Digital Research Reports

The value of structural diversity

Assessing diversity for a sustainable research base.

Digital Science and the Science Policy Research Unit, University of Sussex

DECEMBER 2015

DIGITAL science

CELEBRATING SPRU 1966-2016

About SPRU

The Science Policy Research Unit at the University of Sussex, is internationally recognised as a leading centre of interdisciplinary research on science, technology and innovation policy. Our research addresses pressing global policy agendas, including the future of industrial policy, inclusive economic growth, the politics of scientific expertise, energy policy, security issues, entrepreneurship, and pathways to a more sustainable future. SPRU is driven by a desire to tackle real-world questions, whilst also contributing to a deeper theoretical understanding of how innovation is shaping today's world.

About Digital Science

Digital Science is a technology company serving the needs of scientific research. We offer a range of scientific technology and content solutions that help make scientific research more efficient. Whether at the bench or in a scientific setting, our products help to simplify workflows and change the way science is done. We believe passionately that tomorrow's research will be different – and better – than today's.

Visit www.digital-science.com

This report has been published by Digital Science, which is operated by global media company, the Holtzbrinck Publishing Group.

The Macmillan Building, 4 Crinan Street, London N1 9XW
info@digital-science.com

ISBN: 978-0-9929477-3-6

The value of structural diversity: assessing diversity for a sustainable research base

This report is about structural diversity - the diversity of disciplines, institutions and support mechanisms. Structural diversity is a property of a 'strong' research base that not only produces great research today but also has the capacity to address new challenges flexibly and responsively tomorrow. It is distinct from the contribution made by social diversity - the diversity of gender, nationality and ethnicity - to productivity, innovation and social cohesion.

We need to assess diversity for future research just as much as we evaluate achievement for past research. Research assessment is usually a retrospective analysis of historical data whether it uses grant income, staff capacity, publication output, or citation impact. This is a very limited perspective for policy and investment. It is a skewed view of what might be important for the future of the research base. Awarding more funds to institutions and teams that did well last year is a safe bet only so long as next year looks similar. But the pace of discovery is accelerating, challenges change, new fields emerge and we lack the foresight to predict where demands and the breakthroughs will come next.

The capacity to support excellence and respond to opportunity comes from:

- Diversity of research fields: A broader range of disciplines supports exceptional levels of research excellence, fed through a network of institutions of regional and international significance (Evidence, 2002; Evidence, 2003).
- Diversity in support which gives flexibility of research support to allow a mix of long and short term responses and includes strategic and responsive awards: Government has consistently argued that diverse funding mechanisms are required to enable curiosity-driven research and evolving, targeted programs of high policy priority or scientific need (Cabinet Office, 1993).
- Diversity of research organisations, where mission-led units complement large and small universities with regional as well as international engagement: UK Government Chief Scientific Adviser Bob May showed that research economies with a strong university research base performed consistently better than those committed to narrow, mission-led research institutes (May, 1997).

Because of our uncertainty about the future we need an agile and responsive research base. So why is this agility not core to the assessment of research and innovation? Diversity in the structure of the research system has been overlooked and under-researched because it is in practice a tricky concept to turn into a hard definition, and even trickier to quantify.

What does diversity mean?

- Diversity in nature is readily apparent. Ecologists look at the diversity of natural communities like meadows and woods and need models and methods to enable them to be compared (MacArthur, 1965; May, 1975). Analysing differences in diversity between similar locations provides insights about conditions that affect species and community structure and leads to questions about the relationship between complexity and stability.

- Diversity is a common theme in management. Technological diversity stimulates innovation and productivity (Grabher and Stark 1997). HM Treasury (2004) wanted science 'opened up' to diverse public constituencies and interests. Diversity is a focus in economics (Gatsios and Seabright 1989), systems and organisation theory (Johnson and Longmeyer 1999) and regional development (Dosi 1992).

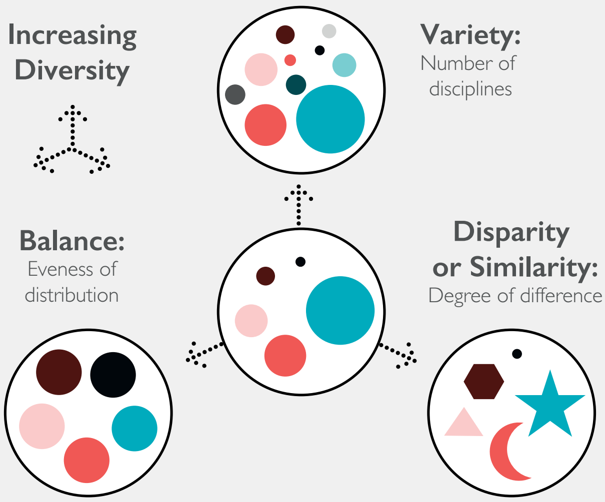


Figure 1: 'conceptualisation of diversity'. Source Rafols and Meyer (2010) and Stirling (1998)

How is diversity made up and how can it be measured? Andy Stirling (2007) reviewed a wide range of work and concluded that diversity concepts display some combination of just three basic properties: 'variety', 'balance' and 'disparity'. Each is a necessary but insufficient property of diversity; they apply across a range of disciplines; and, despite multiple tests, no fourth property has emerged.

- Variety is the number of categories into which system elements are apportioned: how many types of thing do we have? This is highlighted in species-number indices (McIntosh, 1967); enumeration of firms or products in economics (Saviotti and Mani, 1995) or counting technologies in energy policy. All else being equal, the greater the variety, the greater the diversity.

- Balance is a function of the frequency of elements across categories: how much of each type of thing do we have? Analogous to statistical variance, it can be represented by a set of positive fractions that sum to unity and is referred to as evenness (ecology: Hill, 1973) and concentration (economics: Finkelstein and Friedman, 1967). It is captured by the Shannon- Wiener (1962) and Gini (1912) indices. All else being equal, the more even the balance, the greater the diversity.

- Disparity refers to the difference or distance between the varieties of categories: how different from one another are the types of thing that we have? Judgments over disparity (often implicitly) govern the resolving of categories used to characterise variety. It is addressed by an array of taxonomic indices (palaeontology: Williams and Humphries, 1994; economics: Nguyen et al. 2005) usually based on some form of distance measure. All else being equal, the more disparate are the represented elements, the greater the diversity.

For research analysis, we first choose the granularity of our varieties: this is far from obvious and cannot be universal. For example, do we work at the level of natural sciences, chemistry or graphene? Choices will vary but once agreed those choices allow data to be grouped. Then, to enable comparisons, we can index the disparity of our varieties and refer each 'sample' to a global background - akin to normalising citation counts.

This report focusses on one aspect of structural diversity: diversity among research disciplines in different settings. The examples visualise the additional information that a diversity perspective can offer. Later, we turn to the problem of creating a quantitative index.

Diversity for impact

Diversity has been associated with innovative and impactful research outcomes. It is also evident that 'grand challenges' in research - such as climate change or the health of an ageing population - will require cross-disciplinary solutions. The UK's 2014 Research Excellence Framework (REF 2014) included case studies on the societal and economic impact of research for the first time. Whilst there exists a perception that research solving societal challenges often draws on a diversity of research backgrounds, the analysis of universities' REF 2014 impact submissions extended this conversation. Initial text analysis showed a majority of case studies could be categorised with multiple --cognitively distant-- fields (King's College London and Digital Science, 2015).

Figure 4 presents a new analysis of the REF 2014 impact case studies. For clusters of case studies that share similar content we consider the diversity of subject panels to which they were submitted (these are A: Biological Sciences and Medicine, B: Physical Sciences and Engineering, C: Social Sciences, and D: Arts and Humanities). For each case study cluster (e.g. Number 31, labeled Smoking Policy) the difference in the share of contribution for Panel A and B is plotted horizontally, and the contribution difference between C and D appears on the vertical. This puts the Smoking Policy cluster high on the horizontal axis (towards A: Medicine rather than B: Physical Sciences) and more towards C: Social Sciences than D: Arts and Humanities. Compare to 104, labelled Textiles and Fashion, the placement of which suggests is made of up case studies submitted to Panel B (which includes engineering) more than A, and D: Arts and Humanities more than C.

The colour intensity scales with the Shannon Diversity Index of the cluster, and supplements this placement in the subject panel landscape. It is a reflection of how many subject panels the cluster draws on -- and how evenly it does so. Stronger colours on clusters are more diverse in this sense. Poetry (cluster 113) has the lowest diversity, and Criminal Justice and Technology (cluster 88) has the highest.

Does this suggest the biggest challenges facing society require subject diversity for solutions? Here we see a diversity of clusters as well as diversity in clusters; suggesting both mono-disciplinarity and diversity have their place in producing impactful research.

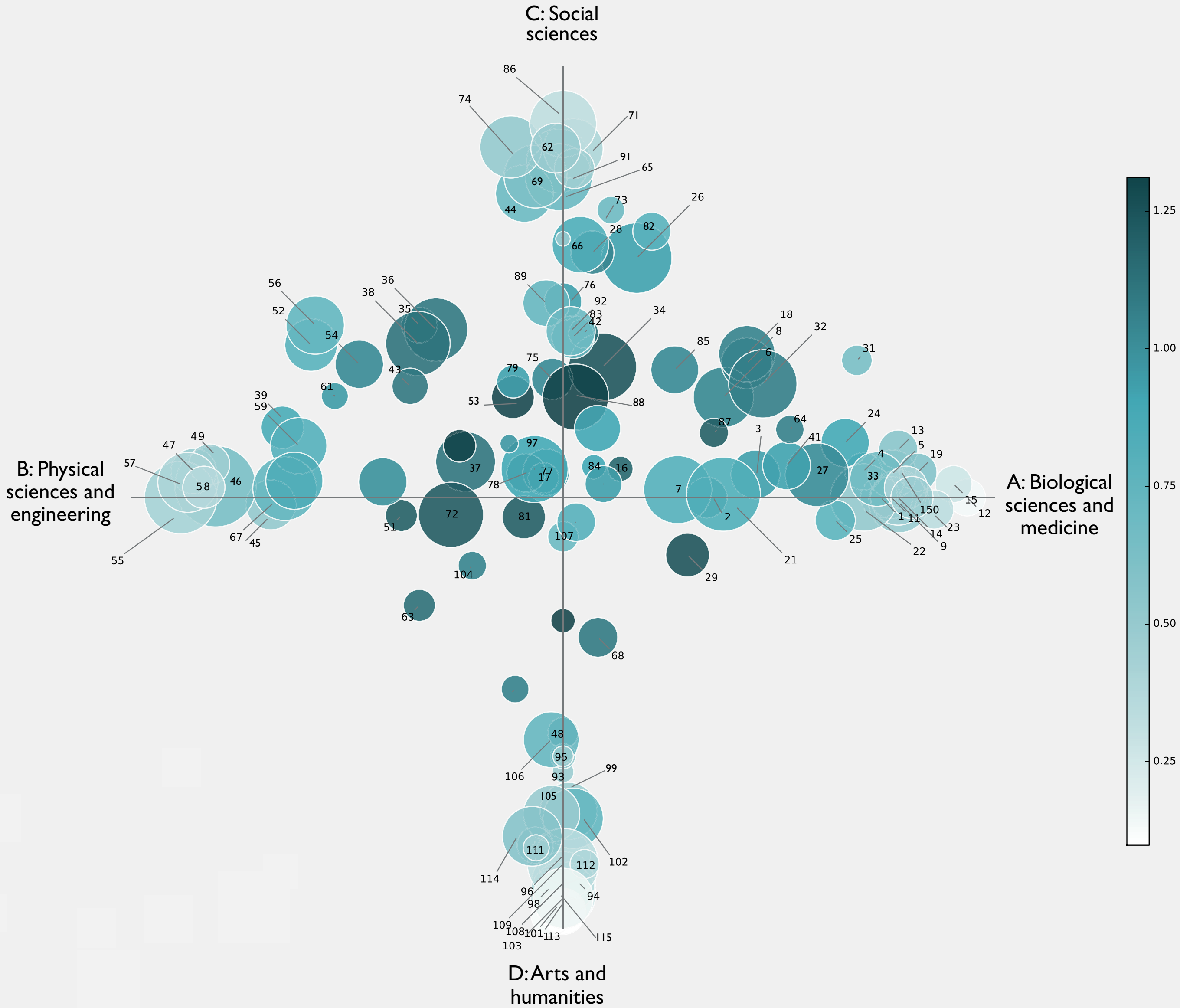


Figure 2 ‘Themed clusters of the UK’s REF impact case studies’Here, themed clusters of the UK’s REF 2014 impact case studies are shown plotted according to contributions from main subject panels. The size of each bubble is scaled with the number of case studies in a cluster. The clusters are enumerated, and the key shows cluster labels. The difference in the share of contribution for Panel A (Biological and medical sciences) and B (Physical sciences and engineering) is plotted horizontally, and the contribution difference between C (Social sciences) and D (Arts and humanities) appears on the vertical. The colour intensity scales with the Shannon Diversity Index of the cluster, and supplements the placement of the cluster in the subject panel landscape. It is a reflection of how many subject panels the cluster draws on – and how evenly it does so.

Diversity for institutions

Research diversity within institutions can be influenced by pressure to fit to the prevailing orthodoxies at the core of major disciplines. Data on the research performance of whole universities and of their departments often draws on citation data associated with their publications. Such an analysis may focus on the average citation rates of papers or it may be based on the ranking of the journals in which staff publish.

A study by Ismael Rafols, Loet Leydesdorff, Alice O'Hare, Paul Nightingale and Andy Stirling (Rafols et al., 2012) provides evidence of how journal rankings can disadvantage diverse, interdisciplinary research in research evaluations. Innovation is key to a competitive business and is often driven by research. They compared the diversity and research performance of Innovation Studies units with that of leading Business & Management schools in the UK.

The study showed that Innovation Studies units are consistently more diverse in their research than Business & Management schools. However, the top journals in a ranking created by the Association of Business Schools' are much less diverse and this favours the performance of disciplinary-focused Business Schools.

This suggests that ostensibly 'excellence-based' journal rankings could exhibit a systematic bias in favour of mono-disciplinary research. Such a bias would affect research evaluation and hence the associated financial resourcing of interdisciplinary research organisations. It might also result in researchers tending to comply with disciplinary authority and be pressurised into writing papers to fit a narrow core of disciplinary journals.

Figure 2 KEY

Cluster No.	Cluster label	Cluster No.	Cluster label	Cluster No.	Cluster label
1	Infectious disease + vaccines	39	Extreme natural events	78	Wales
2	Stem cells	41	Agricultural technology	79	Africa
3	Healthcare, patients and drugs	42	Rural economy and society	81	China
4	Pain management	43	Air quality	82	Violence against women
5	Stroke	44	Urban planning	83	Gender and equality
6	Food, diet, nutrition	45	Technology development	84	LGBTIQ equality
7	Clinical medicine	46	Computing software and systems	85	Offenders and ASB
8	Pediatric health	47	Telecommunications	86	Law and justice
9	Genetic diagnosis	48	Creative digital	87	Alcohol
11	Maternal and perinatal health	49	Optical technologies	88	Criminal justice and technology
12	Disease treatment	51	Sound and noise	89	International law, human rights
13	Cardiovascular disease	52	Built environment	91	International development
14	Specific disease treatment	53	Transport safety	92	Forced migration
15	Malaria	54	Transport	93	Historic slavery
16	Visual impairment	55	Aerospace + automotive	94	Jewish history
17	Medical imaging	56	Fuel and energy	95	History on TV
18	Healthcare and NHS	57	Oil and gas	96	History outreach
19	Health screening	58	Space	97	Archaeology, heritage
21	Drug development	59	Science outreach	98	Classics
22	Cancer	61	Maths education	99	Religion
23	Respiratory illness	62	Education policy	101	Philosophy
24	HIV + AIDS	63	Gaming for education	102	Linguistics and communication
25	Dental health	64	Autism and dyslexia	103	Literature and writing
26	Children, families and welfare	65	Sport	104	Textile fashion
27	Mental health	66	Education	105	Culture and heritage
28	Ageing populations	67	Product development	106	Cultural curation
29	Ethics and health	68	Design	107	Cultural heritage
31	Smoking policy	69	Enterprise and innovation	108	Art, visual media
32	Health and social care	71	Income and employment	109	Music
33	Animal welfare	72	Security	111	Performance art
34	Conservation, biodiversity	73	Tax	112	Dance
35	Flood risk management	74	Financial policy	113	Poetry
36	Water resource management	75	Electoral politics	114	Film
37	Marine environment	76	Europe policy	115	Theatre
38	Climate change	77	Scotland	150	Generic disease

Edinburgh

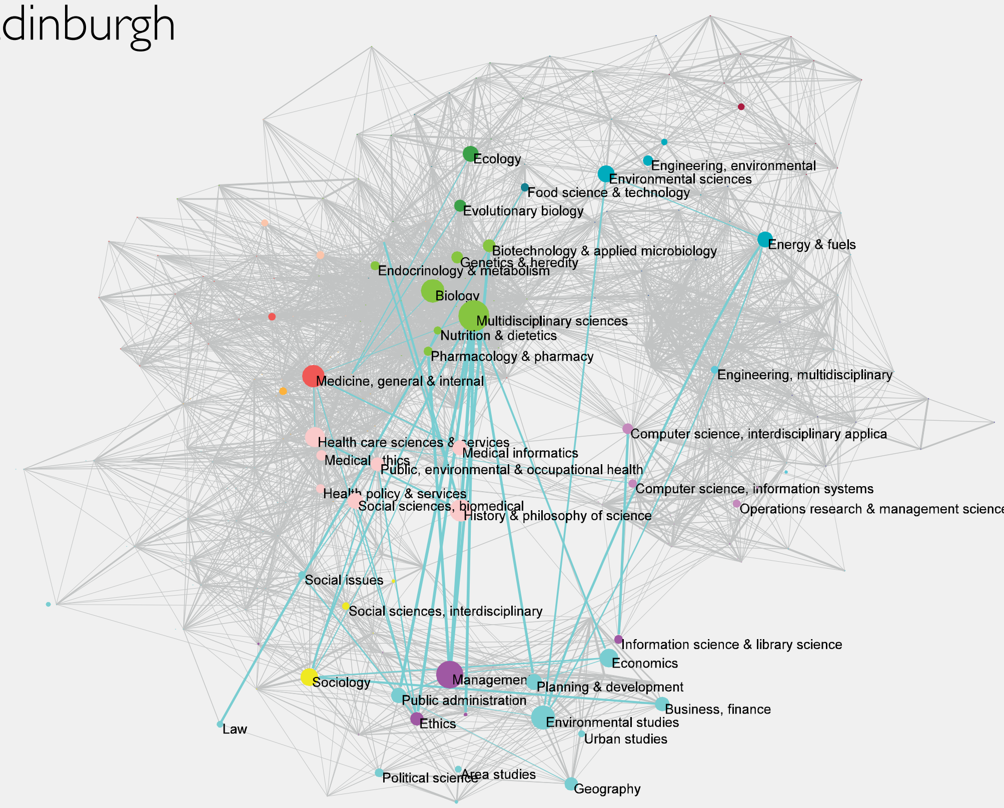
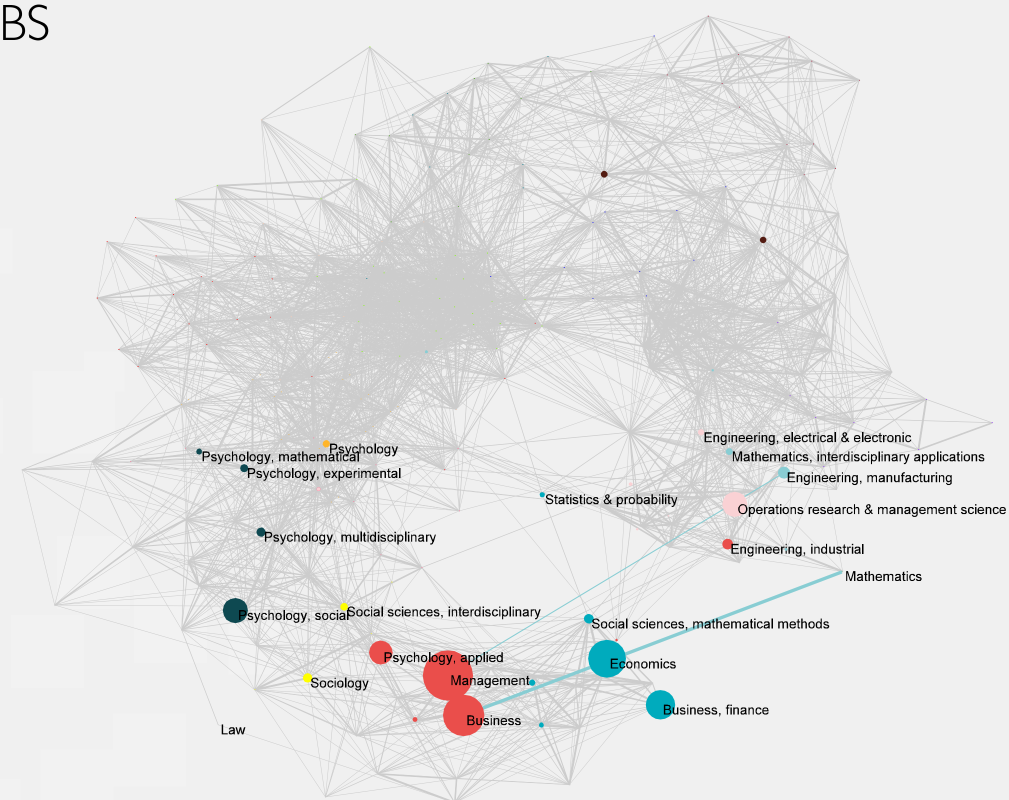


Figure 3 - Overlay of reference frequency by variety for the global map of science: ISSTI (Edinburgh - Figure 3A) and LBS (London - Figure 3B). Citing between categories (as indicated by green links) by a given unit is shown only for observed values five times larger than expected. Each node (variety) is a Thomson Reuters 2009 Web of Science journal category. Grey lines (edges) indicate similarity between nodes. The degree of superposition in the grey background illustrates the degree of similarity between different areas of science for all Web of Science data. Diversity of references (spread of nodes) and referencing across disparate varieties (cross-linking) are also interpreted as signs of interdisciplinarity.

LBS



Diversity for countries

Disciplinary diversity at country level provides a different slant on the question of which country has the 'best performing' research base. High average citation impact is usually seen as an optimal result but averages hide the mix of peaks and troughs. More consistent performance - greater evenness in citation impact across categories - avoids the risks of missing key areas.

In this analysis, varieties are Thomson Reuters Web of Science journal categories and frequency is replaced by citation impact. Disparity does not form part of the analysis. The UK's international comparative research performance has a high average against other G7 nations but some smaller EU nations do better. However, if we track variance in citation impact across the journal categories then the strong peaks of Denmark and the Netherlands' are offset by areas with lower impact. The UK's lower variance reflects more consistent performance and strengthens its competency to invest fruitfully in new areas.

The US has a high average and a low variance. No single EU nation can match this, but the European research area as a whole is entirely competitive with the US on both impact and consistency. There is particular complementarity between France, Germany and the UK, creating a significant European capacity to adapt to change and to exploit new opportunity.

South Korea and Singapore have had lower citation impact than a lot of European countries but their growing research investment and achievement supports both improved impact and significantly more even performance across disciplines.

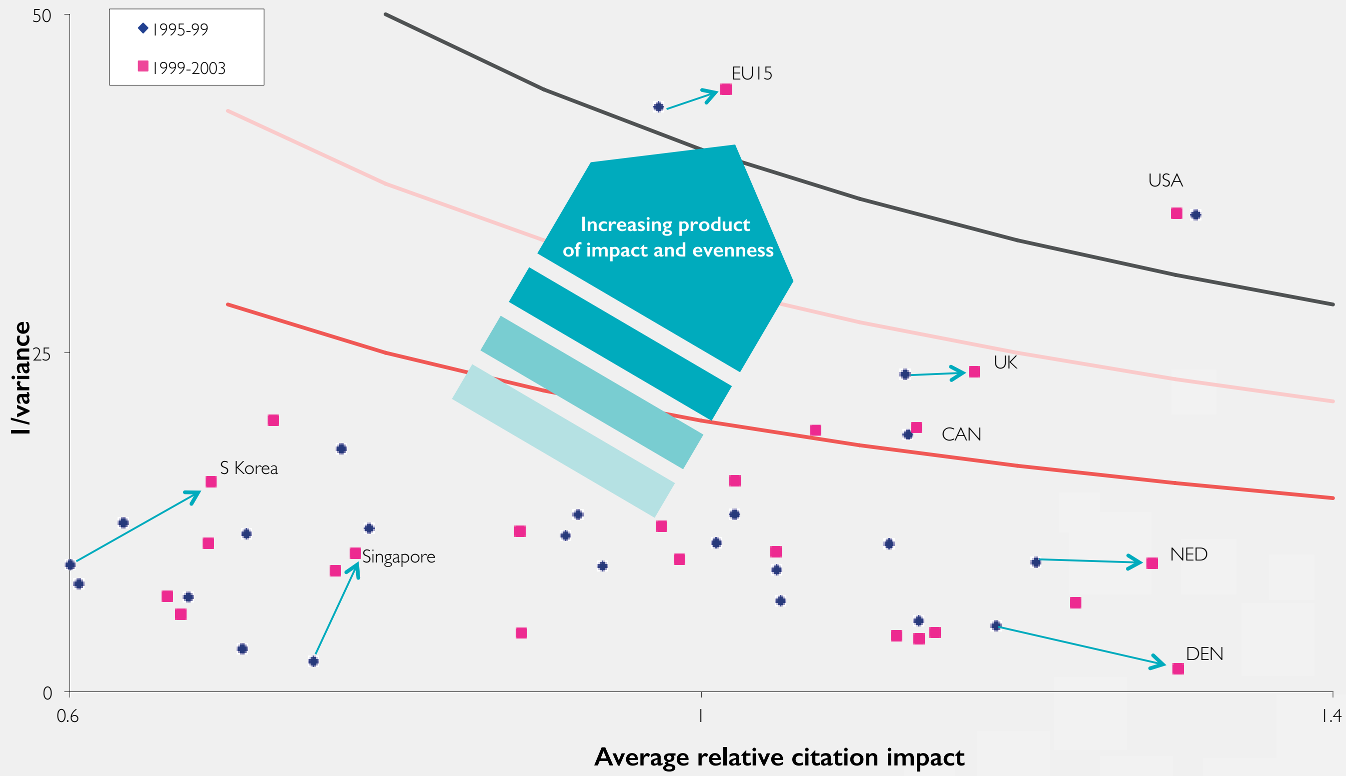


Figure 4: International comparisons of performance (average citation impact, world average = 1.0) and research diversity (indexed via the variance in impact for Thomson Reuters 2005 Web of Science journal categories). We can model the combined impact and variance factors and calculate optimal combinations for any specific level of investment. The graph indicates nominal isoclines for this which indicate that a spread of diversity/variance produces better outcomes: if resources are limited then it is better to reduce variance than specialise in a few limited peaks.

Discussion

Given the pervasive significance of structural diversity evidenced across a spectrum of disciplinary and organisational perspectives, and given the literature evidencing its widespread use - particularly in ecology and economics, it seems extraordinary that the indexing of structural diversity is not as central a part of comparator studies of a country's research base as is, for example, citation analysis.

Scrutiny reveals the limitations of an obsession with performance. Structural diversity is a necessary complement to research excellence. Graphical analyses confirm the additional information that can be acquired from this perspective on the research landscape. At project level, research diversity is at the root of the impact stories submitted for evaluation in the UK's REF 2014 UK case studies. At university level, a department focussing on high-impact journals may not be in the best position to address interdisciplinary policy challenges. At country level, the research base with the highest average citation impact does not necessarily have the best long-term portfolio.

Diversity should be a central part of any country's assessment of its research base if it wants to prepare for opportunities about which it cannot be certain in its planning. Loss of structural diversity is a loss of capacity to respond flexibly when priorities change or when opportunities appear. Diversity builds in sustainable performance.

The Shannon Diversity Index used in Figure 2 is a way of putting a value on varieties (of discipline) in case study documents that are clustered by the text they contain. Figure 3 visualises the disparity of research disciplines as a general global network and then compares specific institutional portfolios with that network. That analysis also points to the long-term risk of overvaluing short-term performance criteria. The implication of Figure 4 is that investment strategies need to balance concentrated investments in peak priorities with a complementary platform of support activity. Collectively, these illustrate the common diversity components identified by Stirling (2007).

This makes intuitive sense at institutional level. The regional network of research-diverse institutions may account for the UK's long record of success and of successful people (Evidence, 2002, 2003; Universities UK, 2010). It also makes sense at disciplinary level. Soil science was important to agriculture fifty years ago, then declined as food markets shifted, but now it has a critical place in climate change research. And structural diversity makes sense for research support. The taxpayer should rightly be assured that significant investment supports current policy priorities, but without curiosity-driven research identified by researchers themselves we will soon be mining worn-out seams.

The next step is to develop the indexing of structural diversity into an analytical framework that provides acceptable general measures, relevant to policy and meaningful to stakeholders. We would need to compare that with models of desirable outcomes. We can then show where diversity has been of value in the past and track where diversity might be lost to the future and take the steps to safeguard our strengths.

References

Cabinet Office (1993). Realising Our Potential: a strategy for science, engineering and technology. Cm 2250. ISBN 0101225024

Dosi, G. (1992). Industrial organisation, competitiveness and growth. Revue d Economie Industrielle 59, 27–45.

Evidence (2002). Maintaining research excellence and volume. A report for the Higher Education Funding Councils for England, Scotland and Wales and for Universities UK, pp. 118. http://www.hefce.ac.uk/pubs/rdreports/2002/rd08_02/

Evidence (2003). Funding research diversity: the impact of further concentration on university research performance and regional research capacity, pp. 36. Universities UK, London. ISBN 1 84036 102 6

Gatsios, K.and Seabright, P. (1989). Regulation in the European community. Oxford Rev. Econ. Policy, 5, 37–60. doi:10. 1093/oxrep/5.2.37

Gini, C. (1912). Variabilita e mutabilita. Studi Economica- Giuridici della R. Universita di Cagliari, 3, 3–159.

Grabher, G. and Stark, D. (1997). Organizing diversity: evolutionary theory, network analysis and postsocialism. Regional Studies, 31, 533–544. doi:10.1080/00343409750132315

HM Treasury. (2004). Science & innovation investment framework 2004–2014: http://www.hmtreasury.gov.uk/spending_review/spend_sr04/associateddocuments/spending_sr04_scien ce.cfm.

Hill, M. (1973). Diversity and evenness: a unifying notation and its consequences. Ecology, 54, 427–432. DOI:10.2307/1934352

Johnson, N. and Longmeyer, S. (1999). The science of social diversity. Los Alamos National Laboratory. Report LA-UR-99-336. USDOE.

King's College London and Digital Science (2015). The nature, scale and beneficiaries of research impact: An initial analysis of Research Excellence Framework (REF) 2014 impact case studies. http://www.hefce.ac.uk/pubs/rereports/Year/2015/analysisREFimpact/

MacArthur, R. (1965). Patterns of species diversity. Biological Review, 40, 510–33.

May, R M. (1975). Patterns of species abundance and diversity. Pp. 81–120, in 'Ecology and the evolution of communities', eds M. Cody & J. Diamond. Cambridge, MA: Belknap Press/Harvard University Press.

May, R M. (1997). The scientific wealth of nations. Science, 275, 793-796 DOI: 10.1126/science.275.5301.793

McIntosh, R. (1967). An index of diversity and the relation of certain concepts to diversity. Ecology 48, 392–404. (doi:10. 2307/1932674)

Nguyen, P., Saviotti, P., Trommetter, M. & Bourgeouis, B. (2005). Variety and the evolution of refinery processing. Ind. Corporate Change 14, 469–500. (doi:10.1093/icc/dth059)

Rafols, I., Leydesdorff, L., O'Hare, H., Nightingale, P. and Andy Stirling. (2012). How journal rankings can suppress interdisciplinary research: a comparison between Innovation Studies and Business & Management. Research Policy., 41, 1262-1282. DOI:10.1016/j.respol.2012.03.015

Rafols, I. and Meyer, M. (2010). Diversity and network coherence as indicators of interdisciplinarity. Scientometrics, 82, 263-287.

Saviotti, P. & Mani, G. (1995). Competition, variety and technological evolution: a replicator dynamics model. J. Evol. Econ. 5, 369–392. (doi:10.1007/BF01194367)

Shannon, A. and Weaver, W. (1962). The mathematical theory of communication. Urbana, IL: University of Illinois Press.

Stirling, A. (2007). A general framework for analysing diversity in science, technology and society. J. R Soc. Interface, 4, 707-719. doi:10.1098/rsif.2007.0213

Universities UK. (2010) The Future of Research. Universities UK, London. ISBN 978 1 84036 232 9

Williams, P. & Humphries, C. (1994). Biodiversity, taxonomic relatedness and endemism in conservation. In Systematics and conservation evaluation (eds L. Forey, C. Humphries & R. Vane-Wright), pp. 269–287. Oxford, UK: Oxford University Press.

DIGITAL science

Work smart. Discover more.

Part of the **Digital Science** family

readcube

BIOKRAFT

labguru

Altmetric

figshare

Overleaf

Dimensions

SYMPLECTIC Elements

digital-science.com