Research Excellence in the 21st Century

Funding a healthy research ecosystem

Discussion paper, December 2014

UNIVERSITY ALLIANCE

About this report

In anticipation of the REF 2014 results to be released 18 December 2014, this discussion paper explores issues relating to research funding and research excellence. University Alliance are grateful for input from experts throughout the drafting process, including:

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A final iteration of this report will be published in 2015, following continuing expert consultations and the publication of the results of the REF.

About University Alliance

University Alliance is a non-partisan, non-political organisation working to promote, safeguard and sustain the public benefit delivered by universities.

University Alliance brings together the UK’s leading innovative and entrepreneurial universities – major institutions combining science, technology and the creative industries with a focus on delivering for the professions, business and the community. Alliance universities are central to the UK's economy, driving growth in new sectors and markets through the delivery of high quality research and industry-ready graduates.

Alliance universities have a ‘revolving door’ approach to business engagement. A key feature of activity is supporting new growth industries and regional development through major partnerships with the likes of Siemens, Hewlett-Packard and GSK, as well as thousands of SMEs. 44% of all revenue from UK graduate start-ups comes from businesses started by Alliance graduates.

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Preface

University Alliance recognises that excellent research is a global competition. We need to make sure that the UK research base remains one of the best of the world despite strong competition from developing and competing nations. This means continued investment in universities, which deliver the vast majority of UK research activities. But especially in times of fiscal pressure investments also need to be cost-effective and efficient by rewarding and developing existing excellence and capability in the system.

The choices we make now will be essential for future-proofing the research base in the fast-paced exploratory world of scientific discovery. With a new ten year Science and Innovation Strategy and the announcement of the latest national research assessment exercise in REF2014, now is a critical time for big decisions that will shape the future of the research base.

Concentration as an explicit policy would not improve the quality of the research base as the evidence presented throughout this paper demonstrates. Open competition, autonomy and peer review must remain the keystone of our dual support system. Yet concentration of funding has increased in the UK in recent years, and is particularly pronounced in support for doctoral students, with serious implications for the diversity and breadth of the future researcher workforce, consequences which may be wider and more deeply felt than policy makers have recognised.

There is also a wider paradigm shift to address for the sake of the future health of the UK's research ecosystem. Research excellence can no longer be narrowly defined in terms of its reach within the academic community, as assessments based on academic output have done in the past.

Instead, there is a new context for research excellence which – quite rightly – demands that impact and benefit to the wider world are reflected in definitions and expectations of excellence. How we understand, recognise and reward excellent research therefore needs to keep pace with this change, and we need to reach a better understanding of the relationship between excellent research and impact.

Collaboration based on specialised and complementary fields of excellence is essential to a successful and efficient research ecosystem in Science 2.0, bringing cost savings as well as driving modern innovation. Alliance universities have developed successful partnerships internationally, nationally and locally, an approach which is generating real-world impact by growing industries, shaping society, improving healthcare and building sustainability as the examples throughout this report show.

We must make sure that UK systems are building a future-proof and responsive science base that can thrive in this new context for research excellence. This report outlines suggestions for delivering this.

University Alliance, December 2014

Executive summary

1. **Peer reviewed selectivity underpins the quality of the UK research base.** The strength and quality of the UK research ecosystem rests on important characteristics of selectivity based on peer review, a dual support system that balances funding for projects with that of strategic investment, and a consensus that universities are the best place to deliver research of all kinds.
2. **The key to maximising on this selectivity is to fund excellence wherever it is found.** Unselective or closed competition allocation methods, including concentration of funding on either basis of scale or historic funding volume, will not drive the overall performance of the research base. International comparisons show that there is no necessary correlation between concentration and excellence.
3. **Concentration based on size of research unit does not drive quality**. The idea of 'critical mass' leading to excellence is a myth in all but a few subjects, where capital costs can make larger teams more effective. Instead, quality is a driver of scale: smaller units that perform good research acquire resources to grow, but larger units do not continue to improve with concentrated funds. This more nuanced understanding of the causative relationship between size and outcome demonstrates that funding on the basis of scale would not improve overall productivity, but might eliminate some of the best units.
4. **Concentration of funding through 'rear-view' historic volume allocation is similarly suboptimal.** Concentrating funding towards previous funding through allocations awarded based on historic funding volume fails to fund excellence wherever it is found, fails to recognise development in the range and scale of research activities, and disincentivises innovation.
5. **Research funding for postgraduate researchers has been particularly concentrated**. This is especially concerning for the future of the research ecosystem and the pipeline of research and innovation talent. Cohort training of PhDs may be one area in which critical mass is important for research environments; but funding should incentivise excellence-seeking across the research base through multi-institutional and collaborative doctoral training, to allow the best of the future to work with the best in the system.
6. **There is a new context for research excellence.** Connectivity, collaboration and openness are essential to the future of world-leading science and open innovation. Research excellence can no longer be narrowly defined in terms of its reach within the academic community, but must deliver and articulate the wider benefits of research for society.
7. **Impact and collaboration are essential to delivering societal and economic benefits from excellent research cost-effectively,** but could be further recognised and incentivised by funding systems. Plurality and complementarity in the system developed by selectivity and strategic research investments underpin strong, effective partnerships and work against duplication and inefficiency. These principles will ensure the UK is well-positioned to remain at the forefront of world-leading science.

1 | Selectivity has driven excellence, not concentration

A system built on selectivity has driven the overall global competitiveness of UK research, and selectivity has resulted in concentration of research funding where quality exists. Policies of funding concentration based on other measures would be detrimental to the quality of UK research.

The UK has one of the most highly selective research funding methods in the world. The policy of selective funding, based on quality established by peer review and a robust dual support system, has driven up the quality of UK research, with a notable increase in the UK's share of world citations since the introduction of the first Research Assessment Exercise (RAE) in 1986.[1] Universities carry out the vast majority of research in the UK compared to OECD averages at 74.3% of publicly-funded Gross Expenditure on Research and Development (GERD) and 26.5% of total GERD.[2]

It is selectivity rather than concentration that has fuelled this progress. This is an important distinction in determining the principles which should underpin research funding policy. Research funding is most effective when allocated selectively according to quality. By its nature, selective funding based on quality leads to some measure of concentration of funds. National and international policies have reflected the increasing recognition that specialisation and complementarity at the unit level is important for the success of the whole at system level, as is seen, for example in the European Commission's smart specialisation agenda.[3] This initiative recognises that enabling units – in this case regions – to focus on their strengths can boost innovation and increase the impact of research investment, preventing unnecessary duplication across the system as a whole.

The same principle applies to universities. The dual support system encourages research activity to become more concentrated, and many universities – like Alliance universities – pursue policies of selectivity in developing these areas of strength, resulting in peaks of excellence. With less public funding for research, these universities are committed to identifying their competitive advantage, to making strategic and focussed decisions about research investments. Differentiation through investment in areas of strength at institutional level supports a rich ecosystem in the UK within which there is often complementarity rather than duplication.

The dual support of research and funding excellence through open competition is the best way to ensure quality, responsiveness and resilience in the research ecosystem

Central to this is the UK's system of dual support and institutional autonomy, which has been shown to correlate directly with the quality of a system and to increase the competitive success of institutions.[4] The UK is recognised as being distinct in both its level of autonomy and its quality.[5]

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[1] J. Adams and D. Smith (2006). Evaluation of the British Research Assessment Exercise. In: L. Bakker, J. Boston, L. Campbell and R. Smyth (eds.) Evaluation of the Performance- Based Research Fund, pp. 109-17; Wellington: Institute of Policy Studies, Victoria, cited in Libby Aston and Liz Shutt, "Concentration and Diversity: Understanding the Relationship between Excellence, Concentration and Critical Mass in UK Research," 2009.

[2] Universities UK, "The Funding Environment for Universities 2014. Research and Postgraduate Research Training," 2014, pp. 6–7.

[3] http://ec.europa.eu/research/regions/index_en.cfm?pg=smart_specialisation

[4] Laura De Dominicis, Susana Elena Pérez and Ana Fernández-zubieta, *European University Funding and Financial Autonomy. A Study on the Degree of Diversification of University Budget and the Share of Competitive Funding*, 2011 <http://dx.doi.org/10.2791/55199>.

[5] Philippe Aghion and others, "Higher Aspirations: An Agenda for Reforming European Universities," *Bruegel Blueprint Series*, V (2008).

Providing the flexibility for universities to invest strategically remains critical to the dynamism and responsiveness of UK research, allowing for universities to invest in their areas of strength in new and high-risk areas, across the spectrum of research activities.[6]

Peaks of excellence are important and are found across the sector

A major part of this picture is institutional diversity which has strengthened the UK's research portfolio. In this context, selectivity rather than concentration leads to peaks of research excellence, which have determined the position of the UK as a world leader. These peaks are more widely distributed across the sector than had previously been recognised before RAE 2008, however. The results showed that world class research activity exists in research units of various sizes and across the UK higher education sector. Furthermore, analysis by *Evidence* has shown that the sector as a whole has a higher percentage of 'highly cited papers' than the major research intensive universities (excluding 'Golden Triangle' institutions).[7]

Funding distribution does not necessarily reflect this spread of excellence, however, as is explored in more detail below. The Higher Education Commission's recent report also underlined the threat that concentration of funding makes to the dynamism of the research ecosystem.[8] Certain myths around the benefits of concentration must be dispelled: first, that policies of funding concentration improve the quality of the whole system; second, that bigger research units perform better and therefore research funding should be allocated on the basis of the size; and third, that allocating funding based on previous funding levels is the most efficient use of public money.

"Whilst concentrating research funding may be more efficient in terms of economies of scale, and enhancing the reputation of a subset of English universities, spreading research funding to wherever excellence is found allows for an element of dynamism in the system and more opportunities for early career researchers to prove themselves. The Commission would recommend that good research, wherever it exists in the sector, continues to be funded."

Higher Education Commission, *Too Good to Fail.* 2014.

1.1 Concentration does not improve whole system performance

International comparisons show that there is no necessary correlation between concentration and research performance

The US system is by most measures the world leader in research and development but has a significantly lower concentration of funding than the UK. As FIgure 1 shows, the concentration of academic R&D funds for science and engineering (S&E) among the top US 100 institutions and the shares held by both the top 10 and the top 20 institutions have remained largely constant over the last two decades (although the make-up of the 'top 10/20' has changed). Similar concentration levels are found among universities that perform non-S&E R&D, where the top 20 performers accounted for 36% of the total non-S&E R&D expenditures in 2009.[9] This compares – as section 1.4 of this report explores – to a much higher level of concentration in the UK. On the other hand, Germany has an explicit policy of concentrating research in a small number of research institutes, but research quality is not higher than in other countries.

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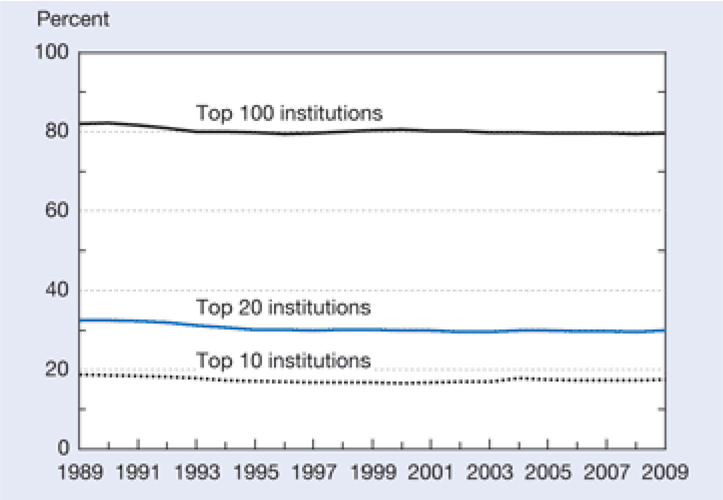
[6] PACEC and Centre for Business Research at the University of Cambridge, *A Review of QR Funding in English HEIs: Process and Impact. Report to the Higher Education Funding Council for England (HEFCE)*, 2014.
[7] Juliet Chester and Bahram Bekhradnia, *Oxford and Cambridge – How Different Are They ?*, 2007, MMVII, HEPI.
[8] Higher Education Commission, *Too Good to Fail. The Financial Sustainability of Higher Education in England*, 2014.
[9] National Science Foundation (2012). *Science and Engineering Indicators*.

Figure 1 Concentration levels in the US have remained largely constant over recent years
Share of US academic R&D by institution rank in R&D expenditures: Financial year 1898-2009, Source: National Science Foundation (2012), Science and Engineering Indicators, fig. 5-9



1.2 The 'critical mass' myth

Bigger does not mean better. Quality is a driver of scale, and not vice-versa.

Arguments that large academic research groups perform better than small ones are not new, and underpin suggestions that funding should be concentrated in fewer institutions.[10] They claim that departments above a certain size – a 'critical mass' – are able to make more effective use of research funding. The critical mass debate deserves revisiting here, because it has a tendency to be oversimplified.

The assumption that volume may lead to improved performance is not without some basis; in fact it is observed to be true for some of the physical and clinical sciences in academia, and in research and development productivity within the pharmaceutical industry.[11] The idea of the 'well-found lab', a research community which benefits from sharing expensive and rare (often unique) capital and technological resources, is widely accepted. The idea of 'critical mass' might also be usefully applied to other elements of the research environment, for example in the creation of a cohort of peer support in doctoral training, as is discussed below. The assumption that this critical mass must exist within one institution is misguided, however. Indeed, often collaborations between experts in different departments or institutions is the most efficient and effective means of creating this mass, as is explored in more detail in section 2.2.

Funding based on the size of a research unit does not and will not improve the quality of the research base.

In general, the evidence does not support a broad-brush presumption that 'bigger means better' for research units. In fact, quite the contrary. Analysis of the RAE 2008 results by *Evidence* (part of Thompson Reuters) in 2011 demonstrated that there is no direct correlation between volume and excellence (in both productivity and performance) in 69 out of 72 Units of Assessment (UoAs) – the three exceptions all being physical sciences.[12] The analysis showed conclusively that there are small

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[10] Russell Group, *Jewels in the Crown : The Importance and Characteristics of the UK ' S World-Class Universities*, 2012.
[11] R Henderson and I Cockburn, "Scale, Scope, and Spillovers: The Determinants of Research Productivity in Drug Discovery," *The Rand journal of economics*, 1996 <http://www.jstor.org/stable/2555791> [accessed 29 October 2014].
[12] Evidence Ltd, *Funding Research Excellence: Research Group Size, Critical Mass & Performance* (University Alliance, 2011).

and medium-sized units that perform as well as, and often better than, the largest units. These findings supported previous studies which showed that the relationship between volume and excellence varies by discipline, and that even in the small number of disciplines where volume correlates to quality, there is no identifiable lower 'threshold' or 'critical mass'.[13] Other studies have shown that in subjects which show a correlation between scale and performance, there is a point above which performance stops increasing as rapidly or, in some cases, starts to decrease.[14]

The *Evidence* analysis of RAE2008 demonstrated further that quality is in fact a driver of scale, and not vice-versa. That is to say, smaller units that perform good research acquire resources to grow, whilst large units that perform poorly lose resources and decline.[15] This more nuanced understanding of the causative relationship between size and outcome demonstrates that concentrating resources on the basis of scale would eliminate many areas of excellence – often small, medium sized and with an essential dynamism that the health of UK research depends on. It is also clear that a policy of growing larger units would not necessarily lead to improvement in quality. Overall, there is insufficient evidence to suggest that concentration of research resources would be the best way to improve UK research performance; in fact, it would risk great damage.[16]

The *Evidence* analysis is worth recapping here, until it can be updated with REF 2014 results. Two areas were analysed: the relationship between size and performance and productivity; and the relationship between size and normalized citation impact, with attention to the performance of University Alliance mapped against the UK as a whole and against units with a below-median number of Category A FTEs. The findings here are extracted from the report - further detail on methodology and scope can be found in the original report,[17] and on the indicators used in the appendix to this paper.

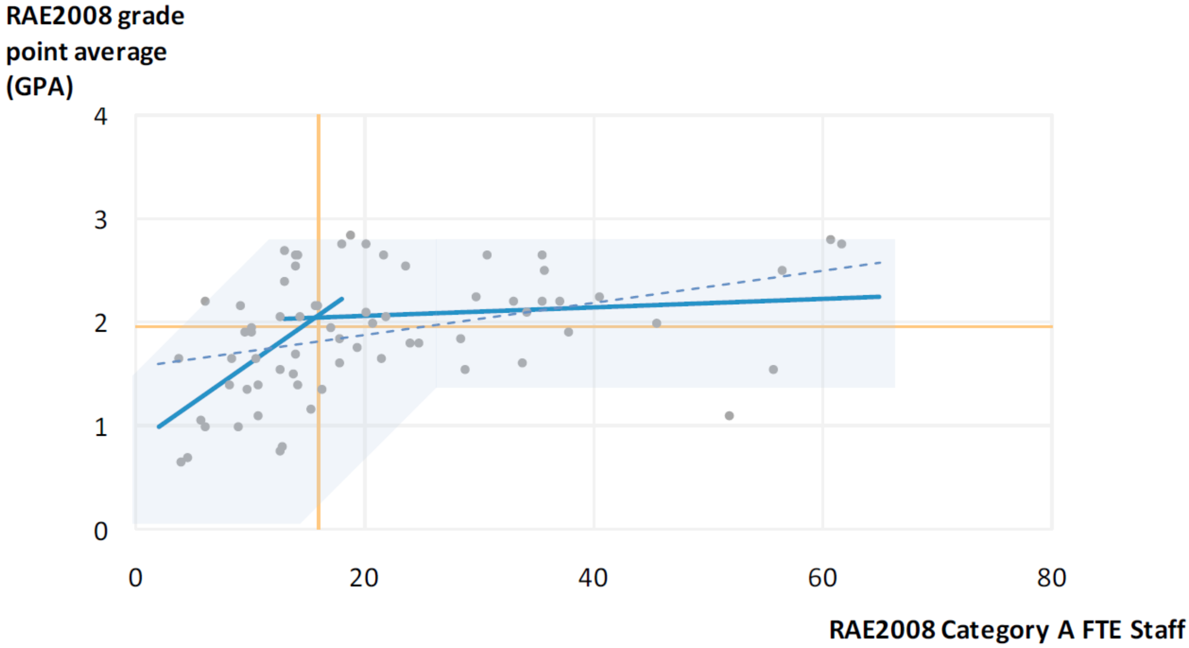
Funding should always follow excellence where it is found, as distribution based on scale would not improve productivity

1.2.1 Bigger research units do not perform better or produce more

Analysis of relationships of size (measured by the number of full-time equivalent Category A Staff) to performance (measured by the outcomes of RAE2008 and citation impact), and productivity (indicated by the number of papers per full-time equivalent Category A Staff) showed that there is no continuous relationship between research unit size and performance and productivity. Indicative graphs are shown here.

[13] Higher Education Policy Unit at the University of Leeds, *HEFCE Fundamental Review of Research Policy and Funding, "The Role of Selectivity and the Characteristics of Excellence". Final Report to HEFCE*, 2000.
[14] See the many sources cited in Evidence Ltd, *Funding Research Excellence: Research Group Size, Critical Mass & Performance*, p. 5.
[15] Evidence, "Funding Research Diversity: The Impact of Further Concentration on University Research Performance and Regional Research Capacity. A Report for Universities UK," 2003.
[16] Mark Harrison, "Does High-Quality Research Require 'Critical Mass'?," in *The question of R&D specialisation: perspectives and policy implications. JRC Scientific and Technical Reports (EUR collection): perspectives and policy implications. JRC Scientific and Technical Reports (EUR collection)*, ed. by Dimitrios Pontikakis, Dimitrios Kyriakou, and Rene van Bavel (Office for Official Publications of the European Communities, 2009), pp. 53–55; Evidence.
[17] Evidence Ltd, *Funding Research Excellence: Research Group Size, Critical Mass & Performance*.

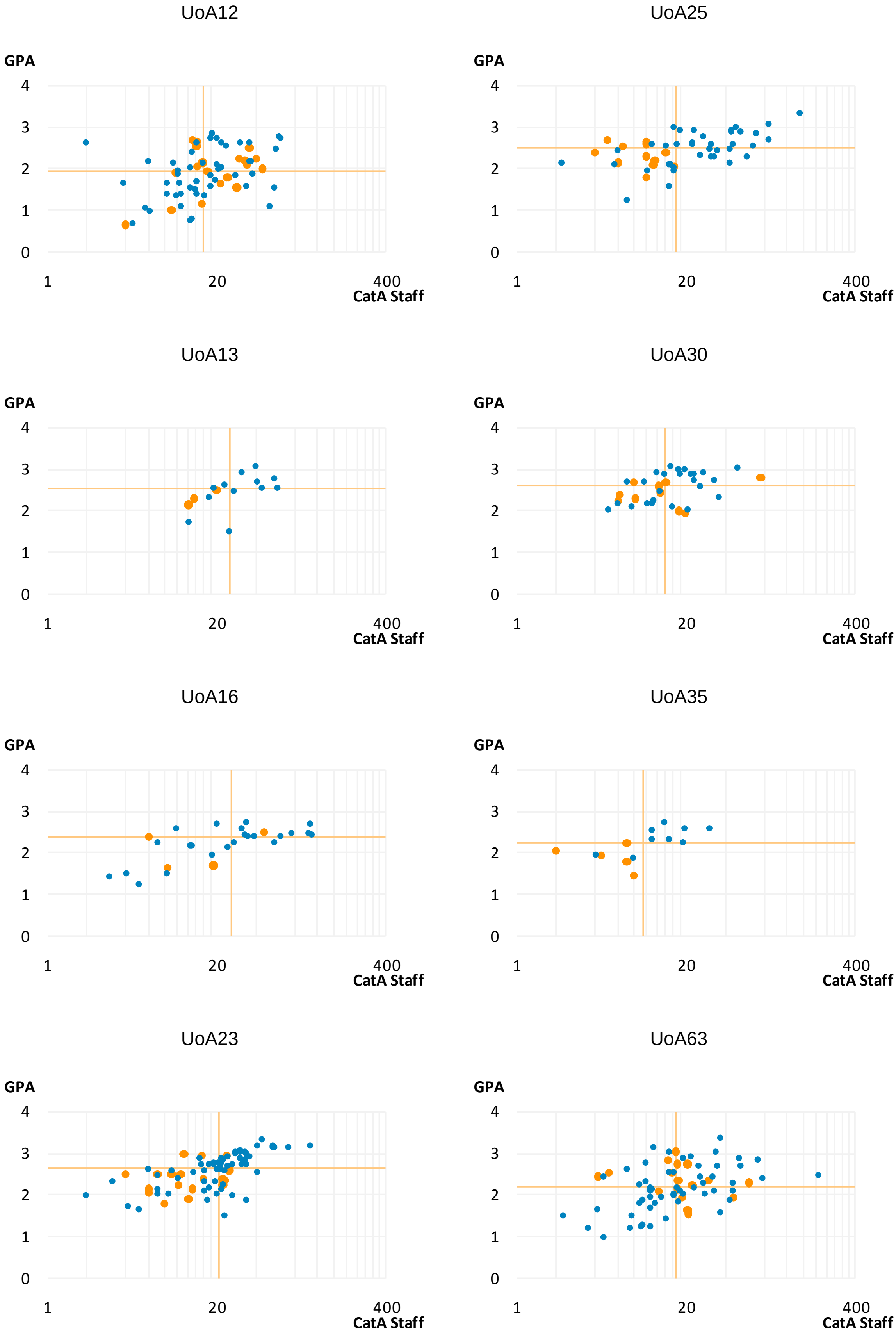
Figure 2 Beyond the very smallest research units there is no correlation in size and performance *(UoA12)*



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

Figure 2 maps RAE2008 results against the size of research units for UoA 12 (Allied Health Professions and Studies). It shows that 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, a pattern which holds for most other disciplines as the following charts (Figure 3) which map University Alliance performance against the rest of the sector show.

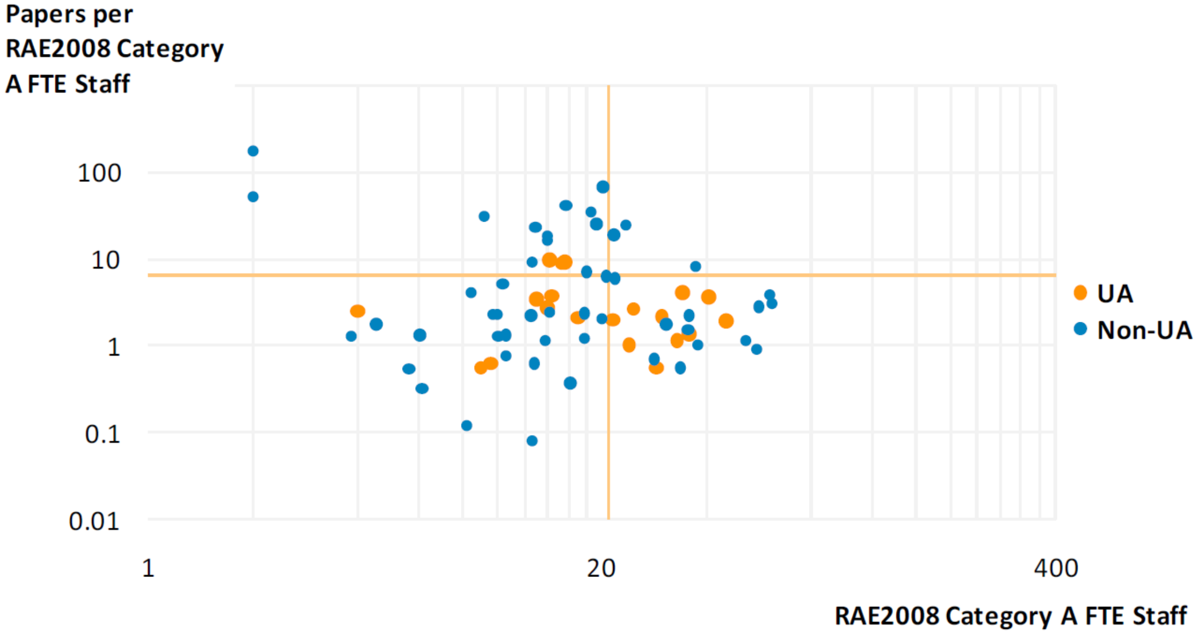
Figure 3 In many UoAs, small and medium size research units perform as well if not better than the largest
University Alliance institutions plotted in yellow



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

Small and median-sized research units also tend to be at least as productive as large units, and peak productivity is not generally associated with the largest units, but is often found around the median. This is consistent with a study concluding that 'middle sized labs do best' and that resources may be best focused on the 'middle'.[18] There is variation between different UoAs, but a general pattern emerges that demonstrates small units can perform as well as the largest units and peak productivity is generally observed amongst the smaller to median-sized units.

Figure 4 There is no correlation between research unit size and researcher productivity *(UoA12)*



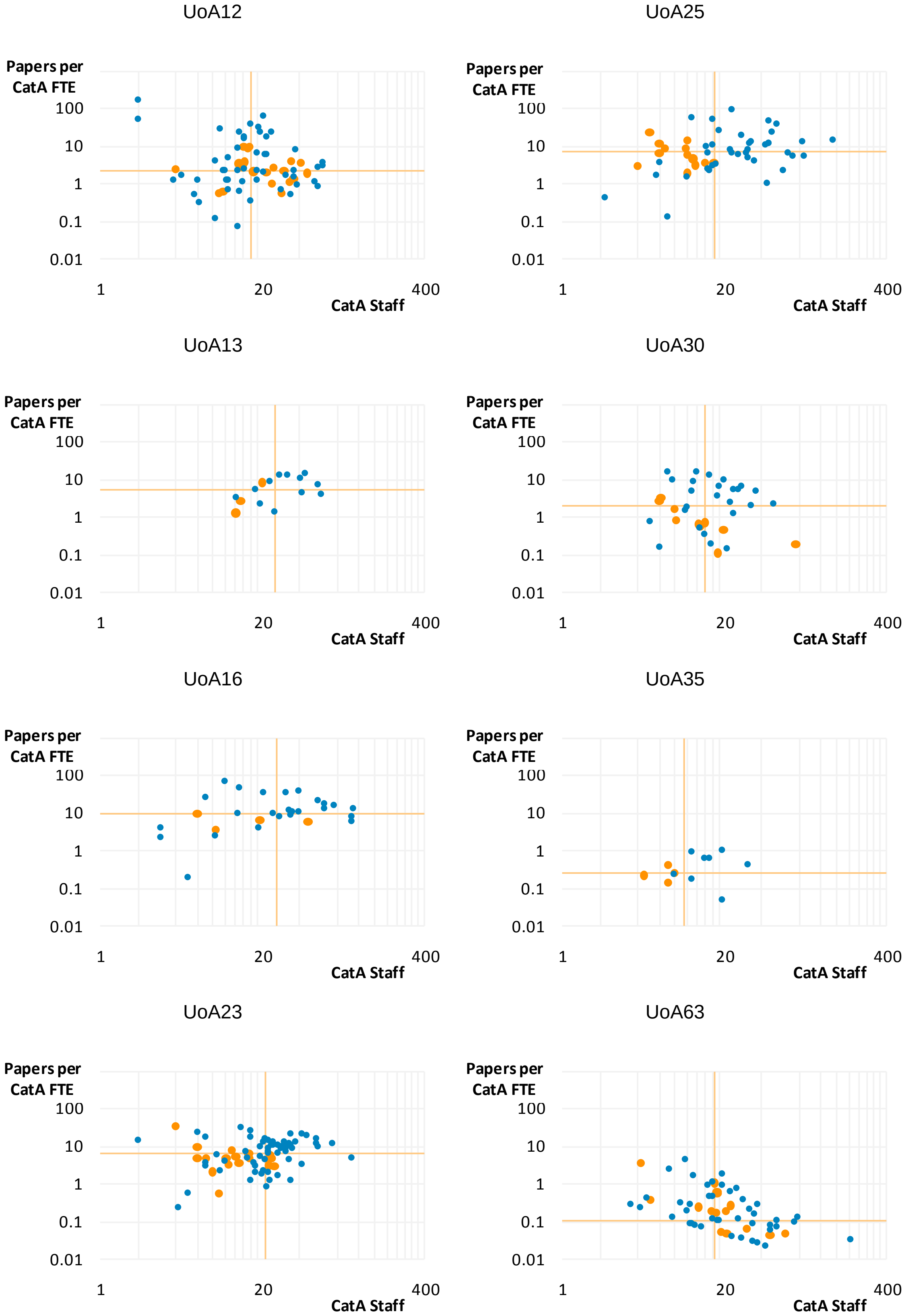
Data: HEFCE and Thomson Reuters. Analysis: *Evidence*, Thomson Reuters

Figure 4 shows the relationship between papers per RAE2008 Category A FTE Staff mapped to UoA12 against the number of RAE2008 Category A FTE Staff submitted to this UoA, and shows the performance of University Alliance against the rest of the sector. It demonstrates broadly that there is no correlation between research unit size and researcher productivity in UoA12. In fact 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.

These results vary between disciplines, as the graphs at Figure 5 show for UoAs that are representative of research fields that Alliance universities are active in. However, the general pattern emerges as exemplified above: that small units can perform as well as the largest and peak productivity is generally observed amongst smaller to median-sized units.

[18] Meredith Wadman, "Study Says Middle Sized Labs Do Best.," *Nature*, 468 (2010), 356–57 <http://dx.doi.org/10.1038/468356a>; R. Kenna and B. Berche, "The Extensive Nature of Group Quality," *EPL (Europhysics Letters)*, 90 (2010), 58002 <http://dx.doi.org/10.1209/0295-5075/90/58002>.

Figure 5 Small units are often just as productive as large ones and median-sized units deliver peak productivity



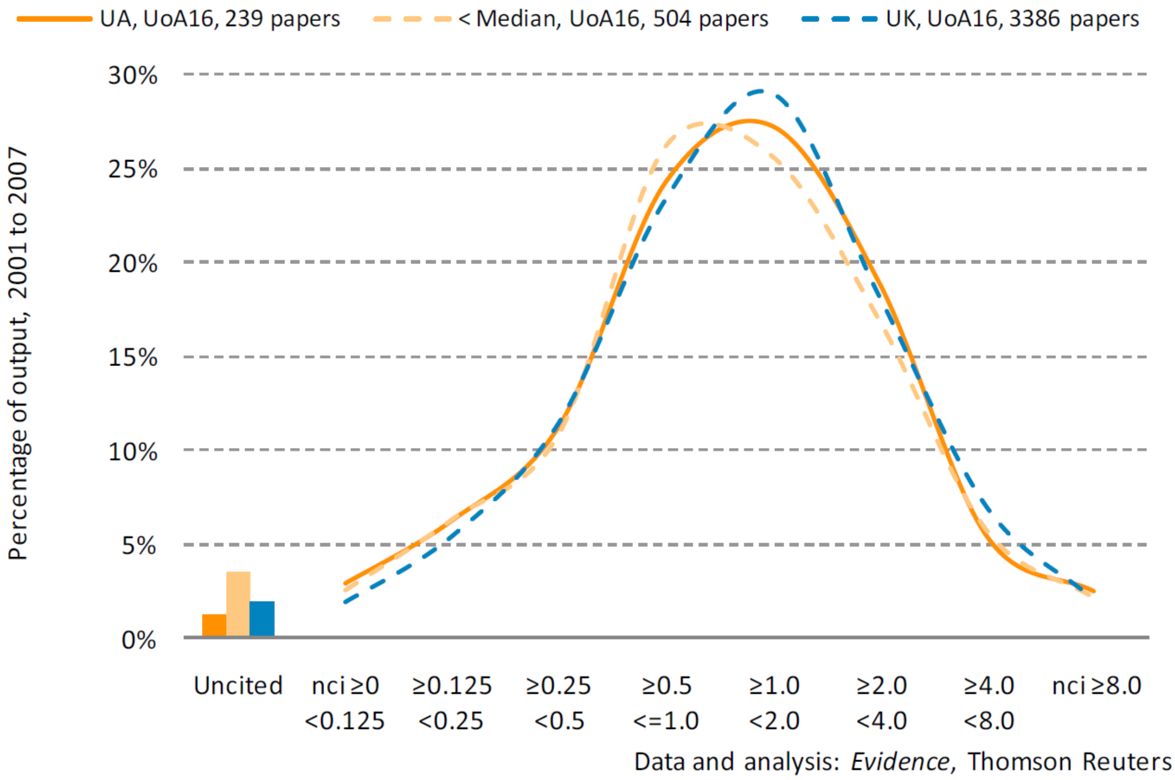
Data: HEFCE and Thomson Reuters. Analysis: *Evidence*, Thomson Reuters

1.2.2 Research quality is distributed widely across the sector

The second part of the analysis used Evidence's Impact Profiles™ to assess the distribution of citation impact. Analysis found 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.

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, as Figure 6 shows for UoA16 (Agriculture, Veterinary and Food Science). This pattern is true for most of the UoAs analysed. There is little difference in the profiles of University Alliance institutions when comparted with the UK as a whole and the group of institutions with fewer than the median number of Category A Staff. A similar percentage of the research papers published by each of these groups receive equivalent numbers of citations.

Figure 6 Larger institutions do not outperform smaller ones in citation impact (UoA16)



> "While a lot of research is undertaken in clusters, we will support excellence wherever it is found; it is not our intention to create a handful of successful institutions." *The Rt Hon, Dr Vince Cable, Business Secretary, 8 September 2011*

The *Evidence* analysis leads to clear conclusion that there is no evidence that funding on the basis of scale would improve overall performance or productivity, but might eliminate some of the best units. Since the quality profile of each of the groups of institutions analysed is similar, evidence does not support the removal of funding from any particular group to increase overall performance. Instead, excellence is a driver of scale. If funding were to be concentrated on the basis of scale, small excellent units would be lost and the development of future niche and specialist areas would be stifled, with dangerous consequences for the UK research base.

1.3 Uncompetitive funding allocation restricts capacity and performance

Just as concentrating research funds according to unit size does not improve productivity and performance, neither does concentrating funding on top of other funding. Data from the US National Institutes of Health (NIH) showed that at higher funding levels publication levels and average 'impact factor' declined discernibly.[19] Likewise, a Canadian study of researchers in the three disciplines funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) noted that citation impact was generally a decelerating function of funding, that impact per dollar was lower for larger grant-holders, and that the citation impact of researchers who received increases in funding did not predictably increase.[20] Over-concentration of funding on the basis of previous funding therefore delivers diminishing returns.

If excellence is not indicated by previous funding levels, or by size of research units, funding decisions must be made upon an openly competitive basis, with peer review. The research assessment exercises (most recently REF2014) and many research council funding approvals ensure that a significant amount of research funds are allocated according to peer-reviewed quality.

Unit size and previous funding are not predictors of quality research units: excellence can only be determined through open competition

However, there are two main mechanisms in the UK which result in some large responsive-mode funding decisions being made through non-competitive allocations. These take a rear-view approach: the first mechanism uses algorithms related to historic funding levels to apportion funds; the second involves restricting competitions for funding to a limited group of institutions, again, ranked on historic funding levels. Both have the effect of *de facto* concentration.

These allocation methods have been favoured by some of the research councils for recent funding schemes. Historic volume algorithms were used, for example, to distribute funding for the ESRC, STEFC and EPSRC's Impact Acceleration Accounts (IAAs), and have also closed off competitive applications for other research council funds for doctoral training including EPSRC Doctoral Training Partnerships (DTPs) and Industrial CASE (iCASE) awards and STFC DTPs.[21]

Funding councils have received large real-term cuts in recent years which have necessarily driven back office efficiencies, and the advantages of these allocation methods are perceived to be in the cost savings related to the processes of assessing applications. But these cost savings could be a false economy, if the research outcomes do not deliver value for money and do not achieve the maximum societal return.

These rear-view allocation methods presume that the historic funding regime recognises all forms of excellence across the whole system, and that all universities' research units are equally well equipped to deliver a full spectrum of research activities. In reality, and as outlined above, different strengths exist in different places; the plurality in the system is its strength. The rear-view approach can fail to divert funds to the existing excellence best suited to deliver the objectives of the latest funding round: those in receipt of funding previous research priority streams from research councils may not be best-placed to deliver the impact objectives of the IAAs, for example. The rear-view

[19] Wadman.
[20] Jean-Michel Fortin and David J Currie, "Big Science vs. Little Science: How Scientific Impact Scales with Funding.," *PloS one*, 8 (2013) <http://dx.doi.org/10.1371/journal.pone.0065263>.
[21] www.esrc.ac.uk/collaboration/knowledge-exchange/opportunities/ImpactAccelerationAccounts.aspx; http://www.stfc.ac.uk/2880.aspx; www.epsrc.ac.uk/skills/students/dta/; www.stfc.ac.uk/1834.aspx; [Accessed September 2014]

allocation model can therefore work against innovation in practice, and stifles competition. This is problematic for the UK's research capability as it both fails to recognise and drive development in a full range and scale of research activities, and does not incentivise innovation or new areas of excellence.

1.3.1 Open innovation needs open competition

A broader principle is at stake. Non-competitive public funding streams are at odds with the market forces that are in play in the wider research and innovation ecosystem. Public funds can be (and increasingly are) used to leverage significant contributions from the private sector, but this private investment cannot be maximised if there are restrictions on where and with which partners the public funds can be spent. In other words, open innovation needs open competition.

Businesses choose to work with a variety of universities which suit their industrial needs. Restricting the public funding which can support these partnerships to only part of the university sector not only fails to make use of existing university-business partnerships, but asks market-based companies to act in a non-competitive funding environment. It is at odds with policies that encourage the leverage of investment from other sources.

One example is a new allocation method of public funding for iCASE awards by the EPSRC, which only the 44 HE institutions in receipt of a Doctoral Training Grant (DTG) are eligible for.[22] These awards are described as 'funding for PhD studentships where businesses take the lead in arranging projects with an academic partner of their choice'. They provide PhD students with a challenging research training experience, including a mandatory industrial placement, within the context of a mutually beneficial research collaboration between academic and non-academic partner organisations. Due to the limitations on the eligibility of academic institutions, businesses do not have a full choice of partners.

The consequence has been that some businesses who were prepared to invest in an iCASE studentship did not, as they could not work with their partner of choice.[23] Collaborative partnerships are based on trust, and often take many years to establish successfully. Institutions with excellent track records in iCASE studentships and business relationships who are disbarred from this part of the public funding system, are prevented from delivering the benefits of their strong industry relationships and collaborative research training offering to students and other business partners. The result of uncompetitive funding allocation in this case means that private funds for investment in PhD training have been left unleveraged. It is symptomatic of a misalignment of the objectives in research funding, and the result of failing to fund excellence wherever it is found as a market would do.

1.4 Funding is becoming more concentrated

Recent further concentration of funding, not channelled towards excellence, threatens the quality of the UK research base

Recent reports for HEFCE and by Universities UK into the funding environment have noted a trend of increasing concentration of research funding across institutions, from both major sources of public funding. 75% of mainstream quality-related (QR) funding from the funding councils was directed to institutions in the fifth quintile (the upper 20% of the funding distribution) in 2013–14, up from 73%

[22] www.epsrc.ac.uk/skills/students/coll/icase/Pages/intro.aspx [Accessed July 2014]
[23] As reported across Alliance institutions.

in 2010–11. The fifth quintile receives over 90% of research council funding.[24] In terms of the top decile, increases in QR and research council funding have risen by 3% and 1% respectively over the last four years (figure 7). 11 universities receive 50% of the funding for which the top 3 account for over 20% (figure 8).

Alliance universities have 12.7% of all departments with 3 or 4* research but receive only 3% of research council and QR funding

Figure 7 Concentration of funding towards the top decile has increased in recent years

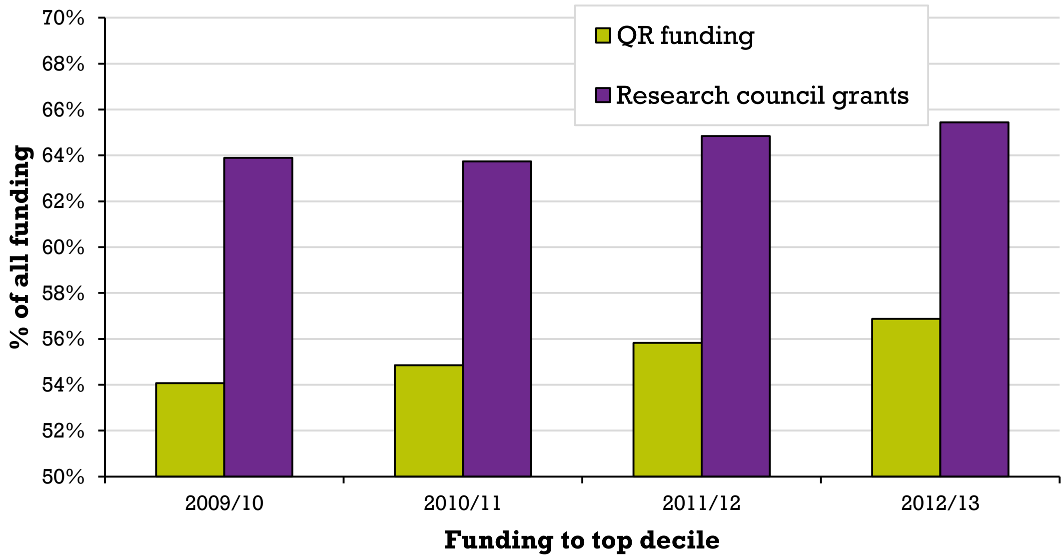
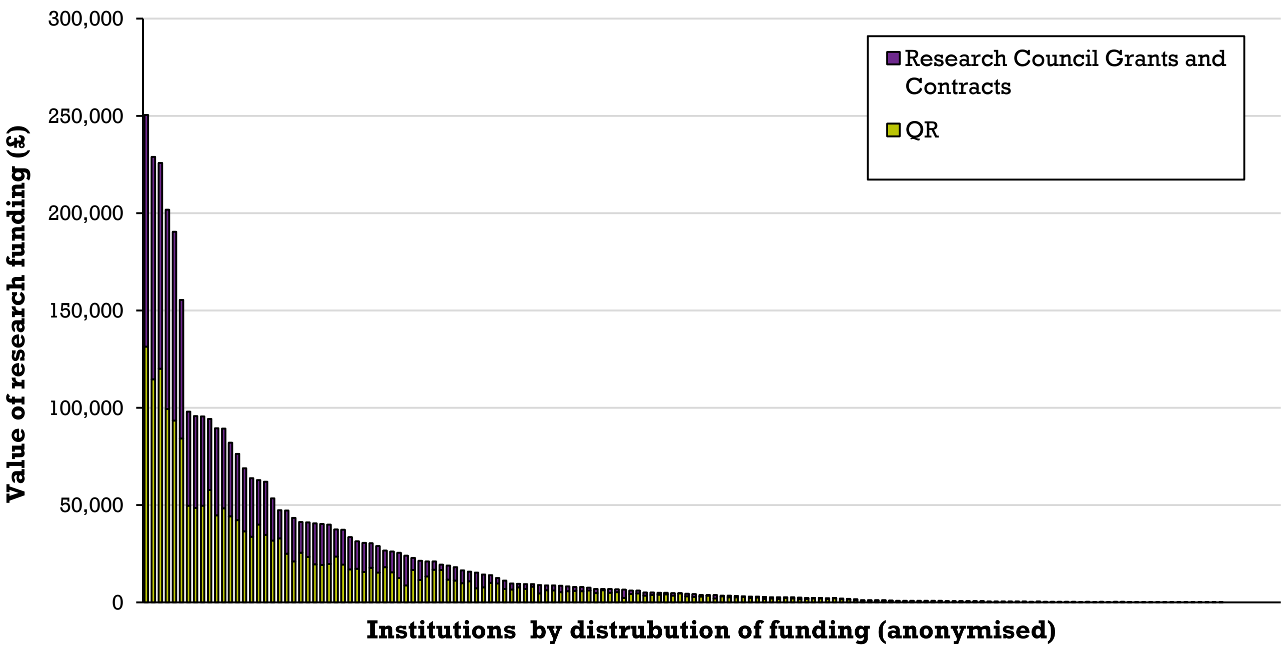


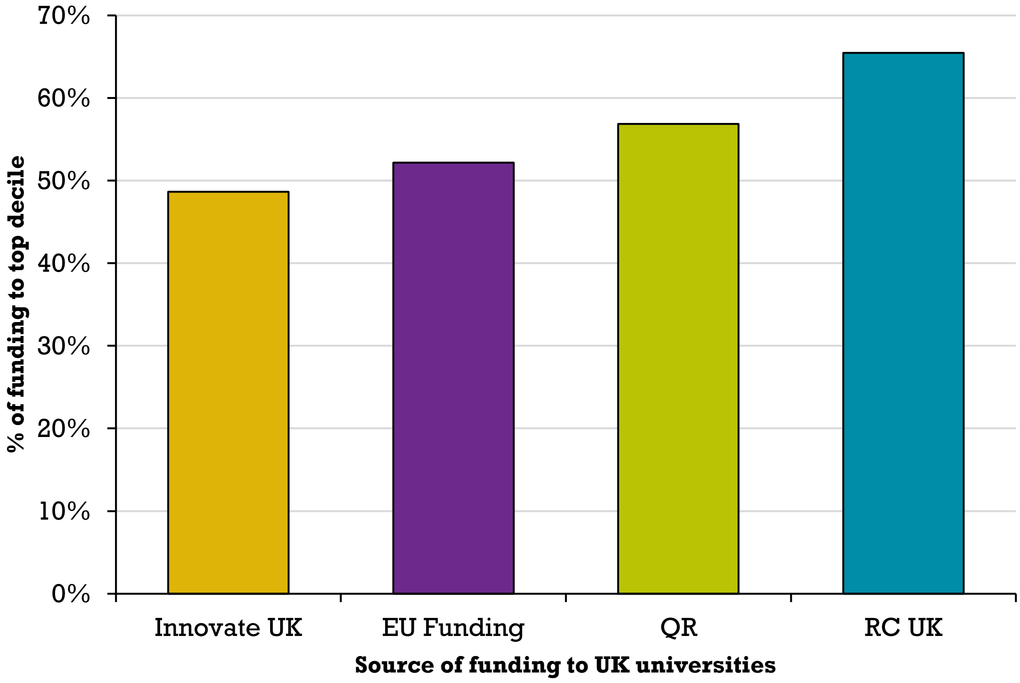
Figure 8 Research funding to UK universities shows pronounced concentration. Source, HESA 2012-13.



[24] Tomas Coates Ulrichsen, "Knowledge Exchange Performance and the Impact of HEIF in the English Higher Education Sector," 2014; Universities UK. Previous reports commissioned by Universities UK into this subject are Evidence; Evidence Ltd, *Monitoring Research Diversity, Changes between 2000 and 2005. A Report for Universities UK*, 2007; Evidence Ltd, *Monitoring Research Diversity and Concentration, Changes between 1994 and 2007. A Report for Universities UK*, 2009.

These levels of concentration are particular to the UK university research funding system. EU funding systems for research result in lower levels of research concentration, with the top decile receiving 52% compared to 57% and 65% for QR and RC UK funding (figure 9). Alliance universities draw over 70% more proportionately from EU public funding sources compared to UK sources. Innovation funding from Innovate UK to UK universities is also markedly less concentrated.

Figure 9 Innovate UK and EU funding is less concentrated than other public funding, particularly from RCUK
Source: HESA Finance Returns



1.5 Funding concentration threatens the future of the research base

The evidence presented demonstrates that the concentration of funding either for reasons of size or on the basis of historical institutional funding would not improve the performance or productivity of the research base. Rather this runs the risk of eliminating pockets of excellence and alienating private investment for research.

Autonomy and selectivity rather than concentration drives progress and performance: specialisation, plurality and avoiding unnecessary duplication is essential to an efficient and maximised research ecosystem. Universities like those who are part of University Alliance are adept at identifying, investing in and developing their strengths in both subjects and research activities. They are also good at spotting complementary strengths elsewhere in the sector and working in partnership to deliver unique responses to the challenges that face society.

This is a further dimension that is often overlooked in debates about critical mass: the essential role of multidisciplinarity and national and international collaboration. It should redefine what ‘counts’ as critical mass; in truth, the institutional and unit-level analyses often presented in arguments for critical mass do not and cannot tell the whole story. There needs to be a new paradigm for the drivers of research excellence, which better recognises the value of collaboration and diversity; the true value of the whole, which cannot be understood by focussing solely on the part. Preliminary thoughts are offered on this in section 3 of this paper.

Excellence should be funded wherever it is found

The policy implication is that the best way to improve the performance of the UK research base is to continue to fund excellence wherever it occurs, identified through free and open competition. As previous studies have also shown, this will help sustain the diverse and complementary network of research activity that will ensure the sector remains dynamic and is able to respond flexibly to the fast-paced changes in the future research system.[25]

Further concentration of research funding could significantly affect the future health of the UK research base, reducing capacity, capability and responsiveness

Alliance universities have 12.7% of departments with 3 or 4* rated research but receive 3% of research funding (around £100 million) from UK public sources. This funding is used effectively to build breadth and capacity in the UK research base. These universities provide complementary strengths that are recognised and valued by university and industry collaborators across the world. Globally connected but locally rooted, they act as a funnel, bringing expertise and partnerships from across the world to the UK and to their regions where they are powerful forces for social improvement and economic growth, as the case studies throughout this report demonstrate. Further concentration and the associated reduction or cessation of research funding to these institutions runs the risk of closing down feeder channels and excellent research that is not duplicated elsewhere, killing off competition and strategic partnerships. Keeping pace with rapid global change and competition in science – let alone leading the way in research innovation - will require flexibility and plurality in the UK system which concentration works against.

[25] Evidence Ltd, *The Future of Research*, 2010.

2 | PhD funding in particular has been concentrated

Recent increases in concentration in research funding for postgraduate researchers is especially concerning for the future of the research ecosystem and the pipeline of research and innovation capability

Postgraduate research students are essential to the UK's research capability and the future economy. A strong research culture is vital for research-informed learning and innovation activities. It is the essence of an enquiry-led, academic university learning environment that delivers the high postgraduate-level skills needed for the economy. As well as contributing to the national and international knowledge base, doctoral-level research and skills play a crucial role in driving innovation and economic growth, attracting global businesses to the UK,[26] and remain in strong demand in the labour market.

Despite broad acceptance of the value of postgraduate students and the need to nurture and retain talented future researchers and innovators, recent funding trends for postgraduate study are affecting the UK's ability to achieve this. As the Higher Education Commission recently pointed out, over-concentration of research funding curtails opportunities to develop early career researchers.[27] In an environment of declining resource, changes to funding systems have increased the concentration of public funding for doctoral training through block grants and studentships into fewer universities and around fewer research areas. These trends carry significant implications for the future capacity of the research base, the economy and society.

2.1 Demand for the next generation of researchers and innovators may not be met under current funding criteria

Despite increases driven by international students, growth in uptake of PhD courses has slowed in the UK due to recent funding squeezes.[28] Universities UK analysis has shown that although demand for PGR study at UK institutions has remained strong over the last decade, it showed signs of stagnating in 2012–13, which 'may be a sign that demand for PGR study may taper down over the next few years, particularly if funding opportunities from the research councils (RCs) continue to shrink and demand for postgraduate taught (PGT) qualifications (which are increasingly often a stepping stone to a doctoral degree) continues to weaken.' There has been a continued upward trajectory in the number of entrants to doctoral training courses with a previous Masters degree (from less than one third in 2002-03 to 59% in 2012/13).[29] The effects of declines in take-up of PGT courses in the last two years may be felt, although are yet to be realised.

At the same time that supply of PGR and doctoral students is threatened in the UK, there is sustained and increasing demand for doctoral graduates in the labour market, as evidenced by secure employment levels and wage premiums relative to other highly qualified individuals, including other postgraduates.[30] Doctoral graduates have proven to be move 'recession-proof' in recent years than

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[26] Adrian Smith, *One Step Beyond: Making the Most of Postgraduate Education*, 2010; Christine Halse and Susan Mowbray, "The Impact of the Doctorate," *Studies in higher education*, 36 (2011), 513–25 <http://dro.deakin.edu.au/view/DU:30035145> [accessed 28 October 2014].

[27] Higher Education Commission.

[28] David Cyranoski and others, "Education: The PhD Factory," *Nature*, 472 (2011), 276–79 <http://dx.doi.org/10.1038/472276a>.

[29] Universities UK.

[30] OECD, "Making the Most of Knowledge. Key Findings of the OECD-KNOWINNO Project on the Careers of Doctorate Holders," 2013; Laudeline Auriol, Max Misu and Rebecca A Freeman, "Areers of Doctorate Holders: Analysis of Labour

other graduates in the UK; doctoral graduates were less likely to be unemployed and retained the same level of full time paid work between 2008 and 2010, during which period Masters and good first degree holders saw a 5% decline in the same.[31] Demand for doctoral skills from a range of disciplines is reflected across sectors, with nearly 60% of doctoral researchers working in sectors outside of Higher Education following graduation.[32]

Given strong demand for doctoral graduates both within the research base and from industry, it is essential that financial opportunities are provided to all those with the talent and drive to undertake advanced research programmes. Similarly, funding systems must evolve to support training that meets the needs of the changing landscape of PhD employability, a landscape in which PhD graduates are increasingly less likely to work in a university-based research role post-study. Less than one third (29%) of 2010 leavers were in pure research roles 3 years after graduating, fewer than the 2008 cohort (32%).[33]

2.2 Funding council support for doctoral training has been concentrated

Public funding for science and research was ring fenced as part of the 2010 Comprehensive Spending Review until 2014-15; welcome protection in an era of fiscal pressure. Real term declines however, combined with a decrease in research capital spending (which lies outside the ring fence), have resulted in a drop of the overall value of grants for research of £248 million in real terms over the last four years.

The effects of this squeeze have been felt in the funding environment for PhD study: a decrease in resource has resulted in overall reduction of 18% in studentships available through research councils, although this was not across the board: provision by the ESRC and NERC has increased.[34] Overall funding for HEFCE's block grant through the research degree programme (RDP) supervision fund did in fact increase in England, as a result of the redistribution of £34 million from mainstream QR funds released as a result of a decision to cease funding for 2* rated research. This extra funding was received by the top 20 universities whilst 56 universities saw a decrease in support. The UK Council for Graduate Education (UKCGE) have analysed this and other effects of the new algorithm, noting that the resulting concentration of RDP funds has 'redress[ed] the funding allocations back to where they were pre-RAE2008'.[35]

Funding has also been concentrated into fewer universities as a result of other allocation reforms. The introduction of 'fewer, larger, longer' awards through Doctoral Training Partnership (DTP) and Centres for Doctoral Training (CDT) mechanisms have been compounded by alignment with priority areas and have been coupled with the removal of PhD researchers as a viable cost in research grants. The 20 institutions at the top of the funding distribution trained 75% of all research council-funded studentships in 2012-13 compared to 51% in 2010-11, and over a fifth of institutions who had previously trained research council students no longer had any.[36] Recognised excellent research units now have no publicly-funded studentships: 36 institutions with 4*-rated research currently receive no research council CDT funding. The implication is that some research students who could have

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Market and Mobility Indicators," *OECD Science, Technology and Industry Working Papers*, 2013/04 (2013) <http://dx.doi.org/10.1787/5k43nxgs289w-en>.

31 Vitae, *What Do Researchers Do? Early Career Progression of Doctoral Graduates 2013*, 2013.

32 Vitae, *What Do Researchers Do? Early Career Progression of Doctoral Graduates 2013*.

33 L DHLE data 2008 and 2010.

34 Universities UK.

35 Mick Fuller, *The Consequences of the HEFCE Change in RDP Qr Calculation*, 2014, UKCGE.

36 Universities UK.

worked with specialists in peaks of excellence are now not able to work in those environments as they lie outside the distribution of RCUK PGR funding.

The DTP and CDT schemes have refocused debates about value added in UK doctoral training and early indications are that they have made good progress. Unlike the US, which embeds PhD students within larger research grants as research apprenticeships, UK funding councils have preferred a cohort training model supported by separate funding for studentships. The cohort model reduces isolation through the support network and opportunities for peer-to-peer learning and development, increases student satisfaction, strengthens operational management, increases flexibility, and provides better resourced (if fewer) studentships – all considered to lead to a richer training experience.[37] The embedded network and peer support benefits of bringing together cohorts of PhD students in CDTs has added value to training environments and has been adopted by other funders including the EU through Marie Curie, the Leverhulme Trust and Wellcome Trust.

In the context of cohorts, 'critical mass' may be a viable consideration for a training environment but this mass in excellence can be and often is created between institutions. As many existing CDT models have demonstrated, the 'critical mass' for training environments does not exist solely within a single institution. Many CDTs are based on multi-institutional partnerships and the true value of the network effect is the bringing together a diverse and far reaching group. Research councils have taken different approaches to collaborative bids in recent allocations: the AHRC encouraged collaborative bids with 35 institutions in 7 DTCs. The EPSRC funded 80 DTCs across 34 institutions. Cohorts of doctoral students provide an important and valuable opportunity to encourage early stage researchers to work with the best throughout the system; funding should incentivise excellence-seeking across the research base through multi-institutional and collaborative doctoral training.

2.3 Concentration of funding for doctoral students risks undermining the future capacity of the research base and workforce

Sustainability. Funding for postgraduates needs to be more sustainable. Applications for DTPs and CDTs represent a financial risk for universities, as the required matched studentships funded by the institution may or may not materialise, dependent on the outcome of their bid.[38] Institutions that fall outside of public funding models for research are increasingly relying on investment of their own resources. Alliance universities realise that postgraduate students are essential to the UK's research and labour force capability, and a strong doctoral community is recognised as strategically important to their institutions' research capacity and integral to university culture. They, like many other universities, are therefore willing to invest their own resources into postgraduate research - nearly 20% of all PGR students are now financed directly by institutions.[39] The long-term sustainability of this approach is questionable however; the consequences may seriously affect the future capacity of the research base, and its ability to respond to the fast-paced changing requirements of research and industry.

Dynamism and responsiveness. The House of Lords' Science and Technology Committee 2012 report into higher education in STEM subjects noted the importance of maintaining a diverse complement

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[37] EPSRC Mid Term Review outcomes: http://www.epsrc.ac.uk/newsevents/news/cdtoutcomes/; Universities UK.
[38] Universities UK.
[39] HESA, 2014.

of training mechanisms, recommending that a variety of PhD delivery models be utilised to ensure that the UK's current breadth of expertise in science and technology is maintained.[40]

Yet shifts and concentration in the funding environment for doctoral students and consequent capacity within UK Higher Education have a narrowing effect. The exclusion of some universities with particular attributes from holding or bidding for publicly funded studentships hinders the development of the next generation of researchers in areas of UK research excellence, and from experiencing and demonstrating high quality training with implications for future funding rounds.

Similarly, senior academics with relevant expertise and skills (including those from outside of academia) may be prevented from taking supervisory roles for PhD students. Given the new employment trajectories for PhD students which lie principally outside of pure research roles, it is increasingly important for doctoral graduates to be widely formed in research and knowledge exchange capabilities, in a way that is responsive to workforce needs. Although doctoral training funding tends to be concentrated in high-research intensive institutions, these institutions attract relatively lower proportions of their staff from the private sector than other parts of the sector.[41]

The closer alignment of public funding for the future generation of researchers with long-term defined research priorities should also be complemented by support for the newer research excellence (which may be riskier for institutions to invest in, although still necessary) which underpins the dynamism of the UK research base. This flexibility is essential to future-proofing the research system and will help ensure the UK remains a top destination for PGR students in a global and rapidly changing research market.

Social mobility and diversity. The success of the UK's society and economy depends on widening participation to higher education at all levels. David Willetts MP, when Minister for Universities and Science, recognised that postgraduate study is "the new social mobility frontier". Social mobility restrictions at undergraduate level are compounded further at postgraduate study.[42] The growth in self-financed PGR students increasing from 37.6% in 2010-11 to 39.1% in 2012-13 suggests this trend is worsening under the current funding system.[43] Therefore University Alliance has welcomed the new provisions for postgraduate student finance announced as part of the 2014 Autumn Statement and, as this system develops, hope that similar opportunities will be extended to research postgraduates in the future.

The effects of fewer studentships and concentration into smaller numbers of universities has raised concerns about a 'two-track' system which delineates the perceived value of a doctoral degree based on where it was taken.

[40] www.publications.parliament.uk/pa/ld201213/ldselect/ldsctech/37/37.pdf
[41] Ulrichsen, p. 6.
[42] HEFCE, *Trends in Transition from First Degree to Postgraduate Study: Qualifiers between 2002-03 and 2010-11*, 2013.
[43] Universities UK. Analysis of HESA 2014 data.

Funding which restricts access to some universities and subjects is likely to have consequences for who can study at post-graduate level, with similarly damaging effects for the economy as observed in limiting access to undergraduate courses.[44] There is widespread acceptance of a chronic underrepresentation of diversity within STEM subjects and careers, for which the recent CaSE report on improving diversity in STEM offers constructive and welcome recommendations.[45] University Alliance is one of the 176 signatories of the 'Your Life' campaign to encourage diversity including through inspiring more young people to study maths and physics, and 90% of Alliance universities are signed up to the Equality Challenge Unit's Athena Swan Charter.[46] Inclusivity agendas include broadening access to all underrepresented groups including those from lower socio-economic backgrounds, and this must be extended to the PhD training environment by learning from expertise in Alliance universities which are sector-leading in their support for improving outcomes for a wider range of students.[47]

Case study: Theoretical Mathematics

Oxford Brookes' theoretical mathematics expertise brings Sony-funded PhD students

Oxford Brookes' researchers shared their computer vision expertise to help enhance interactions in augmented reality (AR) systems, directly contributing to the development of Sony's Wonderbook™. Through the understanding and utilisation of the complex mathematical theory behind computer vision, the partnership was able to create a robust human hand tracker and segmenter that could calculate the position of the player's hand and segment it in a live video in real-time. The resulting display enables books to 'come to life' in dramatic new ways that can be used for entertainment and education.

Sony Computer Entertainment Europe reported that their partnership with Oxford Brookes saved a significant amount of time and money in development and research efforts and have funded three PhD students at the university, as well as creating a hand tracker through a KTP with the university.

Case study: Assistive technology for healthcare

University of Hertfordshire PhD start-up improves sociability for children with autism

Researchers at the University of Hertfordshire developed the humanoid robot Kaspar to help children with autism learn about human communication and interaction. This research led to the development of human-robot interaction technology, interaction scenarios and methods, and stimulated national and international public discourse on robot-assisted therapy for children with autism.

The research also helped to provide knowledge on how to use robot technology in austism therapy. Results have showed positive impact in helping children improve their ability to interact socially. It has also helped change public perceptions about the utility of robots as assistive technologies for autism.

This expertise allowed a former Hertfordshire PhD student to establish an international robotics start-up business Que Innovations through development of QueBall, marketing toys for children with autism.

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44 University Alliance, *Closing the Gap. Unlocking Opportunity through Higher Education*, 2014.
45 CaSE (2014). *Improving Diversity in STEM*.
46 http://partners.yourlife.org.uk/signatories-details?ID=45FD-16052014091551-747; http://www.ecu.ac.uk/equality-charter-marks/athena-swan/
47 University Alliance, *Closing the Gap. Unlocking Opportunity through Higher Education*.

3 | The new context for research excellence

Are current research evaluation and funding systems fit for purpose now and in the future? A broader view of the context for research excellence acknowledges the strong policy imperative for ensuring and articulating societal and economic benefits across the full spectrum of university research.

Whilst strong public funding for research is essential, in times of straitened public spending there also needs to be greater efficiency, smarter deployment of resources and leverage of other sources of funding for research. As we move into Science 2.0, connectivity, collaboration and openness will be essential to the future of world-leading science and the UK's evaluation and funding structures will need to respond to optimize the benefits of research.

> "Research excellence is a critical asset for the UK, providing a competitive advantage in the global race for prosperity. The UK's strong research base is vital in pushing back the frontiers of human knowledge, supporting the wealth and welfare of the nation, tackling current and future challenges and contributing to the cultural richness of the UK. World class research plays a key role in economic growth through creating new businesses, improving the performance of existing businesses, delivering highly skilled people to the labour market, and attracting investment from global businesses. It is also vital to the implementation of the Government's Industrial Strategy. The 8 Great Technologies, launched by the Government in January 2013, illustrate how UK strengths in key areas of research have the potential to drive growth and societal benefits and where the UK has a competitive advantage."
>
> **BIS, *The Allocation of Science and Research Funding 2015/16. Investing in World-Class Science and Research*, 2014.**

3.1 Traditional research indicators have taken an overly narrow view of research excellence

Assessment of research excellence traditionally looks to data on research outputs and citation analysis: frequently-cited bibliometric statistics are used to underline the efficiency and quality of the UK's research base: the UK is responsible for 9.5% of downloads, 11.6% of citations and 15.9% of the world's highly cited articles, is now ranked first in the world for field-weighted citation impact.[48]

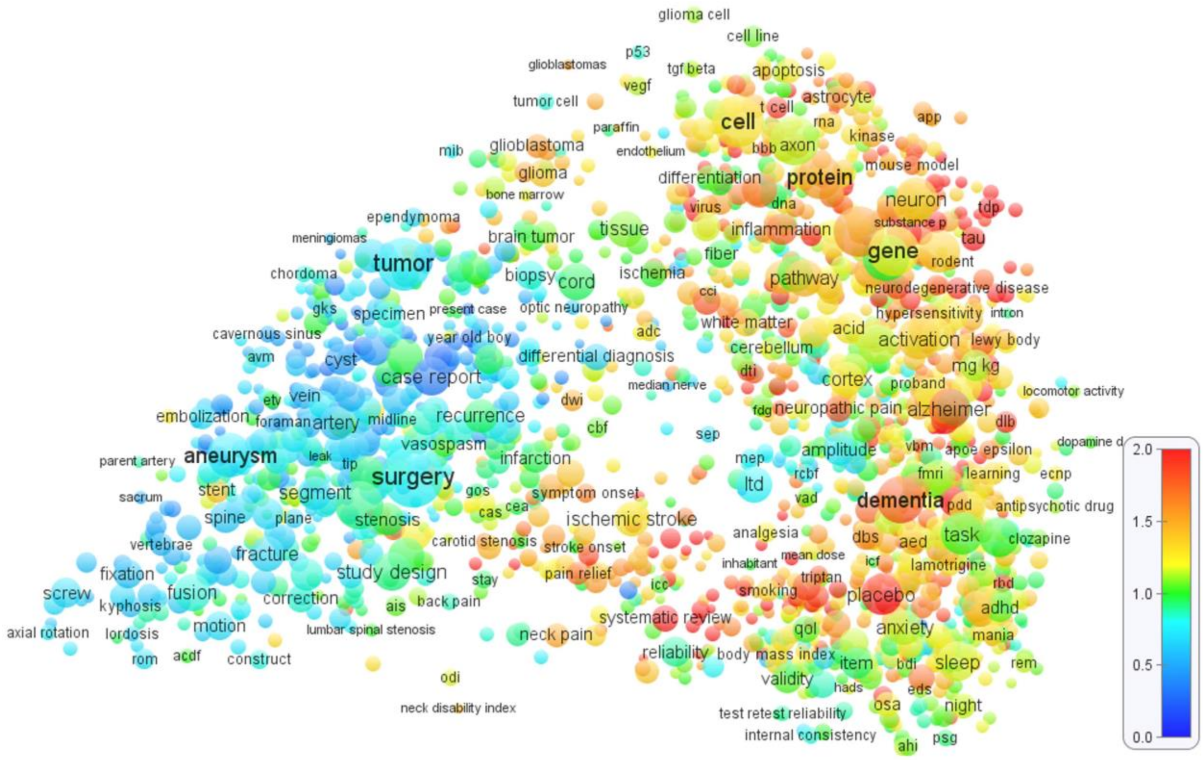
But these evaluative frameworks for research are no longer sufficient. Bibliometric analyses tell us only about outputs and the reach of research within academia, and not about its outcomes more widely; about the value of UK research to global and local society.

Moreover, bibliometric analyses contain inherent biases which may disincentivize research with more immediate societal impact. A recent study has shown how the citation impact of clinical intervention research may be substantially underestimated in comparison with basic and diagnostic research.[49] Figure 14 shows a term map for Clinical Neurology, based on natural language processing of 2000 terms from publications in the Web of Science. Size and colour indicate (respectively) the number of publications in which the term occurs and the average citation impact of these publications (blue represents a low citation impact, green a normal citation impact, and red high citation impact).

[48] Elsevier and BIS, "International Comparative Performance of the UK Research Base 2013," 2013.

[49] Nees Jan van Eck and others, "Citation Analysis May Severely Underestimate the Impact of Clinical Research as Compared to Basic Research.," *PloS one*, 8 (2013), e62395 <http://dx.doi.org/10.1371/journal.pone.0062395>.

Figure 10 Research with more immediate impact may be disadvantaged by bibliometric evaluations
Term map for Clinical neurology, from Van Eck et al.



As is evident, the most common terms relating to clinical practice (towards the left) have a lower (blue) citation impact than those on the right, representing basic research. The implications for researcher behaviour, since performance assessments are based on citation metrics, may be to discourage research in clinical intervention in favour of fundamental research. Yet both activities are essential for society, existing on a co-dependent spectrum. Other studies have shown that bibliometrics (in particular the use of ranked journals) favour mono-disciplinary over interdisciplinary research.[50] Systemic biases like this can warp the potential and innovative capacity of research.

'Research excellence' in the 21st century needs a broader definition and a wider evaluative framework which takes account of the wider societal and economic value of research, and research funding needs to work effectively to achieve its broad societal objectives. Resources can also be made to work more effectively, through greater reward and recognition systems for collaborative activities and 'funding by network'. Two key elements of delivering on these objectives for research – impact and collaboration – will be taken in turn, examining system incentives and disincentives for each.

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[50] Ismael Rafols and others, "How Journal Rankings Can Suppress Interdisciplinary Research: A Comparison between Innovation Studies and Business & Management," *Research Policy*, 41 (2012), 1262–82 <http://dx.doi.org/10.1016/j.respol.2012.03.015>.

3.2 The impact agenda is helping drive broader benefits from publicly funded research

Research impact is, simply put, any non-academic outcome to which research was essential. Those within academia understand that research is best understood as a complex and inter-related spectrum of activity, from exploratory and curiosity-driven research to research aimed at industry solutions. Complex feedback loops continually inform all parts of the spectrum and can create impact at any stage.

The impact agenda has begun to tackle the mismatch between the social and economic objectives of publicly-funded research and the much narrower view of research excellence taken by some evaluation systems. Impact is now a substantial (20%) part of Research Evaluation Framework criteria and a key element of research council bid valuations in the form of Pathways to Impact and Impact Summaries. Other countries are watching closely as funding bodies in the UK pioneer impact criteria as a substantive element of research assessment. Increasingly knowledge exchange and impact activities are being rewarded by institutions in terms of appraisals and promotions.[51]

The thousands of impact case studies submitted to the REF2014 and examples throughout this report demonstrate just a small amount of the value that long-term investment in research brings to society. Demonstrating this utility and value of university research is an imperative for policy makers and academics alike. The impact agenda places this aim at its heart, widening the accountability of researchers and their publicly-funded activities.

3.2.1 Systems for measuring, recognising and rewarding impact should be optimised

Research impact is achieved in many ways and by various interactions that can be hard to capture, as shown by figure 11. Any system of measurement and evaluation must be responsive to the subtleties of the variety of forms research brings value to society.[52] In the UK and elsewhere, including Australia, the question of how to identify and assess the impact of research has been the subject of extensive consultation.[53]

These international consultations have shown that the case study approach is the most useful for analysing this element of research quality, confirmed by feedback from REF2014 panel members. Narrative approaches to impact description allow the subtlety and variety of impacts to be captured, as testified by the rich resource of nearly 7000 impact case studies submitted to HEFCE for the REF 2014. Detailed analysis of these is underway to improve understanding of the impact of university research on society, and will help develop future evaluation systems.[54]

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[51] Vitae, *HR Strategies for Researchers: A Review of the HR Excellence in Research Award Implementation Activities across Europe*, 2013, p. 13. Vitae, *The Engaging Researcher*, 2010. Vitae, *A Career Development Perspective of UK Researcher-Business Interactions 2012*, 2012. Laura Fedorciow and Julie Bayley, "Strategies for the Management and Adoption of Impact Capture Processes within Research Information Management Systems," *Procedia Computer Science*, 33 (2014), 25–32 <http://dx.doi.org/10.1016/j.procs.2014.06.005>.

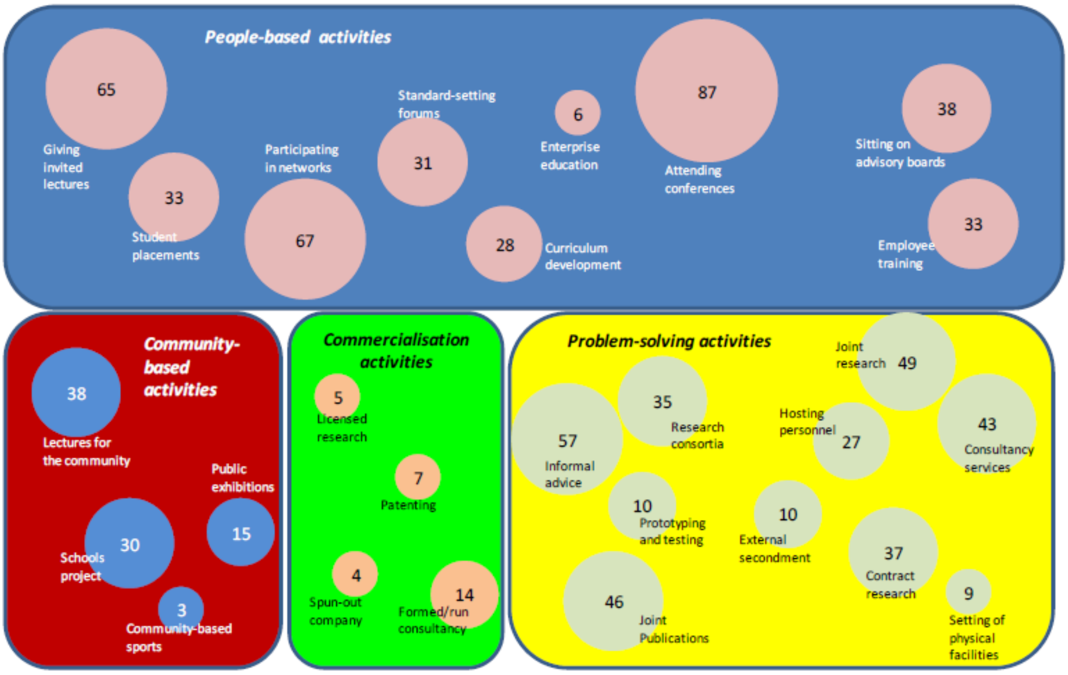
[52] Warnings have been sounded about the integration of impact factors into research assessment: B. R. Martin, "The Research Excellence Framework and the 'Impact Agenda': Are We Creating a Frankenstein Monster?," *Research Evaluation*, 20 (2011), 247–54 <http://dx.doi.org/10.3152/095820211X13118583635693>.

[53] Molly Morgan Jones and others, *Assessing Research Impact An International Review of the Excellence in Innovation for Australia Trial*, 2013.

[54] http://www.hefce.ac.uk/news/newsarchive/2014/news88461.html

Figure 11 Research impact is achieved through a variety of channels

From Alan Hughes and Michael Kitson, "Pathways to Impact and the Strategic Role of Universities," Centre for Business Research, University of Cambridge Working Paper No. 435 (2012), Figure 3.



Because of this multiplicity of routes and types of impacts created, doubts have been raised about using metrics to act as a proxy measure for research impact,[55] although these are being used and developed as performance and behaviour tools as much as for assessment.[56] Even the economic impacts of university research are difficult to capture by standard econometric evaluation: the value that training brings, both for the researcher and to partners is one example of this.[57] In some subjects, including health-related subjects, it is possible to undertake high-quality analytical research to measure the monetary value of research,[58] but routinizing this across all disciplines and impacts in a cost-effective way is much more challenging. Metrics-based measurements of impact are one element of the current independent review chaired by Professor James Wilsdon, which will report in 2015.[59] It is unlikely that the diversity of the research base and the impact that arises from that research will ever be captured by a set of impact metrics, and that case studies, qualitative approaches and narratives will dominate. The technological challenge will be to see whether automated text mining approaches could ease the cost of assessment and analysis.

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[55] Molly Morgan Jones, Jonathan Grant and RAND Europe, "Making the Grade: Methodologies for Assessing and Evidencing Research Impact," in *7 Essays on Impact*, ed. by Andrew Dean, Michael Wykes, and Hilary Stevens (University of Exeter, 2013), pp. 25–35.

[56] Such as the system developed at Coventry University: http://blogs.lse.ac.uk/impactofsocialsciences/2014/02/07/eric-impact-management-tool-for-academics/

[57] Ammon J. Salter and Ben R. Martin, "The Economic Benefits of Publicly Funded Basic Research: A Critical Review," *Research Policy*, 30 (2001), 509–32 <http://dx.doi.org/10.1016/S0048-7333(00)00091-3>.

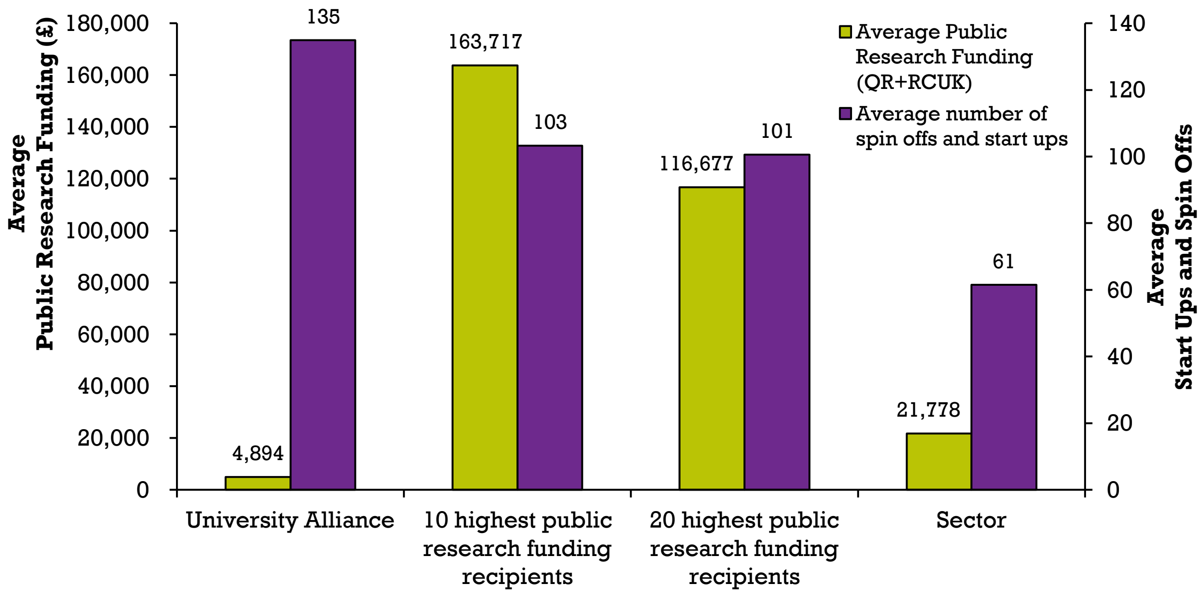
[58] Matthew Glover and others, "Estimating the Returns to UK Publicly Funded Cancer-Related Research in Terms of the Net Value of Improved Health Outcomes.," *BMC Medicine*, 12 (2014), 99 <http://dx.doi.org/10.1186/1741-7015-12-99>.s

[59] http://www.hefce.ac.uk/whatwedo/rsrch/howfundr/metrics/

3.3 Knowledge exchange activities are essential to delivering societal and economic value from research

Taking a specific look at economic contributions to society, it is clear that certain types of these impacts from research – such as spin offs and start-ups – are not achieved from the usual routes of research funding, as Figure 12 shows.

Figure 12 Success in creating start-ups and spin offs is not achieved by usual research funding routes
Source: HE-BCI 2012/13



The contribution of excellent research to society and economic growth is achieved through a range of knowledge exchange channels and interactions, including 'creating new businesses, improving the performance of existing businesses, delivering highly skilled people to the labour market, and attracting investment from global businesses. It is also vital to the implementation of the Government's Industrial Strategy.'[60] Universities play an important bridging role in achieving these types of impact.

Alliance universities generate **44%** of the **£376 million** generated from graduate start-ups

Knowledge exchange

Knowledge Exchange (KE) is an umbrella term that describes all two-way processes between academics and non-academic individuals and groups with the purpose of creating cultural, social, economic and research benefits. Although sometimes referred to as 'third mission' activities, Alliance universities see knowledge exchange as part of their core mission.

There are a variety of mechanisms and modes of interaction which constitute most KE activities, but the common theme is the sharing of learning, ideas and people between research and the private, third and public sectors, and the wider community. The aim of KE is to improve research, and its influence on policy, practice and business; therefore, an identifiable mutual benefit is an implicit requirement. Given the broad remit of KE activities and the diverse constituencies involved, their impact can measured by a variety of metrics, both economic and otherwise.

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[60] Department for Business Innovation & Skills, *The Allocation of Science and Research Funding 2015/16. Investing in World-Class Science and Research*, 2014.

Informal interactions are more difficult to capture but of equally significant and often greater economic importance than patenting and licensing.[61] Evidence repeatedly suggests that the human factor is crucial in helping with absorptive capacity and knowledge exchange and research impact in business.[62] Support systems that promote the movement of people between industry and academic environments should be encouraged. This approach is a central focus of Alliance universities, who have successfully embedded business links and engagement across a range of university activities, not least through their staff who have a powerful combination of industry and academic experience.

HEFCE's Higher Education - Business and Community Interaction Survey (HE-BCI) captures the economic traces of a broad range of informal interactions. As the maps below show, analysis of this data shows the important and diverse role that universities play in delivering economic growth and the Industrial Strategy, particularly through the SME constituency which is vital to the UK economy. This includes creating new businesses through graduate start-ups, consultancy and contract research interactions with other economic stakeholders, and knowledge transfer partnerships in key sectors including life sciences and aerospace, automotive & construction. Peaks of excellence in social and economic contribution also exist throughout the sector, as they do in research.

A 'revolving door' with business

Alliance universities welcomed 19% of their new staff in from the private sector in 2012/13 (compared to 6% in 'Golden Triangle' institutions and a 15% sector average). They work closely with employers to provide 48% of in-course work placements, and lead over one-third of all UK Knowledge Transfer Partnerships (KTPs).

By operating a 'revolving door' attitude towards business, staff and students are encouraged to move between different environments throughout their careers, creating T-shaped employees and relevant, impactful research.

[61] P. D'Este and P. Patel, "University–industry Linkages in the UK: What Are the Factors Underlying the Variety of Interactions with Industry?," *Research Policy*, 36 (2007), 1295–1313 <http://dx.doi.org/10.1016/j.respol.2007.05.002>; Maria Abreu and Vadim Grinevich, "The Nature of Academic Entrepreneurship in the UK: Widening the Focus on Entrepreneurial Activities," *Research Policy*, 42 (2013), 408–22 <http://dx.doi.org/http://dx.doi.org/10.1016/j.respol.2012.10.005>; Rudi Bekkers and Isabel Maria Bodas Freitas, "Analysing Knowledge Transfer Channels between Universities and Industry: To What Degree Do Sectors Also Matter?," *Research Policy*, 37 (2008), 1837–53 <http://dx.doi.org/http://dx.doi.org/10.1016/j.respol.2008.07.007>.

[62] See for example AHRC, *Hidden Connections: Knowledge Exchange between the Arts and Humanities and the Private, Public and Third Sectors*, 2011; CIHE, *Absorbing Research: The Role of University Research in Business and Market Innovation*, 2010.

Map 1. Top 20 for Graduate Start-ups

(By estimated current turnover of all active firms since 2008)

1. University of the West of England, Bristol (£145m)
2. Kingston University (£100m)
3. The University of Central Lancashire (£57m)
4. The University of Northumbria (£54m)
5. Bournemouth University (£44m)
6. Cardiff University (£43m)
7. University for the Creative Arts (£32m)
8. The University of Southampton (£27m)
9. The University of Edinburgh (£26m)
10. The University of Bradford (£25m)
11. University of Bedfordshire (£22.3m)
12. University of South Wales (£22.2m)
13. Liverpool John Moores University (£20.4m)
14. Coventry University (£20.3m)
15. University of St Mark & St John (£20.1m)
16. Royal College of Art (£18m)
17. The Nottingham Trent University (£17m)
18. The University of Sussex (£16.6m)
19. De Montfort University (£16.5m)
20. Edinburgh Napier University (£14m)

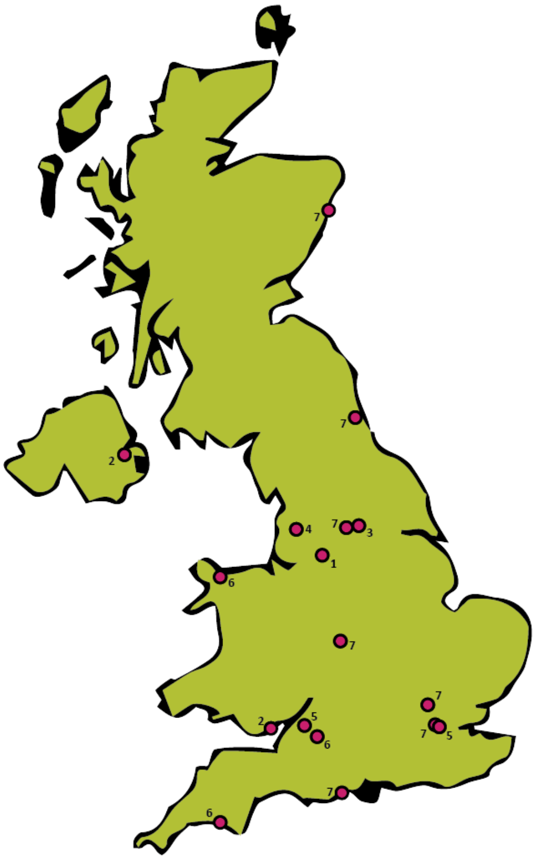
Data from HE-BCI, 2008-2012

Map 2. Top 20 for Consultancy & Contract Research

(Number of interactions with SMEs since 2008)

1. Coventry University (36,310)
2. The University of Liverpool (29,542)
3. SRUC (10,968)
4. The Queen's University of Belfast (3,742)
5. The University of Salford (3,695)
6. Leeds Metropolitan University (3,669)
7. The University of Central Lancashire (2,744)
8. Cardiff University (2,719)
9. The University of Lancaster (2,600)
10. The University of Northampton (2,595)
11. The University of Wolverhampton (2,232)
12. The University of Bristol (2,138)
13. University of Ulster (2,037)
14. Queen Mary, University of London (1,427)
15. The University of South Wales (1,320)
16. Cardiff Metropolitan University (1,145)
17. The University of Cambridge (1,114)
18. University of Derby (1,112)
19. Buckinghamshire New University (934)
20. The University of Newcastle (896)

Data from HE-BCI, 2008-2012



Map 3. Top for Life Sciences sector KTPs

(By number of projects since 2008)

1. The University of Manchester (16)
2. Queen's University Belfast (11)
2. Cardiff University (11)
3. University of Leeds (9)
4. University of Central Lancashire (8)
5. London South Bank University (7)
5. University of the West of England Bristol (7)
6. Bangor University (6)
6. University of Bath (6)
6. University of Plymouth (6)
7. Aston University (5)
7. Bournemouth University (5)
7. King's College London (5)
7. Newcastle University (5)
7. University of Aberdeen (5)
7. University of Bradford (5)
7. University of Hertfordshire (5)

Data from HE-BCI, 2008-2012

Map 4. Top for Aerospace, Automotive & Construction sectors KTPs

(By number of projects since 2008)

1. Queen's University Belfast (31)
2. The University of Sheffield (29)
3. Sheffield Hallam University (26)
3. University of Wolverhampton (26)
4. University of Hertfordshire (21)
5. University of Leeds (20)
6. Glyndwr University (19)
7. University of Bath (18)
8. The University of Nottingham (17)
9. Cardiff University (15)
9. Staffordshire University (15)
10. University of Bradford (14)
10. Birmingham City University (14)
11. The University of Reading (13)
11. University of Brighton (13)
12. University of Portsmouth (12)
12. University of South Wales (12)
12. The University of Liverpool (12)
12. The University of Manchester (12)

Data from HE-BCI, 2008-2012

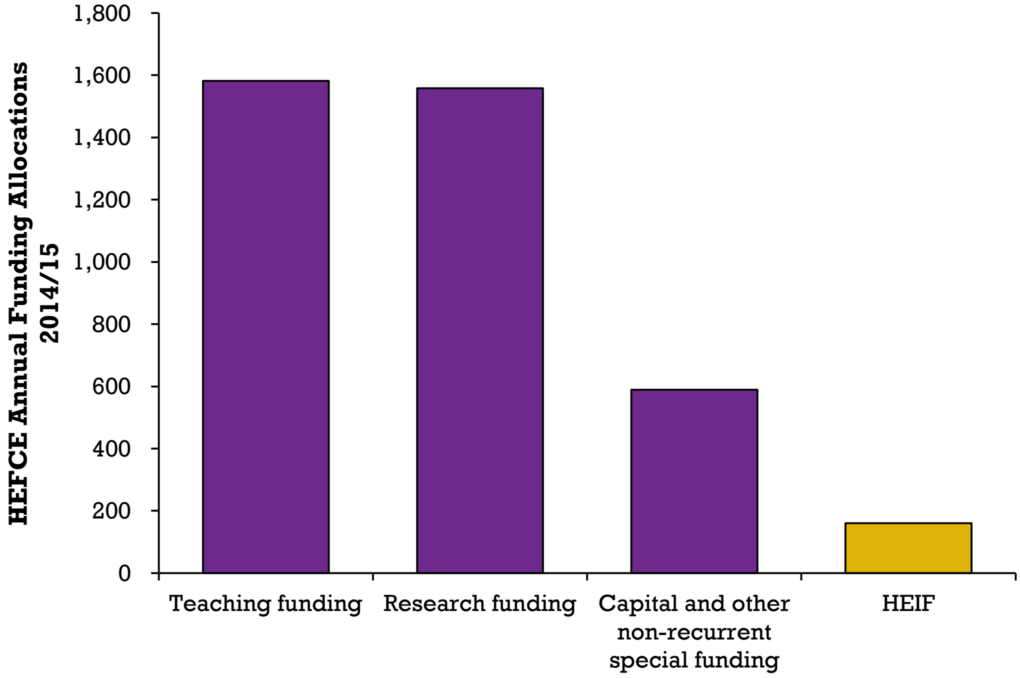
3.3.1 Targeted investment should support more costly SME knowledge exchange activities

Knowledge exchange activities are therefore a key element of delivering impact from university research. Each interaction that universities hav with the wider world, internationally, nationally or regionally, helps to broaden knowledge and share the value of university research across the spectrum of research activities. But these activities are as resource-heavy as they are valuable.

Greater investment is needed to deliver these societal and economic objectives of research. At £160 million Higher Education Innovation Funding (HEIF) is a relatively small – but critical – stream of funding, and its impact far outweighs its size. As the principal dedicated funding stream that allows universities to work innovatively with local SMEs, HEIF has enabled universities to support innovation in growth sectors and it provides an excellent return on government investment. Every pound of HEIF gives a gross return of £6.30 in additional knowledge exchange income, a proxy for the impact on the economy,[63] although this is likely to underestimate the total economic and social benefits.

As Figure 13 shows, knowledge exchange funding through HEIF is currently significantly under-funded and needs to be brought more closely into line with that for the other core missions: research and teaching, but not at the expense of these missions. Sir Andrew Witty recommended that HEIF should be increased to £250 million,[64] which should be directed from other areas of innovation funding.

Figure 13 Funding supporting 'third mission' knowledge exchange activities is much lower than for the other core missions



[63] Tomas Coates Ulrichsen (April 2014). *Knowledge Exchange Performance and the Impact of HEIF in the English Higher Education Sector*, Report for HEFCE.

[64] Sir Andrew Witty, *Encouraging a British Invention Revolution: Review of Universities and Growth*, 2013 (Recommendation 4).

HEIF should also include greater weighting for SME interactions. Innovative SMEs are the driving force of innovation in the UK economy,[65] and the UK's innovation performance showed a marked increase thanks to increases in innovative SMEs collaborating with others during 2009 and 2010.[66]

The research base and anchor institutions have an important role to play in increasing the innovative capacity and investment of SME private funds in research and development.[67] The examples cited throughout this response demonstrate how Alliance universities' connectivity and expertise are driving economic growth through increasing local SME innovativeness and investment in R&D, in processes and services as well as technology and products.

As anchors in their regions and with over 20,000 interactions with SMEs each year, Alliance universities understand that collaboration and partnership working brings huge value to local economies and societies, but is resource-heavy and can be high risk. Engaging with numerous SMEs, for example, uses more resource than fewer collaborations and contracts with large businesses and whilst the impacts of engaging with small businesses (in terms of human resource, percentage increases to profits, and so on) may not equal those on large corporations in purely financial terms the social and economic benefits may be more significant.

As high levels of engagement and innovation with SMEs do not necessarily translate into high levels of income, there are implications for HE-BCI results and, subsequently HEIF which currently only double weights interactions with SMEs. There is also a need for greater transparency in HEIF expenditure, to ensure it is invested in capacity that specifically supports the impact of research: this should take into consideration the quantity of SME partners and interactions, which would be a strong indicator of commitment to impact on the local society and economy.

Case study: Green automotive

Spin out company MicroCab brings Coventry research and cleaner air to our roads

Innovative dual electric/hydrogen fuel cell technology developed by researchers at Coventry University underpins the work of spin-out Microcab Ltd, delivering the eco-friendly car of the future.

Powered by Microcab's most advanced 3kW fuel cell, the lightweight zero-emission vehicle H2EV combines hydrogen with oxygen to create electricity. Unlike a battery-powereed electric vehicle, there is minimal 'recharge' time: H2EV can be refilled with hydrogen in minutes to run for 100 miles.

The West Midlands has excelled in the field of low emissions automotive technology for years, but Coventry University's research has put it on the global low carbon industry map. Technical collaborations with automotive and motorsport industries, including Delta Motorspot and Lotus, allowed production-ready versions of small economical hydrogen fuelled cars to be delivered several years ahead of larger competitors and enabled a number of organisations to benefit economically through the potential to diversify into this new market.

Case study: Marine SMEs

Marine SMEs benefit from collaboration with Plymouth's world-class rseearch

The University of Plymouth is harnessing its marine expertise for economic growth through its new Marine Innovation Centre (MarIC), established to optimise the interface between the University and Marine Sector SMEs. The Centre promotes the industrial uptake and commercialisation of the University's research and world-class facilities, links businesses to the Growth Acceleration and Investment Network (GAIN) and improves SME performance by stimulating innovation and the successful exploitation of new ideas.

The £1.97m project has drawn on investments from industry, ERDF and the University. MarIC expects to deliver a gross increase in GVA of £3.726m and a gross safeguarded GVA of £1.674m through business assists and the creation of new jobs, additional firms involved in business clusters or networks, SMEs launching new or improved products, and gross jobs created in environmental sectors.

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65 NESTA, *Rebalancing Act*, 2010.

66 European Commission, *Innovation Union Scoreboard*, 2014, p. 70.

67 University Alliance, *Growing the Future: Universities Leading, Changing and Creating the Regional Economy*, 2011.

3.4 Collaboration and plurality improve the impact and value for money of UK research

Connectivity, collaboration and openness are essential to the future of world-leading science. Plurality and complementarity in the system underpins strong, effective partnerships and result in more beneficial research

Connectivity, collaboration and openness are essential to the future of world-leading science: teams of people, not individuals, have driven the advances of the modern technological age.[68] Collaboration with research partners outside of academia also ensures benefit to wider society, the spread of ideas and value for money. Interdisciplinary collaborations often prove to be the most innovative.[69] Collaboration delivers cost efficiencies, reducing duplication across the system. Partnerships are built between universities, and with industry and community partners, each playing to their own strengths: as discussed in Part I, this biodiversity strengthens the research ecosystem as a whole.

Most business challenges need multidisciplinary responses. Wider changes in the relationship between business and academic worlds, moving from transactional to strategic relationships, are helping to realign ambitions. Case study examples throughout report show how important end-user access into research base can be directed through entry points into multi-disciplinary research. Portals and open doors are essential to ensure all sectors have access to world-leading research, an approach which University Alliance institutions have embedded across the university.

Despite the merits of collaboration, and as Sir David Watson has pointed out, the present levels of concentration and certain bibliometric indicators encourage the 'winners' to work in a siloed, 'mode one' way, when other parts of the system and government priorities are embracing a 'mode 2' world of knowledge creation and exchange.[70] Whilst Science 2.0, the open access agenda and open innovation are steering policy discourses, there remain systemic disincentives to these agendas, universities switching from competitive to collaborative mode is not always a smooth process as a result.

Over 100 years of partnership working

Collaboration with industry and with other university partners' complementary strengths is essential to the missions of Alliance universities, as demonstrated in the case studies throughout this report. Having built strong strategic partnerships with businesses for over a hundred years, Alliance universities know that multi-disciplinary and multi-partner approaches are key to problem-solving and innovation, and that the connectivity they provide with local, national and international partnerships acts brings real value to society.

University Alliance is also undertaking and supporting efforts to extend existing geographically organised equipment sharing schemes nationally and to business, bringing the benefits of sharing resources to the wider research ecosystem.

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[68] Walter Isaacson, *The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution*, 2014.
[69] See for example the role of design with other disciplines in solving challenges: University Alliance and Design Council, *Design& Education: Creating the Future*, 2014.
[70] David Watson, 'Getting it together', Times Higher Education, 3 April 2008: http://www.timeshighereducation.co.uk/401289.article

Case study: Life Sciences

Collaboration with the University of Huddersfield helps industry profit from innovative physical organic solutions

Huddersfield research in physical organic chemistry has led to process improvements in chemical manufacturing, most notably in the optimisation of the synthesis of antisense oligonucleotides and in the use of liquid ammonia as a solvent. It has also led to the development of new inhibitors of bacterial β-lactamases for use as antibacterials.

The research team's expertise has been shared through the success of IPOS (Innovative Physical Organic Solutions), a research unit offering analytical and chemical process development services to the chemical industry, established in 2006.

IPOS expanded significantly from 2009 to 2013 and has now collaborated with more than 150 companies, many of them based in Yorkshire/Humberside where regeneration is critically dependent on the success of new, non-traditional, high-technology firms. Through these collaborative projects, IPOS has contributed to the growth and prosperity of both regional and national industry.

Case study: Robotics

Collaborative robotics research at the University of the West of England drives cross-industry applications

Bristol Robotics Laboratory is a unique collaborative partnership between the University of the West of England (UWE, Bristol) and the University of Bristol which harnesses the collective strengths of its university partners and the best expertise from industry to spearhead Britain's efforts to be a world leader in modern advanced robotics.

Home to a vibrant community of over 100 academics and industry practitioners, BRL is currently involved in interdisciplinary research projects addressing key areas of robot capabilities and applications. BRL maintains strong national and international links with both industry and other research institutes, and has an enviable track record of successful research and innovation and funding from public and private bodies. BRL researchers and innovators were strongly represented on the UK Autonomous Systems Mission to the USA in 2014.

Case study: Healthcare

Lincoln research pioneers imaging technology in the fight against cancer

An award-winning EPSRC-funded consortium led by the University of Lincoln with the Institute of Cancer Research, University College London and The Royal Marsden Hospital has created DynAMITe: the world's largest radiation-tolerant silicon imager. Designed primarily for medical imaging and 200 times larger than the processing chips in current PCs and laptops, its image clarity shows the impact of radiation on tumours, as well as assisting detection in the earliest stages of disease progression.

Spin-out company Image Sensor Design and Innovation Ltd has signed agreements with a global medical technology company for the exclusive design and provision of all future large area imagers and three international patents have been submitted as well as attracting extra translation funding from the Wellcome Trust.

A new collaboration with the University of Liverpool will combine the imaging techniques from Lincoln with detectors produced at Liverpool to develop unique medical imaging technology that will provide accurate proton therapy doses and 3D images of where radiation is absorbed at a tumour site.

Case study: Manufacturing

Northumbria collaboration generates profit from improved performance of metal cutting tools

Research undertaken by the University of Northumbria in close collaboration with SNA Europe has resulted in the development of new tooth design for metal cutting tools, new coating techniques and new production technologies.

The collaboratively designed research focused on understanding the fundamental mechanisms of material removal and evaluating the optimum performance, efficiency and lifespan of existing tools, with special attention to the cutting performance for wear-resistant and difficult-to-cut materials such as ball bearing steel, stainless steel, Ni–Cr–Mo steel and titanium alloy (Ti-17, which is widely used in aerospace industry).

These results fed into new products which are marketed and sold internationally, and include well known retailers such as B&Q, Homebase and Screwfix. The collaboration has led to 140% per annum return on the research investment, new sales revenue of £2m, reduced manufacturing time and costs and improved life of products.

3.4.1 Extra potential in the research base would be released by further recognising and rewarding collaboration

As discussed in Part 1, selectivity and specialisation results in a plurality of skills, expertise and activities throughout the system which are maximised through collaboration. The benefits of collaborative working include funding by network (ensuring funding reaches the best delivery partners), which can achieve complex outcomes through multi-partnered responses: creating a critical mass of the best across the system, not restricted to unit level. But collaborative working needs to be recognised and rewarded for this to work most effectively.

The USA measures and captures collaboration by counting R&D expenditures passed through to other academic institutions or received by institutions as subrecipient funding. Nearly 90% of these 'pass through' funds in the financial year 2009 were federal (public) funds.[71] Similar attempts in the UK to measure collaborative pursuits would recognise the institutions who already prioritise them, as well as help incentivise collaborative activities further.

Other simple tweaks such as recognising co-investigators and their home institution as well as principal investigators in funding audits (the AHRC are leading the way with this practice), and considering systems of transitive credit which can help give appropriate recognition to all individuals in a team for their work,[72] should also be considered. As well as ensuring the system does not disincentivise collaborative working, the results may also help public funders understand better where excellence lies throughout the system traced through the investment preferences of collaborators.

Funding principles should create an environment which encourages networked collaboration, through increasing opportunities for collaborative, inter-institutional working, for example through multi-partner doctoral training schemes. It could be incentivised further by making a percentage of QR funding dependent on network capacity and partnership working.

[71] National Science Foundation (2012). *Science and Engineering Indicators.*

[72] Daniel S Katz, "Transitive Credit as a Means to Address Social and Technological Concerns Stemming from Citation and Attribution of Digital Products," 2 (2014), 1–4.

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Appendix A

Indicators used in Evidence analysis of RAE 2008 results used the following indicators. The detail below is described in Evidence Ltd. (2011). *Funding research excellence: research group size, critical mass & performance*. University Alliance.

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.

- **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.

- **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.

In discussion with University Alliance we have selected eight representative RAE2008 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[73]:

- **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

[73] 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.