Cancer Research

Current Trends & Future Directions

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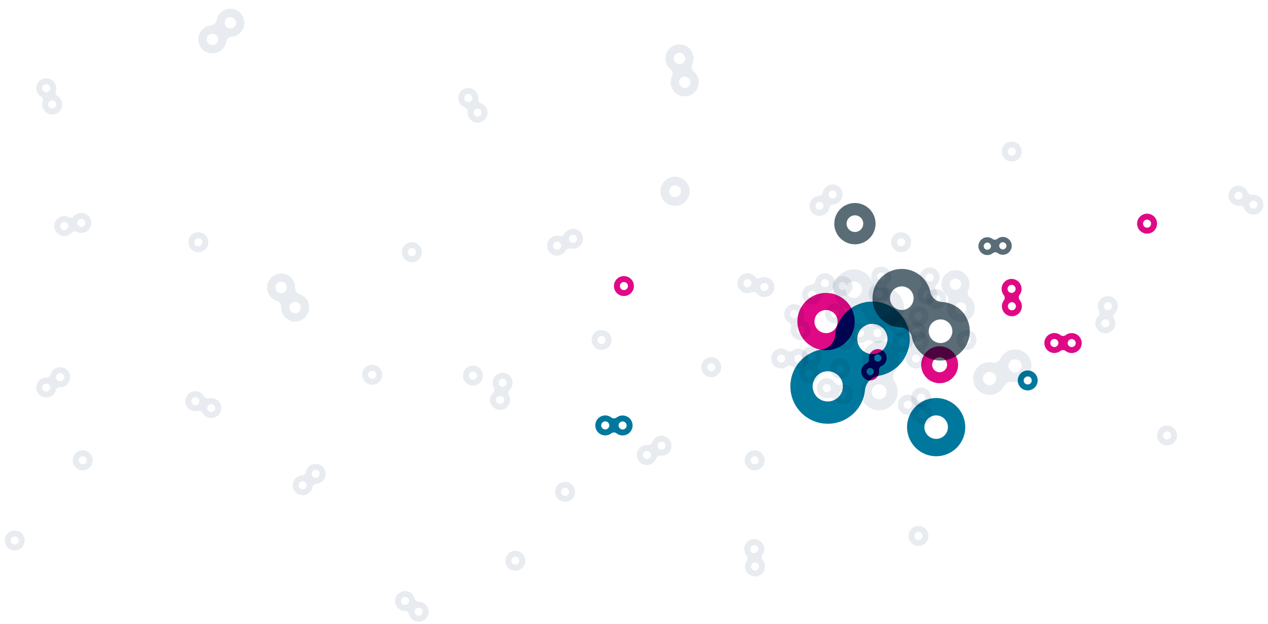


Foreword

Throughout history, progress of humankind can be measured by the achievements and milestones of each generation's new knowledge discoveries and their applications. Scientists, engineers, and inventors' contributions have impacted and in most cases improved society and the human condition. Notably, given the knowledge and tools available at the time, sending men to the moon was one of these. The prevention and cure of most, perhaps all, cancer would be this century's greatest achievement. With some cancers we have never been closer, while with others such a day currently seems unrealistic.

Discoveries in cell and molecular biology as well as biochemistry and genetics, and their application in medicine, have been the foundation for remarkable advances in health care, including cancer. To anyone who has seen the wide-ranging impact of cancer, both emotionally and financially, the goal of finishing the job – the prevention and cure of cancers - is worth the investment and causes us to consider game-changing new ways in which we might undertake this effort.

The 16th century author and scientist Sir Francis Bacon once said *"knowledge itself is power."* Greg Simon, Executive Director of the White House Cancer Moonshot Task Force, when speaking at *Fortune's* 2016 Brainstorm Health conference in San Diego, pointed out that, *"We still live in an information-scarce medical world."*

Thanks to the hard work of researchers, doctors, nurses, healthcare professionals, and the public advocates who support their efforts, early diagnosis and sophisticated new treatments for cancer are now available, and promising new approaches are in the pipeline. But when it comes to cancer, we have had periods of hope that ultimately proved to be unfounded. There is much more to be done, especially when considering that, just in the US, two of every three men and one of every three women will face cancer of some type during their lives.

Because of its privileged position in having developed Scopus, the largest and most comprehensive database of biomedical and clinical research, Elsevier rightfully accepts the obligation to use this valuable tool to support and inform the future of cancer research. In this report, we see the global landscape of cancer research. We hope to help us all see both the forest and the trees, and hopefully a straighter pathway forward. To get where we want to go, we first must take stock in where things stand and how things function currently. In this report, Elsevier, in association with the biomedical research community, endeavors to characterize the cancer research landscape in the hope that it will provide helpful new insights.

Introduction

In association with the scientific community, Elsevier has produced a number of reports that have focused on important and emerging areas of research. These include *Stem Cell Research – Trends and Perspectives of the Evolving International Landscape*; *Brain Science – Mapping the Landscape of Brain and Neuroscience Research*; and *Sustainability Science in a Global Landscape*.

In these cases, the full reports were written and produced prior to their open public release. In the case of this report on cancer research, we are motivated to take a different approach because of the importance and rapidly progressing nature of cancer research. Individual draft installments of the *Cancer Science – Current Trends & Future Directions* report will be produced and openly released for immediate use and input. Essentially, each installment is a type of pre-print that is a common practice in some disciplines and is being considered for adoption by others.

The initiative to speed up cancer research, currently called the "Cancer Moonshot," is administered through the White House. After the incoming administration develops its priorities for its support for the initiative, we are looking forward to continuing to produce additional installments of the report. The nature and number of installments is not set and will be informed by input from the community and an advisory board. We anticipate four to six topic-specific installments plus an analytical summary. Our hope is to release the full report by end of 2017. At the same time, The Lancet Oncology, an Elsevier publication, will produce a specially commissioned issue focused on cancer with direct contributions from leading cancer researchers that will be published during the summer of 2017.

The report is being developed with Elsevier's Research Intelligence products and services; research performance data comes from the Scopus database, which is approaching 1 million peer-reviewed publications and scientific proceedings on cancer research produced in the past decade.

When completed, and in combination with other materials, this report on cancer research will offer the research community, the public, policy makers, and research funding organizations information at a new level of assessment on the current state of cancer related research. We hope that this will be used to inform the development of new operational approaches, policies, and funding strategies at the laboratory, institutional, national, and international levels.

Preface & Context

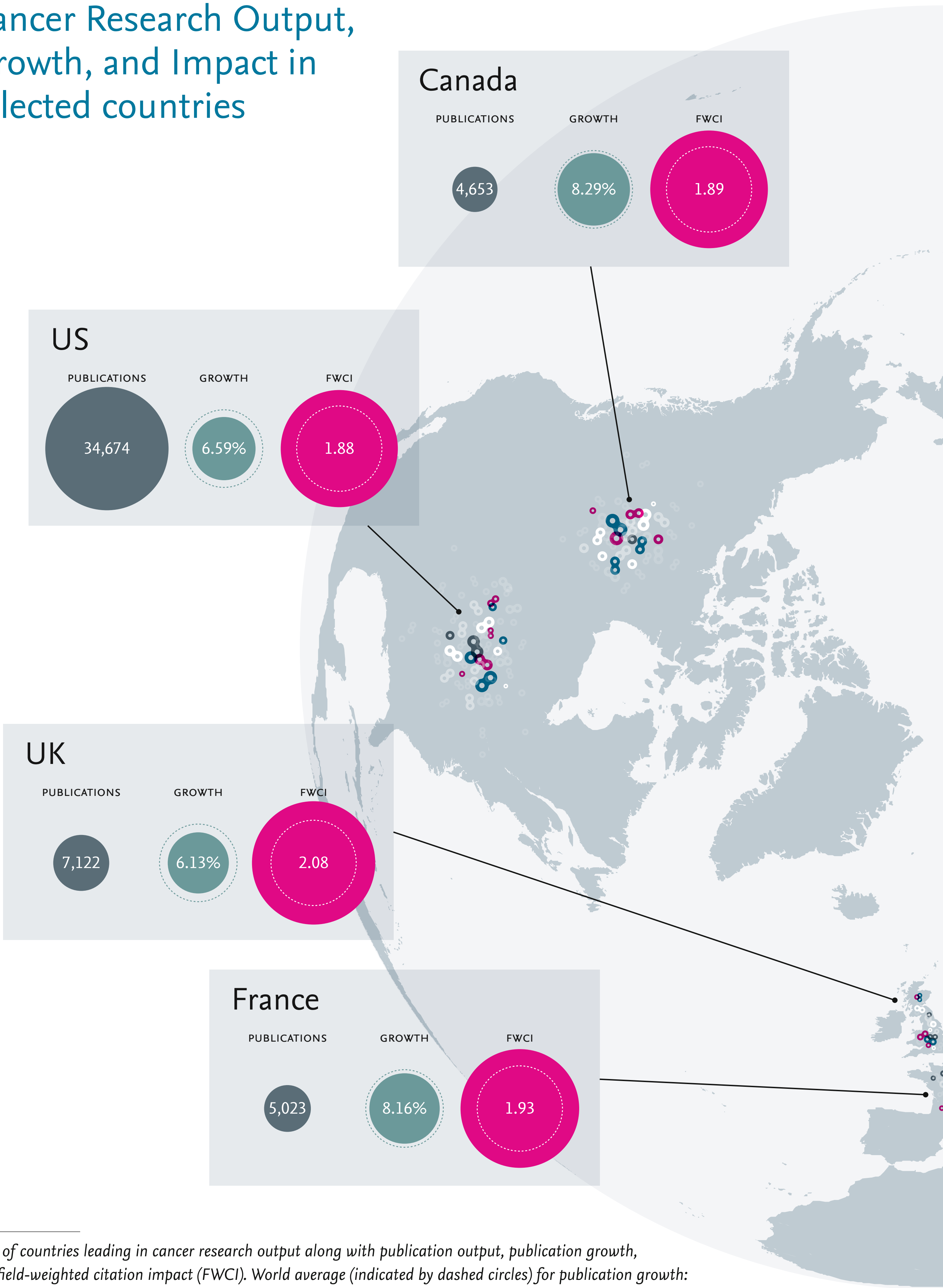
This report is prepared and openly distributed by Elsevier as a service to the research community, policy makers, research funders, and the public.

Elsevier's Research Intelligence collection of solutions is focused on providing objective analytical insights derived from the highest quality data available. This work is based on the Scopus database that is approaching 1 million peer-reviewed publications and scientific proceedings on the topic of cancer research produced in the past decade.

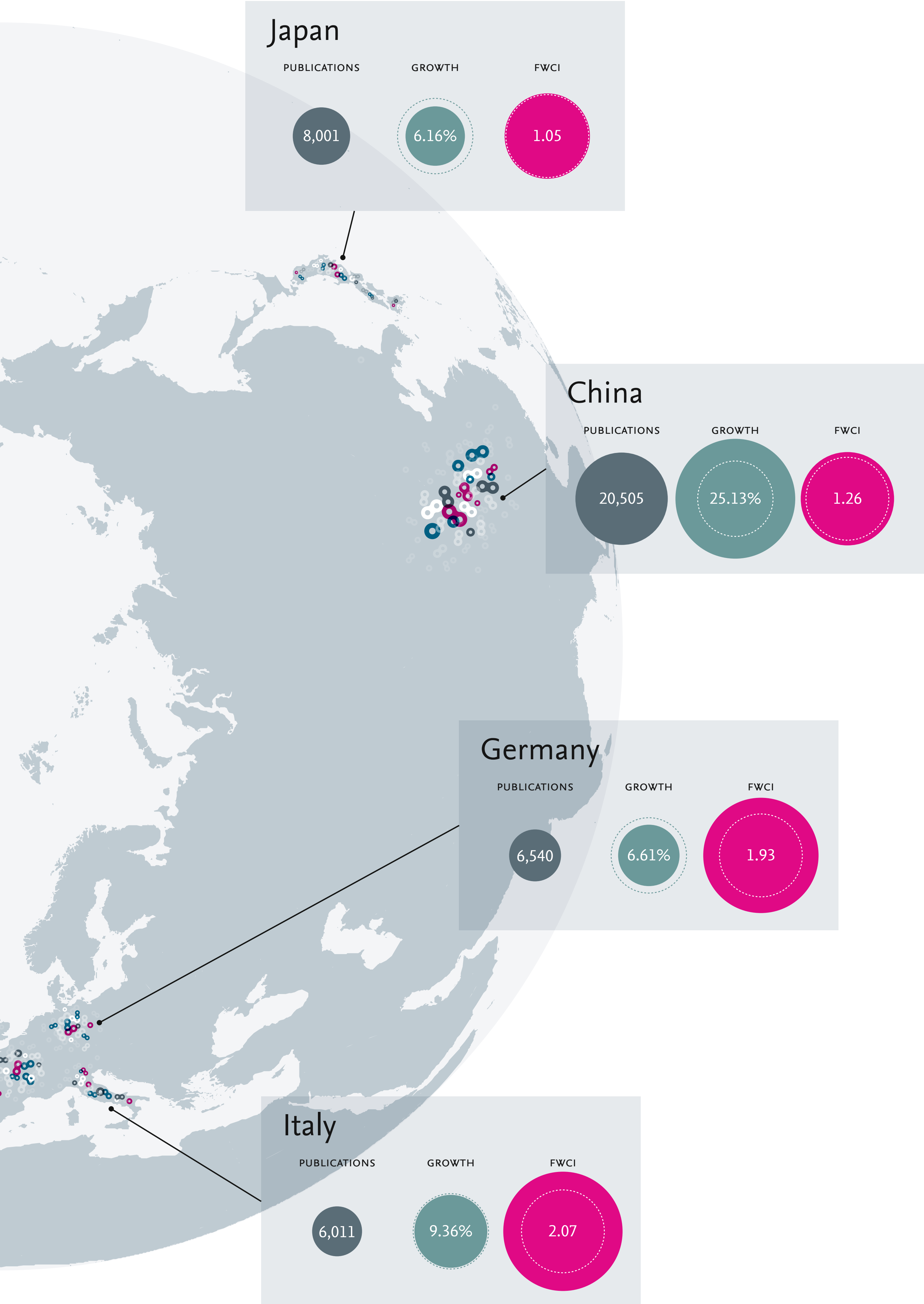
The goal is to inform the selection of approaches, priorities, and strategies in order to produce new knowledge that will address the key challenges related to cancer research in the most effective, efficient, and impactful way possible.

This first instalment presents an overarching view of emerging trends, many of which will be examined in greater detail in subsequent instalments. The maps present the key countries and institutions which form the basis for analysis in this document.

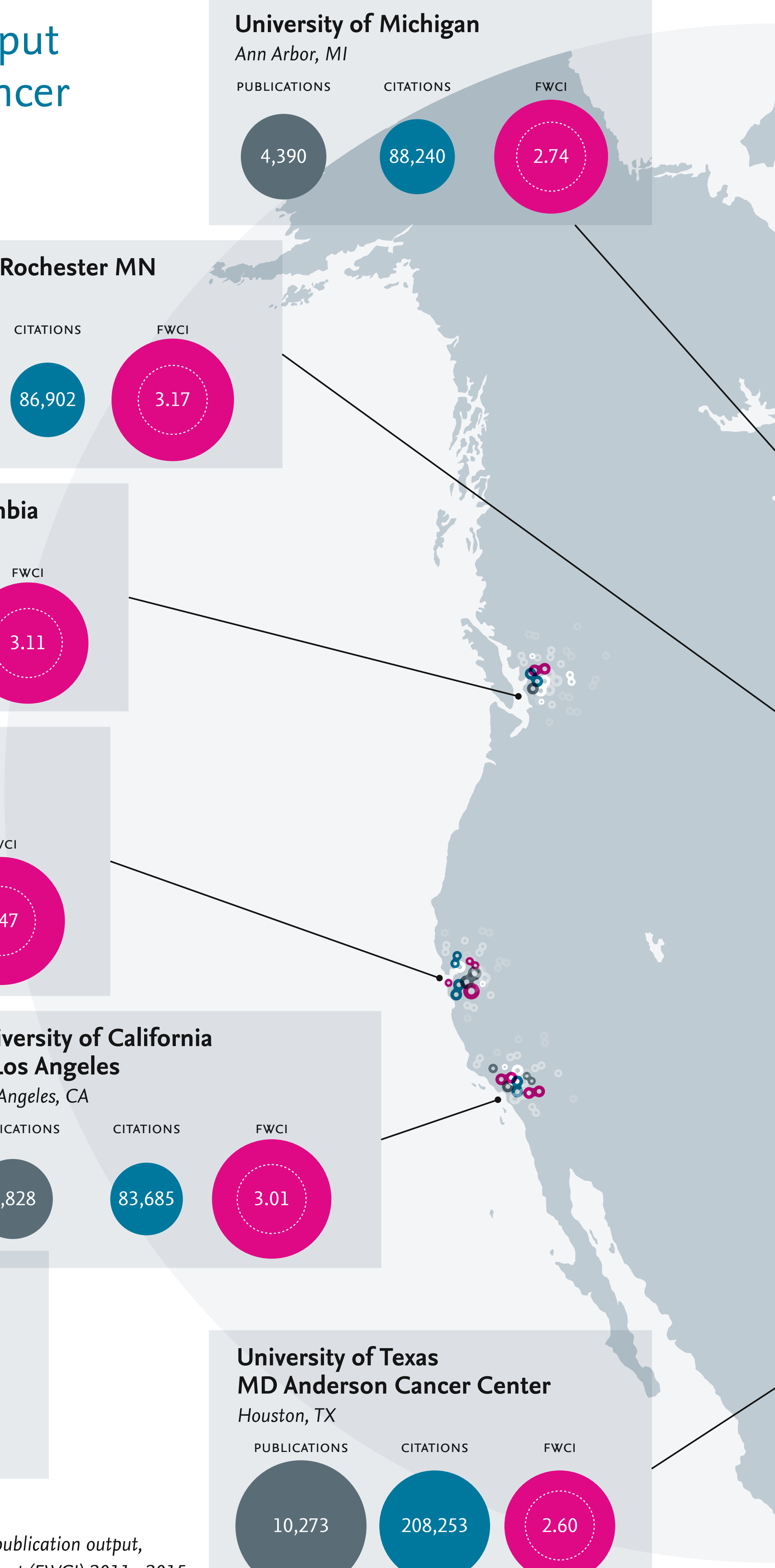
Cancer Research Output, Growth, and Impact in selected countries



Map of countries leading in cancer research output along with publication output, publication growth, and field-weighted citation impact (FWCI). World average (indicated by dashed circles) for publication growth: 9.93% / World average for field-weighted citation impact: 1.00. Data for publication output and field-weighted citation impact: 2014 / Data for publication growth: 5-year period (2010–2014). Source: Scopus


Japan
PUBLICATIONS
8,001
GROWTH
6.16%
FWCI
1.05
China
PUBLICATIONS
20,505
GROWTH
25.13%
FWCI
1.26
Germany
PUBLICATIONS
6,540
GROWTH
6.61%
FWCI
1.93
Italy
PUBLICATIONS
6,011
GROWTH
9.36%
FWCI
2.07

Cancer Research Output and Impact of top cancer research institutions



University of Michigan
Ann Arbor, MI

PUBLICATIONS	CITATIONS	FWCI
4,390	88,240	2.74

Mayo Clinic Rochester MN
Rochester, MN

PUBLICATIONS	CITATIONS	FWCI
3,867	86,902	3.17

University of British Columbia
Vancouver, BC

PUBLICATIONS	CITATIONS	FWCI
3,265	80,461	3.11

University of California at San Francisco
San Francisco, CA

PUBLICATIONS	CITATIONS	FWCI
4,068	120,545	3.47

University of California at Los Angeles
Los Angeles, CA

PUBLICATIONS	CITATIONS	FWCI
3,828	83,685	3.01

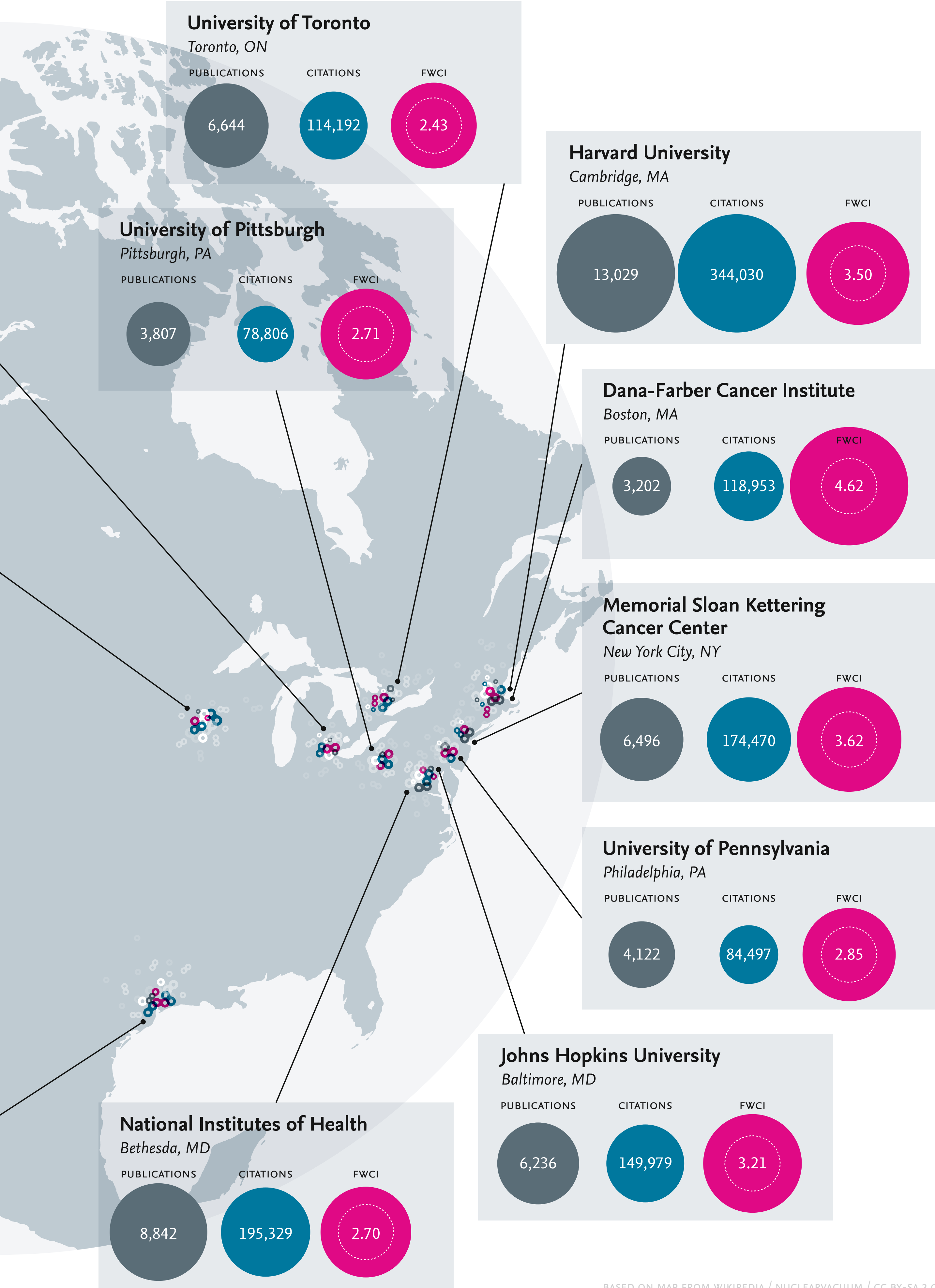
Karolinska Institutet
Solna, Sweden

PUBLICATIONS	CITATIONS	FWCI
3,958	76,583	2.69

University of Texas MD Anderson Cancer Center
Houston, TX

PUBLICATIONS	CITATIONS	FWCI
10,273	208,253	2.60

Map of top cancer research institutes along with publication output, count of citations, and field-weighted citation impact (FWCI) 2011–2015. World average for field-weighted citation impact: 1.00. Source: Scopus

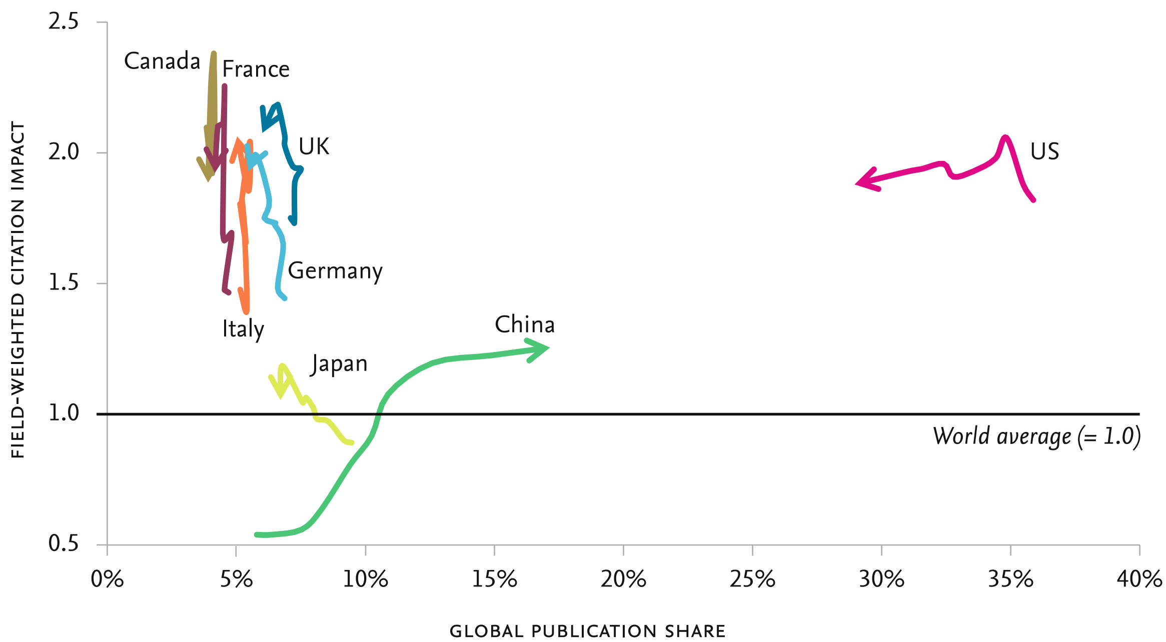

University of Toronto
Toronto, ON
PUBLICATIONS 6,644
CITATIONS 114,192
FWCI 2.43
Harvard University
Cambridge, MA
PUBLICATIONS 13,029
CITATIONS 344,030
FWCI 3.50
University of Pittsburgh
Pittsburgh, PA
PUBLICATIONS 3,807
CITATIONS 78,806
FWCI 2.71
Dana-Farber Cancer Institute
Boston, MA
PUBLICATIONS 3,202
CITATIONS 118,953
FWCI 4.62
Memorial Sloan Kettering Cancer Center
New York City, NY
PUBLICATIONS 6,496
CITATIONS 174,470
FWCI 3.62
University of Pennsylvania
Philadelphia, PA
PUBLICATIONS 4,122
CITATIONS 84,497
FWCI 2.85
Johns Hopkins University
Baltimore, MD
PUBLICATIONS 6,236
CITATIONS 149,979
FWCI 3.21
National Institutes of Health
Bethesda, MD
PUBLICATIONS 8,842
CITATIONS 195,329
FWCI 2.70

▶ Cancer research encompasses a broad array of research and includes a diverse range of specific research topics. Within this report, cancer research is defined as research where the published results include 'cancer' or 'oncology' within the title, abstract, or list of keywords of the publications, as indexed in the Scopus database. This includes all publication types, namely articles, reviews, conference papers, book chapters, notes, letters, short surveys, editorials, articles in press, erratum, books, conference reviews, business articles, and abstract reports. Articles represent 77% of the research, and reviews represent 14% of the publications retrieved. The countries selected for analysis produce the highest number of cancer research publications in 2014. Top cancer research institutions were identified by selecting the institutions with the highest number of citations in cancer research over the period 2011-2015.

In 2014, cancer research represents over 4 % of all research performed globally, reflecting the huge amount of effort that has been invested worldwide to address this multifaceted and complex disease. Today it is the leading cause of premature death in 28 European countries[1] and across the United States (US)[2]. Worldwide, cancer research output has increased year on year over the past decade and has seen notable advances in our understanding, diagnosis, and treatment of this disease. For example, to date, the US Food and Drug Administration has approved two vaccines (Gardasil, and later Cervarix) against Human Papilloma Virus (HPV), a virus that can cause cervical cancer in women. While initially the vaccines were only approved for young women and girls, research that linked HPV to a variety of other cancers led to the expansion of the vaccine recommendation to young men and boys as well. This single advance has cut cervical cancer risk, making it one of the most preventable cancers. Similarly in 2001, Imatinib (Gleevec) was approved for the targeted treatment of a rare chronic myelogenous leukemia. By attacking specific molecular defects in patients while successfully sparing healthy cells, this treatment transformed a rare deadly cancer from being a disease with an acute three to five year life expectancy, into a more chronic long-term, manageable condition. Despite such advances, the impact of cancer remains high and the number of cases is projected to nearly double over the next twenty years as the global population ages[3].

▶ Analysis of cancer research reveals that the US hosts a large fraction of the world's leading cancer research institutions[4] *(see Cancer Research Institutions Map)* and cancer research output from the US represents the largest share of global output in the field *(see Figure 1)*. The US share of cancer research has been declining over the past decade. This is largely the result of significant increase in China's cancer research publication output, which constitutes 17% of the global publication share in 2014, up from 5% in 2005 *(see Figure 1)*. The impact of cancer research, which can be examined via field-weighted citation impact[5] (FWCI), has risen over the past decade for most of the countries included in this analysis. China has seen a particularly large increase in FWCI from just above 0.5 in 2005 to above 1.2 in 2014. Japan, France, Germany, Italy, and the UK have also seen an overall increase in FWCI over the past decade while the FWCI for US cancer research has been stable over the past decade.

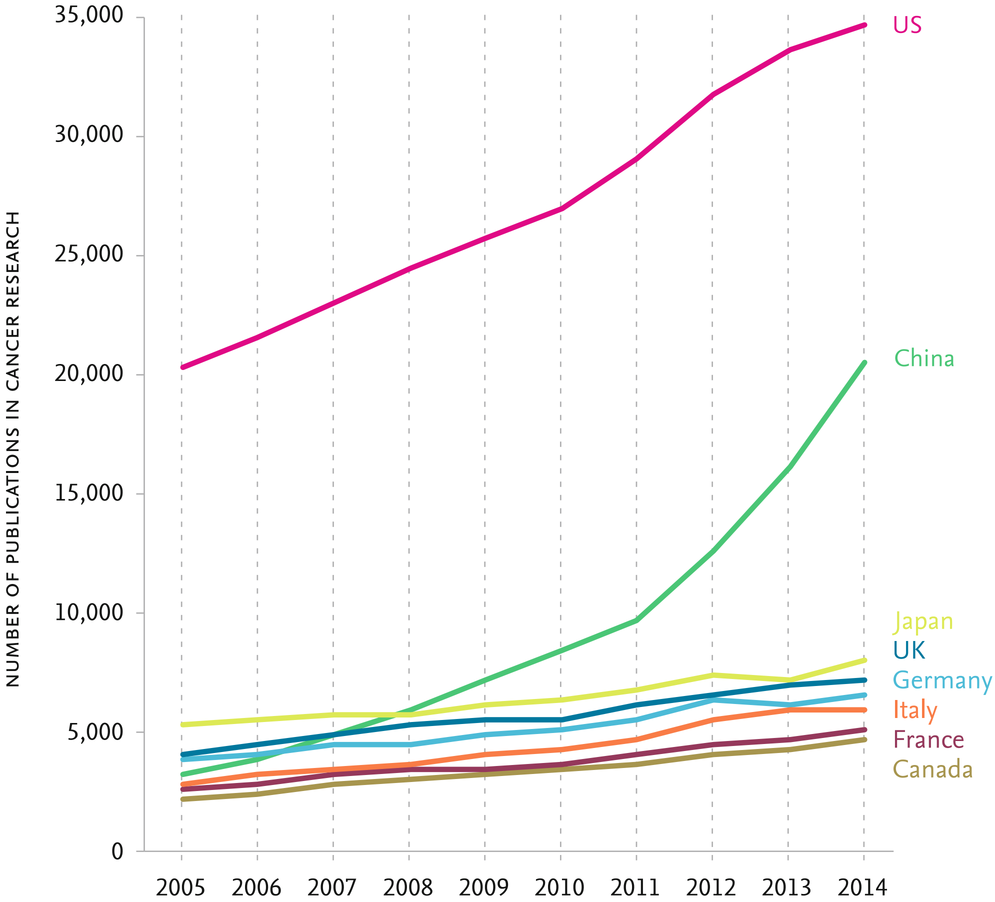
Figure 1 *— Change in publication share and citation record over the past decade for selected countries (2005–2014). Source: Scopus*



▶ The US is the most prolific producer of cancer research *(see Figure 2)*. US researchers have dominated research production for the past decade, producing more publications per annum than Japan, the UK, France, Germany, and Italy combined.

The volume of US cancer research publications has actually increased year on year and it is due to other countries, notably China, rapidly increasing output that the global publication share belonging to the United States has declined (Figure 2). In 2014, China produced approximately the same volume of papers as the US did in 2005.

***Figure 2** — Number of Cancer Research publications for selected countries (2005–2014). Source: Scopus*



1 Leading causes of death in Europe: fact sheet, WHO Europe.

2 http://www.cancer.org/acs/groups/content/@research/documents/document/acspc-047079.pdf

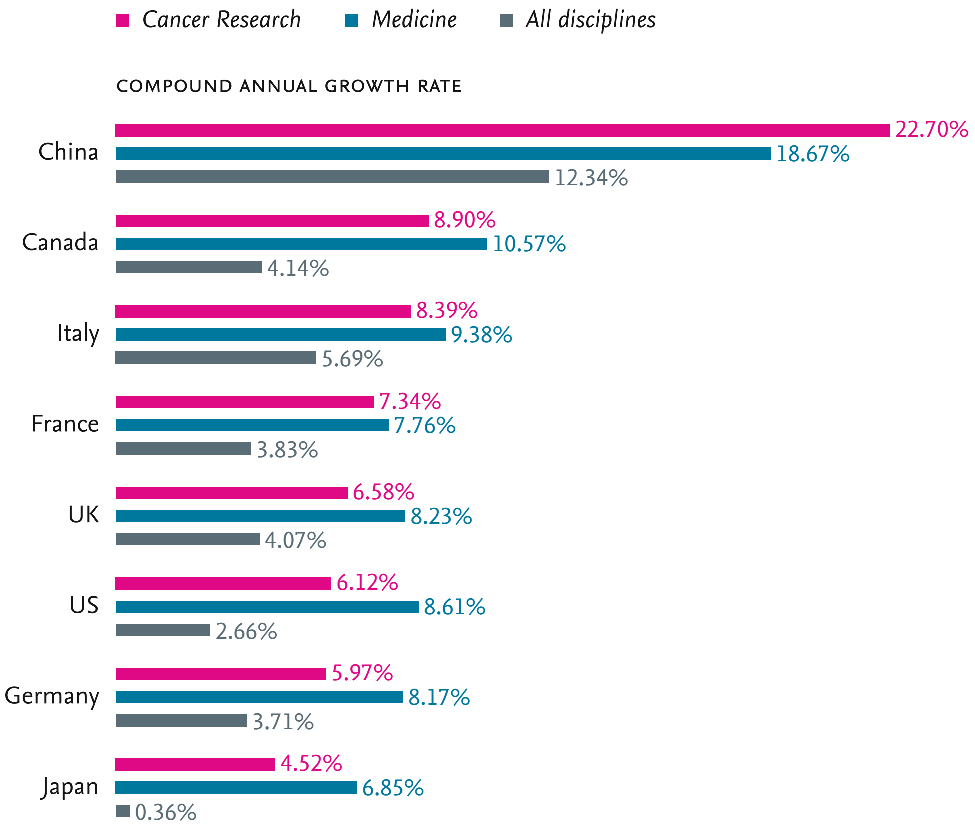
3 WHO Fact sheet N°297, updated February 2015.

4 'Top' institutions were identified by selecting the institutions with the highest number of citations in cancer research over the period 2011–2015.

5 Field Weighted Citation Impact (FWCI) indicates how the number of citations received by publications compares with the average number of citations received by all other similar publications indexed in the Scopus database. It corrects for factors such as the typical citation pattern for that discipline (some disciplines have a stronger culture of citation), the age of the papers (older papers have more time to accrue citations), and their document types (typically, reviews are cited more than articles). A field-weighted citation impact of 1 indicates that the publications have been cited at the world average for similar publications, while a value of 2 indicates they have been cited twice as many times as expected.

Increases in publication output are part of a global trend across all disciplines. Countries in this report see compound annual growth rates[6] (CAGR) in research output between 2-6%, with the exceptions of Japan (CAGR less than 1%) and China (CAGR greater than 12%) *(see Figure 3)*. Medical research however, has been expanding at a more rapid rate than other research fields with growth rates typically 1.5 to 3 times higher than the equivalent figure for all output in the country. Cancer research follows a similar trend to medical research overall but with slightly lower growth rates, particularly in the US, Germany, and Japan. China is the only country where growth in cancer research exceeds the rate of growth for medicine.

Figure 3 *— Compound Annual Growth Rate of publications in Cancer Research, Medicine, and All Disciplines in selected countries (2005–2014). Source: Scopus*



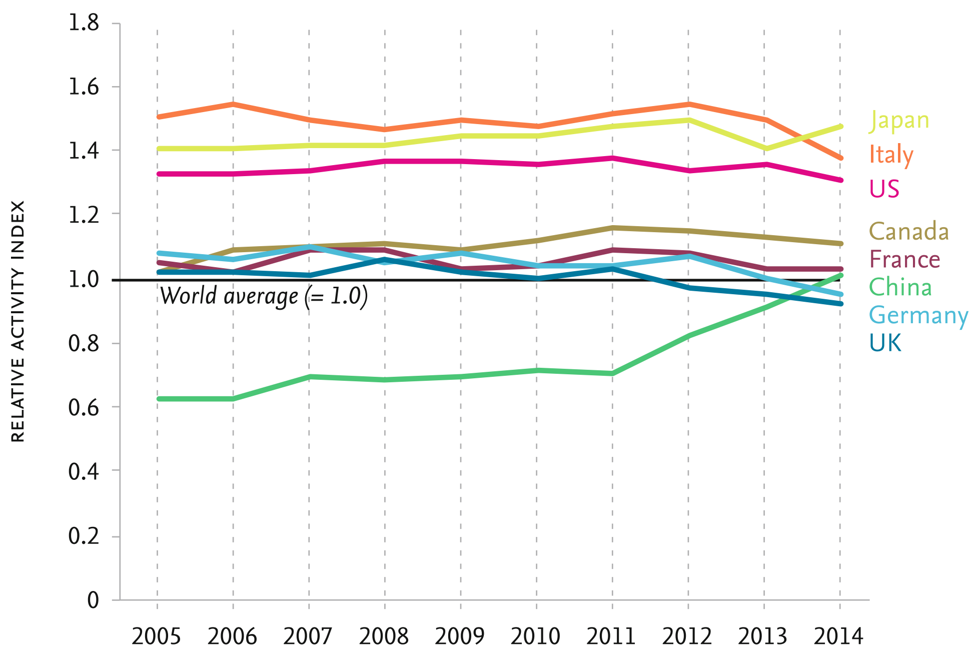
6 Compound annual growth rate (CAGR) is defined as the year-over-year constant growth rate over a specified period of time. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series.

▶ Relative activity indices[7] reflect on whether researchers in a country are focusing more attention on one discipline than another when compared to other countries globally. A value above 1 indicates more emphasis on that discipline compared to the global average. A rising relative activity index reflects increasing prioritization over time compared to the global average. This information provides important context as to whether trends are general worldwide or specific to a country or group of countries.

Except for China, all countries analyzed have a stable relative activity index over the decade, reflecting no change in focus on cancer research relative to global averages in each country over the past decade *(see Figure 4)*. China has seen the greatest increase in relative activity index for cancer research.

Overall, the relative prioritization of cancer research compared to all other disciplines is particularly high in Japan, Italy, and the US, a pattern which has been true throughout the past decade. At the other end of the spectrum are the UK and Germany, with lower relative activity indices and a slow decline over the past decade. This may reflect a more balanced research portfolio. Of note, cancer research within the UK and Germany has maintained a high FWCI over the past decade irrespective of changes in relative activity index.

Figure 4 *— Relative activity index of Cancer Research against all disciplines (2005–2014). Source: Scopus*



7 The relative activity index is equal to the proportion of a country's publications in Cancer Research within all disciplines divided by the proportion of the world's publications in Cancer Research within all disciplines. The world average is 1. Above 1 means more focus/interest in Cancer Research than the global average.

▶ Key terms or phrases appearing in cancer research publications over the past 5 years can provide a high level view of areas of focus. Figure 5 provides a graphical depiction of the 'hot topics' or key phrases in cancer research globally and in the US. The frequency of the term or phrase is reflected by the font size in the figure. To avoid bias, the charts are presented without imposing additional filters and as a result, some general terms naturally appear. The majority of key phrases appear in both US and global research, possibly as a result of the large share of cancer research represented by US publications. Also the majority of terms appear to be increasing over the past 5 years, reflecting the increased importance of cancer research.

Over the past 5 years there has been increasing emphasis on early detection of cancer, neoplastic stem cells, microRNAs, and biological markers. Compared with global research, the US has increased emphasis on developing immunotherapies, xenograft models, and studies of the tumor microenvironment. In contrast, terms such as 'general surgery,' 'recurrence,' and 'lymph nodes' appear exclusively among the top 50 for global cancer research. There were also interesting differences with regards to the types of cancer dominating the research focus in the US compared to globally. The key phrases melanoma, head and neck neoplasms, and thyroid neoplasms were exclusive to the US top 50 key phrase list while stomach neoplasm, hepatocellular carcinoma, and rectal neoplasm were exclusive to the global top 50 key phrase list. Additionally, while both the global and US top 50 lists include the term 'prostatic neoplasm,' the US list includes 3 additional terms related to prostate health: 'prostate-specific antigen,' 'prostatectomy,' and 'prostate,' suggesting a high relative importance of this topic within cancer research in the US.

Figure 5 (next page) *— Top 50 Key Phrases in Cancer Research worldwide (left) and for the US (right), 2011–2015. Source: Scopus*

A A A *Relevance of key phrase* ■ *Growing* ■ *Declining*

World	Rank	USA
Neoplasms	1	Neoplasms
Breast Neoplasms	2	Breast Neoplasms
Patients	3	Prostatic Neoplasms
Prostatic Neoplasms	4	Patients
Cells	5	Cells
Colorectal Neoplasms	6	Therapeutics
Therapeutics	7	Colorectal Neoplasms
Neoplasm Metastasis	8	Early Detection of Cancer
Lung Neoplasms	9	Risk
Carcinoma, Non-Small-Cell Lung	10	Survival
Survival	11	Lung Neoplasms
Stomach Neoplasms	12	Neoplasm Metastasis
Risk	13	Carcinoma, Non-Small-Cell Lung
Drug Therapy	14	Radiation
MicroRNAs	15	Ovarian Neoplasms
Apoptosis	16	Pancreatic Neoplasms
Early Detection of Cancer	17	MicroRNAs
Carcinoma	18	Drug Therapy
Prognosis	19	Survivors
Radiotherapy	20	Breast
Ovarian Neoplasms	21	Women
Pancreatic Neoplasms	22	Neoplastic Stem Cells
Breast	23	Mutation
Uterine Cervical Neoplasms	24	Disease
Adenocarcinoma	25	Biological Markers
Genes	26	Prostate
Radiation	27	Pharmaceutical Preparations
Carcinoma, Squamous Cell	28	Adenocarcinoma
General Surgery	29	Xenograft Model Antitumor Assays
Diagnosis	30	Immunotherapy
Biological Markers	31	Melanoma
Women	32	Molecular Targeted Therapy
Urinary Bladder Neoplasms	33	Genes
Pharmaceutical Preparations	34	Head and Neck Neoplasms
Meta-Analysis as Topic	35	Urinary Bladder Neoplasms
Colonic Neoplasms	36	Carcinoma
Neoplastic Stem Cells	37	Prostate-Specific Antigen
Mutation	38	Receptor, Epidermal Growth Factor
Receptor, Epidermal Growth Factor	39	Apoptosis
Recurrence	40	Humans
Disease	41	Tumor Microenvironment
Carcinoma, Hepatocellular	42	Uterine Cervical Neoplasms
Tissues	43	Antineoplastic Agents
Humans	44	Radiotherapy
Cell Line	45	Tissues
Lymph Nodes	46	Colonic Neoplasms
Esophageal Neoplasms	47	Prostatectomy
Rectal Neoplasms	48	Carcinoma, Squamous Cell
Tumor Markers, Biological	49	Diagnosis
Disease-Free Survival	50	Thyroid Neoplasms

▶ Beyond volume of research published, the quality and influence of the work produced is perhaps of greater importance. Looking at volume data in isolation risks missing the important consideration of the influence of the output and fails to recognize the importance of the spread of discoveries over time.

In many cases, resources are required to drive and accelerate the impact of research beyond publication if a positive impact is to be achieved for wider society. As a result, considerations of metrics which can reflect this effort become imperative.

It is now possible to consider the use and impact of research post publication through analyses of:

a) Citations by other academics, as evidence of influence and academic impact of the work;

b) Frequency with which publications are viewed, to consider the broader reach of publications;

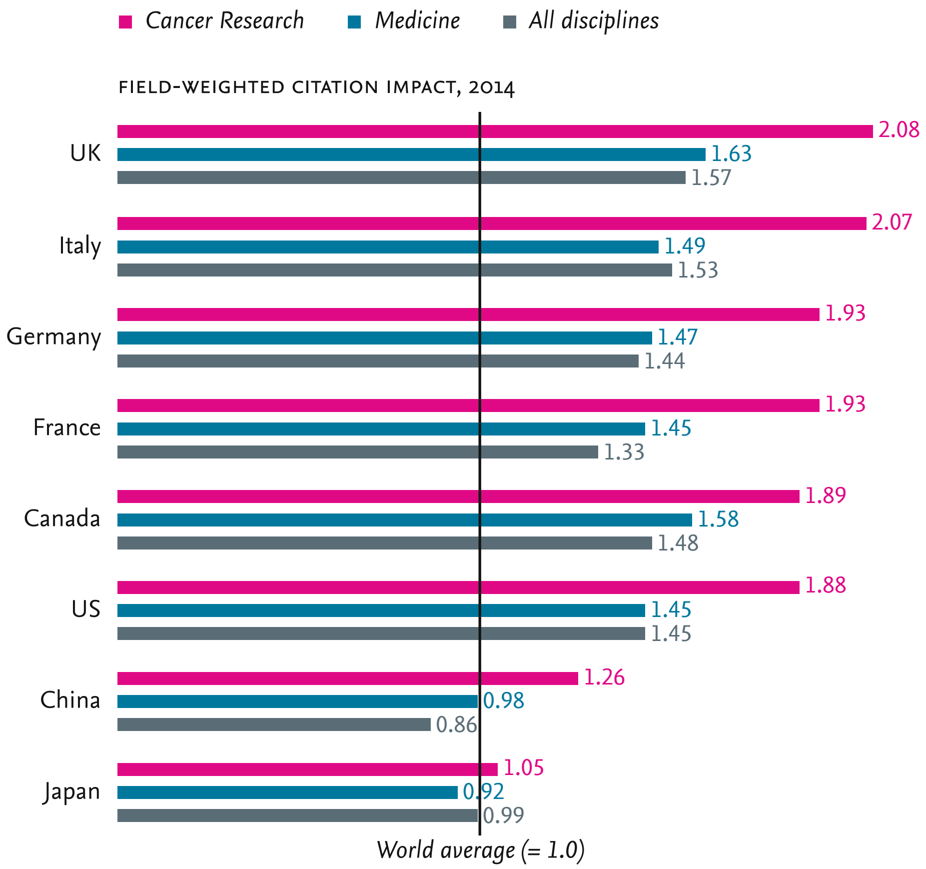
c) Citations of research in patents, as evidence of use of research in the innovation ecosystem.

Changes in metrics over time can be particularly informative, especially when paired with an understanding of shifts in research funding priorities and public policy. Sustained improvements in quality can be harder to attain than increased volume alone, and it is interesting to put them in a wider context to learn about the settings that may be conducive to their emergence.

A country's field-weighted citation impact (FWCI) reflects citations to research of (for instance) a country, compared to the world average, and corrected for factors such as the typical citation pattern for that discipline (the culture of citation differs across disciplines), the age of the papers (older papers have more time to accrue citations), and their document types (typically, reviews are cited more than articles). It is a proxy for the impact of specific research in that field, as far as this can be reflected by citation data. An FWCI equal to 1 represents a citation record equal to the world average.

In most countries analyzed in this report, cancer research represents a stand-out area for the country compared both to medical research and to all other disciplines[8] *(see Figure 6)*, as demonstrated by superior FWCI.

Figure 6 *— Field-weighted citation impact in Cancer Research, Medicine and all disciplines for selected countries in 2014. Source: Scopus*



8 Japan is the exception, where the difference between cancer research, medicine and other disciplines is less marked.

▶ Some countries such as Germany, the UK, and most noticeably China, show a general increase in impact over the period 2005 – 2014 *(see Figure 7)*. The US by contrast displays a relatively static performance, likely as a result of the large volume of publications represented by US output.

▶ It is also possible to assess 'excellence' rather than impact of the field as a whole, in this case through the proxy of publications in the top 10% of all cited publications worldwide *(see Figure 8)*. The US in 2014 for example has 30% of its publications in the top 10% worldwide. While this performance is strong, it is slightly down from 2005 as other countries have increased their excellent output at a faster rate.

China's rise in top cited publications has been remarkable, particularly between 2007 and 2012, and also mirrors its general increase in FWCI over the period.

Figure 7 — *Field-Weighted Citation Impact for Cancer Research in selected countries (2005 – 2014). Source: Scopus*

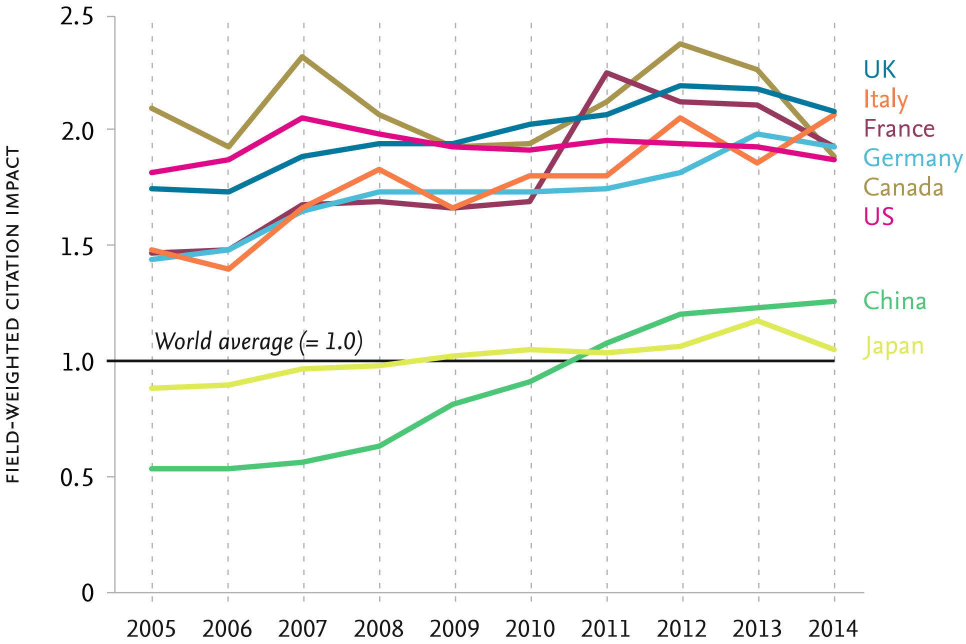


Figure 8 — *Proportion of Cancer Research Publications that are in the top 10 citation percentile for comparator countries (2005 – 2014). Source: Scopus*

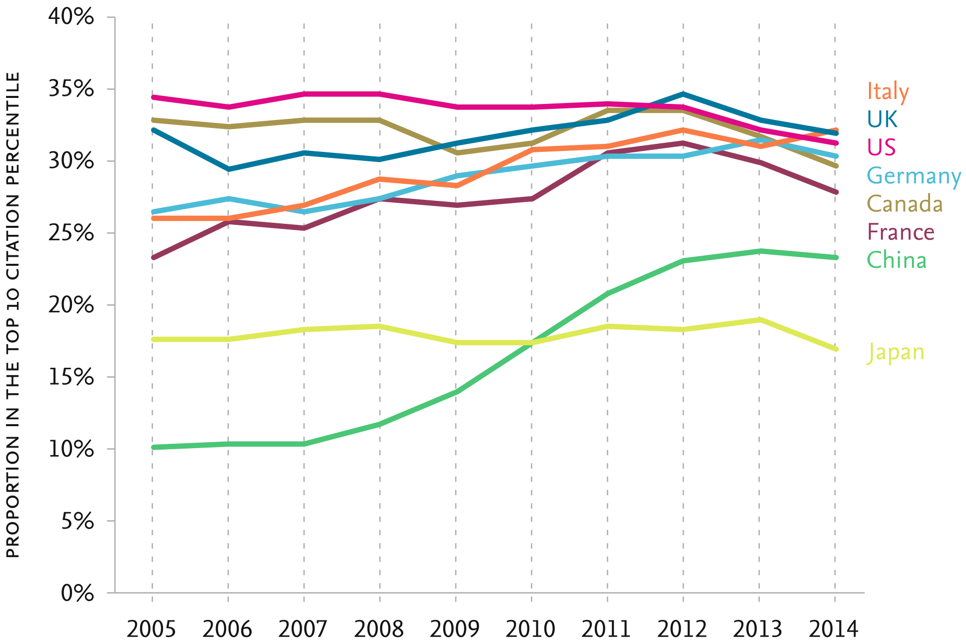


Table 1 — *Most cited publications in Cancer Research published in the period 2010–2014. Note that older publications have more time in which to be cited. Source: Scopus*

Title	Authors	Year	Source title	Citations
Hallmarks of cancer: The next generation	Hanahan D., Weinberg R.A.	2011	*Cell*	12,595
Estimates of worldwide burden of cancer in 2008: GLOBOCAN 2008	Ferlay J. et al.	2010	*International Journal of Cancer*	7,984
Improved survival with ipilimumab in patients with metastatic melanoma	Hodi F.S. et al.	2010	*New England Journal of Medicine*	4,327
Improved survival with vemurafenib in melanoma with BRAF V600E mutation	Chapman P.B. et al.	2011	*New England Journal of Medicine*	3,316
The genome analysis toolkit: A MapReduce framework for analyzing next-generation DNA sequencing data	McKenna A. et al.	2010	*Genome Research*	3,046
Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: A systematic analysis for the Global Burden of Disease Study 2010	Lozano R., Naghavi M., Foreman K., et al	2012	*The Lancet*	2,925
Safety, activity, and immune correlates of anti-PD-1 antibody in cancer	Topalian S.L. et al.	2012	*New England Journal of Medicine*	2,825
Management of hepatocellular carcinoma: An update	Bruix J., Sherman M.	2011	*Hepatology*	2,724
Immunity, Inflammation, and Cancer	Grivennikov S.I., Greten F.R., Karin M.	2010	*Cell*	2,477
Comprehensive molecular portraits of human breast tumours	Koboldt D.C., Fulton R.S., McLellan M.D., et al	2012	*Nature*	2,457
Intratumor heterogeneity and branched evolution revealed by multiregion sequencing	Gerlinger M. et al.	2012	*New England Journal of Medicine*	2,342
Anaplastic lymphoma kinase inhibition in non-small-cell lung cancer	Kwak E.L. et al.	2010	*New England Journal of Medicine*	2,323

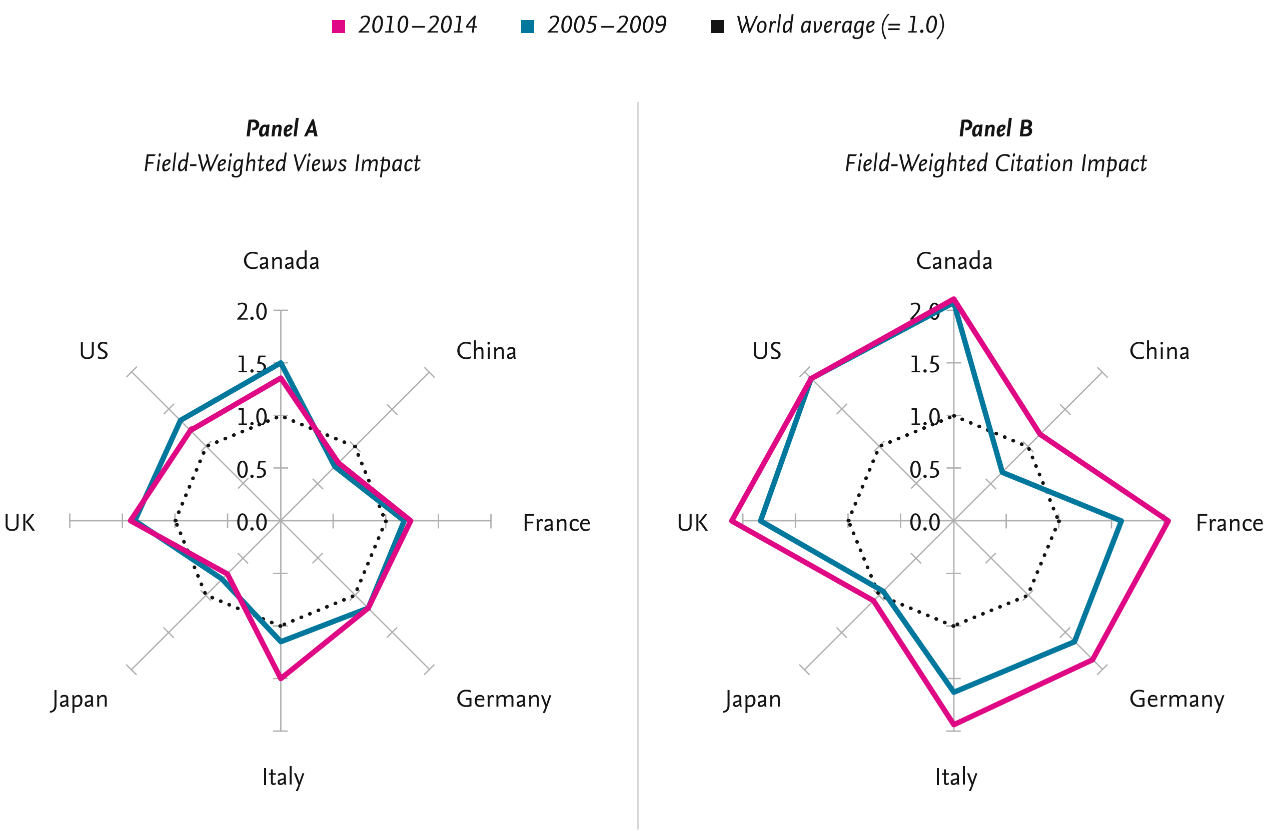
Title	Authors	Year	Source title	Citations
Gefitinib or chemotherapy for non-small-cell lung cancer with mutated EGFR	Maemondo M. et al.	2010	*New England Journal of Medicine*	2,181
Sipuleucel-T immunotherapy for castration-resistant prostate cancer	Kantoff P.W. et al.	2010	*New England Journal of Medicine*	2,174
MTOR signaling in growth control and disease	Laplante M., Sabatini D.M.	2012	*Cell*	2,129
A roadmap for graphene	Novoselov K.S. et al.	2012	*Nature*	2,122
Reduced lung-cancer mortality with low-dose computed tomographic screening	Aberle D.R. et al.	2011	*New England Journal of Medicine*	2,110
Integrated genomic analyses of ovarian carcinoma	Bell D. et al.	2011	*Nature*	2,104
Trastuzumab in combination with chemotherapy versus chemotherapy alone for treatment of HER2-positive advanced gastric or gastro-oesophageal junction cancer (ToGA): A phase 3, open-label, randomised controlled trial	Bang Y.-J. et al.	2010	*The Lancet*	2,061
Inhibition of mutated, activated BRAF in metastatic melanoma	Flaherty K.T. et al.	2010	*New England Journal of Medicine*	2,018

▶ Impact based on a different metric, 'field weighted views impact' (FWVI) relates to the electronic views of publications online. Like FWCI, FWVI is corrected for the field, age, and type of publications. However, unlike citations, which can take a long time to accrue, the measure of views provides a more immediate indication of how much publications are being accessed. It also provides insights into usage beyond the academic and scholarly sphere, for instance by practitioners or students. For all countries except China and Japan, views of publications on cancer research are higher than the global average for cancer research (equal to a FWVI of 1) *(see Figure 9, panel A)*. There is a slightly different pattern over time for views than for citations *(see Figure 9, panel B)*.

Italy is the only country to show a notable increase in FWVI, while relative views for Canada and the US dipped slightly. China does not see the rise in views seen in the citation data.

Recapping the citation data shown in Figure 7 to permit comparison with FWVI, Figure 9 Panel B shows that the US and Canada were the strongest performers with respect to citations in 2005-2009. The UK, France, Germany, and Italy have increased their citation impact in cancer research relative to the world over the last 5 years and now have a similar record to US and Canada. China shows the most rapid improvement and notably moved from below to above world average in the time period.

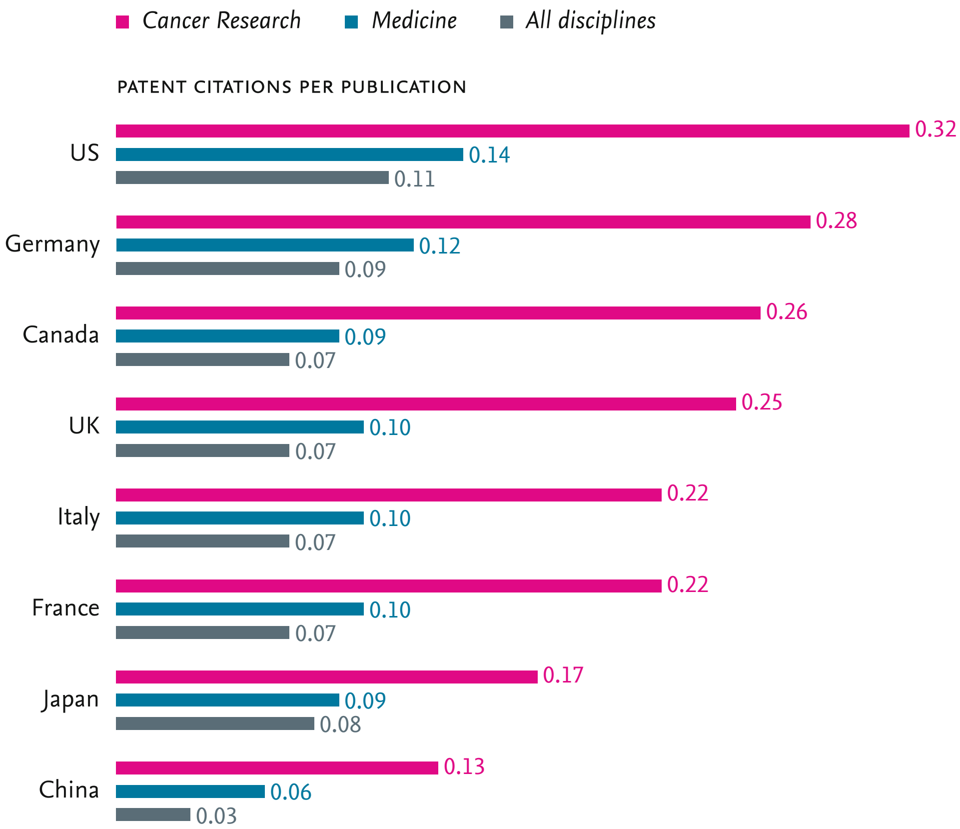
Figure 9 *— Field-weighted citation impact and field-weighted views impact for Cancer Research in selected countries for two time periods: 2005–2009 & 2010–2014. Source: Scopus*



▶ Citation of publications in patents can give an indication of the utility of research in supporting new innovations. Interestingly, publications in cancer research are far more likely to be cited in patents than publications in medicine overall *(see Figure 10)*. In most countries cancer research sees at least double the rate of citation in patents compared to publications in medicine.

The US has the highest rate of patent citations across all fields, closely followed by Germany, Canada, and the UK. This is likely to be at least partly reflective of the US patenting and research culture but may also reflect on aspects such as collaborations, quality, and type of research produced. The citations of publications in patents will be explored in greater detail in subsequent reports.

Figure 10 *— Patent Citations per publication in Cancer Research, Medicine, and All Disciplines for selected countries in 2010. Source: Scopus*

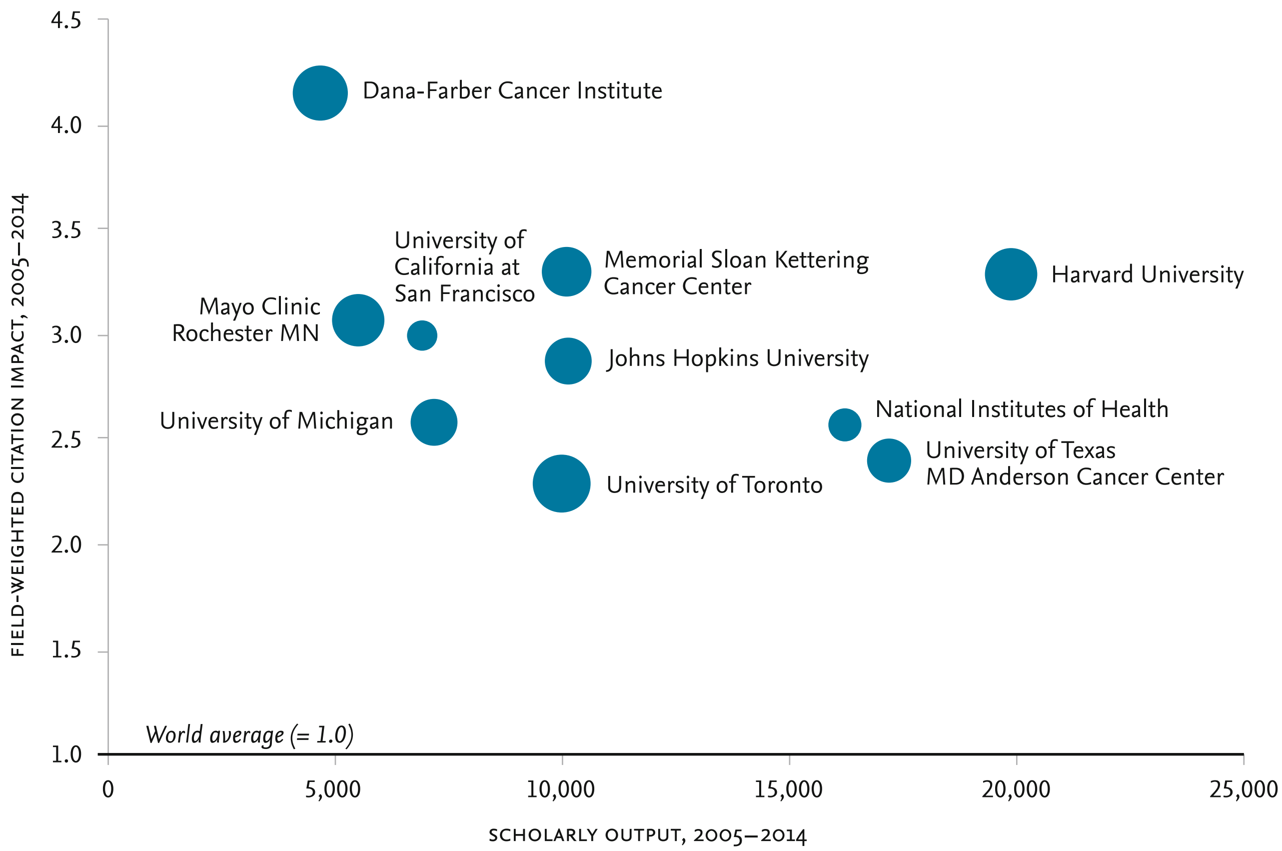


▶ 'Top' institutions in cancer research were identified by selecting the institutions with the highest number of citations in cancer research[9]. This metric partly reflects volume of research and partly the reach and quality of that output. A map of the top institutions can be found pages 10-11. The majority of institutions identified through this metric are based in North America.

Among the top 10 cancer research institutions, all institutions have a field-weighted citation impact (FWCI) more than twice that of the world average and all produced over 3,000 cancer research publications from 2011-2015 *(see Top Cancer Research Institutions Map)*.

Harvard and the Dana-Farber Institute[10] lead with the highest volume and highest FWCI respectively. Combined, they produce over 21,000 publications from 2011-2015 *(see Figure 11)*. They also have some of the highest growth rates of publication output over the period.

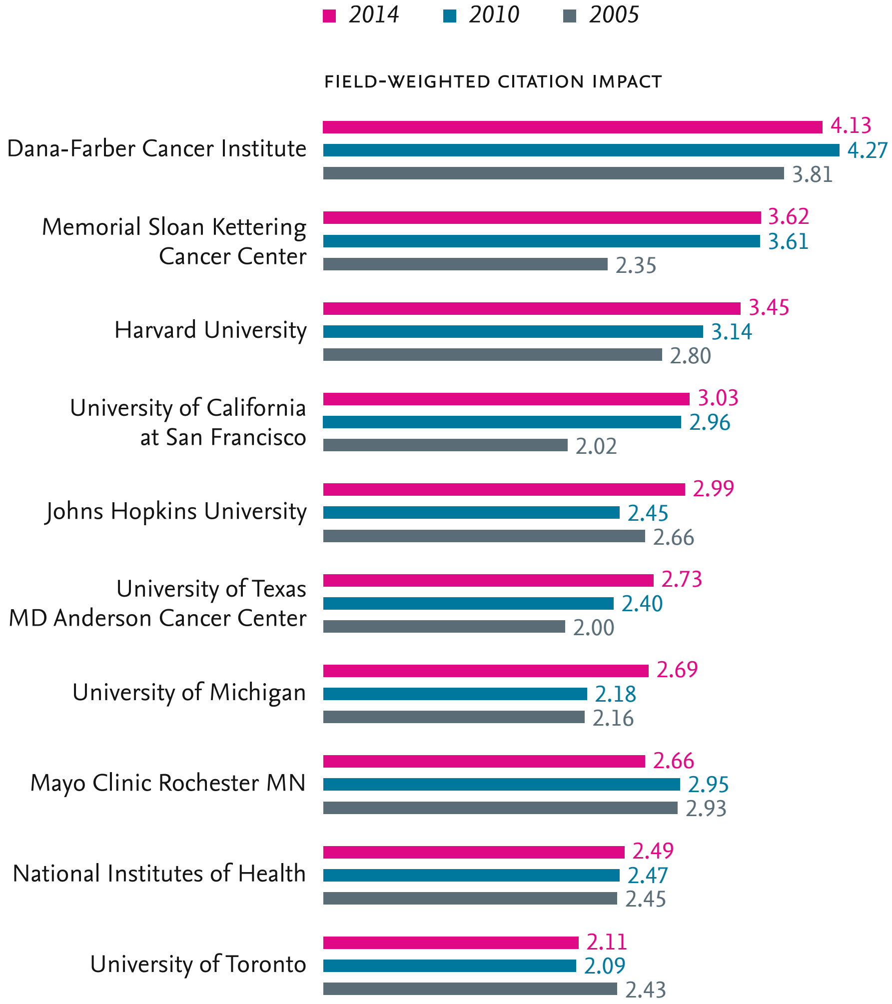
Figure 11 *— Top institutions in cancer research and their publication volume and citation performance over the past decade (2005–2014). Bubble size is proportional to the growth in publication output over the period by compound annual growth rate (CAGR). Source: Scopus*



9 Over the period 2011–2015.
10 The Dana-Farber Cancer Institute is a teaching affiliate of Harvard Medical School.

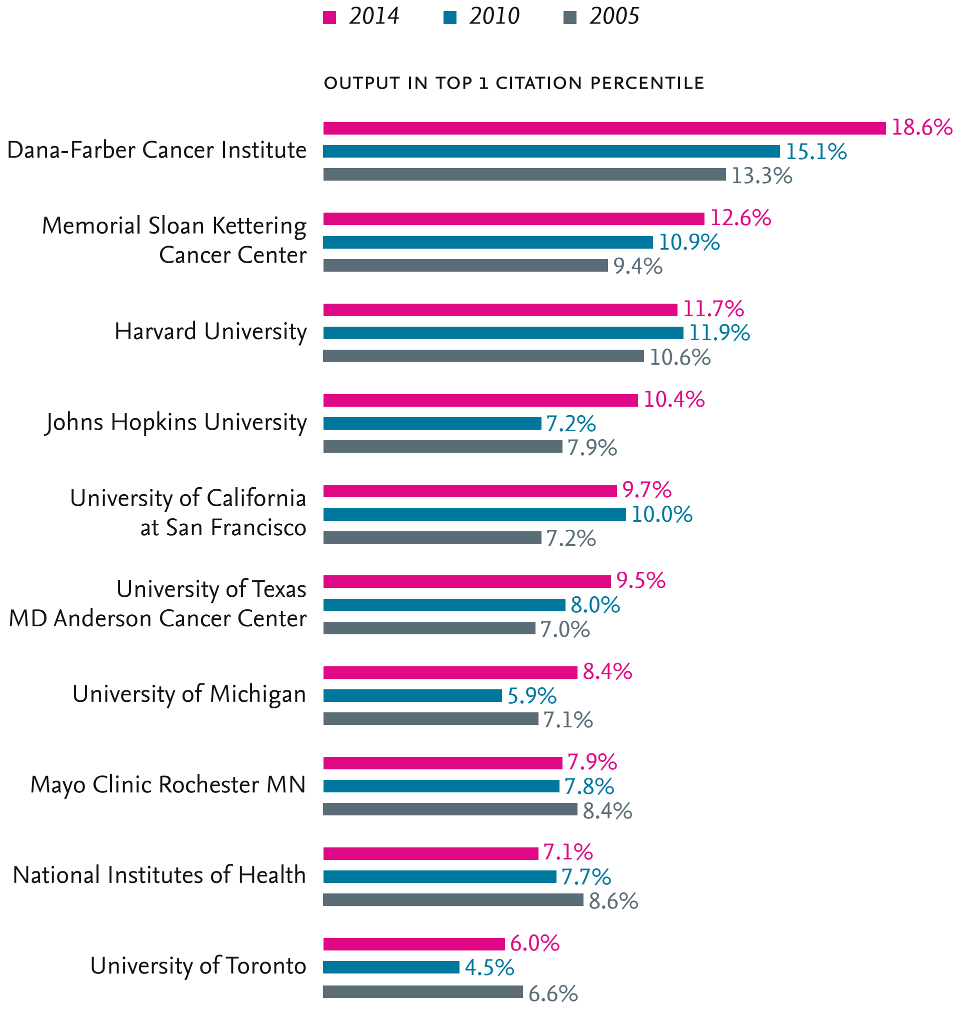
▶ Consistency of research impact over time is an important factor. All top cancer institutions analyzed have an FWCI of 2 or greater for the years shown and many show a trend of improvement over time towards the present day *(see Figure 12)*.

Figure 12 *— Field-weighted citation impact for top institutions in Cancer Research in 2005, 2010 and 2014. Source: Scopus*



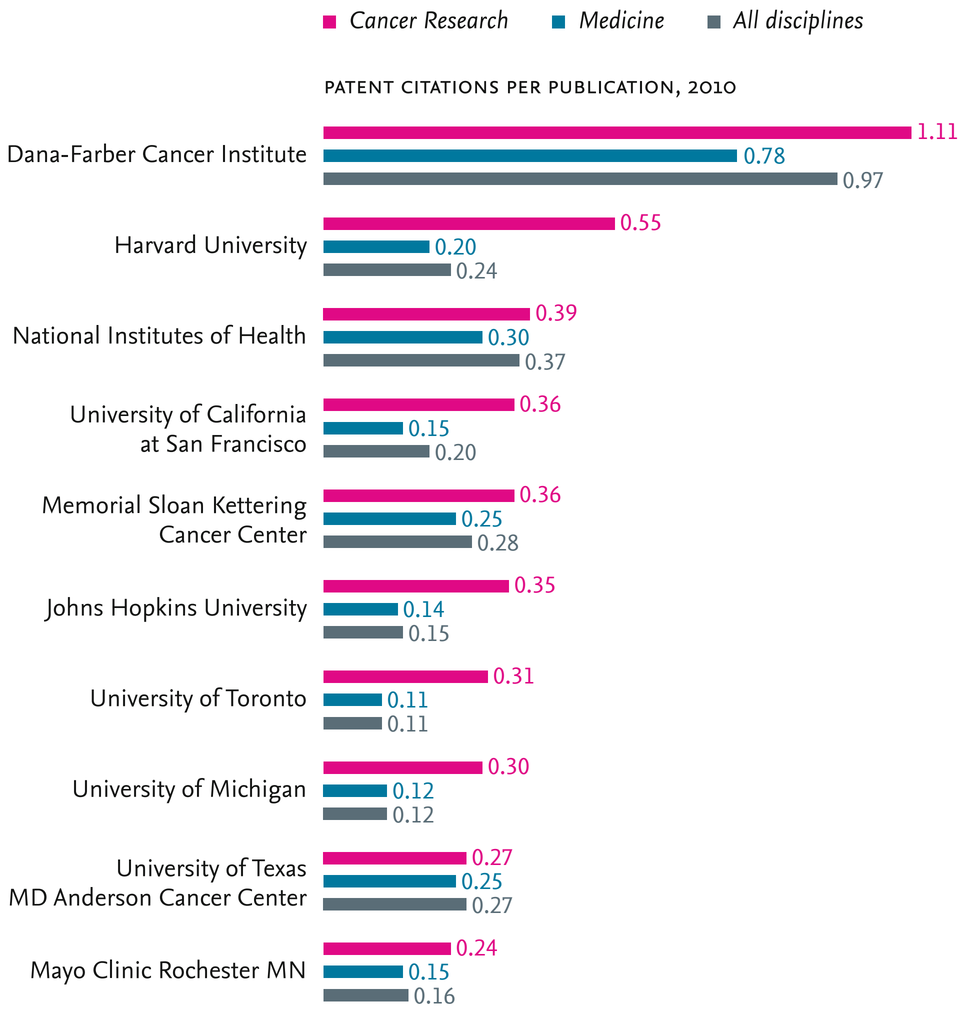
▶ Top cancer research institutions are disproportionately likely to produce top cited publications in their output *(see Figure 13)*. The proportion of their output that is in the top 1% of cited publications worldwide is a means to assess this relationship. In 2014, for the Dana-Farber Cancer Institute over 18% of their output was in the top 1% of cited publications globally.

Figure 13 — *Proportion of all publications in top 1 citation percentile for top cancer institutions in 2005, 2010 and 2014. Source: Scopus*



▶ Patent citations per publication are also highest for the Dana-Farber Cancer Institute, Harvard University, and the University of California at Los Angeles, mirroring the top three institutes with the highest proportion of publications in the top 1% of cited cancer publications *(see Figure 14)*.

Figure 14 *— Patent citations per publication for top institutions in Cancer Research, Medicine and All Disciplines in 2010. Source: Scopus*



Glossary of Terms

Activity index

Activity index is defined as a country's share of its total article output across subject field(s) relative to the global share of articles in the same subject field(s). For example, in 2012, the US published 4.98% of its articles in Cancer, while globally this subject field represents 3.71% of all articles published. The Activity Index for the US in Cancer in 2012 is therefore 4.98%/3.71% = 1.34. A value of 1.0 indicates that a country's research activity in a field corresponds exactly with the global activity in that field; higher than 1.0 implies a greater emphasis while lower than 1.0 suggests a lesser focus.

Article

Article (unless otherwise indicated) denotes all publication types, namely articles, reviews, conference papers, book chapters, notes, letters, short surveys, editorials, articles in press, erratum, books, conference reviews, business articles, and abstract reports.

Article output

Article output for a country is the count of articles with at least one author from that country (according to the affiliation listed in the authorship byline). All analyses make use of 'whole' rather than 'fractional' counting: an article representing international collaboration (with at least two different countries listed in the authorship byline) is counted once each for every country listed.

Citation

Citation is a formal reference to earlier work made in an article or patent, frequently to other journal articles. A citation is used to credit the originator of an idea or finding and is usually used to indicate that the earlier work supports the claims of the work citing it. The number of citations received by an article from subsequently-published articles is a proxy of the quality or importance of the reported research.

Compound Annual Growth Rate (CAGR)

Compound Annual Growth Rate (CAGR) is defined as the year-over-year constant growth rate over a specified period of time. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series.

$$\mathrm{CAGR}\,(t_0, t_n) = (V(t_n)\,/\,V(t_0))\,\frac{1}{t_n - t_0} - 1$$

$V(t_0)$: start value
$V(t_n)$: finish value
$t_n - t_0$: number of years

Field Weighted Citation Impact (FWCI)

Field Weighted Citation Impact (FWCI) is an indicator of mean citation impact, and compares the actual number of citations received by an article with the expected number of citations for articles of the same document type (article, review, or conference proceedings paper), publication year, and subject field. Where the article is classified in two or more subject fields, the harmonic mean of the actual and expected citations rates is used. The indicator is therefore always defined with reference to a global baseline of 1.00 and intrinsically accounts for differences in citation accrual over time, differences in citation rates for different documents types (e.g. reviews typically attract more citations than research articles), as well as subject-specific differences in citation frequencies overall and over time and document types. It is one of the most sophisticated bibliometric indicators.

The Field-Weighted Citation Impact (FWCI) for a set of N publications is defined as:

$$FWCI \equiv \frac{1}{N} \sum_{i=1}^{N} \frac{c_i}{e_i}$$

c_i = citations received by publication i

e_i = expected number of citations received by all similar publications in the publication year plus following 3 years.

When a similar publication is allocated to more than 1 discipline, the harmonic mean is used to calculate e_i. For a publication i that is part of 2 disciplines:

$$\frac{1}{e_i} \equiv \frac{1}{2} \left(\frac{1}{e_A} + \frac{1}{e_B} \right)$$

e_A, e_B = fractional counts of publications and citations, so that publication i will be counted as 0.5 publications in each of e_A and e_B, and the citations it has received will also be shared between A and B.

Field Weighted Views Impact (FWVI)

Field Weighted Views Impact (FWVI) is an indicator of mean usage, and compares the actual number of electronic views of an article with the expected number of views of articles of the same document type (article, review, or conference proceeding paper), publication year, and subject field. Where the article is classified in two or more subject fields, the harmonic mean of the actual and expected view rates is used. The indicator is therefore always defined with reference to a global baseline of 1.00 and intrinsically accounts for differences in views accrual over time, differences in view rates for different documents types (e.g. reviews typically attract more citations than research articles), as well as subject-specific differences in viewed frequencies overall and over time and document types. The principles applied to the calculation of FWVI are the same as those for calculating FWCI.

Global publication share

Global publication share is the share of publications for a specific region expressed as a percentage of the total world output. Using articles share in addition to absolute numbers of articles provides insight by normalizing for increases in overall growth of the world's research.

Publication output

Publication output is the number of publications per country, which have at least one author affiliated to an institute in that country. A publication which is co-authored by authors from different countries, thus counts towards the publication output of each country.

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