Bibliometric analysis of ongoing projects

5th report
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1 EXECUTIVE SUMMARY

This report was commissioned by IMI from Thomson Reuters. It benchmarks research published by IMI-supported projects with other selected public private partnerships. It also analyses the collaboration of IMI-supported projects with the goal of producing a index that IMI can use to incentivize research collaboration. The key findings of this report are:

Benchmarking of IMI project research against selected comparators:

- The output of papers arising from projects supported by IMI increased rapidly between 2010 and 2013 (1966.7%), and compared to the selected comparators its rate of growth was exceptionally high (Section 4.2.1).
- The citation impact of most of the selected comparators has remained at around twice world average between 2010 and 2013, indicating highly-cited internationally significant research (Section 4.2.2).
- IMI project research had the highest citation impact (2.59), and TI Pharma had the lowest (1.70) over the period analyzed (Section 4.2.2).
- The exceptionally high citation impact of IMI project research in 2010 (4.31) is driven by several highly-cited papers (Section 4.2.2).
- IMI project research had a similar percentage of uncited research as the comparators between 2010 and 2013. No IMI project papers published in 2010 are uncited (Section 4.2.3).
- The percentage of highly-cited papers funded by IMI project was second (26.3% overall) to that of FNIH (28.8% overall). And was similar to that of the Wellcome Trust (23.4% overall) and MRC (23.0% overall) (Section 4.2.4).
- The performance of IMI project research and the comparator institutions is similar even though IMI is relatively young (Section 4.2.5).

Research collaboration by IMI-supported projects:

- BTCure has the greatest number of cross sector collaborative publications, 76 out of 132, or 58%. PROactive, PharmaCog, PROTECT, and BioVacSafe have the highest percentage of cross sector collaborative publications (90%, 86%, 80% and 80% respectively) (Section 5.1.1).
- BTCure has the most internationally collaborative publications involving more than two countries (34 out of 132), with an IntlScore of 0.44. PharmaCog, PROactive, and EU-Aims have highest IntlScore (0.69, 0.68, and 0.66 respectively) (Section 5.1.2).
- The organizations that collaborate together the most frequently in IMI project publications are King's College and the University of London (Section 5.1.3).
- PROactive had the highest overall collaboration index score (2.58), followed by PharmaCog, EU-AIMS and PROTECT (2.51, 2.37 and 2.34 respectively) (Section 5.2).

2 INTRODUCTION

2.1 OVERVIEW

The Innovative Medicines Initiative Joint Undertaking (IMI) has commissioned Thomson Reuters to undertake a periodic evaluation of its research portfolio using bibliometric and intellectual property indicators.

The commissioned evaluation comprises a series of bi-annual reports focusing on research publications and patents produced by IMI funded researchers. This report is the fifth evaluation in the series.

2.2 INNOVATIVE MEDICINES INITIATIVE JOINT UNDERTAKING

The Innovative Medicines Initiative (IMI) is working to improve health by speeding up the development of, and patient access to, innovative medicines, particularly in areas where there is an unmet medical or social need. It does this by facilitating collaboration between the key players involved in healthcare research, including universities, the pharmaceutical and other industries, small and medium-sized enterprises (SMEs), patient organisations, and medicines regulators.

IMI is a partnership between the European Union and the European pharmaceutical industry, represented by the European Federation of Pharmaceutical Industries and Associations (EFPIA). IMI has a budget of €3.3 billion for the period 2014-2024. Half of this comes from the EU's research and innovation programme, Horizon 2020. The other half comes from large companies, mostly from the pharmaceutical sector; these do not receive any EU funding, but contribute to the projects 'in kind', for example by donating their researchers' time or providing access to research facilities or resources.

2.3 THOMSON REUTERS

Thomson Reuters is the world's leading source of intelligent information for business and professionals. We combine industry expertise with innovative technology to deliver critical information markets, powered by the world's most trusted news organization. Visit our webpage for more information.

2.4 THOMSON REUTERS RESEARCH ANALYTICS

Thomson Reuters Research Analytics is a suite of products, services and tools that provide comprehensive research analysis, evaluation and management. For over half a century we have pioneered the world of citation indexing and analysis, helping to connect scientific and scholarly thought around the world. Today, academic and research institutions, governments, not-for-profits, funding agencies, and all others with a stake in research need reliable, objective methods for managing and measuring performance. Visit our webpage for more information.

2.5 THOMSON REUTERS CUSTOM ANALYTICS & ENGINEERED SOLUTIONS

Thomson Reuters Custom Analytics & Engineered Solutions provide reporting and consultancy services within Research Analytics using customized analyses to bring together several indicators of research performance in such a way as to enable customers to rapidly make sense and interpret of a wide-range of data points to facilitate research strategy decision-making.

Our consultants have up to 15 years' experience in research performance analysis and interpretation. We have extensive experience with databases on research inputs, activity and outputs and have developed innovative analytical approaches for benchmarking, interpreting and visualization of international, national and institutional research impact.

2.6 SCOPE OF THIS REPORT

The analyses and indicators presented in this report have been specified to provide an analysis of IMI-supported research for research management purposes:

To provide bibliometric indicators to benchmark IMI project research with research supported by a few other selected public private partnerships.

To work towards developing a collaboration index to assess the 'collaborativeness' of IMI projects that could eventually act to incentivize collaboration.

Outline of report

Section 3 describes the data sources and methodology used in this report along with definitions of the indicators and guidelines to interpretation.

Section 4 presents citation analyses of IMI project research benchmarked against research from selected comparators.

Section 5 presents three metrics for measuring collaboration within IMI projects and proposes a collaboration index.

3 DATA SOURCES, INDICATORS, METHODOLOGIES AND INTERPRETATIONS

3.1 BIBLIOMETRIC DATA AND CITATION ANALYSIS

3.1.1 BACKGROUND

Research evaluation is increasingly making wider use of bibliometric data and analyses. Bibliometrics is the analysis of data derived from publications and their citations. Publication of research outcomes is an integral part of the research process and is a universal activity. Consequently, bibliometric data have a currency across subjects, time and location that is found in few other sources of research-relevant data. The use of bibliometric analysis, allied to informed review by experts, increases the objectivity of and confidence in evaluation.

Research publications accumulate citation counts when they are referred to by more recent publications. Citations to prior work are a normal part of publication, and reflect the value placed on a work by later researchers. Some papers get cited frequently and many remain uncited. Highly cited work is recognized as having a greater impact and Thomson Reuters has shown that high citation rates are correlated with other qualitative evaluations of research performance, such as peer review.1 This relationship holds across most science and technology areas and, to a limited extent, in social sciences and even in some humanities subjects.

Indicators derived from publication and citation data should always be used with caution. Some fields publish at faster rates than others and citation rates also vary. Citation counts must be carefully normalised to account for such variations by field. Because citation counts naturally grow over time it is essential to account for growth by year. Normalization is usually done by reference to the relevant global average for the field and for the year of publication.

Bibliometric indicators have been found to be more informative for core natural sciences, especially for basic science, than they are for applied and professional areas and for social sciences. In professional areas the range of publication modes used by leading researchers is likely to be diverse as they target a diverse, non-academic audience. In social sciences there is also a diversity of publication modes and citation rates are typically much lower than in natural sciences.

Bibliometrics work best with large data samples. As the data are disaggregated, so the relationship weakens. Average indicator values (e.g. of citation impact) for small numbers of publications can be skewed by single outlier values. At a finer scale, when analyzing the specific outcome for individual departments, the statistical relationship is rarely a sufficient guide by itself. For this reason, bibliometrics are best used in support of, but not as a substitute for, expert decision processes. Well-founded analyses can enable conclusions to be reached more rapidly and with greater certainty, and are therefore an aid to management and to increased

[1] *Evidence* Ltd. (2002) 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. (Adams J, et al.) 48pp.

confidence among stakeholders, but they cannot substitute for review by well-informed and experienced peers.

3.1.2 PUBLICATION AND CITATION DATA SOURCES

For this project, bibliometric data have been sourced from Thomson Reuters Databases underlying the *Web of Science*^{TM}, which gives access to conference proceedings, patents, websites, and chemical structures, compounds and reactions in addition to journals. It has a unified structure that integrates all data and search terms together and therefore provides a level of comparability not found in other databases. It is widely acknowledged to be the world's leading source of citation and bibliometric data. The *Web of Science*^{TM} *Core Collection* is part of the *Web of Science*, and focuses on research published in journals and conferences in science, medicine, arts, humanities and social sciences. The authoritative, multidisciplinary content covers over 12,000 of the highest impact journals worldwide, including Open Access journals and over 150,000 conference proceedings. Coverage is both current and retrospective in the sciences, social sciences, arts and humanities, in some cases back to 1900. Within the research community these data are often still referred to by the acronym 'ISI'. Thomson Reuters has extensive experience with databases on research inputs, activity and outputs and has developed innovative analytical approaches for benchmarking and interpreting international, national and institutional research impact.

Granularity of analysis is an important issue. Unduly fine analysis at the level of research groups provides little comparability or connectedness, while coarse analysis may miss spikes of excellence in key areas.

Journals are mapped to one or more subject categories, and every article within that journal is subsequently assigned to that category. Thomson Reuters uses these categories as the basis for bibliometric analysis because they are well-established and informed by extensive work with the research community since inception. Papers from prestigious, 'multidisciplinary' and general 'biomedical' journals such as Nature, Science, BMJ, The Lancet, New England Journal of Medicine and the Proceedings of the National Academy of Sciences (PNAS) are assigned to specific categories based on the journal categories of the citing and cited references in each article. Further information about the journals included in the citation databases and how they are selected is available here: http://ip-science.thomsonreuters.com/mjl/.

The bibliometric evaluation of research covered in this report has been based principally on analysis of research published between 2010 and 2014 with citation counts as at July 2014 for all "current" indicators and citation counts as at end-2013 for all indicators calculated with reference to world citation baselines (e.g. normalized citation impact). The analyses presented in this report will not cover conference proceedings, meeting abstracts, books, chapters in books or grey literature such as reports. It therefore captures only a specific part of the total output of the IMI's project research over the period, but this part is usually recognized as describing the most direct contribution to the research base.

Annex 3 provides the standard methodology and data definitions used in bibliometric and citation analyses. A brief summary of citation data definitions is also given in Section 3.1.3.

3.1.3 BIBLIOMETRIC AND CITATION DATA DEFINITION AND INDICATORS

Citations: The citation count is the number of times that a citation has been recorded for a given publication since it was published. Not all citations are necessarily recorded since not all publications are indexed. However, the material indexed by Thomson Reuters is estimated to attract about 95% of global citations.

Citation impact: 'Citations per paper' is an index of academic or research impact (as compared with economic or social impact). It is calculated by dividing the sum of citations by the total number of papers in any given dataset (so, for a single paper, raw impact is the same as its citation count). Impact can be calculated for papers within a specific research field such as Clinical Neurology, or for a specific institution or group of institutions, or a specific country. Citation count declines in the most recent years of any time-period

as papers have had less time to accumulate citations (papers published in 2007 will typically have more citations than papers published in 2010).

Field-normalized citation impact (NCI_F): Citation rates vary between research fields and with time, consequently, analyses must take both field and year into account. In addition, the type of publication will influence the citation count. For this reason, only citation counts of papers (as defined above) are used in calculations of citation impact. The standard normalization factor is the world average citations per paper for the year and journal category in which the paper was published. This normalization is also referred to as 'rebasing' the citation count.

Mean normalized citation impact (mNCI): The mean NCI indicator for any specific dataset is calculated as the mean of the field-normalized citation impact (NCI_F) of all papers within that dataset.

Papers/publications: Thomson Reuters abstracts publications including editorials, meeting abstracts and book reviews as well as research journal articles. The terms 'paper' and 'publication' are often used interchangeably to refer to printed and electronic outputs of many types.

For clarity, in this report:

- **Publication** is used inclusively to refer to all IMI publications whether linked to Thomson Reuters citation data or not.
- ***Web of Science* Publication** is used exclusively to refer to those IMI publications which have been linked to Thomson Reuters citation data.
- **Paper** is used exclusively to refer to substantive journal articles, reviews and some proceedings papers and excludes editorials, meeting abstracts or other types of publication. Papers are the subset of publications for which citation data are most informative and which are used in calculations of citation impact.

Percentage of highly-cited papers: For the purpose of this report, highly-cited papers have been defined as those articles and reviews which belong to the world's top 10% of papers in that journal category and year of publication, when ranked by number of citations received. A percentage that is above 10 indicates above average performance.

Percentage of uncited papers: For the purpose of this report, uncited papers have been defined as those articles and reviews which have not been cited as of July 2014. As more recent research is less likely to be cited than older research, so higher percentage of uncited papers should not be taken as evidence that these researches are more likely to remain uncited.

Research field: Standard bibliometric methodology uses journal category as a proxy for research field. Journals are assigned to one or more categories, and every article within that journal is subsequently assigned to that category. Papers from prestigious, 'multidisciplinary' and general medical journals such as Nature, Science, The Lancet, BMJ, The New England Journal of Medicine and the Proceedings of the National Academy of Sciences (PNAS) are assigned to specific categories based on the journal categories of the references cited in the article. The selection procedures for the journals included in the citation databases are documented here http://ip-science.thomsonreuters.com/mjl/. For this evaluation, the standard classification of *Web of Science* journal categories has been used.

***Web of Science* journal categories or *Essential Science Indicators*® fields**: Standard bibliometric methodology uses journal category or *Essential Science Indicators*® fields as a proxy for research field. ESI fields aggregate data at a higher level than the journal categories – there are only 22 ESI research fields compared to 254 journal categories. Journals are assigned to one or more categories, and every article within that journal is subsequently assigned to that category. Papers from prestigious, 'multidisciplinary' and general medical journals such as Nature, Science, The Lancet, BMJ, The New England Journal of Medicine and the Proceedings of the National Academy of Sciences (PNAS) are assigned to specific categories based on the

journal categories of the references cited in the article. The selection procedures for the journals included in the citation databases are documented here: http://ip-science.thomsonreuters.com/mjl/.

3.1.4 INTERPRETATION OF BIBLIOMETRIC INDICATORS AND CITATION ANALYSES

The following points should be borne in mind when considering the results of these analyses:

IMI JU only started to fund projects in May 2009. Of the 46 active projects, 23 were launched since 1 January 2012. It may take several years for a project to progress from inception to the point where it has generated sufficient data for a publication. It may take further years until it has produced its most valuable results. The IMI JU projects that will be analysed are therefore relatively young, and early bibliometric indicators may not fully reflect their eventual impact.

Bibliometrics work best with large data samples. As the data are disaggregated, so the relationship weakens. Average indicator values (e.g. of citation impact) for small numbers of publications can be skewed by single outlier values. At a finer scale, when analysing the specific outcome for individual departments, the statistical relationship is rarely a sufficient guide by itself. For this reason, bibliometrics are best used in support of, but not as a substitute for, expert decision processes. Well-founded analyses can enable conclusions to be reached more rapidly and with greater certainty, and are therefore an aid to management and to increased confidence among stakeholders, but they cannot substitute for review by well-informed and experienced peers.

As noted above many of the publications associated with IMI JU-funded projects are relatively recent. Publications accumulate citations over time and it may take years until a given publication is cited. While citation counts in early years have been shown to reflect long-term citation performance,[2] indicators based on citation counts may be relatively more volatile in the years immediately following publication

INDICATOR THRESHOLDS

Papers: The minimum number of papers suitable as a sample for quantitative research evaluation is a subject of widespread discussion. Larger samples are always more reliable, but a very high minimum may defeat the scope and specificity of analysis. Experience has indicated that a threshold between 20 and 50 papers can generally be deemed appropriate. For work that is likely to be published with little contextual information, the upper boundary (≥ 50) is a desirable starting point. For work that will be used primarily by an expert, in-house group then the lower boundary (≥ 20) may be approached. Because comparisons for in-house evaluation often involve smaller, more specific research groups (compared to broad institutional comparisons) a high volume threshold is self-defeating. Smaller samples may be used but outcomes must be interpreted with caution and expert review should draw on multiple information sources before reaching any conclusions.

Field normalised citation impact: such values for individual papers vary widely and it is more useful to consider the average for a set of papers. This average can be at several granularities: field (either journal category or field), annual and overall (total output under consideration). When considering such average data points, care must be taken to understand that these data are highly skewed and the average can be driven by a single, highly-cited paper (this would be highlighted in accompanying text though not apparent from Tables & Figures). The world average is 1.0, so any value higher than this indicates a paper, or set of papers, which are cited more than average for similar research worldwide. For research management purposes, experience suggests that values between 1.0 and 2.0 should be considered to be indicative of research which is influential at a national level whilst that cited more than twice the world average has international recognition.

[2] Adams, J. et al. (2002) 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, http://www.hefce.ac.uk/pubs/rdreports/2002/rd08_02/rd08_02.pdf

Research field: A problem frequently encountered in the analysis of data about the research process is that of 'mapping'. For example, a funding body allocates money for chemistry but this goes to researchers in biology and engineering as well as to chemistry departments. Clinicians publish in mathematics and education journals. Publications in environmental journals come from a diversity of disciplines. This creates a problem when we try to define, for example, 'Parasitology research'. Is this the work funded under Parasitology programmes, the work of researchers in Parasitology units or the work published in Parasitology journals? For the first two options we need to track individual grants and researchers to their outputs, which is feasible but not within the scope of this study nor for every comparator institution. Therefore, to create a simple and transparent dataset of equal validity across time and geography, we rely on the set of journals associated with Parasitology as a proxy for the body of research reflecting the field.

3.1.5 DATASET DEFINITIONS USED IN THE BIBLIOMETRIC INDICATORS AND CITATION ANALYSIS

IMI project publications/papers: This dataset comprises publications from IMI-supported projects identified using bibliographic data supplied by IMI, or through specific keyword searches using funding acknowledgment data in *Web of Science*.

Benchmark publications/papers: This benchmark dataset has been created using specific keyword searches on funding acknowledgment data in Thomson Reuters *Web of Science* to define those publications where the other selected PPIs have been acknowledged as a funder. This is the same process by which IMI project publications have been identified.

3.2 COLLABORATION ANALYSIS AND METHODOLOGY

3.2.1 BACKGROUND

Increasing research collaboration is a global trend. Whilst in academia collaboration is driven by factors such as esteem, visibility in high impact journals and access to pioneering research techniques, IMI's Executive Director, Michel Goldman, has observed that there is no analogous driver incentivizing corporate research collaboration. IMI has therefore commissioned Thomson Reuters to work towards the development of a new metric to assess the 'collaborativeness' of researchers that could eventually act to incentivize collaboration.

3.2.2 DATA SOURCES

For this project, bibliometric data have been sourced from Thomson Reuters Databases underlying the *Web of Science*^{TM} (described previously in section 3.2.1). Thomson Reuters will use IMI project publications identified in section 3.1.5 of this report and IMI author sectors identified by IMI.

3.2.3 COLLABORATION DATA DEFINITION AND INDICATORS

Collaboration: A collaboration is an instance of co-authorship on a publication from the list of IMI project publications

Cross Sector Collaboration: A cross sector collaboration is a publication containing multiple sectors in the author affiliations. Organizations from author affiliations were classified into one of four sectors: academic, government, patient organization, or research/other.

International Collaboration: An international collaboration is a publication containing multiple countries in the author affiliations.

Collaboration Intensity: IMI is interested in examining the similarity of collaborations within each project. To examine this feature, we will use a cosine similarity function to describe the consistency (or not) of collaboration pairs within each project.

3.2.4 INTERPRETATION OF BIBLIOMETRIC INDICATORS AND CITATION ANALYSES

In addition to those discussed in section 3.1.4 above, the following points should be borne in mind when considering the results of these analyses:

Each organization affiliated with an IMI Project publication was classified into sectors manually by Thomson Reuters analysts. Each organization was assigned to one sector only. 95.6% of the organizations were classified.

3.2.5 DATASET DEFINITIONS USED IN THE BIBLIOMETRIC INDICATORS AND CITATION ANALYSIS

IMI project publications/papers: This dataset comprises publications from IMI-supported projects identified using bibliographic data supplied by IMI, or through specific keyword searches using funding acknowledgment data in *Web of Science*.

Co-authors from IMI project publications: The IMI project publications were run through a person disambiguation engine (PDE) prior to analysis. This data was used to examine collaborations between IMI-funded researchers and those outside of IMI (hereafter referred to as non-IMI-funded).

Country affiliation: The country affiliation of IMI- and non-IMI-funded researchers was determined using data from author affiliations in the *Web of Science*.

4 BENCHMARKING ANALYSIS – IMI PROJECT RESEARCH AGAINST OTHER RESEARCH FROM SELECTED COMPARATORS

This section of the report presents analyses of output and citation impact of IMI project research benchmarked against research associated with other selected Public-Private Partnerships, several leading funding organizations of biomedical research across USA and Europe.

Publications from IMI-supported projects were identified using bibliographic data supplied by IMI, or through specific keyword searches using funding acknowledgment data in *Web of Science*. The data presented in this report cover publication years 2008 to 2013 with citations to the end of 2013.The updated IMI-supported publications since fourth report are collected (see list in Annex 1) and thus the changes of IMI activity will be reflected.

Publications for analyses include all publications supported by selected comparators were identified through specific keyword searches using funding acknowledgment data in Thomson Reuters *Web of Science*.

4.1 IDENTIFYING COMPARATORS

A total of seven candidate comparators was reviewed by Thomson Reuters and supplied to IMI for further verification prior to inclusion in the analyses.

Following discussion with IMI, four comparator institutions (Foundation for the National Institutes of Health (FNIH), Medical Research Council (MRC), Top Institute Pharma (TI Pharma), and Wellcome Trust) were selected for further analysis in this report. All of the selected comparators have sufficient publications to allow a robust analysis (Table 4.1.1).

TABLE 4.1.1 SUMMARY INFORMATION OF SELECTED COMPARATORS

Comparators	# Funded Publications (2008-2014)	Country	Region
Foundation for the National Institutes of Health	1,038	USA	U.S.
Medical Research Council	22 567	UK	Europe
Top Institute Pharma	989	Netherland	Europe
Wellcome Trust	27 710	UK	Europe

4.2 TRENDS IN OUTPUT AND CITATION IMPACT: IMI PROJECT RESEARCH COMPARED WITH SELECTED COMPARATORS

This section of the report analyses trends in the performance of IMI project research and benchmarks this against four selected comparators (Foundations for National Institutes of Health (FNIH), Medical Research Council (MRC), Top Institute Pharma (TI Pharma), and Wellcome Trust).

The publications funded by each comparator were identified using specific keyword searches of the funding acknowledgment data provided by authors and abstracted in *Web of Science*. This is the same process by which IMI project publications have been previously identified (see the fourth Report). Authors may not always acknowledge their sources of funding, and may not always do so correctly. Therefore, the coverage of the datasets used in these analyses may not be complete and may not be entirely accurate.

4.2.1 TRENDS IN OUTPUT: IMI PROJECT RESEARCH COMPARED WITH 4 SELECTED COMPARATORS

The output of IMI and the comparators varies widely (some produce many papers and some relatively few), therefore a visual comparison of absolute paper counts would not provide an understanding of their growth relative to one another. In order to provide a more easily interpretable comparison, Figure 4.2.1 shows the percentage of each institution's papers published in total between 2010 and 2013 that were published in each year.

- The output of papers arising from projects supported by IMI increased rapidly between 2010 and 2013 (1966.7%), and compared to the selected comparators its rate of growth was exceptionally high (Figure 4.2.1).
- Regarding the number of funded papers, IMI overtook FNIH and TI Pharma's in 2013 (Table 4.2.1).
- Wellcome Trust and MRC experienced similar slower growth over this time period, whereas the exceptional large publication base (Table 4.2.1) still indicating their position as well-established funding initiative.

FIGURE 4.2.1 TRENDS IN OUTPUT: IMI PROJECT RESEARCH COMPARED WITH 4 SELECTED COMPARATORS

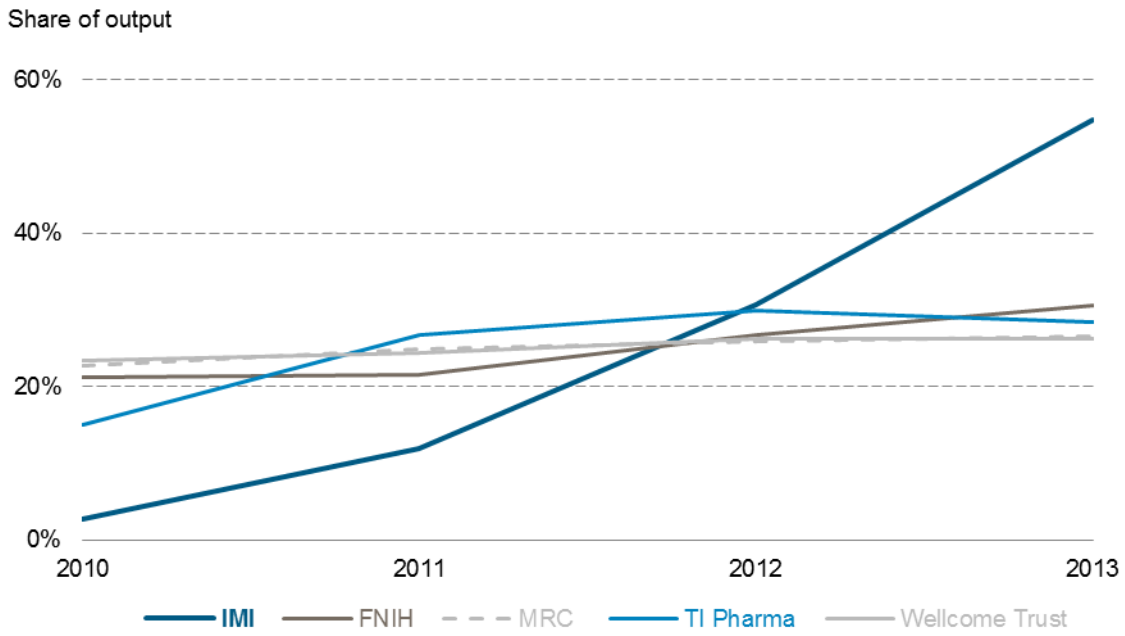


TABLE 4.2.1 TRENDS IN NUMBER OF PAPERS: IMI PROJECT RESEARCH COMPARED WITH 4 SELECTED COMPARATORS

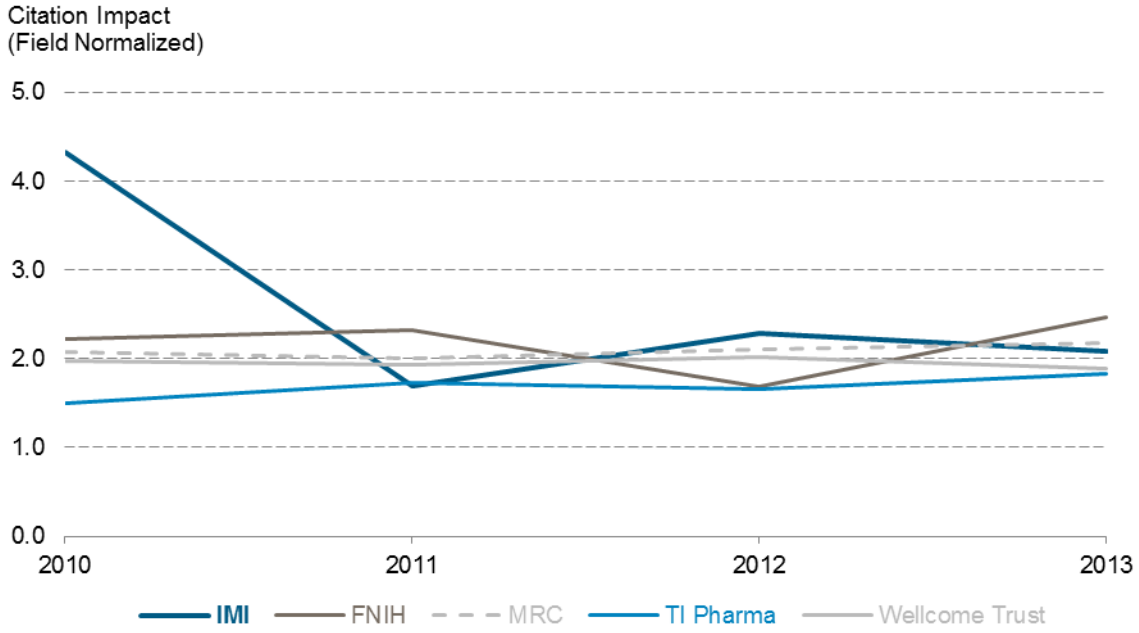
	IMI	FNIH	MRC	TI Pharma	Wellcome Trust
2010	18	177	3 948	128	4 990
2011	77	180	4 307	227	5 210
2012	198	223	4 508	255	5 608
2013	354	256	4 604	242	5 613

4.2.2 TRENDS IN FIELD NORMALISED CITATION IMPACT: IMI PROJECT RESEARCH COMPARED WITH 4 SELECTED COMPARATORS

As discussed in Section 3.1.2, citations accumulate over time at a rate that is dependent upon the field of research. Therefore, it is standard bibliometric practice to normalize citation counts for these two factors. In this report, field-normalized citation impact has been calculated by dividing the citations received by each publication by the world average citations per publication for the relevant year and field.

- The citation impact of most of the selected comparators has remained at around twice world average between 2010 and 2013 (Figure 4.2.2), indicating highly-cited internationally significant research.
- IMI project research had the highest citation impact (2.59), and TI Pharma had the lowest (1.70) over the period analyzed.
- The citation impact of MRC and Wellcome Trust has remained relatively stable, while IMI and FNIH showed greater variability. This is to be expected given the smaller number of papers funded by IMI and FNIH, and its growth relative to the output of more established research institutions like MRC and Wellcome Trust.
- The exceptionally high citation impact of IMI project research in 2010 (4.31) is driven by several highly-cited papers (listed in Annex 2).

FIGURE 4.2.2 TRENDS IN FIELD NORMALISED CITATION IMPACT: IMI PROJECT RESEARCH COMPARED WITH 4 SELECTED COMPARATORS

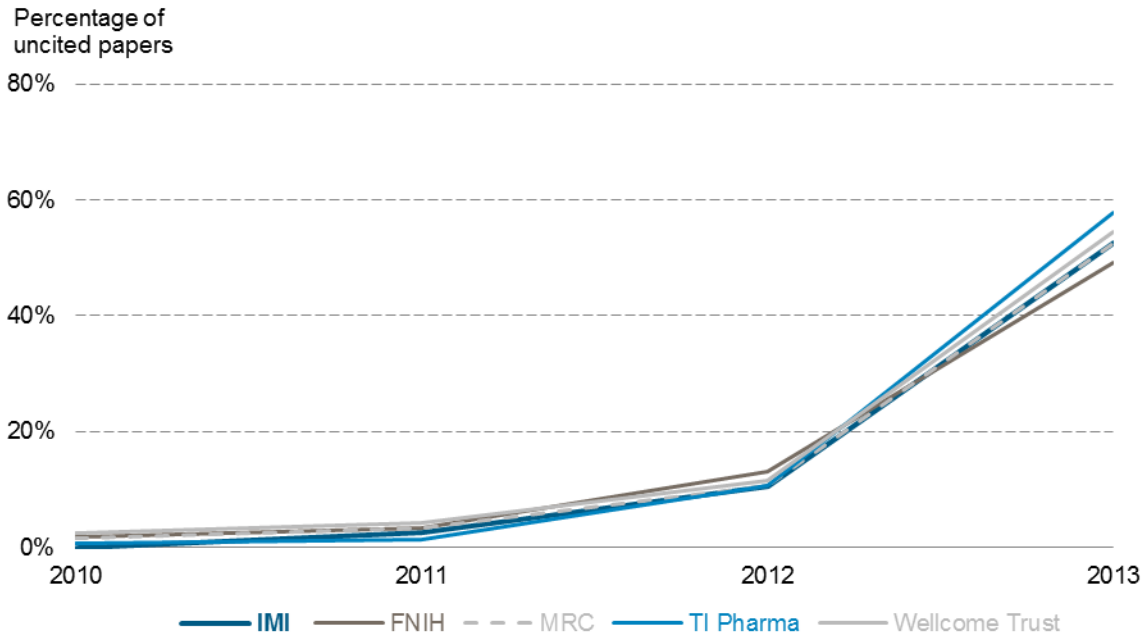


4.2.3 TRENDS IN UNCITED RESEARCH: IMI PROJECT RESEARCH COMPARED WITH OTHER 4 COMPARATORS

Figure 4.2.3 shows the percentage of uncited papers between 2010 and 2013.

- IMI project research had a similar percentage of uncited research as the comparators between 2010 and 2013. No IMI project papers published in 2010 are uncited.
- The similar trends in uncited papers indicate the similar citation life-cycle for biomedical research funded across all the benchmarking entities. As more recent publications are less likely to be cited than older publications, so higher percentage of uncited papers in 2013 should not be taken as evidence that these researches are more likely to remain uncited.

FIGURE 4.2.3 TRENDS IN UNCITED PAPERS: IMI PROJECT RESEARCH COMPARED WITH 4 SELECTED COMPARATORS

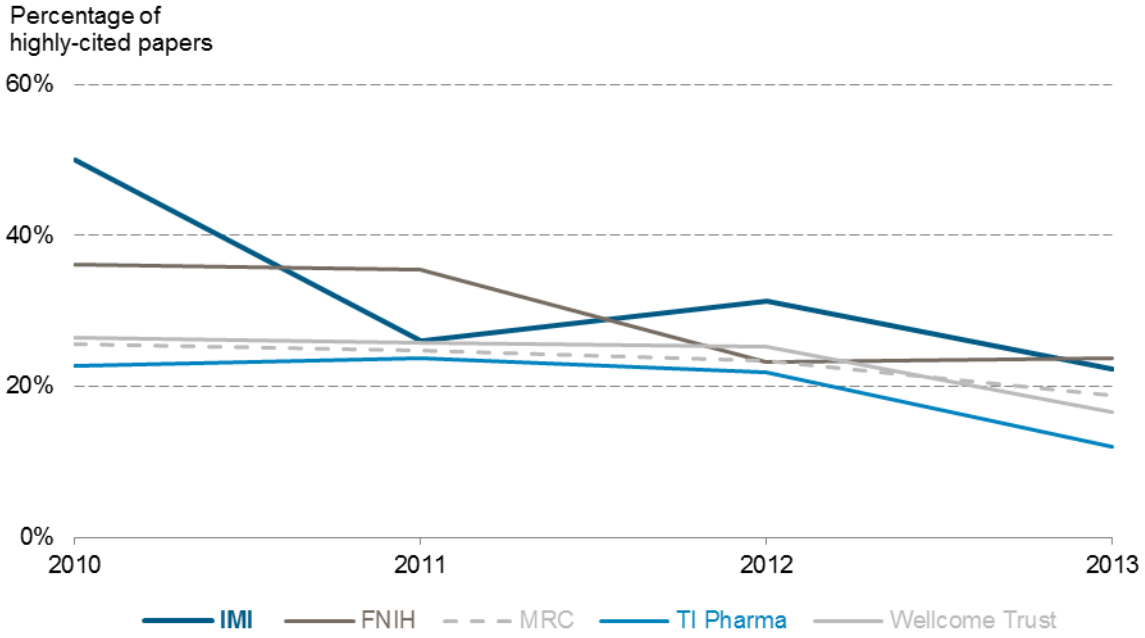


4.2.4 TRENDS IN HIGHLY CITED RESEARCH: IMI PROJECT RESEARCH COMPARED WITH 4 SELECTED COMPARATORS

As discussed in Section 3.1.2, high-cited work is recognized as having a greater impact and Thomson Reuters correlates with other qualitative evaluations of research performance, such as peer review. For institutional research evaluation we have found that the world's top 10% of most highly-cited papers is often a suitable definition of highly-cited work. Therefore, if more than 10% of an entity's publications are in the top 10% of the world's most highly-cited papers then it performs better than expected.

- All of the entities had a higher than expected percentage of highly-cited papers between 2010 and 2013.
- The percentage of highly-cited papers funded by IMI project was second (26.3% overall) to that of FNIH (28.8% overall). And was similar to that of the Wellcome Trust (23.4% overall) and MRC (23.0% overall).
- IMI's highly-cited papers are listed in Annex 2.

FIGURE 4.2.4 TRENDS IN HIGHLY CITED PAPERS: IMI PROJECT RESEARCH COMPARED WITH 4 SELECTED COMPARATORS



4.2.5 SUMMARY OF BIBLIOMETRIC INDICATORS: IMI PROJECT RESEARCH COMPARED WITH 4 SELECTED COMPARATORS

Though IMI is a 'young' funding agency compared with well-established funding bodies like MRC and Wellcome Trust. The performance of IMI project research and the comparator institutions is similar as indexed by the citation indicators listed below (Table 4.2.2).

TABLE 4.2.2 SUMMARY OF BIBLIOMETRIC INDICATORS: IMI PROJECT RESEARCH COMPARED WITH 4 SELECTED COMPARATORS, 2010-13

	Number of Papers	Citation Impact (normalised at field level)	Percentage of uncited papers	Percentage of highly cited papers
IMI	647	2.59	32.3%	26.3%
FNIH	836	2.17	19.6%	28.8%
MRC	17 367	2.09	17.9%	23.0%
TI Pharma	852	1.70	20.1%	19.7%
Wellcome Trust	21 421	1.95	18.9%	23.4%

5 DEVELOPMENT OF A 'COLLABORATION INDEX' FOR IMI RESEARCHERS

As described in Section 3.2.1, IMI wishes to monitor and incentivize research collaboration on the projects it supports. This section of the report analyses the types of collaboration that occur within each IMI project publication and examines the intensity of collaborations within each project.

IMI project publications were previously identified by using text searches of the funding acknowledgment data provided by authors and abstracted in *Web of Science* (see Report 4 and section 3.1.5 of this report). Authors may not always acknowledge their sources of funding, and may not always do so correctly. Therefore, the coverage of the datasets used in these analyses may not be complete and may not be entirely accurate. In addition, some projects have relatively few publications associated with them. In common with other metrics based on publications and citations, the indicators we present here work best with larger sample sizes. Indicators based on small numbers of publications will therefore be less informative than those calculated for larger bodies of work.

Three metrics were chosen to evaluate the collaborativeness of IMI project:

- Metric 1 – Fraction of publications with co-authors affiliated to organizations in different sectors.[3] The organizations affiliated with each author on a publication within the dataset were manually assigned by Thomson Reuters to the relevant sector. Author affiliations were obtained through *Web of Science*.
- Metric 2 – Percentage of internationally collaborative publications. The country location of each author was determined using author addresses abstracted in the *Web of Science*.
- Metric 3 – Intensity of collaboration. Pairs of collaborating organizations were identified for each IMI project publication and intensity of each pair assessed. The collaboration intensities of the pairs of organizations for each IMI project were averaged.

The collaboration index is a sum of all three metrics. Further evolution of the collaboration index could include weighting of individual metrics to provide an improved measure of IMI-related work.

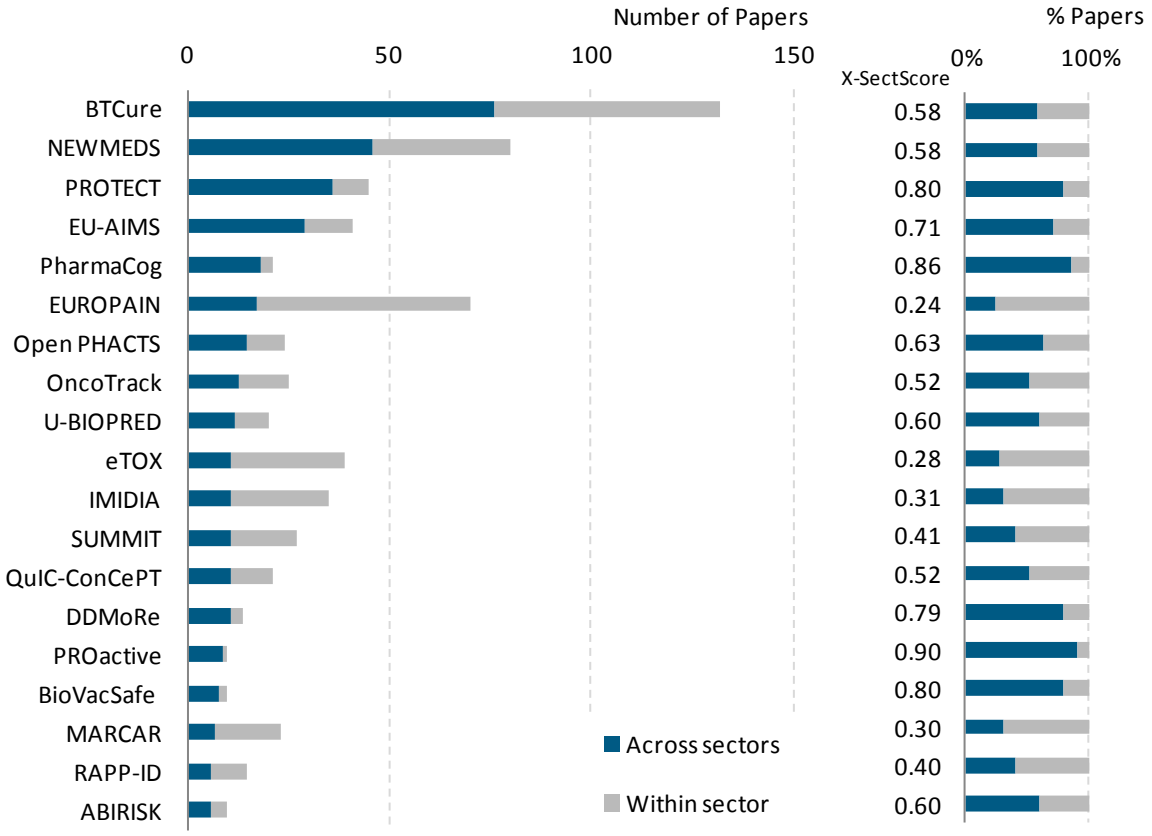
5.1 COLLABORATION METRICS

5.1.1 METRIC 1: FRACTION OF CROSS SECTOR COLLABORATIVE PUBLICATIONS

The sectors involved in each IMI project publication were used to classify each publication as "within one sector" or "cross sector". Figure 5.1.1 below shows the total number of publications for each project. Projects are ordered beginning with the project that has the largest number of cross sector collaborative publications. Only projects with more than ten associated publications are shown. The dark blue bars represent number of publications or fraction of publications that include at least one cross sector collaboration. "X-SectScore" labels the fraction of publications in each project that are cross sector. BTCure has the greatest number of cross sector collaborative publications, 76 out of 132, or 58%. PROactive, PharmaCog, PROTECT, and BioVacSafe have the highest percentage of cross sector collaborative publications (90%, 86%, 80% and 80% respectively).

[3] These sectors are: academic, corporate, medical, government, or other. Medical includes hospitals and organizations that provide information to patients such as the American Cancer Society. Government includes state or federally funded research organisations such as NIH or WHO. Other includes any other research institutions.

FIGURE 5.1.1 FRACTION OF CROSS SECTOR COLLABORATIVE PUBLICATIONS BY PROJECT

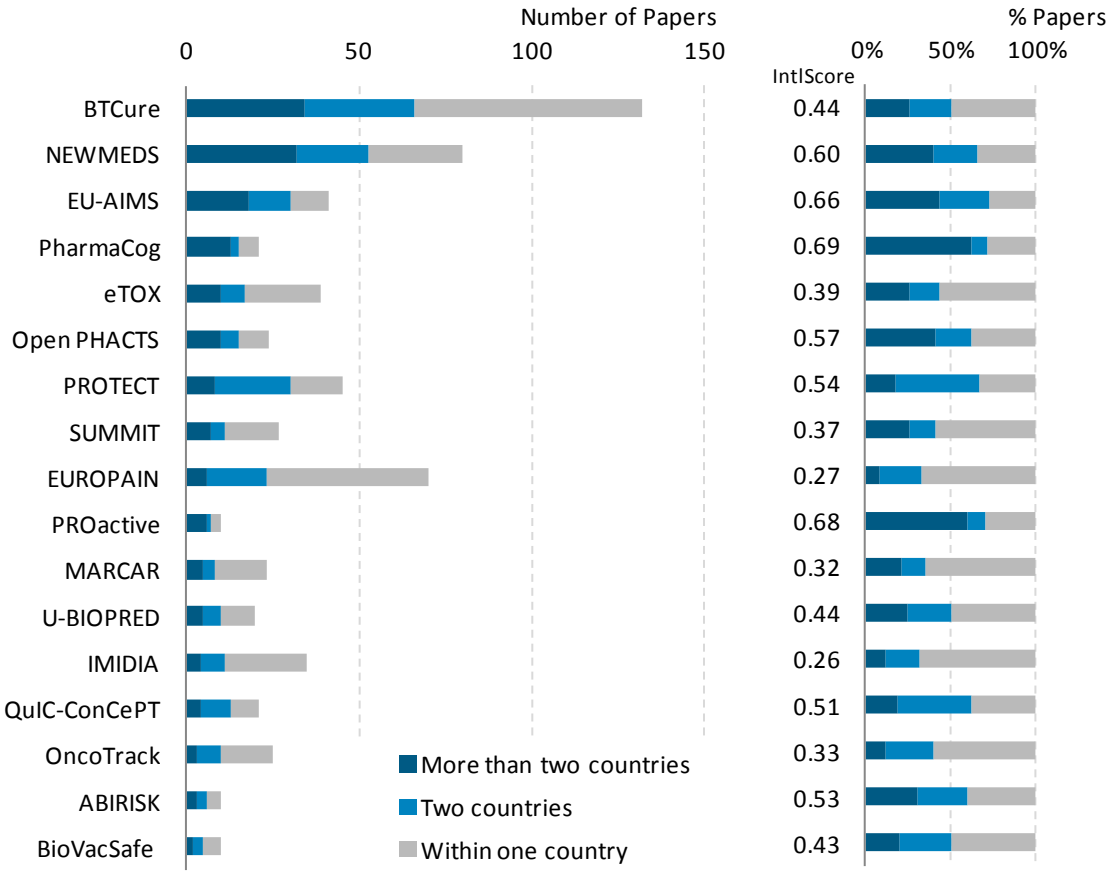


5.1.2 METRIC 2: FRACTION OF INTERNATIONALLY COLLABORATIVE PUBLICATIONS

Authors and author affiliations were extracted from the *Web of Science* for all IMI project publications. The total number of countries present in the author affiliations of each publication was then counted to classify the publication as “More than two countries”, “Two countries” or “Within one country”.

Figure 5.1.2 below shows the total number of publications for each project. Projects are ordered beginning with the project that has the largest number of internationally collaborative publications. The bar colors reflect the fraction of publications that include international collaboration. Only projects with more than ten associated publications are shown. The International Score (or “IntlScore”) was calculated by weighting each publication that involved only two countries by 0.75 and each publication that involved more than two countries by 1.00. The sum of the weighted publications was then divided by the total number of publications. BTCure has the most internationally collaborative publications involving more than two countries (34 out of 132), with an IntlScore of 0.44. PharmaCog, PROactive, and EU-Aims have highest IntlScore (0.69, 0.68, and 0.66 respectively).

FIGURE 5.1.2 FRACTION OF INTERNATIONALLY COLLABORATIVE PUBLICATIONS BY PROJECT



5.1.3 METRIC 3: TOP COLLABORATING ORGANIZATIONS PER PUBLICATION

Metric 3 focuses on the top collaborating organizations and the number involved in publications associated with each project.

Figure 5.1.3 shows the top eleven collaborating organization pairs and the total number of collaborating publications for each pair of organizations. The organizations that collaborate together the most frequently in IMI project publications are King's College and the University of London. Figure 5.1.4 shows the number of collaborating organizations for each organization. Harvard University has collaborated with 220 different organizations within the IMI project publications. The Karolinska Institute has collaborated with 187 organizations (see Annex 4 for acronym key of organizations in Figure 5.1.4).

The top 50 most diverse collaborating organizations were used to assign each project a score (metric 3). The average number of top 50 organizations per publication was calculated for each project. If the average was above or equal to one, the project was given a score of 1.00. Otherwise, the project was given a score equal to the average number of top collaborating organizations per project publication. Only the projects with at least ten project publications were scored (see Annex 4 for full table of project scores). Figure 5.1.5 shows the distribution of metric 3 scores for each project.

FIGURE 5.1.3 THE 11 MOST PRODUCTIVE PAIRS OF COLLABORATING ORGANIZATIONS

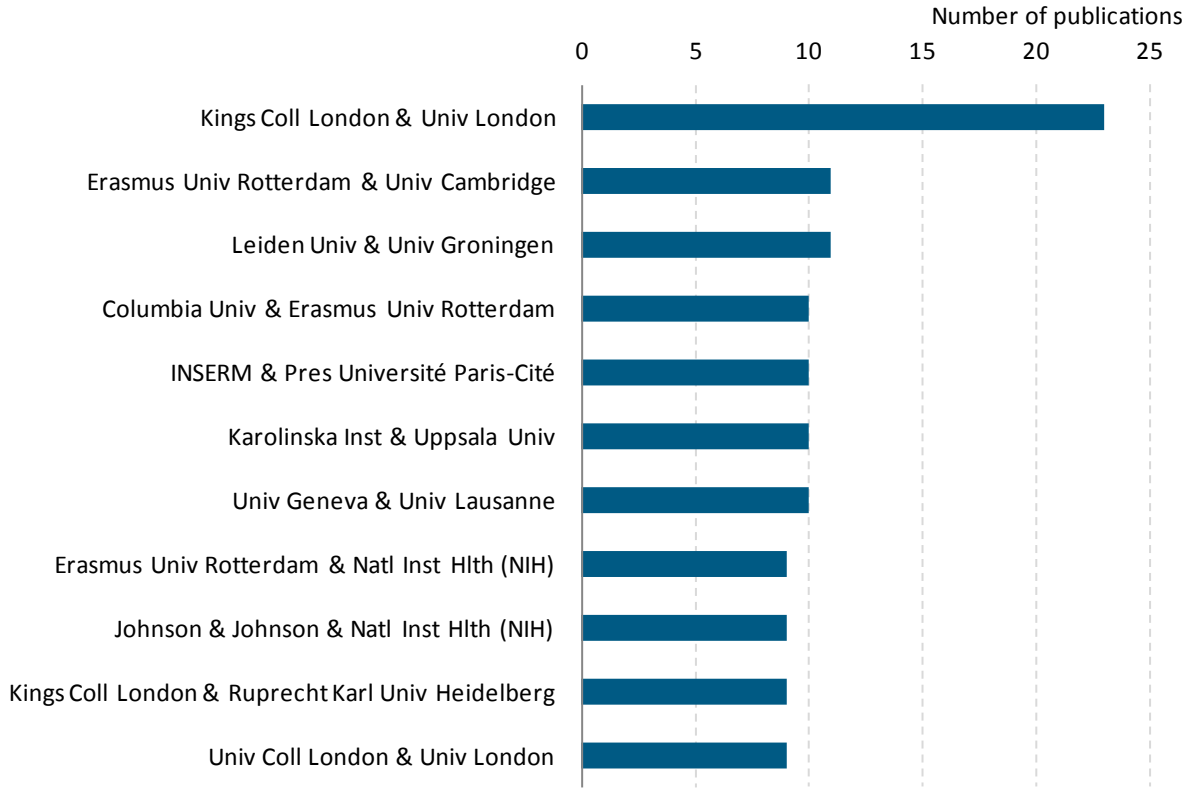


FIGURE 5.1.4 THE 12 MOST DIVERSE COLLABORATIVE ORGANIZATIONS

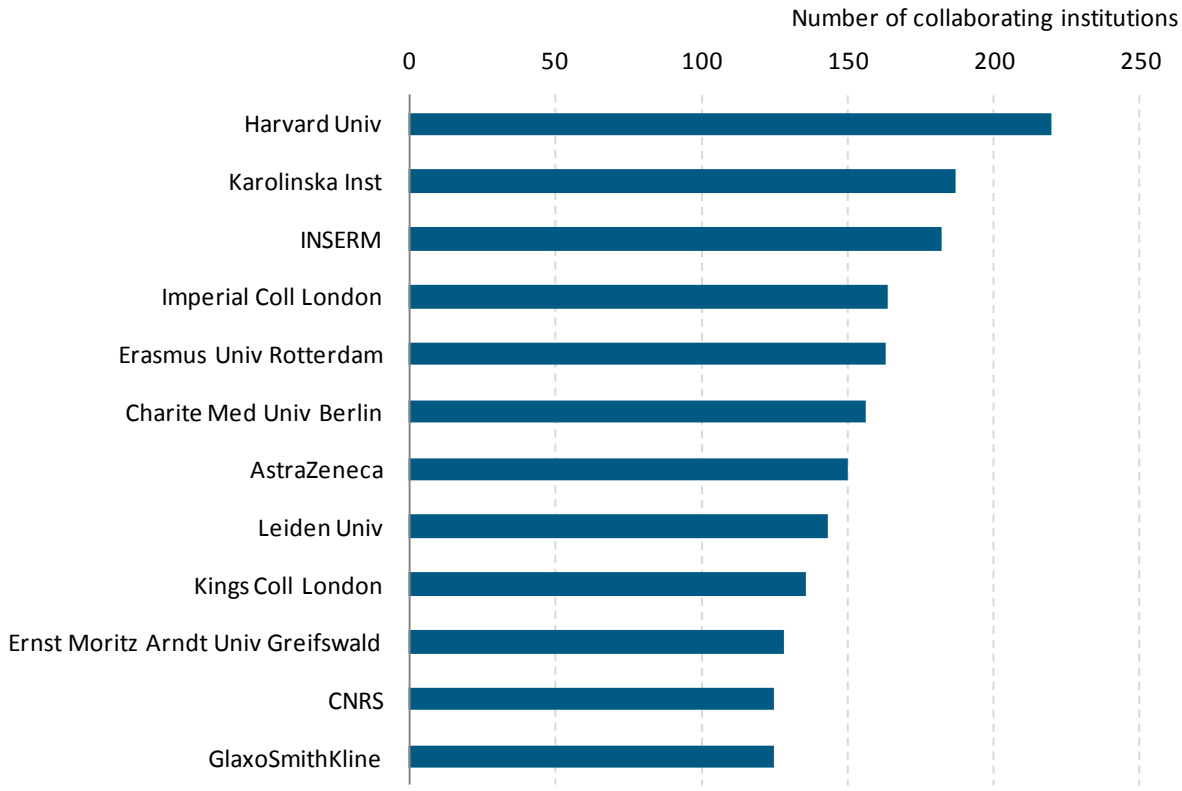
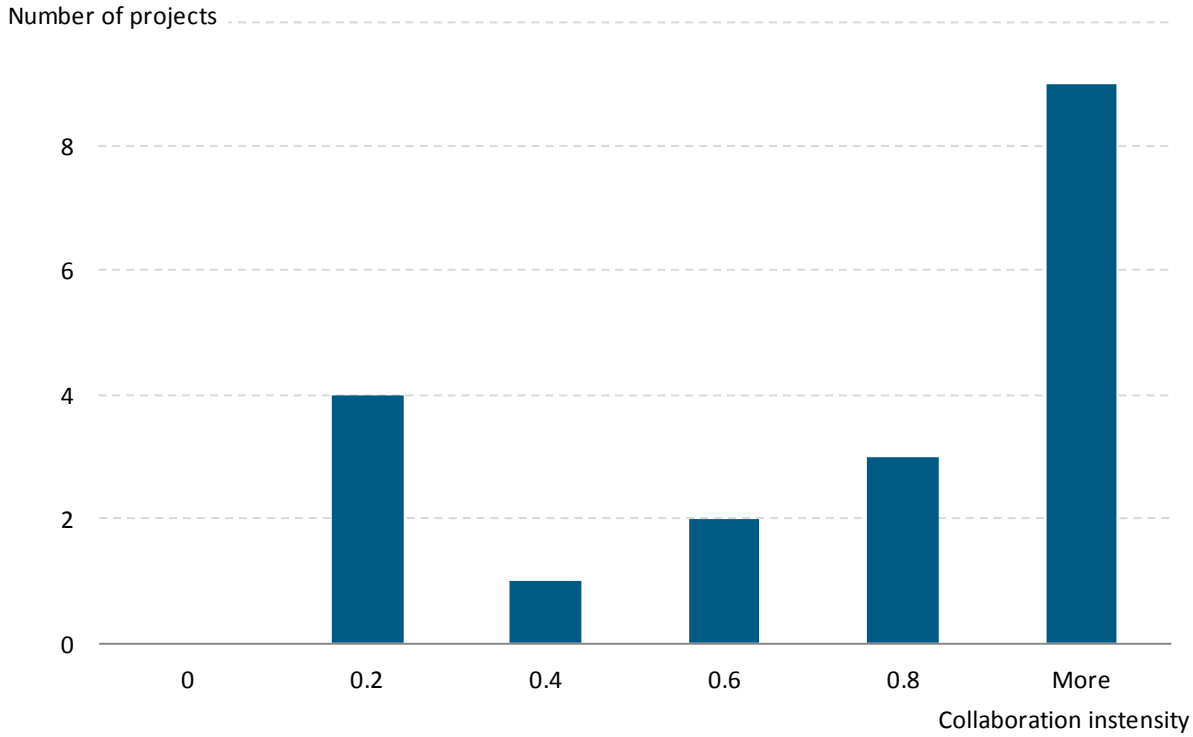


FIGURE 5.1.5 METRIC 3 SCORE DISTRIBUTION



5.2 COLLABORATION INDEX

Metrics 1 and 2 (described above) measure different types of collaboration diversity. The first measures the fraction of publications that involve cross sector collaborations and the second measures the fraction of publications that involve international collaborations. Metric 3 is based on the average number of top collaborating organizations per publication within each project. We compute a "collaboration index" across IMI projects as the sum of all three of the metrics described above (Figure 5.1.6 and Table 5.1.6). We note that a revised collaboration index might not include equal weighting of each metric, depending upon the relative importance IMI places on each collaboration type. PROactive had the highest overall collaboration index score (2.58), followed by PharmaCog, EU-AIMS and PROTECT (2.51, 2.37 and 2.34 respectively).

No substantial correlation is apparent between the collaboration index, or any of the component metrics, and the field-normalized citation impact of the research published by IMI projects. However, given the limited volumes of publications analyzed and the many factors which influence citation rates, we cannot draw any strong conclusions from this observation.

FIGURE 5.1.6 COLLABORATION INDEX VERSUS NUMBER OF PUBLICATIONS PER PROJECT

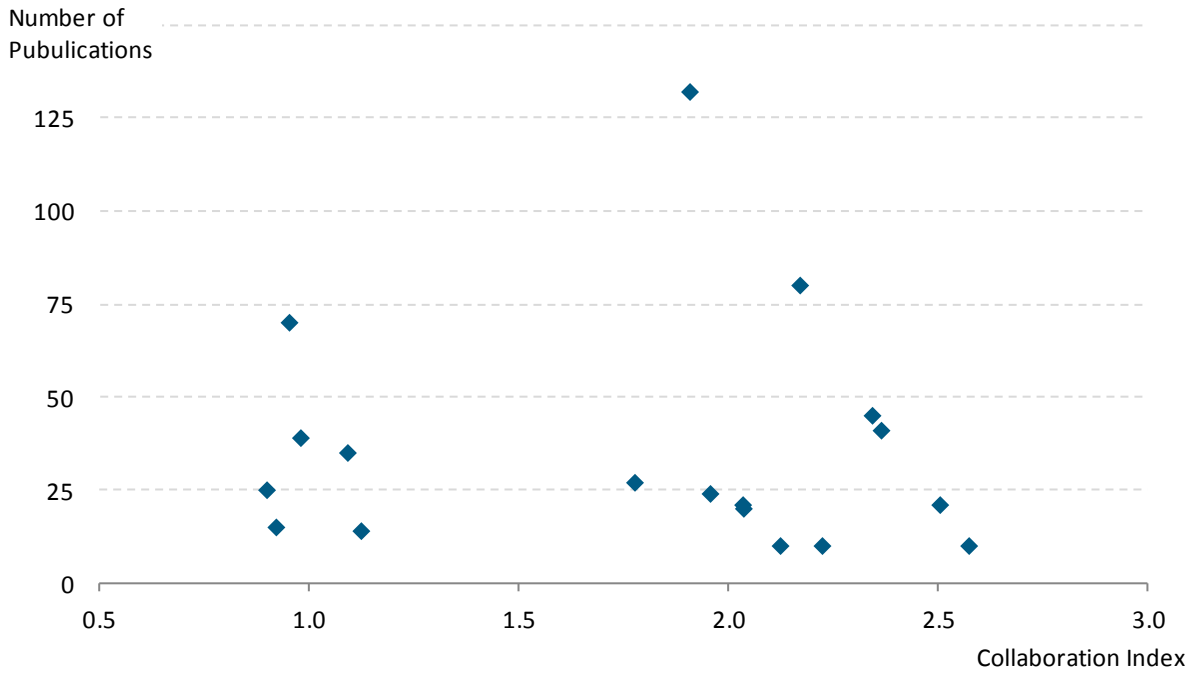


TABLE 5.1.6 COLLABORATION INDEX BY IMI PROJECT

IMI_project	frac cross sector	Intl score	Metric 3	Collaboration index	Total publications	Field-normalised citation impact
PROactive	0.90	0.68	1.00	2.58	10	1.38
PharmaCog	0.86	0.69	0.96	2.51	21	2.20
EU-AIMS	0.71	0.66	1.00	2.37	41	4.33
PROTECT	0.80	0.54	1.00	2.34	45	3.99
BioVacSafe	0.80	0.43	1.00	2.23	10	0.82
NEWMEDS	0.58	0.60	1.00	2.17	80	2.51
ABIRISK	0.60	0.53	1.00	2.13	10	1.51
U-BIOPRED	0.60	0.44	1.00	2.04	20	3.01
QuIC-ConCePT	0.52	0.51	1.00	2.04	21	2.17
Open PHACTS	0.63	0.57	0.76	1.96	24	2.11
BTCure	0.58	0.44	0.89	1.91	132	1.96
SUMMIT	0.41	0.37	1.00	1.78	27	1.45
DDMoRe	0.79	0.34	0.00	1.13	14	0.54
IMIDIA	0.31	0.26	0.51	1.09	35	1.20
eTOX	0.28	0.39	0.31	0.98	39	1.78
EUROPAIN	0.24	0.27	0.44	0.95	70	2.32
RAPP-ID	0.40	0.43	0.09	0.92	15	1.03
OncoTrack	0.52	0.33	0.05	0.90	25	2.26

ANNEX 1: BIBLIOGRAPHY OF NEW IMI-SUPPORTED PUBLICATIONS

This Annex lists the 132 IMI publications identified since our fourth report to IMI and the commencement of this project.

- AIGNER, S et al. (2014) Human pluripotent stem cell models of autism spectrum disorder: emerging frontiers, opportunities, and challenges towards neuronal networks in a dish. Psychopharmacology, 231(6), 1089-1104. doi: 10.1007/s00213-013-3332-1
- AMESS, B et al. (2013) Application of meta-analysis methods for identifying proteomic expression level differences. Proteomics, 13(14), 2072-2076. doi: 10.1002/pmic.201300034
- ANKERST, DP et al. (2014) Evaluating the Prostate Cancer Prevention Trial High Grade prostate cancer risk calculator in 10 international biopsy cohorts: results from the prostate biopsy collaborative group. World Journal of Urology, 32(1), 185-191. doi: 10.1007/s00345-012-0869-2
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- CAO, H et al. (2014). Test-retest reliability of fMRI-based graph theoretical properties during working memory, emotion processing, and resting state. Neuroimage, 84, 888-900. doi: 10.1016/j.neuroimage.2013.09.013
- COCKS, G et al. (2014). The utility of patient specific induced pluripotent stem cells for the modelling of Autistic Spectrum Disorders. Psychopharmacology, 231(6), 1079-1088. doi: 10.1007/s00213-013-3196-4
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ANNEX 2: BIBLIOGRAPHY OF HIGHLY-CITED PAPERS SUPPORTED BY IMI PROJECT

This Annex considers the cumulative dataset of IMI project publications that have been linked to records in Thomson Reuters citation databases.

For the purpose of this report, highly-cited papers have been defined as those articles and reviews which belong to the world's top decile of papers in that journal category and year of publication, when ranked by number of citations received. A percentage that is above 10 indicates above-average performance.

Below lists the 170 papers in the IMI project publications dataset that have been identified as highly-cited. Papers are listed in ascending alphabetical order (first author).

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ANNEX 3: BIBLIOMETRICS AND CITATION ANALYSIS

Bibliometrics are about publications and their citations. The academic field emerged from 'information science' and now usually refers to the methods used to study and index texts and information.

Publications cite other publications. These citation links grow into networks, and their numbers are likely to be related to the significance or impact of the publication. The meaning of the publication is determined from keywords and content. Citation analysis and content analysis have therefore become a common part of bibliometric methodology. Historically, bibliometric methods were used to trace relationships amongst academic journal citations. Now, bibliometrics are important in indexing research performance.

Bibliometric data have particular characteristics of which the user should be aware, and these are considered here.

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

The origins of citation analysis as a tool that could be applied to research performance can be traced to the mid-1950s, when Eugene Garfield proposed the concept of citation indexing and introduced the Science Citation Index, the Social Sciences Citation Index and the Arts & Humanities Citation Index, produced by the Institute of Scientific Information (currently the IP & Science business of Thomson Reuters)4.

We can count citations, but they are only 'indicators' of impact or quality – not metrics. Most impact indicators use average citation counts from groups of papers, because some individual papers may have unusual or misleading citation profiles. These outliers are diluted in larger samples.

DATA SOURCE

The data we use come from the Thomson Reuters *Web of Science*^{TM} databases which give access not only to journals but also to conference proceedings, books, patents, websites, and chemical structures, compounds and reactions. It has a unified structure that integrates all data and search terms together and therefore provides a level of comparability not found in other databases. It is widely acknowledged to be the world's leading source of citation and bibliometric data. The *Web of Science*^{TM} *Core Collection* is part of the *Web of Science*, and focuses on research published in journals and conferences in science, medicine, arts, humanities and social sciences.

The *Web of Science* was created as an awareness and information retrieval tool but it has acquired an important primary use as a tool for research evaluation, using citation analysis and bibliometrics. Data coverage is both current and retrospective in the sciences, social sciences, arts and humanities, in some cases back to 1900. Within the research community this data source is often still referred to by the acronym 'ISI'.

Unlike other databases, the *Web of Science* and underlying databases are selective, that is: the journals abstracted are selected using rigorous editorial and quality criteria. The authoritative, multidisciplinary content covers over 12,000 of the highest impact journals worldwide, including Open Access journals, and over 150,000 conference proceedings. The abstracted journals encompass the majority of significant, frequently cited scientific reports and, more importantly, an even greater proportion of the scientific research output which is cited. This selective process ensures that the citation counts remain relatively stable in given research fields and do not fluctuate unduly from year to year, which increases the usability of such data for performance evaluation.

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

[4] Garfield, E (1955) Citation Indexes for Science – New dimension in documentation through association of ideas. Science: 122, 108-111.

DATABASE CATEGORIES

The source data can be grouped in various classification systems. Most of these are based on groups of journals that have a relatively high cross-citation linkage and naturally cluster together. Custom classifications use subject maps in third-party data such as the OECD categories set out in the Frascati manual.

Thomson Reuters frequently uses the broader field categories in the *Essential Science Indicators*^{SM} system and the finer journal categories in the *Web of Science*. There are 22 fields in *Essential Science Indicators* and 254 fields in *Web of Science*. In either case, our bibliometric analyses draw on the full range of data available in the underlying database, so analyses in our reports will differ slightly from anything created 'on the fly' from data in the web interface.

The lists of journal categories in these systems are attached at the end of this document.

Most analyses start with an overall view across the data, then move to a view across broad categories and only then focus in at a finer level in the areas of greatest interest to policy, programme or organizational purpose.

ASSIGNING PAPERS TO ADDRESSES

A paper is assigned to each country and each organization whose address appears at least once for any author on that paper. One paper counts once and only once for each assignment, however many address variants occur for the country or organization. No weighting is applied.

For example, a paper has five authors, thus:

Author	Organization	Country		
Gurney, KA	Univ Leeds	UK	Counts for Leeds	Counts for UK
Adams, J	Univ Leeds	UK	No gain for Leeds	No gain for UK
Kochalko, D	Univ C San Diego	USA	Counts for UCSD	Counts for USA
Munshi, S	Gujarat Univ	India	Counts for Gujarat	Counts for India
Pendlebury, D	Univ Oregon	USA	Counts for Oregon	No gain for USA

So this one paper with five authors would be included once in the tallies for each of four universities and once in the tallies for each of three countries.

Work carried out within Thomson Reuters, and research published elsewhere, indicates that fractional weighting based on the balance of authors by organization and country makes little difference to the conclusions of an analysis at an aggregate level. Such fractional analysis can introduce unforeseen errors in the attempt to create a detailed but uncertain assignment. Partitioning credit would make a greater difference at a detailed, group level but the analysis can then be manually validated.

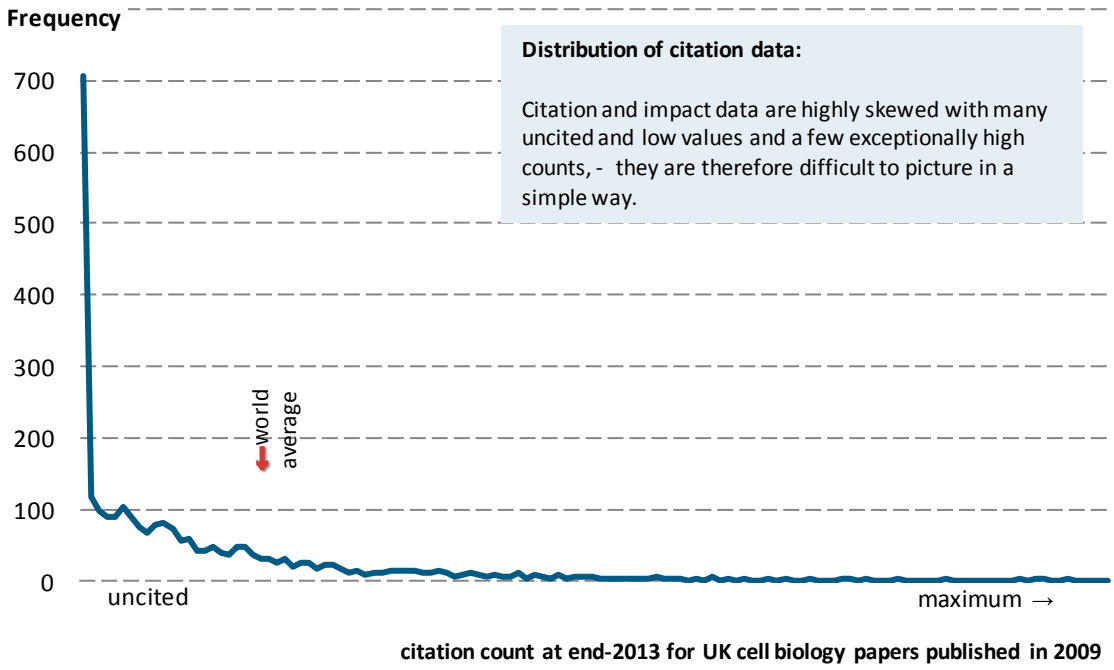
CITATION COUNTS

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

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

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

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



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

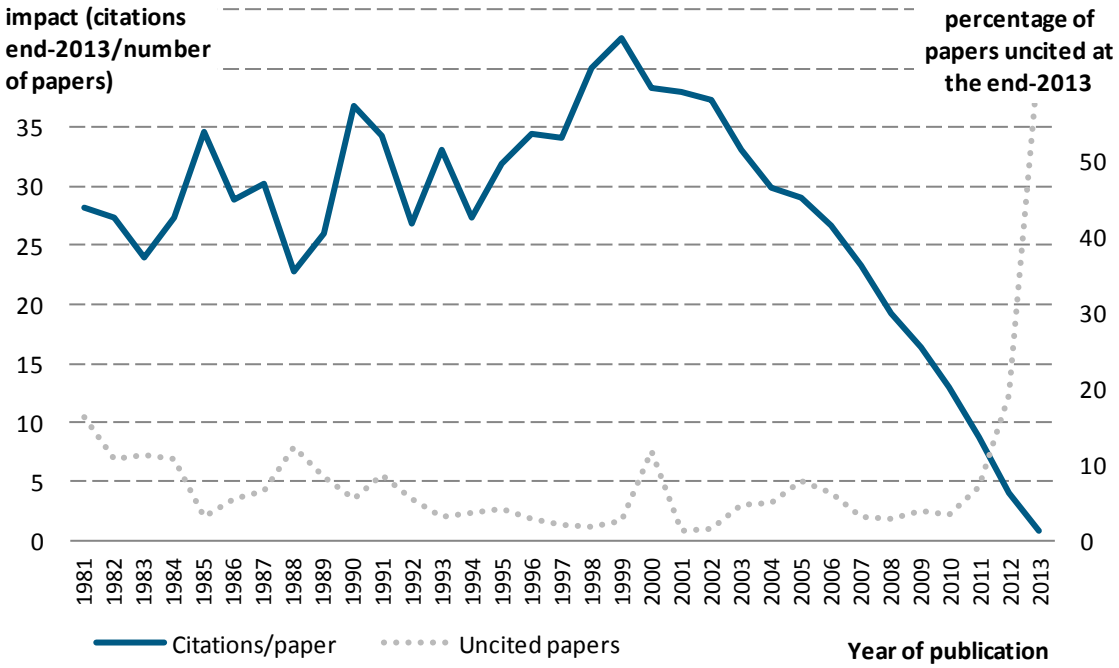
We do not seek to account separately for the effect of self-citation. If the citation count is significantly affected by self-citation then the paper is likely to have been infrequently cited. This is therefore only of consequence for low impact activity. Studies show that for large samples at national and organizational level the effect of self-citation has little or no effect on the analytical outcomes and would not alter interpretation of the results.

TIME FACTORS

Citations accumulate over time. Older papers therefore have, on average, more citations than more recent work. The graph below shows the pattern of citation accumulation for a set of 33 journals in the journal category ***Materials Science, Biomaterials***. Papers less than eight years old are, on average, still accumulating additional citations. The citation count goes on to reach a plateau for older sources.

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

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



DISCIPLINE FACTORS

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

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

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

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

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

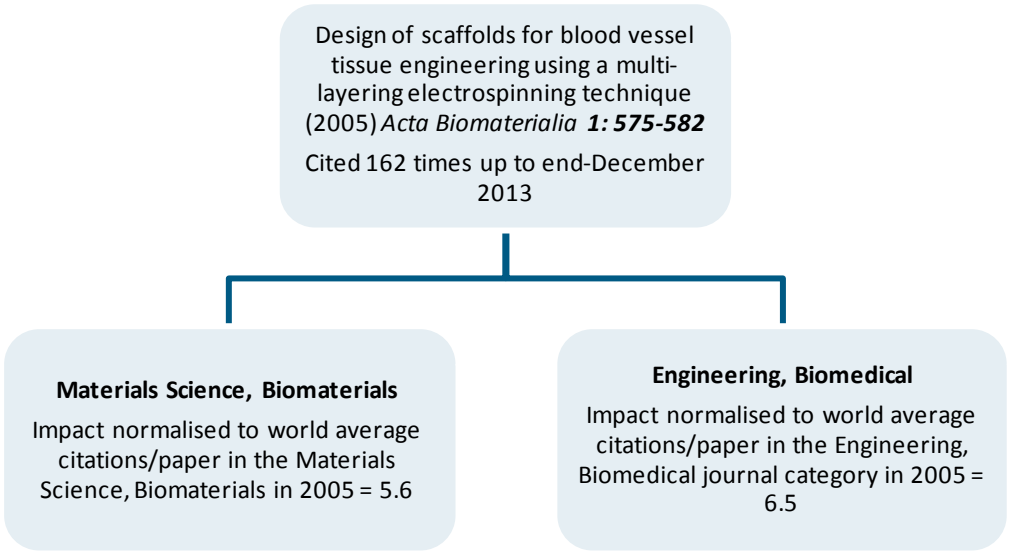
NORMALISED CITATION IMPACT

Because citations accumulate over time at a rate that is dependent upon the field of research, all analyses must take both field and year into account. In other words, because the absolute citation count for a specific article is influenced by its field and by the year it was published, we can only make comparisons of indexed data after normalizing with reference to these two variables.

We only use citation counts for reviews and articles in calculations of impact, because document type influences the citation count. For example, a review will often be cited more frequently than an article in the same field, but editorials and meeting abstracts are rarely cited and citation rates for conference proceedings are extremely variable. The most common normalization factors are the average citations per paper for (1)

the year and (2) either the field or the journal in which the paper was published. This normalization is also referred to as 'rebasing' the citation count.

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



This article in the journal *Acta Biomaterialia* is assigned to two journal categories: ***Materials Science, Biomaterials*** and ***Engineering, Biomedical***. The world average baselines for, as an example, Materials science, Biomaterials are calculated by summing the citations to all the articles and reviews published worldwide in the journal *Acta Biomaterialia* and the other 32 journals assigned to this category for each year, and dividing this by the total number of articles and reviews published in the journal category. This gives the category-specific normalised citation impact (in the above example the category-specific NCIF for ***Materials Science, Biomaterials*** is 5.6 and the category-specific NCIF for ***Engineering, Biomedical*** is higher at 6.5). Most papers (nearly two-thirds) are assigned to a single journal category whilst minorities are assigned to more than 5.

Citation data provided by Thomson Reuters are assigned on an annual census date referred to as the Article Time Period. For the majority of publications the Article Time Period is the same as the year of publication, but for a few publications (especially those published at the end of the calendar year in less main-stream journals) the Article Time Period may vary from the actual year of publication.

World average impact data are sourced from the Thomson Reuters National Science Indicators baseline data for 2013.

MEAN NORMALISED CITATION IMPACT

Research performance has historically been indexed by using average citation impact, usually compared to a world average that accounts for time and discipline. As noted, however, the distribution of citations amongst papers is highly skewed because many papers are never cited while a few papers accumulate very large citation counts. That means that an average may be misleading if assumptions are made about the distribution of the underlying data.

In fact, almost all research activity metrics are skewed: for research income, PhD numbers and publications there are many low activity values and a few exceptionally high values. In reality, therefore, the skewed distribution means that average impact tends to be greater than and often significantly different from either the median or mode in the distribution. This should be borne in mind when reviewing analytical outcomes.

The average (normalised) citation impact can be calculated at an individual paper level where it can be associated with more than one journal category. It can also be calculated for a set of papers at any level from a single country to an individual researcher's output. In the example above, the average citation impact of the *Acta Biomaterialia* paper can be expressed as ((5.6 + 6.5)/2) = 6.1.

IMPACT PROFILES®

We have developed a bibliometric methodology[5] that shows the proportion of papers that are uncited and the proportion that lie in each of eight categories of relative citation rates, normalised (rebased) to world average. An Impact Profile® enables an examination and analysis of the strengths and weaknesses of published outputs relative to world average and relative to a reference profile. This provides much more information about the basis and structure of research performance than conventionally reported averages in citation indices.

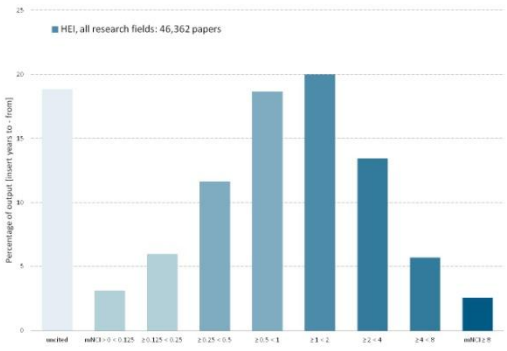
Papers which are "highly-cited" are often defined in our reports as those with an average citation impact (NCI_F) greater than or equal to 4.0, i.e. those papers which have received greater than or equal to four times the world average number of citations for papers in that subject published in that year. This differs from Thomson Reuters database of global highly-cited papers, which are the top 1% most frequently cited for their field and year. The top percentile is a powerful indicator of leading performance but is too stringent a threshold for most management analyses.

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

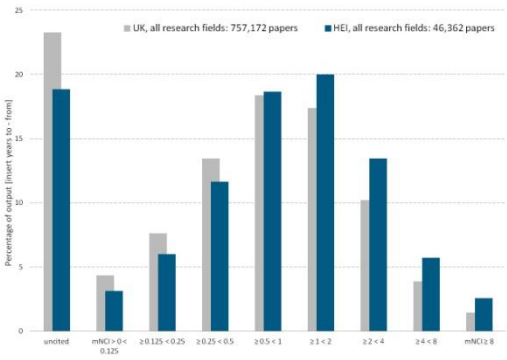
[5] Adams J, Gurney K & Marshall S (2007) Profiling citation impact: A new methodology. Scientometrics 72: 325-344.

The Impact Profile® histogram can be presented in a number of ways which are illustrated below.

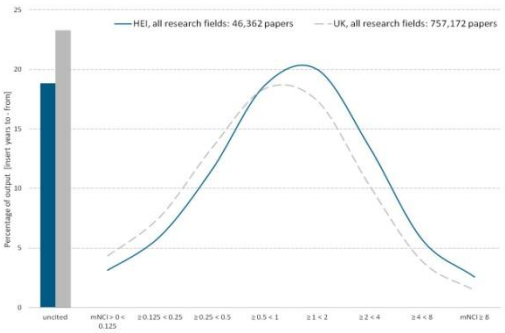
A



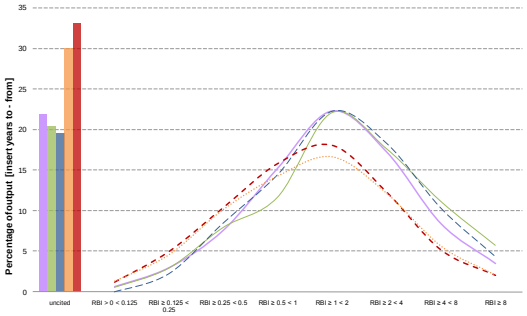
B



C



D



A: is used to represent the total output of an individual country, institution or researcher with no benchmark data. Visually it highlights the numbers of uncited papers (weaknesses) and highly cited papers (strengths).

B & **C**: are used to represent the total output of an individual country, institution or researcher (**client**) against an appropriate benchmark dataset (**benchmark**). The data are displayed as either histograms (B) or a combination of histogram and profile (C). Version C prevents the 'travel' which occurs in histograms where the eye is drawn to the data most offset to the right, but can be less easy to interpret as categorical data.

D: illustrates the complexity of data which can be displayed using an Impact Profile®. These data show research output in defined journal categories against appropriate benchmarks: **client, research field X**; **client, research field Y**; **client, research field Z**; **benchmark, research field X+Y**; **benchmark, research field, Z**.

Impact Profiles® enable an examination and analysis of the balance of published outputs relative to world average and relative to a reference profile. This provides much more information about the basis and structure of research performance than conventionally reported averages in citation indices.

An Impact Profile® shows what proportions of papers are uncited and what proportion are in each of eight categories of relative citation rates, normalised to world average (which becomes 1.0 in this graph). Normalised citation rates above 1.0 indicate papers cited more often than world average for the field in which that journal is categorised and in their year of publication.

Attention should be paid to:

- The proportion of uncited papers on the left of the chart
- The proportion of cited papers either side of world average (1.0)
- The location of the most common (modal) group near the centre
- The proportion of papers in the most highly-cited categories to the right, (≥4 x world, ≥8 x world).

WHAT ARE UNCITED PAPERS?

It may be a surprise that some journal papers are never subsequently cited after publication, even by their authors. This accounts for about half the total global output for a typical, recent 10-year period. We cannot tell why papers are not cited. It is likely that a significant proportion of papers remain uncited because they are reporting negative results which are an essential matter of record in their field but make the content less likely to be referenced in other papers. Inevitably, other papers are uncited because their content is trivial or marginal to the mainstream. However, it should not be assumed that this is the case for all such papers.

There is variation in non-citation between countries and between fields. For example, relatively more engineering papers tend to remain uncited than papers in other sciences, indicative of a disciplinary factor but not a quality factor. While there is also an obvious increase in the likelihood of citation over time, most papers that are going to be cited will be cited within a few years of publication.

WHAT IS THE THRESHOLD FOR 'HIGHLY CITED'?

Thomson Reuters has traditionally used the term 'Highly Cited Paper' to refer to the world's 1% of most frequently cited papers, taking into account year of publication and field. In rough terms, UK papers cited more than eight times as often as relevant world average would fall into the Thomson Highly Cited category. About 1-2% of papers (all papers, cited or uncited) typically pass this hurdle. Such a threshold certainly delimits exceptional papers for international comparisons but, in practice, is an onerous marker for more general management purposes.

After reviewing the outcomes of a number of analyses, we have chosen a more relaxed definition for our descriptive and analytical work. We deem papers that are cited more often than four times the relevant world average to be relatively highly-cited for national comparisons. This covers the two most highly-cited categories in our graphical analyses.

JOURNAL CATEGORY SYSTEMS USED IN OUR ANALYSES

Web of Science

Acoustics	Classics	Engineering, multidisciplinary
Agricultural economics & policy	Clinical neurology	Engineering, ocean
Agricultural engineering	Communication	Engineering, petroleum
Agriculture, dairy & animal science	Computer science, artificial intelligence	Entomology
Agriculture, multidisciplinary	Computer science, cybernetics	Environmental sciences
Agriculture, soil science	Computer science, hardware & architecture	Environmental studies
Agronomy	Computer science, information systems	Ergonomics
Allergy	Computer science, interdisciplinary applications	Ethics
Anatomy & morphology	Computer science, software engineering	Ethnic studies
Andrology	Computer science, theory & methods	Evolutionary biology
Anesthesiology	Construction & building technology	Family studies
Anthropology	Criminology & penology	Film, radio, television
Applied linguistics	Critical care medicine	Fisheries
Archaeology	Crystallography	Folklore
Architecture	Dance	Food science & technology
Area studies	Demography	Forestry
Art	Dentistry, oral surgery & medicine	Gastroenterology & hepatology
Asian studies	Dermatology	Genetics & heredity
Astronomy & astrophysics	Developmental biology	Geochemistry & geophysics
Automation & control systems	Ecology	Geography
Behavioral sciences	Economics	Geography, physical

Biochemical research methods
Biochemistry & molecular biology
Biodiversity conservation
Biology
Biology, miscellaneous
Biophysics
Biotechnology & applied microbiology
Business
Business, finance
Cardiac & cardiovascular systems
Cell biology
Chemistry, analytical
Chemistry, applied
Chemistry, inorganic & nuclear
Chemistry, medicinal
Chemistry, multidisciplinary
Chemistry, organic
Chemistry, physical
International relations
Language & linguistics
Language & linguistics theory
Law
Limnology
Linguistics
Literary reviews
Literary theory & criticism
Literature
Literature, African, Australian, Canadian
Literature, American
Literature, British Isles
Literature, German, Dutch, Scandinavian
Literature, romance
Literature, Slavic
Management
Marine & freshwater biology
Materials science, biomaterials
Materials science, ceramics
Materials science, characterization & testing
Materials science, coatings & films
Materials science, composites
Materials science, multidisciplinary
Materials science, paper & wood
Materials science, textiles
Math & computational biology
Mathematics
Mathematics, applied
Education & educational research
Education, scientific disciplines
Education, special
Electrochemistry
Emergency medicine
Endocrinology & metabolism
Energy & fuels
Engineering, aerospace
Engineering, biomedical
Engineering, chemical
Engineering, civil
Engineering, electrical & electronic
Engineering, environmental
Engineering, geological
Engineering, industrial
Engineering, manufacturing
Engineering, marine
Engineering, mechanical
Mining & mineral processing
Multidisciplinary sciences
Music
Mycology
Nanoscience & nanotechnology
Neuroimaging
Neurosciences
Nuclear science & technology
Nursing
Nutrition & dietetics
Obstetrics & gynecology
Oceanography
Oncology
Operations research & management science
Ophthalmology
Optics
Ornithology
Orthopedics
Otorhinolaryngology
Paleontology
Parasitology
Pathology
Pediatrics
Peripheral vascular disease
Pharmacology & pharmacy
Philosophy
Physics, applied
Geology
Geosciences, multidisciplinary
Geriatrics & gerontology
Health care sciences & services
Health policy & services
Hematology
History
History & philosophy of science
History of social sciences
Horticulture
Humanities, multidisciplinary
Imaging science & photographic technology
Immunology
Industrial relations & labor
Infectious diseases
Information & library science
Instruments & instrumentation
Integrative & complementary medicine
Psychology
Psychology, applied
Psychology, biological
Psychology, clinical
Psychology, developmental
Psychology, educational
Psychology, experimental
Psychology, mathematical
Psychology, multidisciplinary
Psychology, psychoanalysis
Psychology, social
Public administration
Public, environmental & occupational health
Radiology, nuclear medicine & medical imaging
Rehabilitation
Religion
Remote sensing
Reproductive biology
Respiratory system
Rheumatology
Robotics
Social issues
Social sciences, biomedical
Social sci, interdisciplinary
Social sci, mathematical methods
Social work
Sociology
Soil science

Mathematics, interdisciplinary applications
Mechanics
Medical ethics
Medical informatics
Medical laboratory technology
Medicine, general & internal
Medicine, legal
Medicine, research & experimental
Medieval & renaissance studies
Metallurgy & metallurgical engineering
Meteorology & atmospheric sci
Microbiology
Microscopy
Mineralogy
Urban studies
Urology & nephrology
Veterinary
Veterinary sciences
Virology
Water resources
Women's studies
Zoology

Physics, atomic, molecular & chemical
Physics, condensed matter
Physics, fluids & plasmas
Physics, mathematical
Physics, multidisciplinary
Physics, nuclear
Physics, particles & fields
Physiology
Planning & development
Plant sciences
Poetry
Political science
Polymer science
Psychiatry

Spectroscopy
Sport sciences
Statistics & probability
Substance abuse
Surgery
Telecommunications
Theater
Thermodynamics
Toxicology
Transplantation
Transportation
Transportation science & technology
Tropical medicine

ANNEX 4: ACRONYM KEY FOR TOP MOST DIVERSE COLLABORATIVE ORGANIZATIONS

INSERM – French Institute of Heart and Medical Research

CNRS – French National Centre for Scientific Research

Table of Metric 3 Scores

IMI_Project	InstanceTopCol	Total Pubs	Avg Top Org per Pub	Score
EU-AIMS	75	41	1.83	1.00
U-BIOPRED	32	20	1.60	1.00
ABIRISK	13	10	1.30	1.00
BioVacSafe	11	10	1.10	1.00
QuIC-ConCePT	10	10	1.00	1.00
PharmaCog	23	24	0.96	0.96
BTCure	118	132	0.89	0.89
Open PHACTS	19	25	0.76	0.76
IMIDIA	18	35	0.51	0.51
SAFE-T	7	15	0.47	0.47
EUROPAIN	31	70	0.44	0.44
eTOX	12	39	0.31	0.31
MIP-DILI	5	23	0.22	0.22
SafeSciMET	2	21	0.10	0.10
RAPP-ID	4	45	0.09	0.09
Translocation	2	27	0.07	0.07
OncoTrack	4	80	0.05	0.05
PreDiCT-TB	1	21	0.05	0.05