Institute for Scientific Information

Research impact in society and the economy: The digital health revolution in medical care

June 2024

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Clarivate™

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Gaurav Agnihotri is an Associate Director within the IP service operations group at Clarivate ™. Gaurav has over 15 years of experience in patent analytics and excels in deriving insights from large amounts of data. He is passionate about assisting his clients – mostly IP managers, R&D heads, and innovation strategy teams, in their research and innovation initiatives. Gaurav holds a B.E. (Bachelor of Engineering) degree in Instrumentation and Control Sciences. He has led several patent intelligence studies on emerging technologies, such as quantum computing, artificial intelligence and green sustainable technologies.

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Acknowledgements

With assistance from colleagues at the Institute for Scientific Information:
Dmytro Filchencko, Ryan Fry, Lisa Hulme, Milovan Kovač, Jana Milivojević, Ross Potter and Gordon Rogers.

Additional analysis provided by *Times Higher Education*, where indicated.

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About the Institute for Scientific Information

The Institute for Scientific Information at Clarivate has pioneered the organization of the world's research information for more than half a century. Today it remains committed to promoting integrity in research while improving the retrieval, interpretation and utility of scientific information. It maintains the knowledge corpus upon which the Web of Science index and related information and analytical content and services are built. It disseminates that knowledge externally through events, conferences and publications while conducting primary research to sustain, extend and improve the knowledge base.

For more information, please visit **www.clarivate.com/isi**

About the Clarivate Center for IP and Innovation Research

Combining more than 60 years of intellectual property experience, the Clarivate Center for IP and Innovation Research empowers organizations worldwide to excel by providing expert guidance grounded in pioneering benchmarks and data-driven insights. Bringing together senior practitioners, consultants and data analysts, the Center performs research to establish and disseminate benchmarks that guide management and strategy. It works with legal, IP and innovation leaders to optimize IP operations and technology and improve IP decision-making, supported by industry-leading data, analytics and proven practices.

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ISBN: 978-1-7395906-6-6
DOI: 10.14322/isi.grr.research.impact.in.society

Executive summary

Balancing internal and external research impacts remains essential to capturing and demonstrating the comprehensive value of research to society's prosperity, well-being and economic growth and to the climate and the environment.

Incorporating research, commercial and healthcare data for a comprehensive approach forms a solid foundation to track how research can make a lasting impact on our world.

This report delves into the topic of digital health, exemplifying our capabilities by way of a recent project carried out in collaboration with *Times Higher Education (THE)* and delivered at an industry-wide event at Stanford University, California in February 2024. This required the integration of multiple data sources from across the Clarivate portfolio to construct complex cross-dimensional perspectives to shed light on both societal and academic benefits.

A focused review of the academic literature conducted by the ISI at Clarivate revealed a significant surge in publications recorded with the term "digital health" and associated terms. In 2013, a mere 39 publications featured the term in their titles, abstracts or keywords; by 2022 publications on this topic had risen nearly 70-fold. **(Figure 1)**

Papers in the sub-field of AI and advanced analytics have seen the greatest growth over the past decade. This upward trend predates the popularization of AI technologies like ChatGPT, which are often considered the catalysts for AI's mainstream commercial success.

We identify the Top 10 countries/regions ranked by output of articles on 'digital health and AI and related methods' published in journals indexed in the Web of Science, 2013-2022. **(Table 1)** and we name the research institutions ranked by output of articles on 'digital health and AI and related methods' published in journals indexed in the Web of Science, 2013-2022. **(Table 2)**

We found that patenting activity in digital health outpaced the rate of growth of the publications in the scientific and scholarly literature, 2013-2022. We identified ~140K patented inventions, discovering that the growth in patent filings **(Figure 2)** outpaced the increase in academic papers **(Figure 1)** during the period 2013-2022.

Clarivate also examined the leading innovative entities with strong patent portfolios in digital health research and technologies. The majority of patent assignees were corporates, indicating that corporate activity in digital health has outstripped academic research, presumably to secure intellectual capital and gain early market advantage. These include both well-established and start-up firms and a surprising and unusual mix of organizations. **(Table 3)**

As was evident in the analysis of the journal literature, Mainland China, represented by the Chinese Academy of Sciences, Mainland Chinese universities, and Mainland Chinese corporations, is the dominant national player in AI patenting related to digital health. **(Figures 4 and 5)**

We could also trace the impact of university research on digital health innovation as research papers authored by these firms addressing digital health and cited papers authored by universities offer a parallel route to tracing non-academic impact. While it is relatively rare for research papers to cite patents, doing so can provide an additional link in the chain of innovation. **Tables 4 and 5** list the top 10 institutions and countries/regions, respectively, by documents cited by patents for each of the three digital health topic fields. This helps us understand how impactful research documents are for IP advancements.

Introduction

Research underpins knowledge discovery and verification, delivering essential benefits to the health and wealth of societies. While governments and other funders of research recognize this importance it is crucial to rely on empirical evidence, rather than anecdotal accounts, to maintain effective consensus. This report demonstrates how Clarivate can harness its extensive data resources to describe and track those benefits. However, it concludes with a cautionary note: while assessment of the societal impact of certain research endeavors is feasible, the establishment of universally applicable, verifiable and replicable indicators that would provide valid and sound comparisons across various fields remains an ongoing challenge.

The excellence of research is partly signaled by internal indicators within the academic community, such as the significance of journal publications as reflected in citation indicators. Academic excellence, highlighted by these measures, is rightly admired and praised. Yet it is imperative to recognize that funded research yields numerous other benefits beyond academic metrics. Therefore, we must also consider external indicators of societal impact.

The capture and documentation of the downstream societal impact of upstream investments in research is challenging. Moreover, evaluation systems may be in conflict: "the [policy] emphasis on societal impact on the one hand, and an [academic] assessment focus on recent past performance on the other, are at least partially conflicting policy incentives." (Moed, *The problem of assessing social impact*).

There is a widespread notion that the societal impact of research is a new concern for funding agencies. While it can be difficult to measure and is rarely the main impetus behind research effort, the expectation that publicly funded research should yield benefits for the public investor is intrinsic to its political support. It is for this reason that we at the Institute for Scientific Information (ISI) have been investigating these topics for the past few decades.

To date, national agencies have often focused solely on internal research criteria when prioritizing ideas and reporting outcomes. Two key things explain why. Publication serves as the backbone to the academic process; citation is core to academic culture, guided by established peer norms. Universally embraced by all, across disciplines and geographical regions, academic citation practices exhibit remarkable consistency – i.e. everyone provides authorship, affiliation and location details in a similar way. The ability to index and utilize this consistent information enabled the ISI to provide a high-quality, meticulously curated, comprehensive and trustworthy repository of publication records and metadata, now embodied in the Web of Science. And we demonstrated how this data could be leveraged to derive 'impact' indicators.

"While it can be difficult to measure and is rarely the main impetus behind research effort, the expectation that publicly funded research should yield benefits for the public investor is intrinsic to its political support."

Balancing internal and external research impacts remains essential to capturing and demonstrating the comprehensive value of research to society's prosperity, well-being and economic growth and to the climate and the environment.

However, the same level of feasibility does not extend to the measurement of other (external) research impacts. Projects spanning medical, technological, social and cultural domains exhibit varying – sometimes overlapping – impacts that differ in characteristics, challenging efforts to quantify and compare them due to their diversity and timeframes ranging from 5, 10 or even 20 years.

In the United Kingdom, the 2014 and 2021 Research Excellence Frameworks (REF), which audit higher education institutions and inform government research funding, asked how research had "an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia." A 2015 study of some 6,700 case studies submitted to the REF, used text-mining and other techniques to draw out considerable evidence for the Higher Education Funding Council of England (HEFCE). However, little of this permitted measurement or comparisons and it was concluded that "quantitative evidence supporting claims for impact was diverse and inconsistent, suggesting that the development of robust impact metrics is unlikely."

Several factors contribute to this complexity:

1. There is a time lag for the new knowledge emerging from research to be understood, developed and applied to policies, new products and processes, social or technological.

2. Many research discoveries spawn multiple applications and most new products are the result of multiple, collaborative lines of development.

3. The lack of social or commercial conventions for assigning credit to or acknowledging the origins of ideas, outside of patenting, hampers impact assessment.

4. Societal impact is difficult to scale and the fractional attribution of any one discovery to an improvement is near impossible.

It is also evident from many studies that successful innovation is rarely linear and more often takes place in an interplay between research producer and societal user. The idea that research takes place in an 'ivory tower' is inaccurate as most leading scientists, technologists and social researchers work collaboratively. Recognizing this, the Australian Research Council evaluates both 'Engagement and Impact'.

The establishment of standards for impact indicators poses challenges requiring deep thinking and broad data resources. Research impact progresses gradually, akin to the movement of a glacier rather than a stream, suggesting that in the short-term indicators might well have to be applied to 'indicative' or 'anticipated' rather than observed or realized impact outcomes.

Balancing internal and external research impacts remains essential to capturing and demonstrating the comprehensive value of research to society's prosperity, well-being and economic growth and to the climate and the environment. We are committed to working alongside our partners to develop multiple perspectives to demonstrate broader contributions, while remaining vigilant against the pitfalls of oversimplifying impact through solitary metrics.

02. The remarkable rise of digital health

The subsequent sections of this report delve into the topic of digital health, exemplifying our capabilities by way of a recent project carried out in collaboration with *Times Higher Education* and delivered at an industry-wide event at Stanford University, California in February 2024. This study integrates multiple data sources from across the Clarivate portfolio to construct complex cross-dimensional perspectives to shed light on both societal and academic benefits.

Times Higher Education

In February 2024, some 200 research leaders from 23 nations representing universities, corporations, government agencies and foundations gathered at Stanford University. Their focus: to explore, discuss and debate the ongoing revolution created by combining digital technologies with conventional healthcare. Digital Health 2024 was sponsored by Stanford Center for Digital Health, the Stanford Healthcare Innovation Lab, and Times Higher Education, with Clarivate providing essential research and innovation data and in-depth analysis to inform the discussions.

The landscape of digital health is rapidly evolving, driven by research, innovation and the pressing need to enhance patient care. Research and innovation in other disciplines are also creating new capabilities that can be effectively applied to healthcare. The technologies being envisioned and developed hold significant potential for both commercial and clinical success, advancing the cause of human health. This is to the benefit of all — individuals, research institutions, commercial organizations, healthcare providers, funders and governments. Clarivate, with its deep and broad-reaching data resources across research, innovation and healthcare, coupled with its expert analysts, is well-positioned to review a field like digital health and look at its potential societal impacts.

The World Health Organization (WHO) defines 'digital health' as *"the field of knowledge and practice associated with* ***the development and use of digital technologies to improve health.*** *This expands the concept of eHealth to include digital consumers, and a wider range of smart devices and connected equipment."*

Related terms such as 'eHealth' typically refer to electronically provided healthcare information and services via the internet, while 'mHealth' designates mobile applications, including those on cell phones and connected wearable devices.

Ed White, Head of the Clarivate Center for IP and Innovation Research and Global Head of Intelligence Consulting at Clarivate shared insights at the Stanford conference and suggested that digital health as a term may soon be passé. "We used to talk about big data — but now we just say data. It's probably the same with digital health — it's just healthcare."

The anticipated societal benefits of accessing and utilizing digital health are manifold, including improving access to and the quality of medical care, enabling more personalized care with greater patient involvement and commitment, fostering a shift towards preventive rather than reactive care, streamlining healthcare delivery, and reducing costs. However, concerns arise regarding inequities in access, privacy and ethical issues, regulatory oversight and reimbursement policies, new workflow procedures for healthcare providers, as well as the validation of devices and services for effectiveness and cost efficiency. Navigating this landscape is complex.

The February 2024 *Times Higher Education* analysis shared, "'Poverty, lack of access to digital health, poor engagement with digital health for some communities, and barriers to digital health literacy are some factors that can contribute to poor health outcomes,' read one 2020 paper, "Digital health equity and COVID-19: the innovation curve cannot reinforce the social gradient of health", published in the *Journal of Medical Internet Research* — the journal that has published the biggest share of digital health papers in this study."

03. What papers and citations say about research in digital health

With the advent of wearable technology, the proliferation of fitness applications, and the integration of telemedicine into mainstream healthcare since the Covid-19 pandemic, it is hardly surprising that research into digital health has grown significantly. Yet, the extent of this growth remains truly remarkable.

Research in digital health spans many diverse fields, ranging from basic science to technology applications, biomedical and clinical investigation to materials science, engineering and computer science, and even social science studies in policy, ethics, management, sociology and psychology. It also exemplifies how research spanning academia, industry and government laboratories moves into the realm of new technologies and applications, uses and services.

To gain deeper insights into these developments, analysts from the Life Sciences & Healthcare division at Clarivate shared a taxonomy to categorize the topic of digital health into three major fields:

1. **Devices and hardware:** wearable devices, connected devices, sensors and gaming.

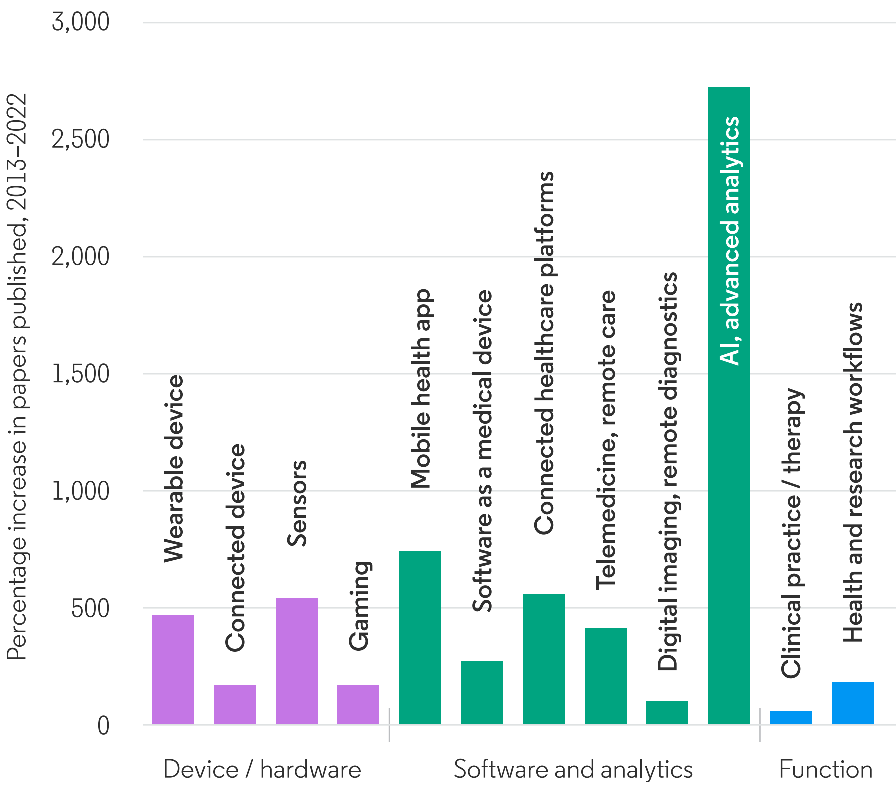
2. **Software and analytics:** mobile health apps, software as a medical device, connected healthcare platforms, telemedicine and remote care, digital imaging and remote diagnostics, and artificial intelligence and advanced analytics.

3. **Function:** clinical practice itself and health and research workflows.

A focused review of the academic literature conducted by the ISI at Clarivate, analyzing articles and reviews (papers) across 22,000 trusted journals in the Web of Science database, revealed a significant surge in publications recorded with the term "digital health*" (the asterisk incorporates associated terms). In 2013, a mere 39 publications featured the term in their titles, abstracts or keywords; by 2022 publications on this topic had risen nearly 70-fold to 2,641 papers, totaling 7,944 over the decade.

The search strategies employed to pinpoint papers related to these three sub-field themes were significantly more intricate than a simple query for the term 'digital health'. This refined approach yielded approximately 125,000 publications, a substantial increase from the 8,000 initially identified in the preliminary sweep discussed earlier.

Figure 1: (Published in *Times Higher Education*) Percent growth in papers published in subfields related to digital health in journals indexed in the Web of Science, 2013-2022: AI and advanced analytics papers grew 2,724% since 2013. (Data source: Web of Science, Clarivate).



Investors pour billions into digital health startups, sparking a lucrative era for universities in a fast-moving ecosystem

The accompanying article published in *Times Higher Education* used Clarivate data to highlight the potential of this field for research institutions.

"With investors sniffing round universities for the next big thing – they piled £21 billion into digital health start-ups in 2022 and £31 billion in 2021 – the golden age of digital health research could also be a very lucrative one for scientists and their institutions. But where do university researchers, with their traditional focus on publications and long-term projects, fit into a fast-moving ecosystem that supporters hope will also offer huge gains for public health?"

Top 25 institutions with citation impact

Rank	Institution	Digital health papers in the Web of Science	Citations	Percentage of papers in the top 10% by citation	CNCI
1	Beth Israel Deaconess Medical Center	70	1,444	28.57	4.11
2	Yale University	51	532	17.65	3.49
3	University of Copenhagen	50	1,011	26.00	2.59
4	University of Manchester	75	1,582	32.00	2.50
5	Harvard University	284	4,885	28.52	2.46
6	World Health Organization	53	917	28.30	2.22
7	Brigham & Women's Hospital	68	1,116	22.06	2.20
8	University of Oxford	130	2,844	26.92	2.10
9	Stanford University	129	2,899	26.36	1.98
10	Imperial College London	131	2,631	21.37	1.93
11	University College London	198	4,021	30.81	1.92
12	University of Edinburgh	60	746	26.67	1.85
13	Massachusetts General Hospital	80	1,350	30.00	1.83
14	ETH Zurich	55	634	25.45	1.70
15	Karolinska Institute	66	1,200	24.24	1.64
16	University of Pennsylvania	69	933	15.94	1.60
17	National University of Singapore	81	1,535	24.69	1.59
18	University of California, San Diego	71	1,532	25.35	1.58
19	University of Queensland	68	668	22.06	1.56
20	University of California, Los Angeles	72	1,446	22.22	1.51
21	Nanyang Technological University	55	1,082	16.36	1.47
=22	University of California, San Francisco	134	1,935	20.90	1.45
=22	London School of Hygiene & Tropical Medicine	58	1,182	17.24	1.45
24	University of Toronto	163	1,765	16.56	1.43
25	Free University of Berlin	87	841	20.69	1.42

Data source: Clarivate. Note: CNCI = Category Normalized Citation Impact. This is a measure of the relative rate of citation for an institution given papers' age and field classification (older papers will be more cited than younger ones and different fields carry different average rates of citation).

04. Can artificial intelligence (AI) make healthcare more efficient and impactful?

AI and advanced analytics have seen the greatest growth over the past decade. Beginning with just 93 papers in 2013, the publication pool expanded to 7,662 papers for the period 2013-2022, rising annually through 335 (2018), 1,320 (2020), and 2,626 (2022). This upward trend predates the popularization of AI technologies like ChatGPT, which are often considered the catalysts for AI's mainstream commercial success. (Figure 1)

The United States led in most of the major fields and subfield areas in our taxonomy, with the notable exception of AI and advanced analytics. In this area, Mainland China outproduced the United States and nearly matched it in research influence, as measured by citation impact. (Table 1)

Table 1: Top 10 countries/regions ranked by output of articles on 'digital health and AI and related methods' published in journals indexed in the Web of Science, 2013-2022. (Data source: Web of Science and InCites™, Clarivate)

	Web of Science Items	Citations	Category Normalized Citation Impact (CNCI)	% Top 10%
Dataset baseline	**7662**	**170877**	**1.99**	**26.82**
Mainland China	2191	62362	2.26	27.93
United States	1808	52565	2.51	33.74
India	721	11529	1.79	24.27
United Kingdom	687	20374	2.69	36.83
South Korea	379	8141	1.90	26.65
Canada	362	11158	2.81	36.19
Italy	336	7821	2.15	33.04
Australia	301	6924	2.23	30.23
Germany	298	6206	2.19	29.87
Saudi Arabia	278	4421	2.33	34.89

Table 2: Research institutions ranked by output of articles on 'digital health and AI and related methods' published in journals indexed in the Web of Science, 2013-2022. (Data source: Web of Science and InCites, Clarivate)

	Web of Science Items	Citations	Category Normalized Citation Impact (CNCI)	% Top 10%
Dataset baseline	**7662**	**170877**	**1.99**	**26.82**
Harvard University	234	8714	3.16	37.18
University of Toronto	113	3369	3.00	39.82
Stanford University	106	4403	3.95	50.00
Huazhong University of Science & Technology	97	5792	4.36	47.42
Chinese Academy of Sciences	95	2903	2.06	33.68
University College London	88	3306	3.24	43.18
Shanghai Jiao Tong University	83	2304	2.17	25.30
Massachusetts General Hospital	81	3756	3.95	41.98
Xi'an Jiaotong University	77	9465	7.30	54.55
Imperial College London	73	1523	2.23	41.10

Among top-ranked universities and other research institutions, Harvard University, the University of Toronto and Stanford University each produced more than 100 papers related to digital health that dealt with AI and machine learning methods (see Table 2). Mainland Chinese entities, including the Chinese Academy of Sciences, account for four of the top 10 in line with national activity.

Across the three main areas and 12 subfields of the digital health taxonomy common patterns emerge on a national level. The United States typically leads in terms of output and exhibits high citation impact. Mainland China consistently ranks second in output and in some areas surpasses the United States in impact.

Both India and South Korea contribute more than their overall world share would suggest, while Japan's publication output falls below expectations. South Korea consistently exhibits high citation impact, whereas India and Japan lag other nations, sometimes markedly. European Union (EU) nations and Australia generally score well in citation impact and exhibit substantial output.

It is important to note that these publication and citation statistics reflect academic research activity and influence. They do not serve as indicators of research impact beyond the scientific and scholarly community. The subsequent sections of this report explore our work on these essential and complementary approaches.

"The vast streams of medical data emitted from thousands of wearable devices or mobile phones would have once overwhelmed even the most data-savvy researcher. But thanks to artificial intelligence, researchers do not need to be skilled coders to meaningfully navigate such oceans of information. Similarly, hospitals and health centres across the world are sharing patient records in a way that lets algorithms pick up trends, even identifying new pandemics in their early stages."

Source: Times Higher Education

05. What can our patent data tell us about the technological and economic impact of digital health research?

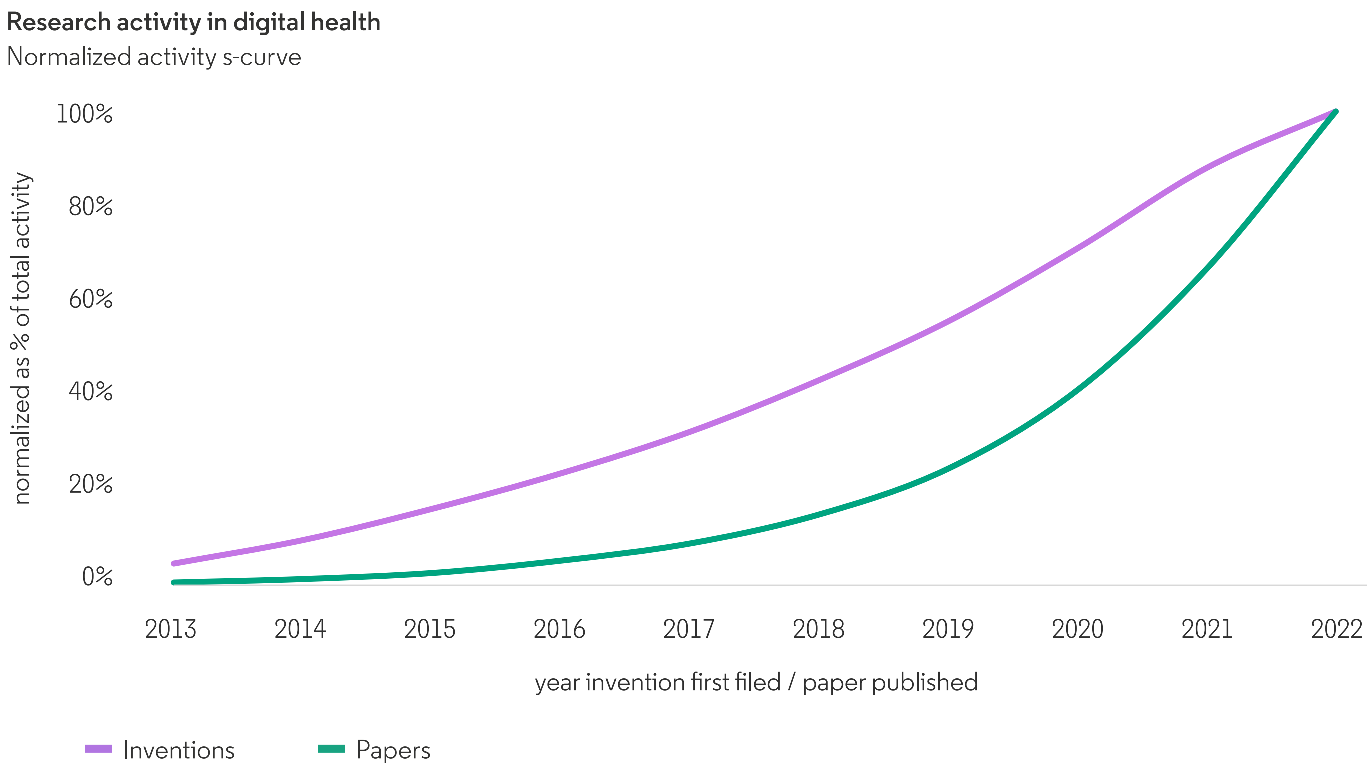
The variety of societal effects and the range of data available to track these outcomes makes some engagement and impact indicators more direct and robust than others. In analyzing the patent literature, experts within the Clarivate Center for IP and Innovation Research utilize a comprehensive library of informed search terms and strategies to identify relevant documents within the Derwent World Patents Index™ (DWPI™).

Patent indicators, particularly when citations connect them to research literature, serve as a strong source of technological and economic evidence. Francis Narin, formerly of CHI Research, pioneered the use of patent data in so-called science linkage studies that revealed the extent to which the United States patent literature drew on science. His team found that "73% of the papers cited by U.S. industry patents are public science, authored at academic, governmental, and other public institutions" and concluded that "the cited U.S. papers [in patent references] are from the mainstream of modern science…and heavily supported by NIH, NSF, and other public agencies."

This confirms the substantial influence of taxpayer-funded research on societal outcomes and impact.

Counting patent applications as a share of university publication output provides a size-independent indication of a university's orientation to knowledge transfer and practical applications. Co-inventing and co-assignment of patents granted with industry partners indicates both orientation and a pathway to technological impact.

Figure 2: Patenting activity in digital health outpaced the rate of growth of the publications in the scientific and scholarly literature, 2013-2022. (Data source: Derwent World Patents Index, Clarivate)



Analysts in the Intellectual Property division at Clarivate used the digital health taxonomy to search for relevant patents in its Derwent World Patents Index. They identified approximately 140K patent inventions, discovering that the growth in patent filings (Figure 2) outpaced the increase in academic papers (Figure 1) during the period 2013-2022. The majority of patent assignees were corporate firms, indicating that corporate activity in digital health has outstripped academic research, presumably to secure intellectual capital and gain early market advantage.

Clarivate also identified the leading innovative corporate entities with strong patent portfolios in digital health research and technologies. These include both well-established firms and start-ups. Our Derwent Strength Index™ uses facets of the international patent system to score inventions based on their significance, including normalized citation impact (adjusted for geography, time and subject area), the GDP of patent protection locations, investment levels in patent protection by the patent applicant, and the rarity of the technical approach mix described in the invention. (Table 3)

What is striking about this list is the diverse nature of the firms listed. Our analysts agreed that it is very rare indeed to see such an eclectic mix of firms, side-by-side within one patent analysis — Snap and AstraZeneca, Nike and Johnson & Johnson or Eli Lilly and Nvidia — demonstrating the convergent and collaborative nature of the field of digital health.

Table 3: Established and start-up firms with strong patent portfolios in digital health-related research and applications. (Data source: Derwent World Patents Index, Clarivate)

Abbott	Cognex	Huawei	Nvidia	Smilables
Abiomed	Danaher	IBM	Omron	Snap
Alcon	Datavant	ICU Medical	Olympus	Solvay
Align Technology	Deka Products	Innodisk	Oppo	Sony
Alphabet	Dental Monitoring	Inspire Medical	Osstem Implant	Starkey Labs
Apple	DentlyTec	Intel	Paige.Ai	Stryker
Anta Sports Products	Dentsply Sirona	Intuitive Surgical	Panasonic	Synaptive Medical
AstraZeneca	Dexcom	Invoy	PerkinElmer	Sysmex
Becton Dickinson	Dräger	Johnson & Johnson	Pfizer	Tegway
Baidu	Edwards Lifesciences	LG	Philips	Teletracking Technologies
Baxter	Eli Lilly	LI-COR Biosciences	Ping An Group	Tempus
Biolinq	eMed Labs	LifeQ	PrecisionOS	Tencent
BIOTRONIK	Elekta	LymphaTech	Procter & Gamble	Terumo
Big Foot Biomedical	Fortive	Magic Leap	Profound Medical	Teva Pharmaceuticals
BOE Technology	Fresenius Medical Care	Masimo	Qualcomm	Tobi
Boston Scientific	Fuji Film	Medtronic	Reliant Immune Diagnostics	United Imaging Healthcare
Brainlab	Garmin	Meta Platforms	Resmed	Universal Display
Bristol-Myers Squibb	General Electric	Microsoft	Roche	Viatris
Butterfly Network	Gilead Sciences	myCardio	Samsung	Xpectvision Technology
Canon	Globus Medical	Nike	Sanofi	Ypsomed
Carestream Health	Heuron	Nokia	Shimadzu	
Casio	Honeywell	Novartis	Siemens	

The dynamism of AI and advanced analytics was noted in the earlier discussion on the scientific and scholarly literature and is corroborated by the patent literature. (Figure 3)

Figure 3: Patent indicators demonstrate the current leading role of AI and advanced analytics — mirroring the findings revealed in the scientific and scholarly literature. (Data source: Derwent World Patents Index, Clarivate)

Digital Health - Technology Dynamics

Plot of mean Derwent Strength Index v mean age by technical sub-themes

As was evident in the analysis of the journal literature, Mainland China, represented by the Chinese Academy of Sciences, Mainland Chinese universities, and Mainland Chinese corporations, is the dominant national player in AI patenting related to digital health. (Figures 4 and 5)

Figure 4. Number of patent filings and assignees related to AI and digital health, 2013-2022, revealing the extensive activity of Mainland Chinese institutions. (Data source: Derwent World Patents Index, Clarivate)

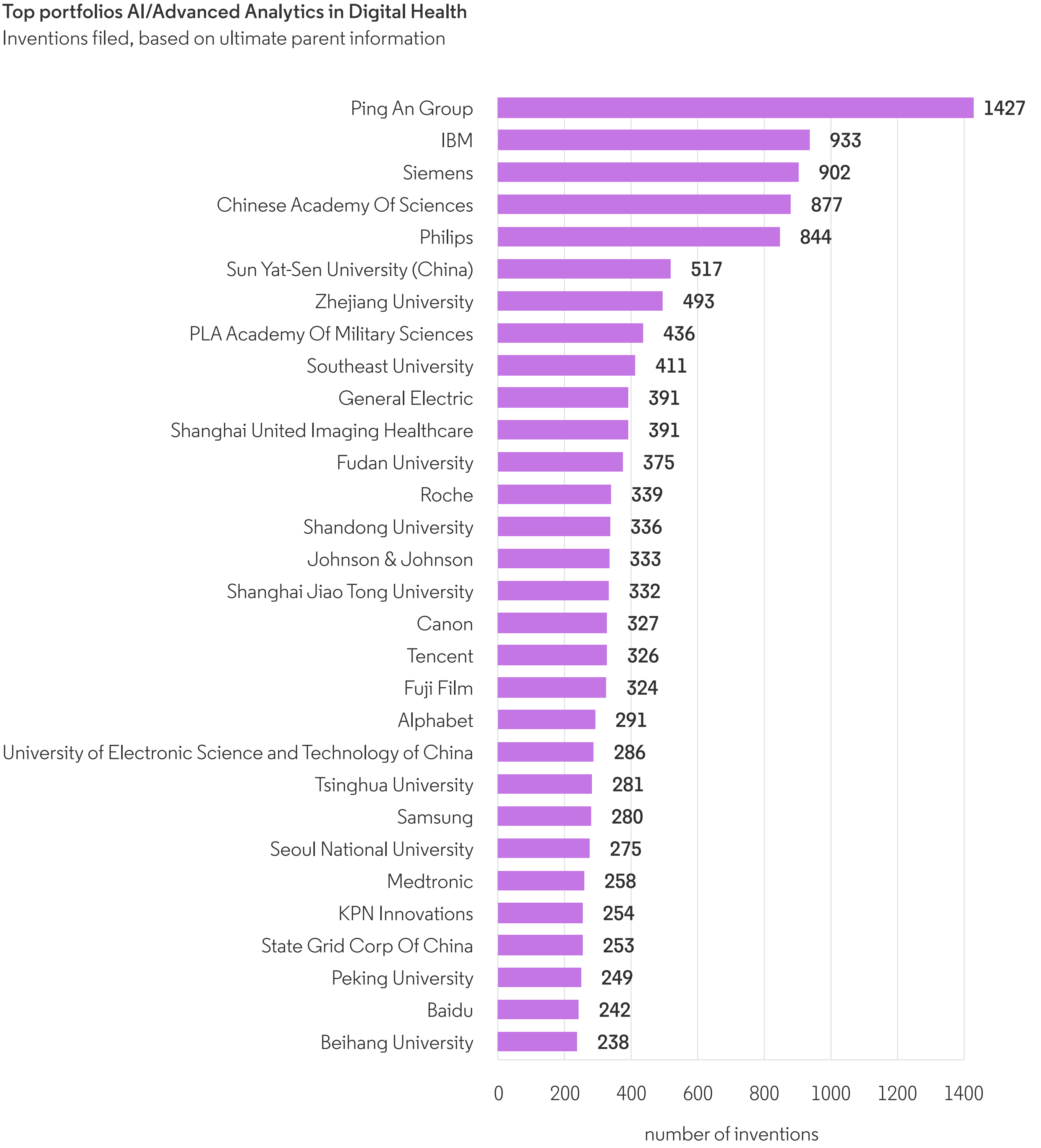
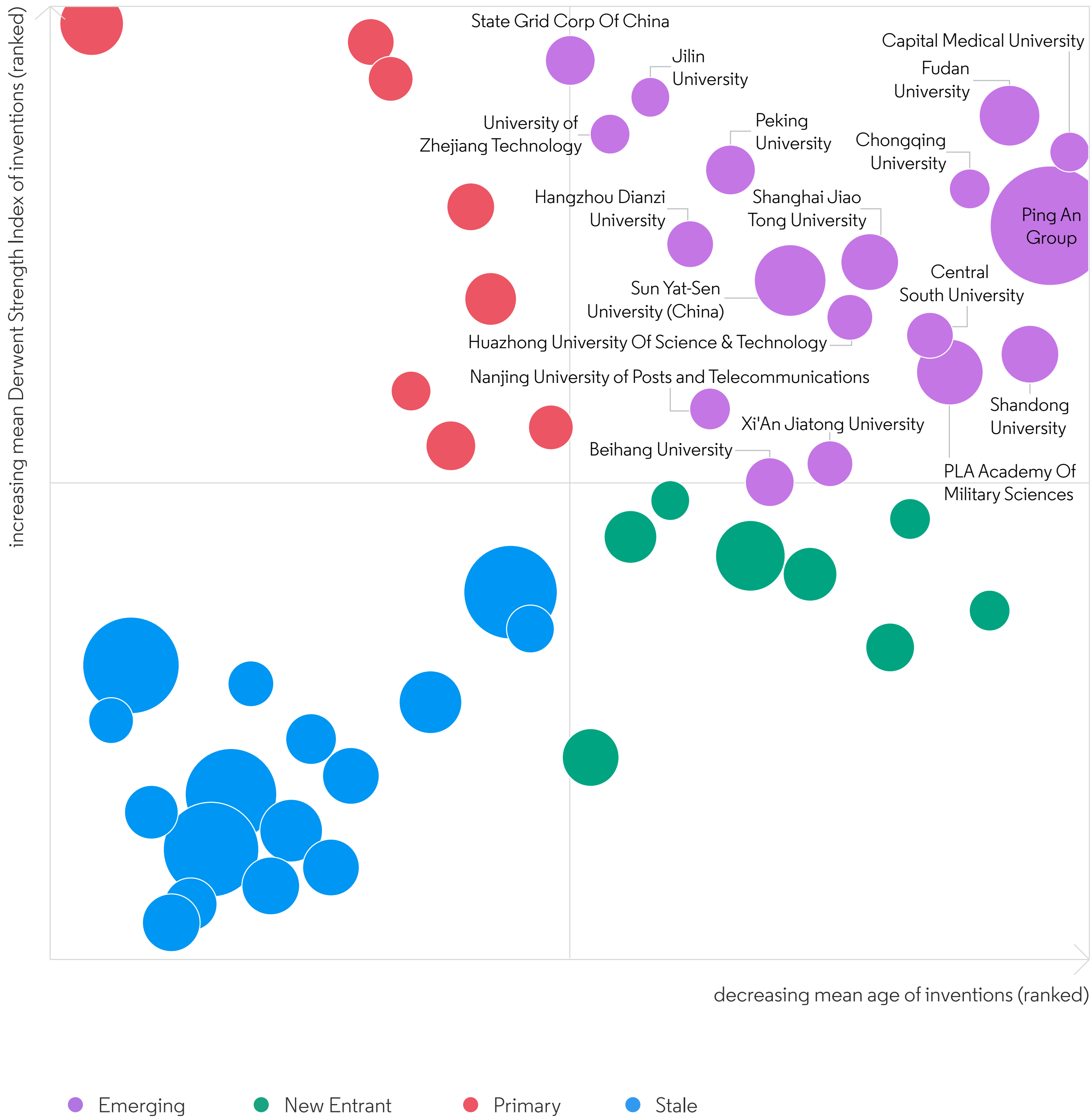


Figure 5. Mainland Chinese institutions dominate the emerging quadrant of patenting in AI and digital health, which combines strength and age of a portfolio. (Data source: Derwent World Patents Index, Clarivate)

AI/ Advanced Analytics commercial dynamic model

Plot of mean Derwent Strength Index v mean age of top 50 portfolios by volume



To consistently link and count citations from patents to research papers, extensive metadata curation needs to be added to patent records issued by government agencies. Derwent analysts have been undertaking this task for many decades.

Patent indicators come with their own share of challenges. Citations within patents are added for many reasons and one must distinguish between those added by the examiner and those included in the filing by the applicant.

A patent grants exclusive rights to an invention in exchange for making the details of the invention public. As part of the disclosure, applicants must cite previous related inventions or works, which serves to show how the new invention differs from (or builds upon) existing knowledge. This process ensures transparency and helps maintain the integrity of the patent system.

Patent examiners, who review patent applications, also add citations. These are independent and mandatory, unlike academic citations, which are voluntary. Examiner citations are considered very reliable because they are added by a third-party professional who is assessing the novelty of the application.

While voluntary and involuntary citations provide context and background, examiner citations in patents are particularly powerful due to their independent nature. This distinction is crucial in evaluating the impact and legitimacy of a patent, which is why some programs, like the Top 100 Global Innovators™, only count examiner citations from third parties to ensure the accuracy and impartiality of the citations.

In essence, patent citations are a mandatory part of the patent application process to ensure transparency and to establish the novelty of the invention. Examiner citations, being involuntary and independent, add a layer of credibility that voluntary academic citations may not always provide.

To consistently link and count citations from patents to research papers, extensive metadata curation needs to be added to patent records issued by government agencies. Derwent analysts have been undertaking this task for many decades. Despite the complexities involved, patent indicators of innovative capacity and success remain the most common source for evidencing the technological and economic impact of research today.

06. Tracing the impact of university research on digital health innovation

The examination of patent portfolios can reveal references to university papers added to the filing by the inventor or examiner, indicating the transition from research to innovation and eventual application. From the bibliometrics side, research papers authored by these firms addressing digital health and cited papers authored by universities offer a parallel route to tracing non-academic impact. While it is relatively rare for research papers to cite patents, doing so can provide an additional link in the chain of innovation.

Tables 4 and 5 list the top 10 institutions and countries/regions, respectively, by documents cited by patents for each of the three digital health topic fields. This helps us understand how impactful research documents are for IP advancements.

The United States has the most documents cited by patents in each topic field, but not necessarily the highest percentage. South Korea has a slightly higher percentage of documents cited by patents for devices and hardware (5.0 vs 4.7) and Germany has a slightly higher percentage for software and analytics (2.4 vs 2.0). For Function, the United States has the lowest percentage share of the top 10 countries/regions; Switzerland has over 12% of its documents cited by patents for Function, with Germany and Belgium also above 9%. Mainland China has the second most documents cited in Devices and hardware and Software and analytics but is absent from Function (it ranks 11th). Documents cited by patents generally receive 2-4 citations per document.

Table 4: The top 10 countries/regions by documents cited by patents for the three major digital health topic fields identified in our taxonomy.

Field	Rank	Country/region	Documents cited by patents	Percentage of total documents cited by patents	Mean number of patent citations by document
Devices and hardware	1	United States	399	4.7	3.4
Devices and hardware	2	Mainland China	126	2.9	1.8
Devices and hardware	3	United Kingdom	75	3.6	2.2
Devices and hardware	4	South Korea	69	5.0	4.8
Devices and hardware	5	Germany	66	2.8	1.7
Devices and hardware	6	Italy	57	2.6	3.1
Devices and hardware	7	Canada	39	3.0	1.7
Devices and hardware	8	Spain	39	3.3	2.1
Devices and hardware	9	Japan	36	2.6	3.0
Devices and hardware	10	Netherlands	35	3.4	1.7

Table 4 (continued): The top 10 countries/regions by documents cited by patents for the three major digital health topic fields identified in our taxonomy.

Field	Rank	Country/region	Documents cited by patents	Percentage of total documents cited by patents	Mean number of patent citations by document
Software and analytics	1	United States	634	2.0	2.3
Software and analytics	2	Mainland China	303	2.4	1.6
Software and analytics	3	United Kingdom	154	1.9	2.4
Software and analytics	4	Australia	72	1.1	2.4
Software and analytics	5	India	71	1.3	1.3
Software and analytics	6	Canada	106	2.0	2.0
Software and analytics	7	Germany	109	2.4	2.2
Software and analytics	8	Italy	79	1.9	2.5
Software and analytics	9	Spain	67	1.8	1.7
Software and analytics	10	Brazil	28	0.9	2.1
Function	1	United States	72	5.5	4.1
Function	2	Germany	44	9.2	2.2
Function	3	United Kingdom	40	7.4	2.0
Function	4	Switzerland	28	12.1	2.0
Function	5	France	27	7.6	2.2
Function	6	Spain	25	6.1	2.1
Function	7	Italy	23	4.8	2.0
Function	8	Canada	22	6.8	3.5
Function	9	Netherlands	19	6.8	1.8
Function	10	Belgium	15	9.5	2.7

Given the country/region profiles, it is unsurprising that the top 10 organizations are dominated by the United States and Mainland China (though no Mainland Chinese institution features in the Function top 10). Many are research-intensive universities (e.g., Stanford, MIT) but the lists also include medical centers (e.g., Mayo Clinic, Massachusetts General Hospital). The highest-ranked institutions from another country/region are McMaster and McGill Universities, Canada, which rank fourth and fifth for Function. Function is the smallest field, but the top 10 institutions have at least 10% of their total documents cited by patents.

Of those documents cited by patents, the mean number of patent citations can be significant. The University of Michigan and University of California San Diego averaged just over 13 and 10 patent citations per document, respectively, in devices and hardware.

Table 5: The top 10 organizations by documents cited by patents for the three digital health topic fields.

Field	Rank	Organization	Documents cited by patents	Percentage of total documents cited by patents	Mean number of patent citations by document
Devices and hardware	1	Stanford University	24	11.3	4.8
Devices and hardware	2	Chinese Academy of Sciences	21	5.1	1.7
Devices and hardware	3	University of California, San Diego	20	12.8	10.3
Devices and hardware	4	Massachusetts Institute of Technology	20	18.7	2.3
Devices and hardware	5	Georgia Institute of Technology	19	9.1	1.8
Devices and hardware	6	University of California, Los Angeles	16	8.1	1.3
Devices and hardware	7	Northwestern University	15	7.3	4.5
Devices and hardware	8	University of Michigan	13	4.9	13.2
Devices and hardware	9	University of Illinois	13	8.7	5.1
Devices and hardware	10	Ohio State University	12	7.7	9.9
Software and analytics	1	University of California, Los Angeles	36	5.1	2.4
Software and analytics	2	Stanford University	34	3.6	3.0
Software and analytics	3	Chinese Academy of Sciences	29	3.1	2.0
Software and analytics	4	Massachusetts Institute of Technology	26	12.0	2.6
Software and analytics	5	University of Michigan	24	2.4	2.5
Software and analytics	6	Harvard Medical School	23	1.6	2.8
Software and analytics	7	University of Oxford	19	2.9	1.3
Software and analytics	8	Tsinghua University	19	5.7	1.5
Software and analytics	9	Massachusetts General Hospital	18	2.7	2.5
Software and analytics	10	Harvard University	18	3.8	2.3
Function	1	Mayo Clinic	19	20.2	4.4
Function	2	Johns Hopkins University	11	15.3	1.5
Function	3	University of Michigan	9	13.6	8.3
Function	4	McMaster University	8	11.3	6.3
Function	5	McGill University	7	14.6	1.6
Function	6	University of Pittsburgh	7	16.7	5.8
Function	7	Royal Marsden Hospital	7	25.9	2.3
Function	8	University of California, San Francisco	6	10.2	1.3
Function	9	Cleveland Clinic	6	10.5	7.4
Function	10	Massachusetts General Hospital	6	12.8	6.5

07. The societal impact of research is multi-dimensional

Mention of research beyond academia marks its transition towards practical application and utility. While publications and patents reveal economic and technical impacts, they represent only two of many types of societal impacts stemming from research that could be considered and on which data might be sought. Other areas include improvements in medical care, health and welfare; enhancements in education leading to the creation and expansion of human capital; as well as impacts in social, cultural, environmental, legal and political spheres.

The analysis of digital health highlights the potential for constructing a robust evidential framework around the identification of leading research and commercial organizations, patenting trends, innovative applications and economic outcomes. However, the clarity provided by well-defined actors and identifiable beneficiary groups is often lacking for many other potential pathways from research to impact.

How can we effectively assess the social and policy impact of academic research? One promising route — long discussed but only recently developed — involves the examination of policy documents such as reports, strategic plans and spending intentions that are issued by regional and national governments, and by non-governmental and charitable organizations for both explicit and implicit references to scholarly research (see Bornmann et al 2016, Bornmann and Haunschild, 2019, Bornmann et al 2022, Haunschild and Bornmann, 2017, Szomszor and Adie, 2022, and Yu et al, 2023).

A significant challenge arises from the lack of standardized referencing for background research relevant to policy. Many references are obscure, garbled or incomplete. While mentions of specific research in congressional or parliamentary debate or citation in actual legislation would provide further evidence of social impact in policymaking, such occurrences are even less frequent than in the policy documents themselves.

Clearer evidence of healthcare research exerting social impact can be found in mentions in 'guidelines' papers published in clinical medical journals or in systematic reviews that inform good practice (see, Kryl et al 2012, Thelwall and Maflahi, 2015, Bornmann and Haunschild, 2019). While the source of citation may still be within the scientific and scholarly literature — and is not itself proof of uptake of research results outside academia — guidelines and systematic reviews are clearly intended to influence medical protocols, reimbursements and ultimately patient care.

Various uncertainties persist. Some research areas such as medicine and healthcare, social sciences issues, economics and the environment are more likely to be mentioned in policy documents. The style of mentions is inconsistent, as noted, and only about 1% of research papers are cited in policy documents. Scant data do not make indicators impossible, but appropriate calculations will be needed on a field-by-field basis.

The analysis of digital health highlights the potential for constructing a robust evidential framework around the identification of leading research and commercial organizations, patenting trends, innovative applications and economic outcomes.

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Environment is an area where societal impact likely can be evaluated. The 17 Sustainable Development Goals (SDGs) established by the United Nations serve as a collective roadmap for addressing grand societal challenges. Among the goals are several environmental concerns: 6. Clean water and sanitation; 7. Affordable and clean energy; 11. Sustainable cities and communities; 12. Responsible production and consumption; 13. Climate action; 14. Life below water; and 15. Life on land. Research focused on these topics, frequently cited by policy documents and utilized for education and management directives, serves as a powerful indication of societal use and influence.

Identifying research with societal impact such as contributions to the environmental SDGs requires a combination of text mining, citation network analysis and application of AI tools and techniques. Adding metadata to designate socially relevant research is increasingly becoming a standard practice in indexing the scientific and scholarly literature.

While social media metrics have been considered as a potential tool for understanding and tracking societal recognition of research findings, the data are subject to forces that can make them unreliable as evidence. Lutz Bornmann and Robin Haunschild of the Max Planck Society emphasized a need for caution: "… only a subset of social media metrics can actually be used for societal impact measurement… we do not regard it as sensible to use raw counts for impact measurement or to combine the raw counts of various altmetric sources into composite indicators, but rather to undertake a field- and time-normalized impact measurement, which is target-oriented (and focused on such groups in society as students or others)." (Bornmann and Haunschild, 2019).

Despite the array of opportunities presented in this analysis, each one with significant challenges and data limitations, it is important to recognize that these approaches will only address research areas where clear connections exist between academic documents and societal impact. Much societal impact from academic impact falls outside these, notably in cultural disciplines, and the prospect of developing robust and comparable indicators widely acceptable to the scientific and scholarly community is a challenge for the immediate future. However, we remain committed to refining evaluation approaches to ensure the accurate measurement and recognition of the full spectrum of societal impact.

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