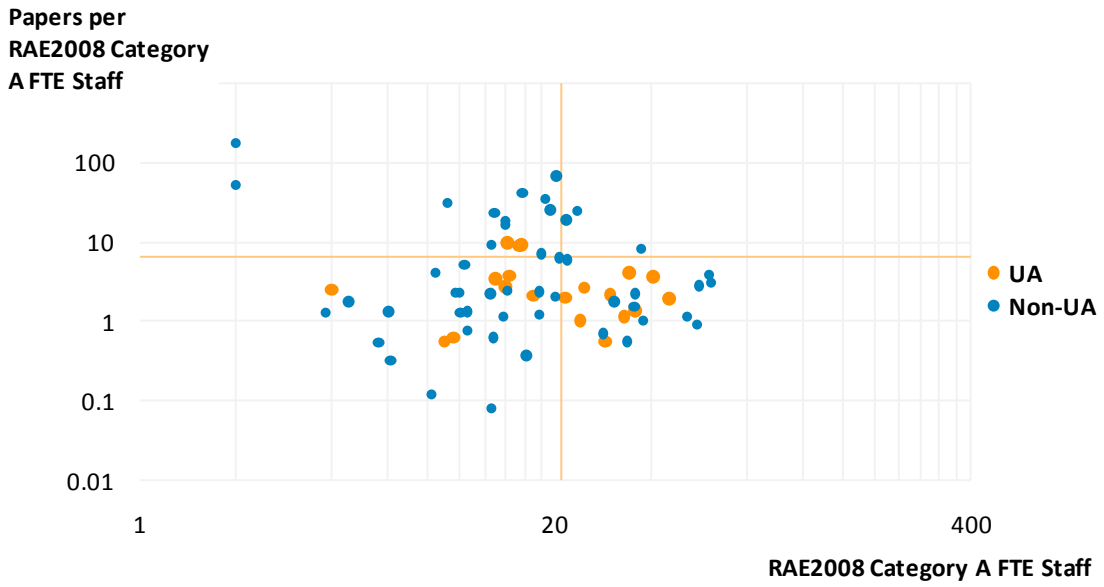
Data: HEFCE. Analysis: *Evidence*, Thomson Reuters

3.5 Research unit size and researcher productivity

In this Section we analyse the relationship between research unit size and researcher productivity. Research unit size is indicated by the number of RAE2008 Category A FTE Staff, and researcher productivity is measured by the number of articles and reviews (which we collectively term 'papers' here) on the Thomson Reuters Web of Knowledge℠ databases per RAE2008 Category A FTE Staff. We analyse this relationship for each of the eight UoAs described above. We have shown the data as a series of scatter plots with University Alliance institutions highlighted in orange and the median number of RAE2008 Category A FTE Staff and median nci indicated by vertical and horizontal lines, respectively. As mentioned above, such data are heavily skewed so we have presented the x-axis for 'RAE2008 Category A FTE Staff' logarithmically to better visualise the distribution of data points. We have also presented the y-axis for 'papers per RAE2008 Category A FTE Staff' logarithmically given that this data is also heavily skewed with a greater number of low values than high values.

Figure 3.5.1 is a scatter plot showing the relationship between papers per RAE2008 Category A FTE Staff mapped to UoA12 (Allied Health Professions and Studies) against the number of RAE2008 Category A FTE Staff submitted to this UoA. As papers per RAE2008 Category A FTE Staff is an indicator derived from RAE2008 Category A FTE Staff, we technically cannot correlate the two variables directly using parametric correlations, rather a rank correlation could be used. There are very powerful outliers with a high number of papers per RAE2008 Category A FTE Staff, heavily skewing these data. Given these caveats, it appears broadly that there is no correlation between research unit size and researcher productivity in UoA12. Furthermore, there are small and median-sized research units which appear to perform as well as larger research units (give or take the outliers) and the highest productivity is observed for units with around the median number of RAE2008 Category A FTE Staff. University Alliance members appear to perform similarly to the overall distribution of data.

Figure 3.5.1 The relationship between research unit size and researcher productivity – UoA12



Data: HEFCE and Thomson Reuters. Analysis: *Evidence*, Thomson Reuters

Figure 3.5.2 comprises a series of scatter plots illustrating that there is a mixed relationship between capacity and researcher productivity. There are numerous reasons that could account for this, including:

- **Subject mappings:** For this analysis we have mapped research papers in the Thomson Reuters Web of Knowledge℠ database to the UoAs used in RAE2008. Because of differences between the Web of Knowledge℠ journal categories and the UoAs, direct mappings for some areas are less robust than in others.

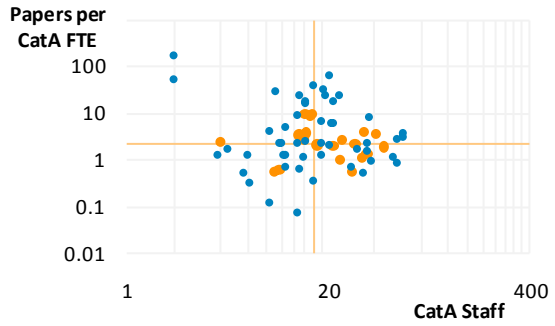
- **RAE2008 submissions versus institutional research:** The publication data from the Thomson Reuters Web of Knowledge℠ covers all research related to a given UoA regardless of where in an institution this takes place. The RAE2008 Category A FTE Staff from UoA submissions will, however, reflect organizational divisions within institutions. For example, the Sociology research taking place in a given institution is not the same as the research taking place in that institution's Sociology department.

- **Discipline factors:** The subject focus of University Alliance institutions is generally on the professions, and this is reflected in the selection of UoAs surveyed here. Research in these disciplines is often communicated using media other than scholarly journals and these areas tend to be less well covered by publication databases making literature-based studies less appropriate.

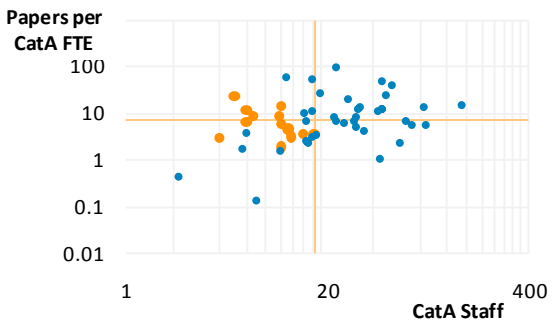
Nevertheless, a general pattern emerges, as exemplified by UoA12 (above): small units can perform as well as the largest units and peak productivity is generally observed amongst the smaller to median-sized units. Therefore, these data suggest that concentration of resources on the basis of size alone will not improve overall performance.

Figure 3.5.2 The relationship between research unit size and researcher productivity – All UoAs

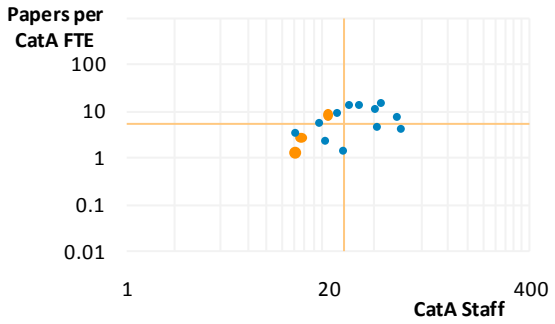
UoA12



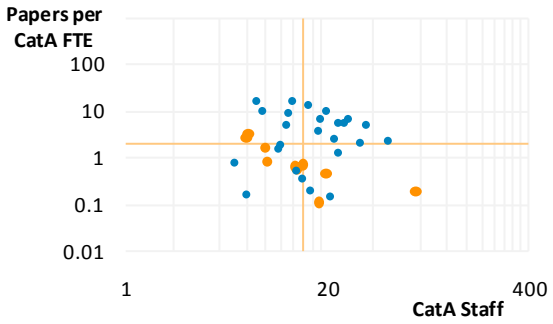
UoA25



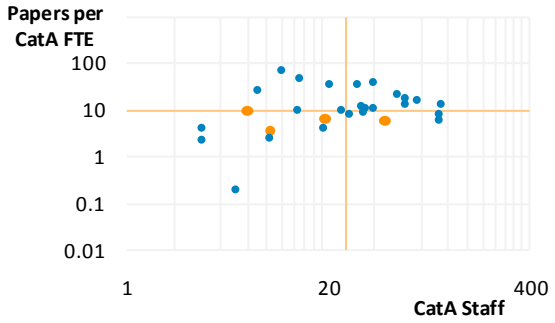
UoA13



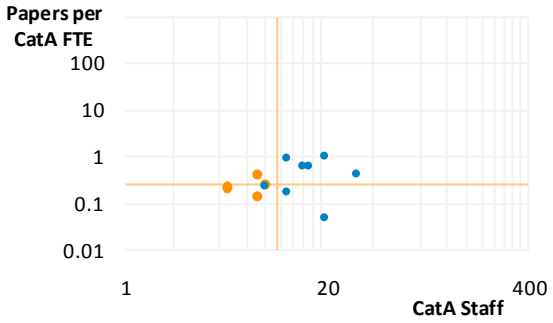
UoA30



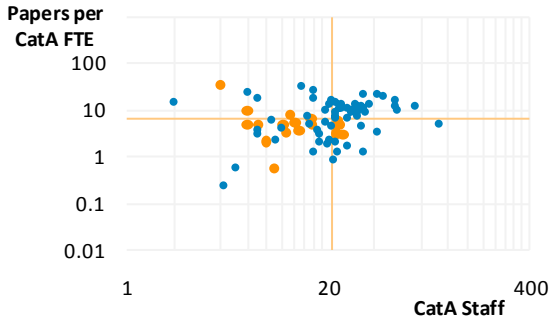
UoA16



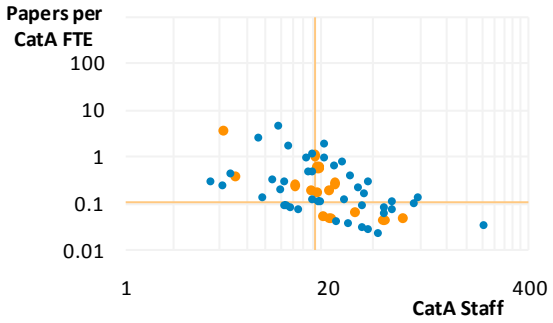
UoA35



UoA23



UoA63



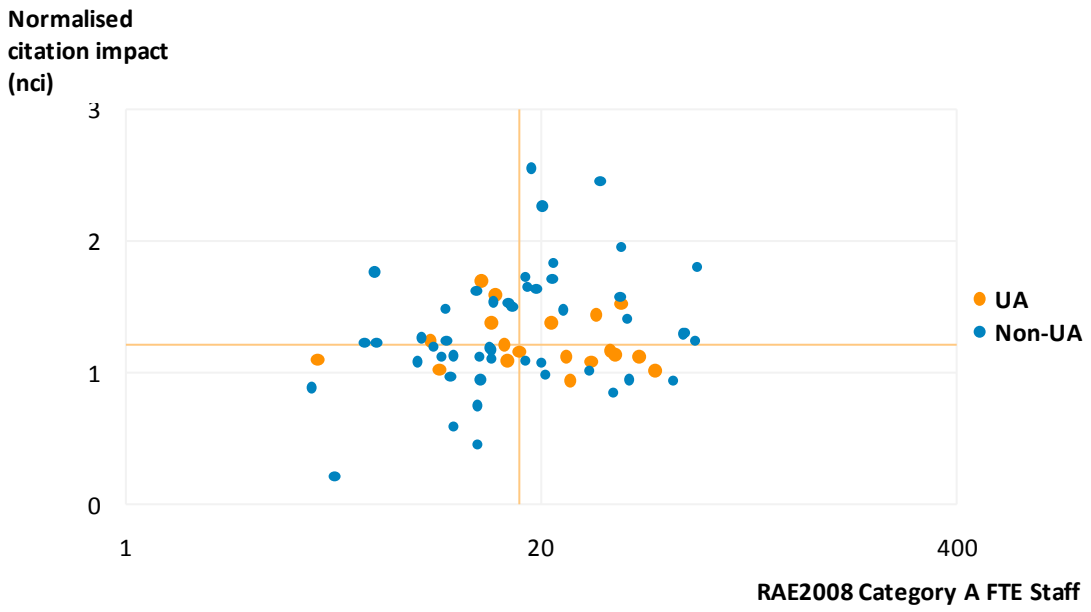
Data: HEFCE and Thomson Reuters. Analysis: *Evidence*, Thomson Reuters

3.6 Research unit size and citation impact

In this Section we analyse the relationship between research unit size and normalised citation impact (nci). Research unit size is indicated by the number of RAE2008 Category A FTE Staff. We have mapped the research papers submitted to RAE2008 to Thomson Reuters Web of Knowledge℠ databases. Using these data we have calculated the nci of those papers. We have analysed this relationship for each of the eight UoAs described above. We have shown the data as a series of scatter plots with University Alliance institutions highlighted in orange and the median number of RAE2008 Category A FTE Staff and median nci indicated by vertical and horizontal lines respectively. As described above we have presented the x-axis for RAE2008 Category A FTE Staff logarithmically to better visualise the distribution of data given that they are often heavily skewed with a greater number of smaller research units than larger research units.

Figure 3.6.1 is a scatter plot showing the nci of research papers submitted to UoA12 (Allied Health Professions and Studies) against the number of RAE2008 Category A FTE Staff submitted to UoA12. These data show a correlation between research unit size and performance as measured by nci. In general, smaller research units tend to perform less well than larger research unit, and have a lower range of nci compared to larger research units. Nevertheless, there are median size research units which perform as well as, if not better than, larger research units, and the very largest research units do not seem to perform better than those of around median size. The research units submitted to RAE2008 by University Alliance institutions vary in size from relatively small to relatively large but tend to have an nci of around the median value.

Figure 3.6.1 The relationship between research unit size and nci – UoA12

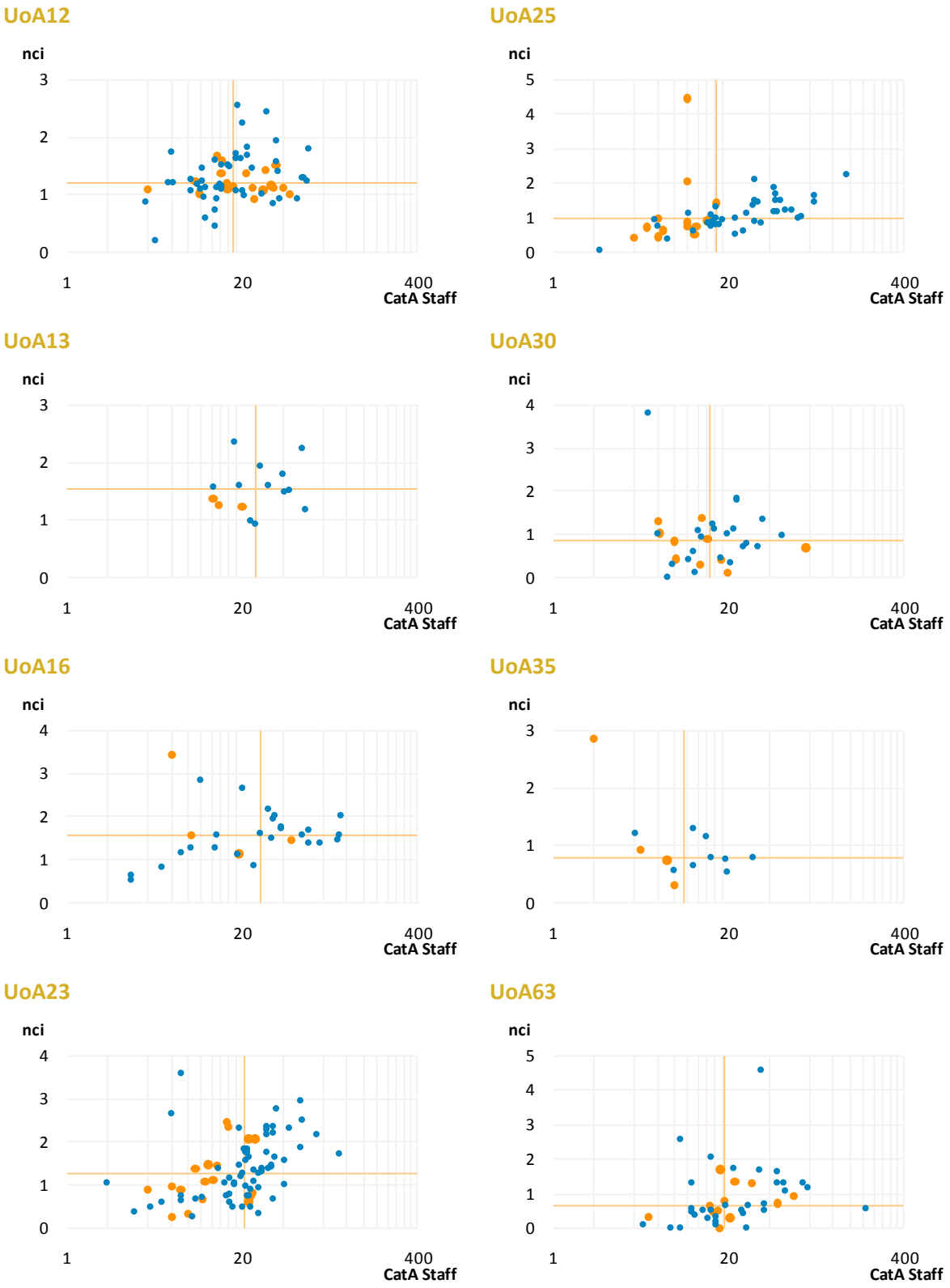


Data: HEFCE and Thomson Reuters. Analysis: *Evidence*, Thomson Reuters

Figure 3.6.2 comprises a series of scatter plots illustrating the relationship between nci and numbers of RAE2008 Category A FTE Staff. The data show that the relationship differs by UoA. As above, this may be because of mapping issues or discipline factors, where journal-based measures may not be appropriate for the unit in question. Often, these data do not show a positive correlation between capacity and performance as measured by nci. However, the general distribution of the data is similar to the relationship between productivity and capacity (Section 3.5). There are smaller research units that perform as well as the largest units, and that peak performance is generally not

observed amongst the largest units. This suggests that size is not the most significant driver of research performance as indicated by nci. In fact, the data suggest that if further concentration of research resources were to occur on the basis of scale alone, some strongly performing units may indeed be sacrificed.

Figure 3.6.2 - Normalised citation impact (nci)



Data: HEFCE and Thomson Reuters. Analysis: *Evidence*, Thomson Reuters

4. The distribution of research quality

Indicators of research quality are highly skewed, with many low performance values and a few exceptionally high values. In such distributions the average (normalised citation impact (nci) in the tables below) is far from the median or centre of the distribution and gives less information than might be expected about the balance between poor, good and excellent performance. The policy issue is that there may be excellent activity present even where the average outcome is less than in other units.

To overcome the problem of analysing the distribution of skewed citation data, *Evidence* has developed a bibliometric methodology which shows the percentage of papers which are uncited and the percentage of papers that lie in each of the eight categories of nci. An Impact Profile® therefore allows the distribution of citation impact within a body of research papers to be visualised relative to the world average and relative to reference profiles. We compare three groups using submissions to RAE2008 by UoA:

- University Alliance institutions (UA)
- Institutions with below median RAE2008 Category A FTE Staff as submitted to RAE2008 (<Median)
- All institutions in the UK which submitted to the UoA (UK)

Impact Profiles® show the distribution of research performance and indicate excellent research as those papers receiving the most citations. Thomson Reuters has traditionally used the term 'highly-cited paper' to refer to the world's 1% of most frequently cited papers, taking into account year of publication and field. In rough terms, UK papers cited more than eight-times as often as relevant world average would fall into the Thomson Reuters highly-cited category. About 1%-2% of papers (all papers, cited or un-cited) typically pass this hurdle. Such a threshold certainly delimits exceptional papers for international comparisons but, in practice, is an onerous marker for more general purposes. In this report 'highly-cited' papers are defined as those with an nci greater than or equal to 4.0, i.e. those papers which have received greater than or equal to four times the world average number of citations for the relevant field and year. Impact Profile® methodology is described more fully in Appendix A.

In order to supplement the visualisation of research performance data presented in the Impact Profiles® below, we have supplied tables of data showing the nci and the percentage of highly-cited papers. We have also presented the average percentile of those papers. A paper lying in the first percentile is one that is cited in the world's top 1% by year and category – therefore, lower percentiles indicate higher research performance. We have also presented papers in the world's top 10% by year and category. Using the top 10% as our threshold of highly-cited, a highly performing research unit is one that has more than 10% of its papers in this category.

Data presented in these profiles and tables illustrate that there is excellent research present in University Alliance institutions in terms of papers submitted to RAE2008 across most of the selected UoAs where bibliometric analysis provides suitable indicators. Whilst the performance indicators are typically lower than for the UK as a whole (and, in some cases, for institutions with below median RAE2008 Category A FTE Staff), they still reveal a substantial amount of highly cited research and performance that is well above the world average.

Figure 4.1 UoA12 – Allied Health Professions and Studies

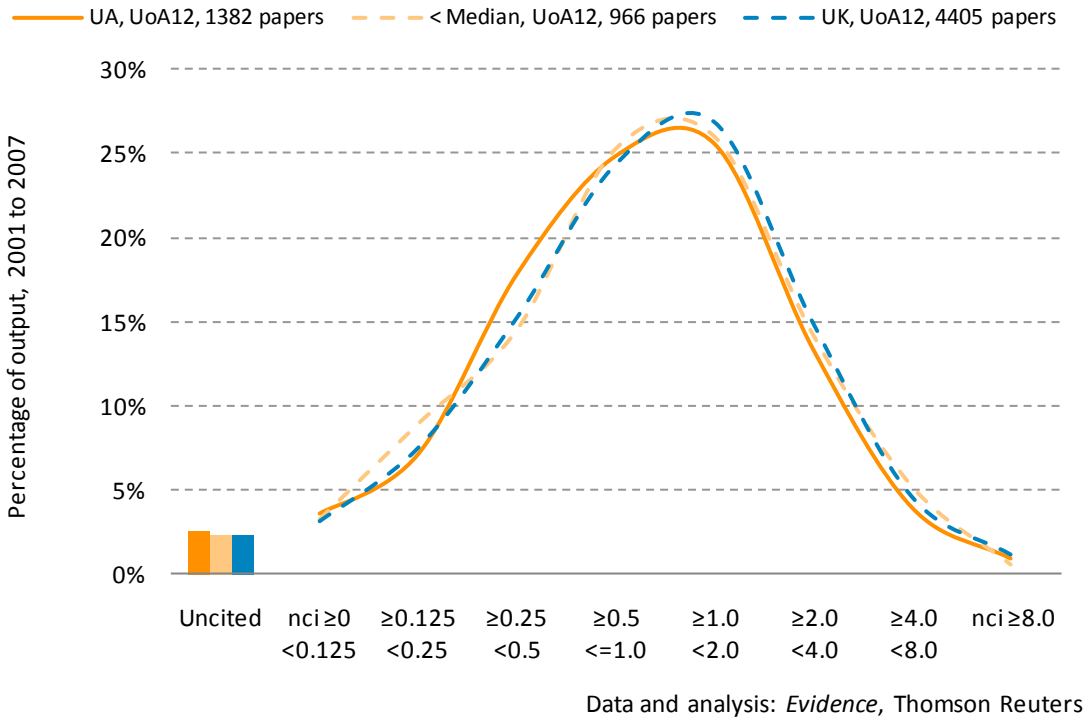


Table 4.1 UoA12 – Allied Health Professions and Studies

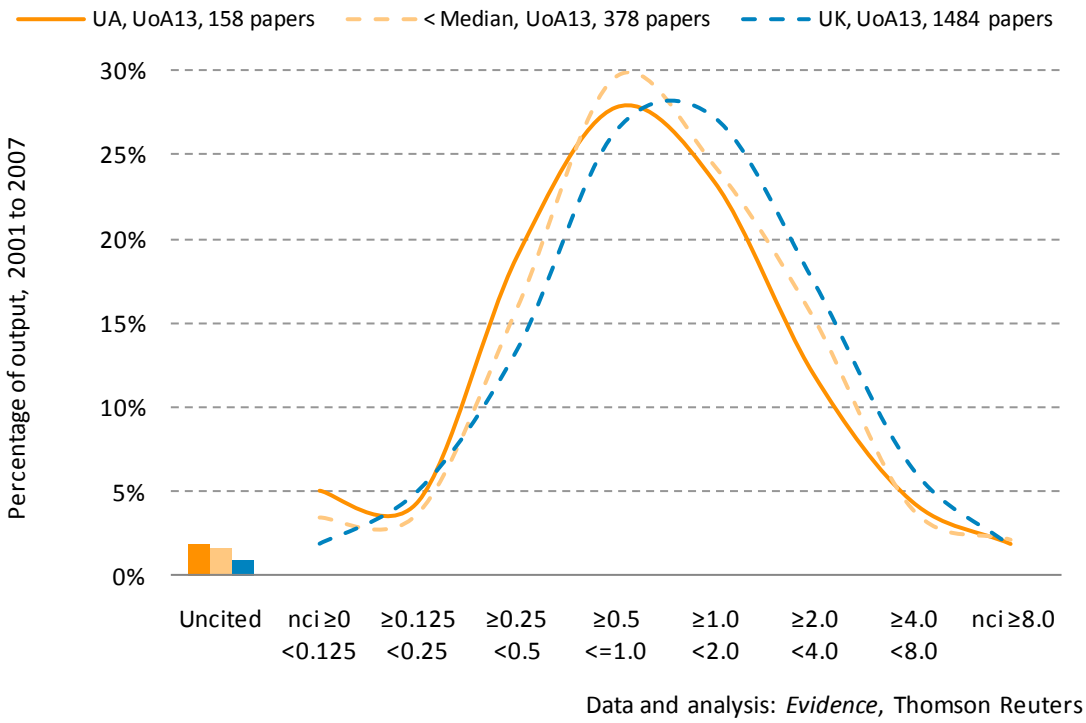
	nci	Highly-cited papers	Average percentile	Top 10%
UA	1.21	4.9%	40.8	14.9%
< Median	1.23	5.7%	39.7	14.6%
UK	1.36	5.8%	38.9	16.3%

The Impact Profile® for UoA12 (Allied Health Professions and Studies) shows that the distribution of citation impact for University Alliance RAE2008 papers is broadly similar to the UK background, and to institutions with below median RAE2008 Category A FTE Staff.

The percentage of papers in UoA12 that are uncited is broadly similar for each of the three comparators. Of the University Alliance institutions' research papers in UoA12, 4.9% are highly-cited compared to the UK background figure of 5.8%, an insubstantial difference. The average percentile of University Alliance research in this subject is 40.8, which is again similar to the UK background of 38.9. The percentage of University Alliance research in the top 10% worldwide is 14.9%, indicative of above world average performance. This is below the UK background figure of 16.3% but higher than the figure for institutions with below median RAE2008 Category A FTE Staff (14.6%). The nci of University Alliance members (1.21) is slightly below the UK nci (1.36) and that of institutions with below median RAE2008 Category A FTE Staff (1.23).

These data show that the performance of University Alliance institutions is very similar to the UK background using a variety of indicators. The effect of concentrating resources in larger institutions is, therefore, unlikely to lead to substantial improvements in overall performance.

Figure 4.2 UoA13 – Pharmacy



Data and analysis: *Evidence*, Thomson Reuters

Table 4.2 UoA13 – Pharmacy

	nci	Highly-cited papers	Average percentile	Top 10%
UA	1.28	6.3%	40.8	13.3%
< Median	1.43	6.1%	37.7	16.7%
UK	1.59	8.0%	33.9	21.8%

The Impact Profile® for UoA13 (Pharmacy) shows that the distribution of citation impact for University Alliance RAE2008 papers is slightly lower than the UK background and those institutions with below median RAE2008 Category A FTE Staff.

There are small differences between the percentage of University Alliance papers which are uncited and the UK background. University Alliance members have fewer highly-cited papers (6.3%) compared to the UK (8.0%) but marginally more than institutions with below median RAE2008 Category A FTE Staff (6.1%). The nci of University Alliance members (1.28) is above the world average of 1.0, but below the UK background (1.59). A similar pattern can be observed when analysing the average percentile of University Alliance research (40.8 versus 33.9 for the UK). University Alliance members have 13.3% of their RAE2008 papers in the top 10% worldwide which, whilst below the UK figure (21.8%), is still above the world average (10%).

These data illustrate that whilst the performance of University Alliance members is below the UK background in UoA13, they produce significant levels of highly-cited research and they perform above the world average.

Figure 4.3 UoA16 – Agriculture, Veterinary and Food Science

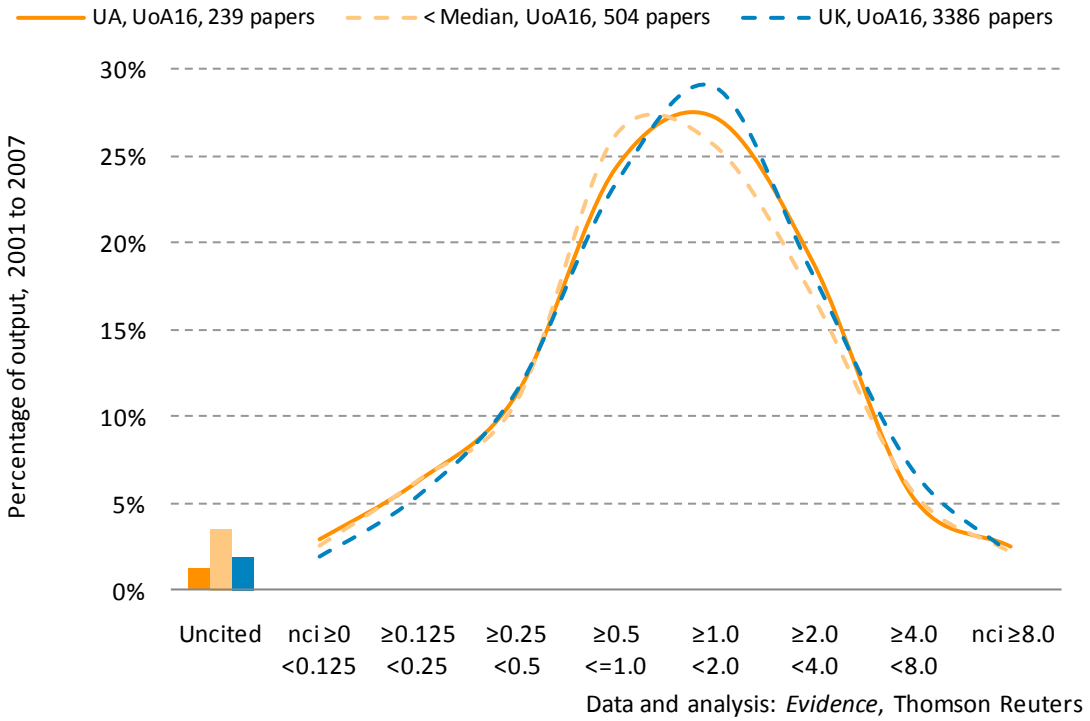


Table 4.3 UoA16 – Agriculture, Veterinary and Food Science

	nci	Highly-cited papers	Average percentile	Top 10%
UA	1.58	7.9%	35.0	21.8%
< Median	1.60	7.9%	37.3	20.2%
UK	1.66	9.0%	33.7	22.0%

The Impact Profile® for UoA16 (Agriculture) shows that the distribution of research impact for University Alliance RAE2008 papers is broadly similar to the UK background and that of institutions with fewer than the median number of RAE2008 Category A FTE Staff.

University Alliance institutions produce fewer uncited papers than the UK background and those institutions with below median RAE2008 Category A FTE Staff. The nci of University Alliance members (1.58) is significantly above the world average of 1.0, but marginally below the UK background (1.66). University Alliance has fewer highly-cited papers (7.9%) compared to the UK (9.0%) and the average percentile of its research (35.0) is not as high as the UK (33.7), but these differences are all quite small. University Alliance has 21.8% of its RAE2008 papers in the top 10% worldwide, over double the world average, and this is almost the same as the figure of 22.0% for the UK background.

These data illustrate that the performance of University Alliance institutions is similar to the UK background in UoA16, and is significantly above the world average.

Figure 4.4 UoA23 – Computer Science and Informatics

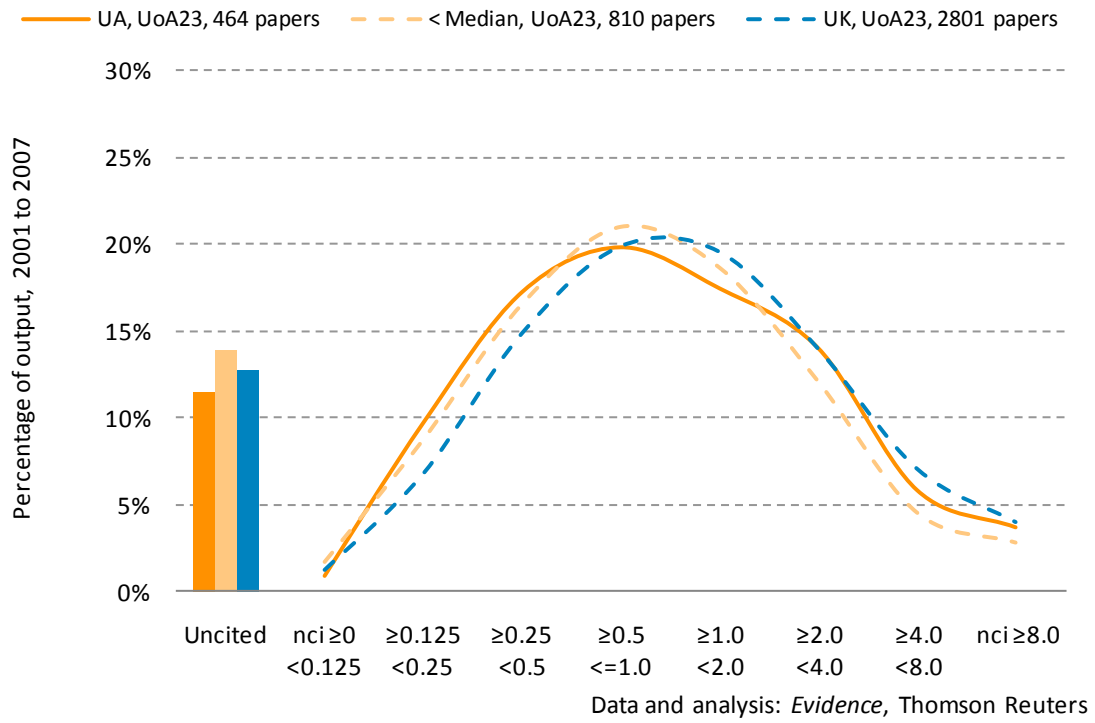


Table 4.4 UoA23 – Computer Science and Informatics

	nci	Highly-cited papers	Average percentile	Top 10%
UA	1.39	9.5%	42.3	17.7%
< Median	1.29	7.4%	44.9	14.4%
UK	1.57	11.1%	41.0	19.8%

The Impact Profile® for UoA23 (Computer Science and Informatics) shows that the distribution of research impact for University Alliance RAE2008 papers is broadly similar to that of the UK background and institutions with below median RAE2008 Category A FTE Staff.

University Alliance institutions produce fewer uncited papers, but more papers with lower citation rates, than the UK background and those institutions with below median RAE2008 Category A FTE Staff. The general pattern of performance is that whilst University Alliance is below the UK on a range of indicators in UoA23, it performs better than institutions with below median RAE2008 Category A FTE Staff. For example, the nci of University Alliance RAE2008 papers submitted to UoA23 is well above the world average (1.39), but lower than the UK (1.57) and higher than for institutions with below median RAE2008 Category A FTE Staff (1.29). A similar pattern can be observed for highly-cited papers (9.5% versus 11.1% for the UK and 7.4% for <Median), average percentile (42.3 versus 41.0 for the UK and 44.9 for <Median) and RAE2008 papers in the top 10% worldwide (17.7% versus 19.8% for the UK and 14.4% for <Median).

These data illustrate that the performance of University Alliance institutions in UoA23 is similar to the UK background. The University Alliance institutions produce significant levels of highly-cited research and perform better than the world average in all indicators.

Figure 4.5 UoA25 – General Engineering and Mineral & Mining Engineering

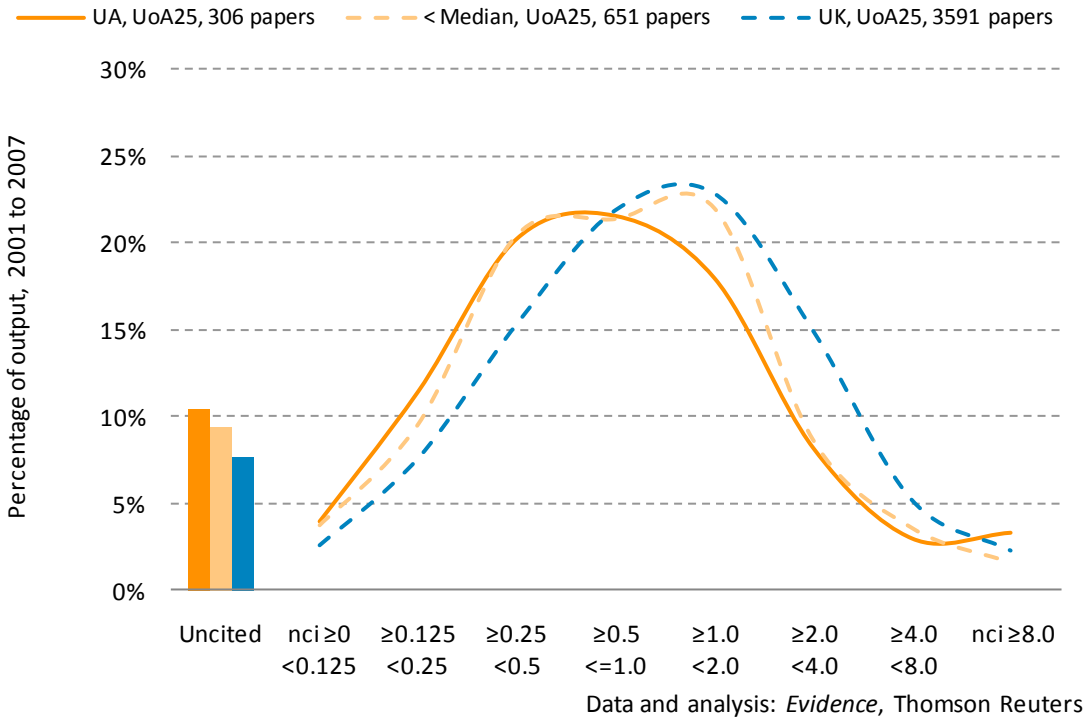


Table 4.5 UoA25 – General Engineering and Mineral & Mining Engineering

	nci	Highly-cited papers	Average percentile	Top 10%
UA	1.26	6.2%	48.2	10.5%
< Median	1.09	5.1%	47.0	10.1%
UK	1.38	7.3%	40.5	16.8%

The Impact Profile® for UoA25 (General Engineering and Mineral & Mining Engineering) shows that the University Alliance institutions generally perform less well than the UK background. Compared with those institutions with below median Category A FTE Staff, however, the University Alliance institutions performance appears somewhat mixed across the different indicators.

University Alliance institutions produce more uncited papers, and proportionately more papers with lower citation rates, than the UK background and those institutions with below median RAE2008 Category A FTE Staff. The nci of University Alliance RAE2008 papers submitted to UoA 25 is 1.26, which is well above world average, and much higher than institutions with below median RAE2008 Category A FTE Staff (1.09) but below the UK figure of 1.38. Approximately 6.2% of papers submitted to RAE2008 were highly-cited, below the UK figure of 7.3% but above that of institutions with below median RAE2008 Category A FTE Staff (5.1%). A similar pattern can be observed for papers in the top 10% worldwide with 10.5% of University Alliance papers in this category (marginally, but not notably, above the world average) compared to 16.8% for the UK and 10.1% for institutions with below median RAE2008 Category A FTE Staff. In terms of average percentile the University Alliance institutions (48.2) are slightly below the UK background (40.5).

These data illustrate that in UoA25, whilst the University Alliance institutions perform less well than the UK background, they still produce significant levels of excellent research. The reason for the weaker performance of the University Alliance compared to the UK background is difficult to determine, but differences in institutional strategies for submissions to the RAE are likely to be a contributory factor.

Figure 4.6 UoA30 – Architecture and the Built Environment

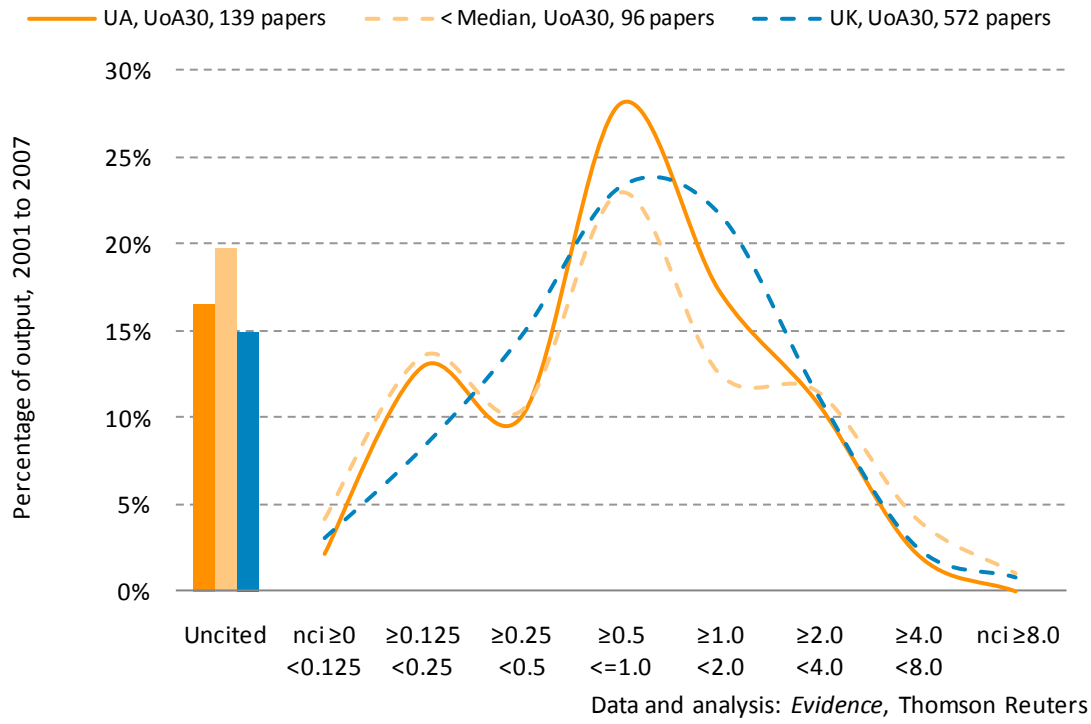


Table 4.6 UoA30 – Architecture and the Built Environment

	nci	Highly-cited papers	Average percentile	Top 10%
UA	0.77	2.2%	53.6	7.2%
< Median	0.90	5.2%	55.9	14.6%
UK	0.98	3.1%	49.7	10.3%

The Impact Profile® for UoA30 (Architecture) is noisy because of the small volumes of research paper mapped to this UoA.

Both the University Alliance institutions and those institutions with below median RAE2008 Category A FTE Staff produce higher proportions of uncited papers than the UK background. It is notable that for UK institutions as a whole the nci in UoA30 is below world average (0.98), well below average for institutions with below median RAE2008 Category A FTE Staff (0.90) and for University Alliance (0.77) which is a very low value. Only 3.1% of UK papers in UoA30 were highly-cited, and the figure is lower for University Alliance (2.2%). The average percentile of UK institutions' research in UoA30 is 49.7 (which is just above the median), but both institutions with below median RAE2008 Category A FTE Staff (55.9) and University Alliance (53.6) have below median performance in this subject area. University Alliance has well below the world average percentage of papers in the top 10% worldwide at 7.2%.

It is difficult to say whether these differences indicate significant differences in performance because of the small volumes of papers mapped to this UoA.

Figure 4.7 UoA35 – Accounting and Finance

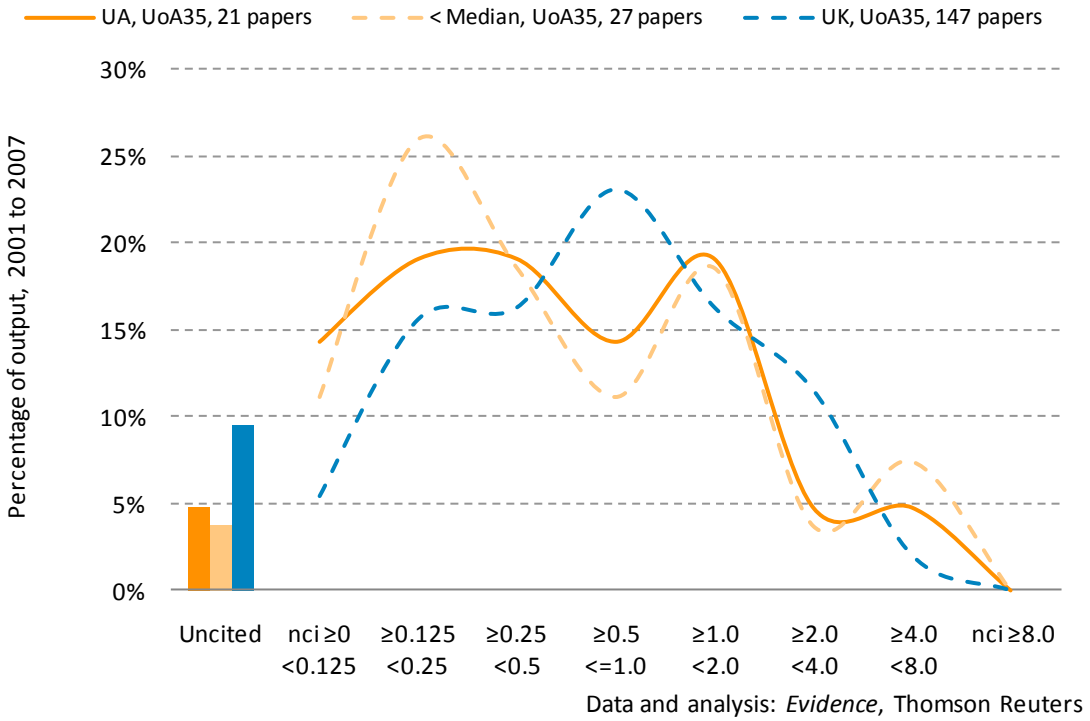


Table 4.7 UoA35 – Accounting and Finance

	nci	Highly-cited papers	Average percentile	Top 10%
UA	0.77	4.8%	47.9	9.5%
< Median	0.80	7.4%	48.8	11.1%
UK	0.86	2.0%	45.4	10.9%

The Impact Profile® for UoA35 (Accounting and Finance) is very noisy. This is because the very small number of papers mapped to this UoA.

Less than 10% of UK papers in UoA35 are uncited, and 10.9% of papers are in the top 10% worldwide, which is around the world average. The average percentile of UK research is 45.4 which is above the median. However, the nci of the UK is 0.86 and only 2.0% of papers are highly-cited.

It is difficult to draw meaningful conclusions on the distribution of high quality research because of the small volumes of papers mapped to this UoA.

Figure 4.8 UoA63 – Art and Design

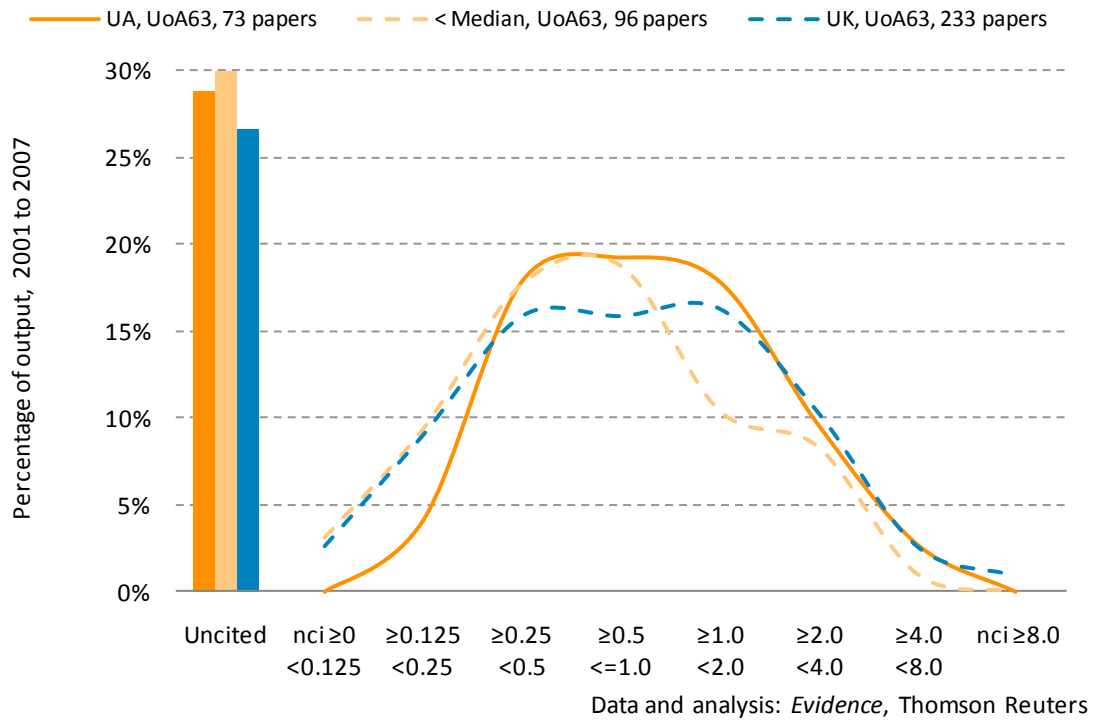


Table 4.8 UoA63 – Art and Design

	nci	Highly-cited papers	Average percentile	Top 10%
UA	0.76	2.7%	55.7	11.0%
< Median	0.57	1.0%	62.5	4.2%
UK	0.84	3.4%	56.4	10.7%

The Impact Profile® for UoA63 (Art and Design) is based on very low numbers of papers but appears less noisy than that for other fields (e.g. UoA35 – Accounting and Finance). Nevertheless, it is difficult to say whether the differences between the comparators are significant.

Compared to other subject areas, it is evident that a high percentage of UK institutions' research papers are uncited, and these figures are highest for institutions with below median RAE2008 Category A FTE Staff and University Alliance institutions. This is a characteristic of subjects like art and design which rely less on research papers published in scholarly journals for the dissemination of research findings than in other subjects. The nci of the papers is well below the world average for the field and the year of publication for the UK (0.84) and University Alliance (0.76), but lower still for institutions with below median RAE2008 Category A FTE Staff (0.57). The average percentile of research is also lower than the median: 56.4 for the UK, 62.5 for institutions with below median RAE2008 Category A FTE Staff and 55.7 for University Alliance institutions. There are few highly-cited papers – 3.4% for the UK, 1.0% for institutions with below median RAE2008 Category A FTE Staff and 2.7% for University Alliance. The UK and University Alliance have more than 10% of their papers in the top 10% worldwide (10.7% and 11.0%, respectively), but institutions with below median FTE have only 4.2%.

Because of the relatively low numbers of research papers mapped to this UoA it is difficult to draw meaningful conclusions, but in general the performance of University Alliance institutions is similar to the UK background.

5. Research training capacity

Table 5.1 shows the number of doctoral degrees awarded, by UoA, in the calendar years 2001 to 2007 by all HEIs in the UK and the number specifically awarded by University Alliance institutions. The table also shows doctoral degrees awarded by University Alliance institutions as a percentage of all UK doctoral degrees awarded. Those UoAs in which University Alliance accounts for at least 10% of the UK's doctoral degree awards are shown (University Alliance accounts for 8.0% of all UK PhD awards). The data show that a substantial proportion of the UK's doctoral training capacity in certain subjects, particularly the professional subjects, is provided by University Alliance institutions. In some UoAs, over a quarter of the UK's doctorates are awarded by these institutions.

Table 5.1 UK and University Alliance doctoral degrees awarded in the calendar years 2001 to 2007 by Unit of Assessment

UoA	UoA Name	UK doctoral degree awards (2001-7)	UA doctoral degree awards (2001-7)	UA % of UK doctoral degree awards (2001-7)
12	Allied Health Professions and Studies	2084.5	648.7	31.1%
11	Nursing and Midwifery	442.4	134.4	30.4%
30	Architecture and the Built Environment	821.8	244.5	29.8%
37	Library and Information Management	404.0	113.0	28.0%
50	European Studies	343.9	81.0	23.6%
63	Art and Design	710.6	157.5	22.2%
46	Sports-Related Studies	550.2	121.8	22.1%
35	Accounting and Finance	148.0	31.5	21.3%
66	Communication, Cultural and Media Studies	442.1	88.0	19.9%
56	Celtic Studies	124.3	22.0	17.7%
31	Town and Country Planning	453.1	79.7	17.6%
36	Business and Management Studies	3492.4	547.5	15.7%
29	Metallurgy and Materials	1426.4	217.5	15.2%
23	Computer Science and Informatics	2993.2	401.5	13.4%
40	Social Work and Social Policy & Administration	1235.7	164.4	13.3%
43	Development Studies	345.0	38.1	11.0%
17	Earth Systems and Environmental Sciences	2241.9	226.8	10.1%
45	Education	3106.3	312.9	10.1%
32	Geography and Environmental Studies	1648.6	164.9	10.0%

Appendix A - Bibliometrics and citation analysis

Bibliometrics are about publications and their citations. The field has emerged from 'information science' and refers to analyses and methods used to study and index texts and information.

Publications cite and are cited by other publications. This provides linkages and networks. Many links are likely to be related to significance or impact. Meaning is determined from keywords and content. Citation analysis and content analysis are therefore commonly used bibliometric methods. Historically, bibliometric methods had been used to trace relationships amongst academic journal citations. Bibliometrics now are increasingly important in indexing research performance. Bibliometric data have particular characteristics of which the user should be aware, and these are considered here.

Journal papers (publications, sources) report research work. Papers refer to or 'cite' earlier work relevant to the material being reported. New papers are cited in their turn. Papers that accumulate more citations are thought of as having greater 'impact', interpreted as significance or influence in their field. Citation counts are therefore recognised as a measure of impact, which can be used to index the excellence of the research from a particular group, institution or country.

The origins of citation analysis as a widespread tool of research performance can be traced to the mid-1950s, when Eugene Garfield proposed the concept of citation indexing and introduced the Science Citation Index, the Social Sciences Citation Index and the Arts & Humanities Citation Index, produced by the Institute of Scientific Information (ISI, currently the IP & Science business of Thomson Reuters).

Most impact measures use average citation counts from groups of papers, because some individual papers may have unusual or misleading citation profiles. These outliers are diluted in larger samples.

Data sources

The data used by *Evidence* come from Thomson Reuters databases, including the Web of Science®, a single source collated to the same standard and therefore providing a level of comparability not found in other databases. These data are also valuable because they can readily be disaggregated by field, by year, by country and by institution. The Web of Science® is part of a larger entity, the Web of Knowledge℠, focussing on research published in journals and conferences in science, medicine, arts, humanities and social sciences. The Web of Science® was primarily regarded as an awareness and information retrieval tool but has an increasingly important secondary use for citation analysis and bibliometrics for research evaluation. Coverage is both current and retrospective in the sciences, social sciences, arts and humanities, in some cases back to 1900. Within the research community these data are often still referred to by the acronym 'ISI'.

Unlike other databases, the Thomson Reuters Web of Science® and underlying databases are selective, that is, the journals abstracted are selected using rigorous editorial and quality criteria. The authoritative, multidisciplinary content covers over 11,500 of the highest impact journals worldwide, including Open Access journals and over 110,000 conference proceedings. The abstracted journals actually encompass the majority of significant scientific reports and, more importantly, an even greater proportion of the scientific research output which is cited. This selective process ensures that the citation counts remain relatively stable in given research fields and do not fluctuate widely from year to year, which increases the usability of such data for performance evaluation.

Evidence, now as part of Thomson Reuters, has extensive experience with databases on research inputs, activity and outputs and has developed innovative analytical approaches for benchmarking and interpreting international, national and institutional research impact.

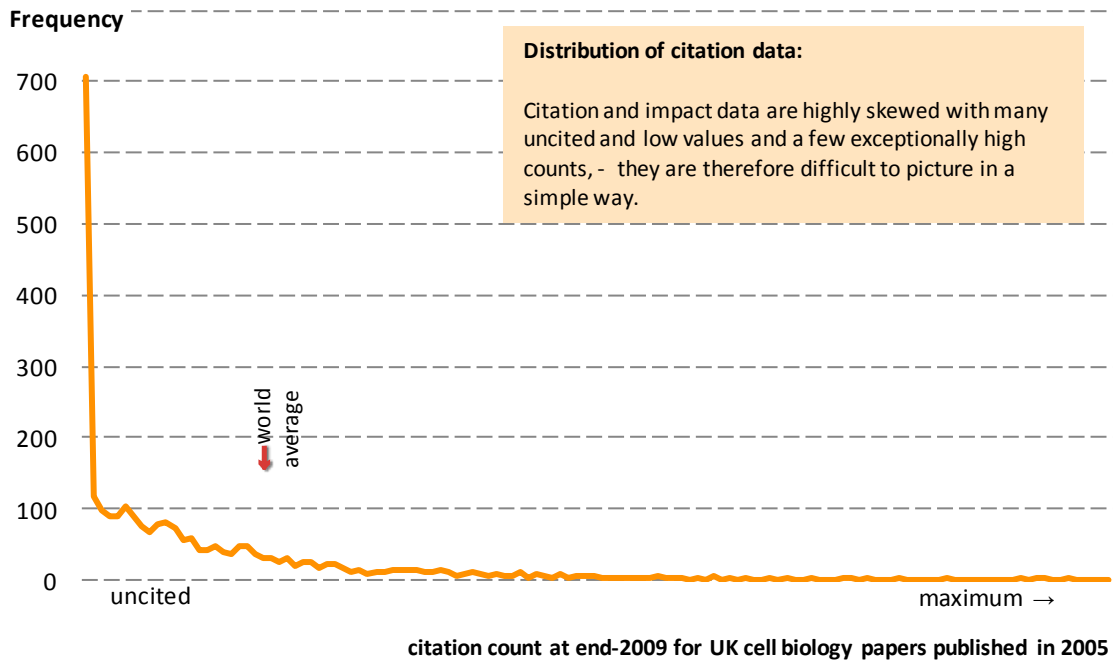
Citation counts

A publication accumulates citation counts when it is referred to by more recent publications. Some papers get cited frequently and many get cited rarely or never, so the distribution of citations is highly skewed.

Why are many papers never cited? Certainly some papers remain uncited because their content is of little or no impact, but that is not the only reason. It might be because they have been published in a journal not read by researchers to whom the paper might be interesting. It might be that they represent important but 'negative' work reporting a blind alley to be avoided by others. The publication may be a commentary in an editorial rather than a normal journal article and thus of general rather than research interest. Or it might be that the work is a 'sleeping beauty' that has yet to be recognised for its significance.

Other papers can be very highly cited: hundreds, even thousands of times. Again, there are multiple reasons for this. Papers receiving many citations are usually being recognised for their innovative significance and impact on the research field to which they relate. Impact here is a good reflection of quality: it is an indicator of excellence. But there are other papers which are frequently cited because their significance is slightly different: they describe key methodology; they are a thoughtful and wide-ranging review of a field; or they represent contentious views which others seek to refute.

Citation analysis cannot make value judgments about why an article is uncited nor about why it is highly cited. The analysis can only report the citation impact that the publication has achieved. We normally assume, based on many other studies linking bibliometric and peer judgments, that high citation counts correlate on average with the quality of the research.



The figure shows the skewed distribution of more or less frequently cited papers from a sample of UK authored publications in cell biology. The skew in the distribution varies from field to field. It is to compensate for such factors that actual citation counts must be normalised, or rebased, against a world baseline.

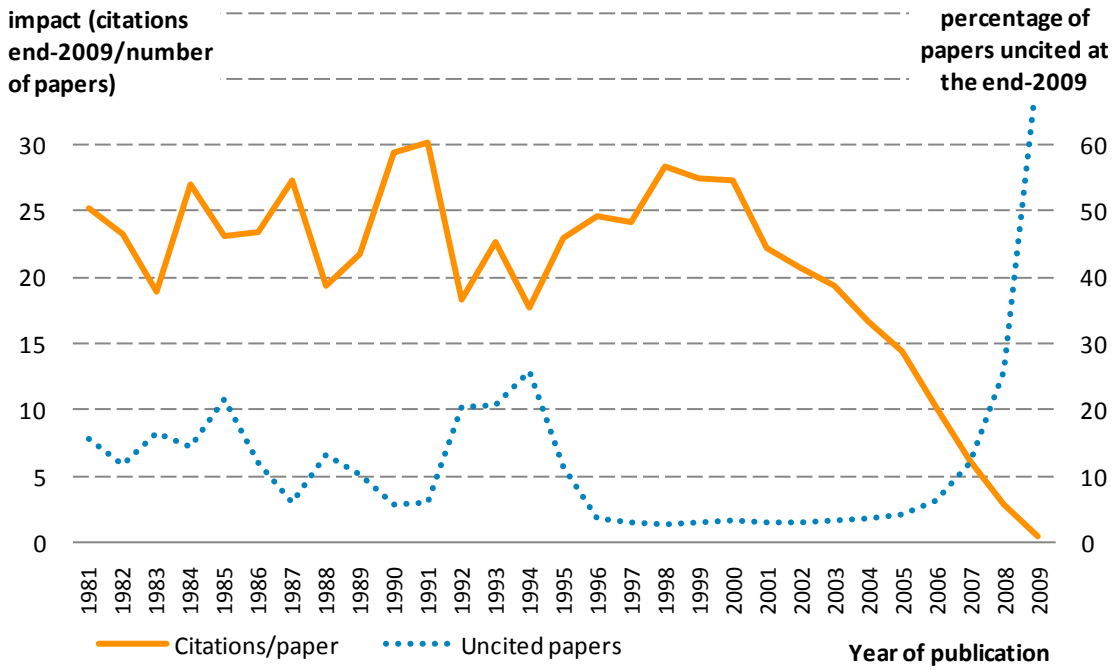
Time factors

Citations accumulate over time. Older papers therefore have, on average, more citations than more recent work. The graph below shows the pattern of citation accumulation for a set of 33 journals in

the journal category ***Materials Science, Biomaterials***. Papers less than eight years old are, on average, still accumulating additional citations. The citation count goes on to reach a plateau for older sources.

The graph shows that the percentage of papers that have never been cited drops over about five years. Beyond five years, between 5% and 10% or more of papers remain uncited.

Account must be taken of these time factors in comparing current research with historical patterns. For these reasons it is sometimes more appropriate to use a fixed five-year window of papers and citations to compare two periods than to look at the longer term profile of citations and of uncitedness for a recent year and an historical year.



Discipline factors

Citation rates vary between disciplines and fields. For the UK science base as a whole, 10 years produces a general plateau beyond which few additional citations would be expected. On the whole, citations accumulate more rapidly and plateau at a higher level in biological sciences than physical sciences, and natural sciences generally cite at a higher rate than social sciences.

Papers are assigned to disciplines (journal categories or research fields) by Thomson Reuters, bringing cognate research areas together. The journal category classification scheme has been recently revised and updated. Before 2007 journals were assigned to the older, well established Current Contents categories which were informed by extensive work by Thomson Reuters and with the research community since the early 1960s. This scheme has been superseded by the 252 Web of Science® journal categories which allow for greater disaggregation for the growing volume of research which is published and abstracted.

Papers are allocated according to the journal in which the paper is published. Some journals may be considered to be part of the publication record for more than one research field. As the example below illustrates, the journal *Acta Biomaterialia* is assigned to two journal categories: ***Materials Science, Biomaterials*** and ***Engineering, Biomedical***.

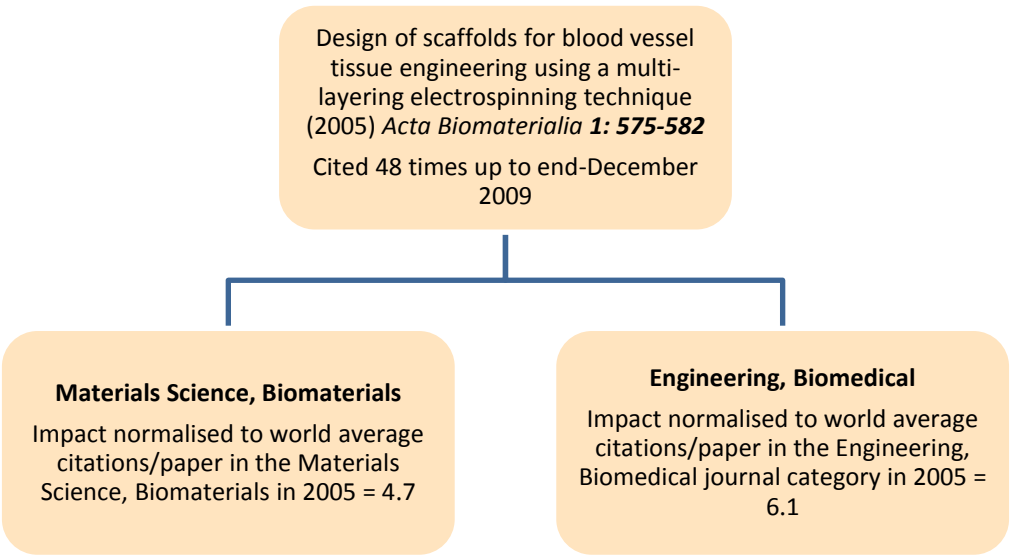
Very few papers are not assigned to any research field and as such will not be included in specific analyses using normalised impact data. The journals included in the Thomson Reuters databases and how they are selected are detailed here http://scientific.thomsonreuters.com/mjl/.

Some journals with a very diverse content, including the prestigious journals *Nature* and *Science*, were classified as ***Multidisciplinary*** before 2007. The papers from these ***Multidisciplinary*** journals are now re-assigned to more specific research fields using an algorithm based on the research area(s) of the references cited by the article.

Normalised citation impact

For the reasons given above, all analyses must take both field and year into account. In other words, because the absolute citation count for a specific article is influenced by its field and by the year it was published, we can only make comparisons of indexed data after normalising with reference to these two variables. In addition, the type of publication will influence the citation count. For example, a review will typically be cited more frequently than an article, and both of these types will tend to be cited more than editorials or meeting abstracts. Consequently, only citation counts from reviews and articles are used in calculations of impact. The most common normalisation factors are the average citations per paper for the year and either the field or journal in which the paper was published. This normalisation is also referred to as 'rebasing' the citation count.

Impact is therefore most commonly analysed in terms of 'normalised impact', or nci. The following schematic illustrates how the normalised impact is calculated at paper level and journal category level:



This article in the journal *Acta Biomaterialia* is assigned to two journal categories: ***Materials Science, Biomaterials*** and ***Engineering, Biomedical***. The world average baselines for, as an example, ***Materials Science, Biomaterials*** are calculated by summing the citations to all the articles and reviews published worldwide in the journal *Acta Biomaterialia* and the other 32 journals assigned to this category for each year, and dividing this by the total number of articles and reviews published in the journal category. This gives the category-specific normalised citation impact (in the above example the category-specific nci_F for ***Materials Science, Biomaterials*** is 4.7 and the category-specific nci_F for ***Engineering, Biomedical*** is higher at 6.1). Most papers (nearly two-thirds) are assigned to a single journal category whilst a minority are assigned to more than 5.

Average impact

As noted above, the distribution of citations amongst papers is highly skewed, many papers are uncited and very few papers accumulate high citation counts. Historically, research performance has been indexed using average impact (normalised as described to a world average that accounts for time and discipline).

An average may be misleading if assumptions are made about the distribution of the data beneath it. Almost all research activity metrics are skewed: many low performance values and a few exceptionally high values. In reality, therefore, the average impact tends to be significantly different from either the median or mode in the underlying distribution.

The average (normalised) impact can be calculated at an individual paper level where it can be associated with more than one journal category. It can also be calculated for a set of papers at any level from a single country to an individual researcher's output.

Thus, in the example above, the average nci of the *Acta Biomaterialia* paper can be given as 5.4.

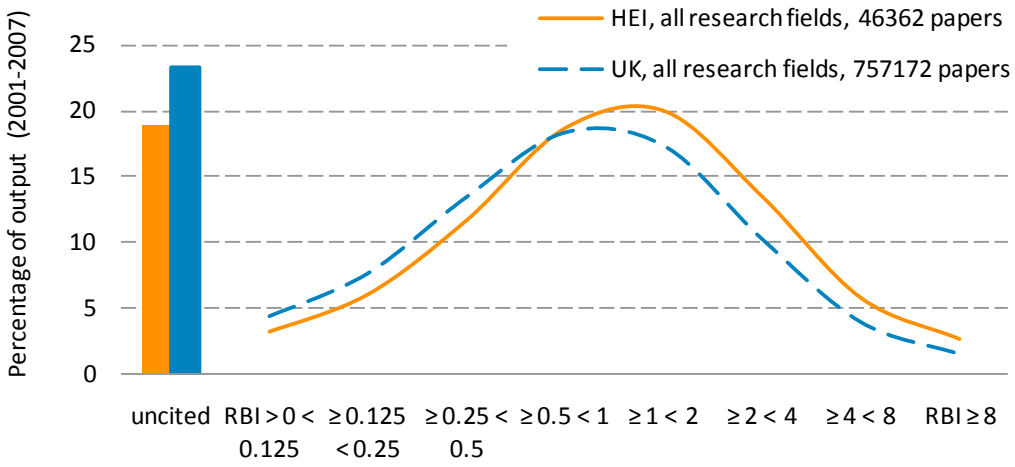
Impact Profiles®

Evidence has developed a bibliometric methodology which shows the proportion of papers that are uncited and the proportion that lie in each of eight categories of relative citation rates, normalised (rebased) to world average. An Impact Profile® enables an examination and analysis of the strengths and weaknesses of published outputs relative to world average and relative to a reference profile. This provides much more information about the basis and structure of research performance than conventionally reported averages in citation indices.

Papers which are "highly-cited" are defined as those with an average normalised citation impact (nci) greater than or equal to 4.0, i.e. those papers which have received greater than or equal to four times the world average number of citations for papers in that subject published in that year.

The proportion of uncited papers in a dataset can be compared to the benchmark for the UK, the USA or any other country. Overall, in a typical 10-year sample, around a quarter of papers have not been cited within the 10-year period the majority of these, of course, are those that are most recently published.

The following is an example of an Impact Profile® showing how the distribution of citations can be visualised and compared to a suitable reference. The bars on the left of the profile show the proportion of papers that are uncited. The curves make it easy to visualise key aspects of the citation distribution. For example, modal citation impact, the proportion of papers that are cited less than world average (nci < 1.0), and the proportion that are highly-cited (nci ≥ 4).



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