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A Bird's Eye View of Worldwide University Science[1]

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Abstract

The last three decades have seen the evolution of a networked global science system, sustained by sharing and collaboration and codified by journal publishing and bibliometric inclusion/exclusion, that has come to play the leading epistemic role in the natural science-based disciplines. Global science is dominated by scientists from the leading Anglophone universities and almost exclusively published in English, excluding the larger part of the world's knowledge. However, the networked science system has encouraged the entry of new incoming countries, and production in science has become much more plural. Almost half of all science papers within the English-language science system are generated from outside the Euro-American 'West', not to mention the work done in other languages that is not part of the common conversation because it is not translated into the sole global language – it is treated as solely local rather than universal knowledge. In other words, there is a fundamental lack of fit between the broad post-colonial distribution of capacity and the continuing neo-colonial structure of institutional and cultural power. There is also both ongoing tension and also synergy between the global science system and national systems and purposes. The paper summarises and critically reviews these developments, supporting its exposition with data mapping of global science. It notes that nationally centred geo-political conflict, partly powered by the tension between established and rising science powers, now threaten to disrupt the peaceful evolution of global cooperation in science. The way forward lies in the reassertion of open cooperation, within a global knowledge system reconfigured to include the full diversity of languages and cultures.

Keywords: Science, research, knowledge, bibliometrics, globalisation, geo-politics

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Introduction

This paper focuses on global science, which in many disciplines has become the dominant part of scientific work in epistemic terms. Why talk about relations of power in global research and science in a book on higher education? Science and higher education are closely joined (Powell et al, 2017). Only a minority of higher education institutions conduct research but those that do are important in science, and research is the marker of status in higher education worldwide. More than four fifths of published science papers have at least one university author. And science matters, so relations of power in science also matter.

'Global science' is here defined as knowledge in the two main bibliometric collections, Web of Science (WoS, 2024) and Scopus (Elsevier, 2024). This includes some work in social sciences and a minority part of world scholarship in the humanities. As this suggests, global science, which is almost entirely published in the English language, is not equivalent to human knowledge as a whole. This is so even in the natural sciences. *'Global science' as structured by human action is not the whole of world knowledge, most of which is outside recognised global science.* This is a crucial issue in relations of power in science. The limits of the bibliometric collections as repositories of knowledge is expanded on below.

The paper begins with the global science system, and the relation between on one hand global science, and on the other hand national government and national science. Then it moves to who and what are dominant in global science, and who and what are excluded. This is followed by a discussion of changes in global science and the implications of these changes for relations of power. Global science is continually evolving (Marginson, 2022a).

Growth of global science

First, the growth of global science. This is an outcome of the spread of Internet-mediated communications. In *Theory of Society* Luhmann (2012) notes that the decisive step towards world society was 'the full discovery of the globe as a closed sphere of meaningful communication' (Volume 1, p. 85). After 1989 the Internet facilitated the rapid expansion of networked communications.

Electronically-mediated communication made possible the foundation and expansion of a new global science system, not driven by technology but by human agents. North American universities had a large presence in the early Internet and the early building of networked science was led by faculty in the United States.

This meant that the global science system became patterned by the expansionary dynamics of an open network, and also that it became closely shaped by American faculty norms. Fortunately, this included the robust practice of autonomous professional regulation in disciplinary communities with free bottom up interaction between researchers that was independent of government. On the downside it meant that from the beginning that global science embodied the equally robust Anglophone sense of cultural superiority.

Since 1996 the number of papers in the global literature has grown by over 5 per cent per year. Published science has doubled every 12 years or so. There has also been rapid growth in the number and proportion of papers with international co-authors; and partly through this, active science has spread to many countries. In the STEM disciplines, though less so in other disciplines, most important new science starts in the global literature, not single nation literatures. As noted, global science has become epistemically primary.

Open networks

There's much to be said for the open network in science. In networks, knowledge, messages and information travel with lightning speed without respect for national borders. Innovations spread very rapidly. Networks become cheaper per connection as they grow (Castells 2000). By joining the pre-existing network, new researchers and new national science systems readily gain access to immense resources. Established institutions and large countries cannot gate-keep in the global science system because researchers can freely form ties with any other researcher in the network, and do so.

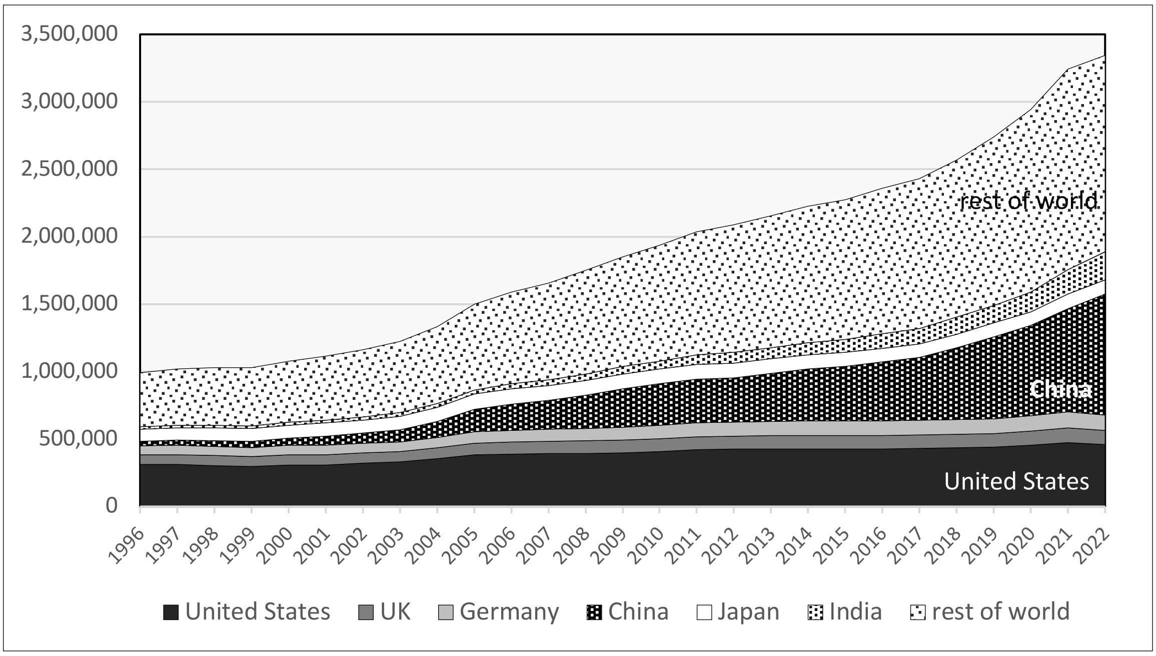
> The organization may be more open to new members, since greater density of the network and the lowered in-betweenness measures suggest that fewer of the communications pass through the leading nodes or countries … international cooperation is

> particularly advantageous for less advanced countries…. With improved scanning of research and more effective communications, [researchers can] leverage foreign research, data, equipment, and know-how. ... The global network is arguably now a more stable system that serves as a source of vitality and direction to R&D at all lower levels… (Wagner et al, 2015).

The fastest growth in collaborative relations in global science has been the growth in relations between researchers in different emerging science countries.

Figure 1 shows especially rapid growth since 1996 in science papers in China, India and the rest of the world. Established science in the US, UK, Germany and Japan grew more slowly. The Anglophone countries, Western Europe, Russia and Japan once produced nearly all global science, but no longer. Countries generating 90 per cent of science increased from 20 in 1987 to 33 in 2022. Their researchers produced over 15,000 papers in Scopus in 2022; 59 countries produced over 5,000 science papers (NSB, 2024): all of these countries had viable endogenous science systems, as indicated by local doctoral graduates in at least some disciplines, and all of these countries connected to the shared global science system.

Figure 1. Growth of science papers in Scopus by large country/world region, 1996-2022



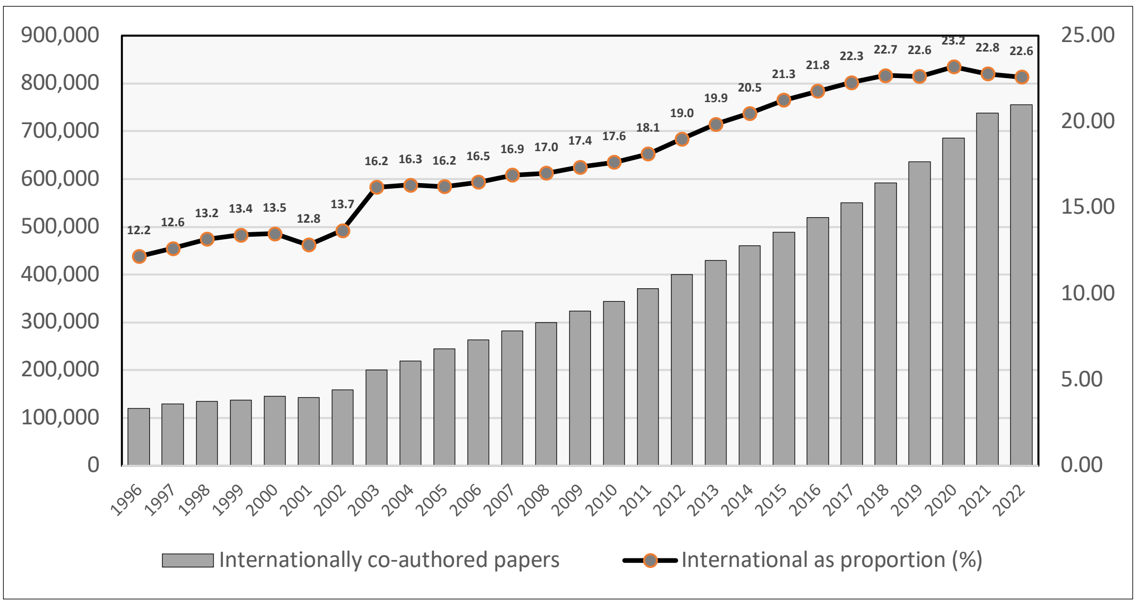
Source: NSB (2024)

Cross-border collaboration and mobility

The number and proportion of papers co-authored in more than one institution in the same country has risen sharply, and papers co-authored in more than one country have risen faster. Figure 2 indicates the growth of cross-border papers in Scopus from 1996 to 2022. The proportion of all published science papers that entail authors from institutions in more than one country jumped from less than 2 per cent of all Web of Science papers in 1970 (Olechnicka et al, 2019) to a highpoint of 23.2 per cent of papers in Scopus in 2020. Figure 2 uses the Scopus data. Since 2020 there has been a slight falling away to 22.6 per cent of all papers in 2022 (NSB, 2024), partly because of a decline in the volume of US-China collaborations, but clearly collaborative science now has a major global component.

Mobile doctoral students play a large part in the globalisation (meaning the cross-border convergence and integration) of science, though the proportion of doctoral students who come from another country varies between the national systems. In Canada in 2021, 35 per cent of doctoral students were classified as foreign students in terms of citizenship, compared to 24 per cent in the United States. In the UK, 41 per cent of doctoral students were classified as international in that they had crossed the border (OECD, 2023, p. 259).

Figure 2. Number and proportion (%) of papers in Scopus that were internationally co-authored, World: 1996-2022



Source: NSB (2024). A change to data compilation in 2003 disrupts comparison over the full period.

Why do researchers collaborate internationally? Several answers are offered in the research literature on science (see, for example, Georghiou, 1998; Birnholtz, 2007; Winkler et al, 2015, Chen et al, 2019). Funding and programme structures often incentivise cooperation. For example, in Europe the conditions of research funding often require cross-country teams. Government policies can also weaken collaboration, as will be discussed. But the intrinsic motives of researchers also matter. There can be career gains in going global: for example, partnerships between researchers in the global North and emerging researchers in the global South are common, often through the doctoral education of the global South researchers. Career motivated collaboration is referred to as 'preferential attachment' (Wagner and Leydesdorff, 2005). Interviews with scientists suggest that epistemic motivations are also often strong: most researchers want to make a significant contribution to discovery and many want to work with good researchers in their own research domain. The research literature mentions shared problems and factors such as respect and trust (Melin, 2000). Disciplinary ties are strong and often readily operate across borders.

Other affinities are also explanatory of cross-border patterns of co-authorship. All of linguistic, cultural, historical, geographic and political proximities can encourage scientific collaboration across national borders (Chen at al, 2019; Graf and Kalthaus, 2018, 1200).

So that is the global science system. It is open, fast growing and spreading. It is partly shaped by agreements between governments, and universities and also shaped from the bottom up and sustained by collegial norms within the different fields of research. Science is bottom up but not egalitarian. Resources, capacity and influence in science are not equivalent across the world or across the different institutions and still less are they equal. Global science is not a level playing field. Later the paper will return to that point.

National and global science

The bottom-up faculty to faculty dynamic might be more potent in shaping the epistemic content of global science than the policies and actions of national governments. Yet in conventional descriptions of science it is seen to be organised in separated national systems, and its distinctive and separate global aspect is invisible. Data describing science often split intentionally collaborative papers on an arbitrary proportional basis between the countries concerned, which is highly misleading. It seems that 'the only reality we are able to comprehensively describe statistically is national, or at best international' (Dale 2005). Yet as the parent of comparative studies of science, Robert May, puts it, in the founding paper, data on 'comparisons are to a degree confounded because a large and growing fraction of scientific work involves international collaborations' (May, 1997, p. 795)

Does it have to be either/or, though? Can science be global, local and national simultaneously? What then are the relations between global and national science?

National governments and public research agencies are essential to science in the material sense. They provide the infrastructure of the institutions that house nearly all basic science: universities and government laboratories. They part fund those institutions and largely fund their research projects. They often (though not always) provide a stable policy, legal and regulatory framework for science. This might suggest that cross-border science, the global science system, is simply an outgrowth of national science. But this would miss the fact of global networking, collaboration and creativity, where most of the discoveries in natural science are made. In global science, knowledge and its organisation are grounded not in universities or in countries but in the disciplines and cross-disciplinary groups, in freely connecting research networks. The global science system is much more than the sum of the different national parts. It has its own networked relations and dynamics of growth. Its practical autonomy from national authorities creates challenges for governments.

Table 1 distinguishes global and national science (see also Marginson, 2022b).

	Global science system	**National science system**
Core components	Codified, globally legitimated knowledge, people, networked communications, norms	Institutional structure of science activity ordered and resourced primarily by nation-state
Enabling conditions	Global communications, resources, institutions, and (often national) agencies/policies/rules	Sufficient political and economic stability and policy commitment to science activity
Main functions	Production, codification and legitimation, circulation, of new shared knowledge in English (inclusion/exclusion function)	Legal, political, financial conditions of science. New national knowledge, new applications of knowledge
Boundary	World society, but only some knowledge and knowledge producers are included	Nation-state, limits of activity are set by state policies and willingness to fund
Normative centre	No normative centre. Diffuse disciplinary community of persons sharing knowledge	Normatively centred on state and institutions
Growth dynamics	Continually expands to all possible networked connections, intensifies existing connections ('edges')	Growth is less inherently dynamic, being determined by national policy and funding, and industry take-up of research
Social-relational	Collegial scientists in professional organisations, forums and networks	Government agencies, research organisations and institutions, networked scientists in national and local scales
Regulation	Local self-regulation using global collegial scientific norms (norms of dominant science nations)	National law, official regulation, policy, financing systems, cultural norms
Division of labour	Knowledge potential of global science stimulates national system building and state funding	National science provides institutions, personnel, resources essential to global science

Source: author

> The global network has a culture, pathways, and norms of communication specific to its structure, and diverging from national, regional, or disciplinary norms (Wagner et al, 2017, p. 1646).

> Collaboration has grown for reasons independent of the needs and policies of the state ... This dynamic system, operating orthogonally to national systems, is increasingly difficult to influence and even less amenable to governance as it grows... nations must learn to manage and benefit from a network (Wagner et al, 2015, p. 2, p. 12)

Science is multi-scalar in the geographic sense (for more discussion see Marginson 2022c). It operates at different levels – it is individual, it is locally collaborative, it is national, often regional, and global now in a very visible way, all at the same time. These levels of science differ from each other in fundamental ways. National science is firmly centred by the nation-state, by governments. Global science has no normative centre. It is bottom-up. It is regulated not by rules and funding allocations but by voluntary cooperation, shared understanding, and the protocols that govern scientific work. It is influenced by national governments but is partly outside them. To understand worldwide science, it is essential to recognise this heterogeneity of science in the different geographical scales.

At the same time, while global and national science are different, they also overlap in important ways and there is mostly a symbiotic relationship, a functional division of labour, between them. Much scientific activity takes place in both scales simultaneously. Scientists who lead their global discipline often also lead science at institutional and national level. Knowledge generated originally for national government purposes can finds its way into the global conversation. Reciprocally, globally sourced knowledge becomes part of national scientific, governmental and industrial agendas. National governments mostly support global science and encourage international scientific collaboration because this is seen as beneficial for parties located at national level and makes it possible for government itself to be in touching distance of innovations in science and technology.

> The sciences develop internationally, but the funding is mainly national (Bornmann et al, 2018, p. 931).

> … international and national networks may be shaping each other in a process of co-evolution between the national institutional structure and the global network. The relative influences of national and international networks appear to vary among nations (Wagner et al, 2015, p. 11)

It is nevertheless a complex relationship. When nations treated science as a common human endeavour, focused on shared global problems such as climate change or epidemic diseases, the relationship is more seamless. However, nations often treat science as a tool of 'technological nationalism', hoping to mobilise science to pursue competitive nation-bound agendas. Then global science and national science find themselves pulling different ways. The nation-bound outlook can limit what science can achieve. It leads to confusion about the nature of science and its relation with the national economy.

For example, governments hope that by investing in science within national universities and other agencies, they thereby foster economic innovation. But the 'knowledge economy' is a myth. On the balance of probability, national science that enters the global pool is more likely to be used by foreign not local capital. Innovations by national industry are mostly sourced in foreign science. In any case, the majority of research is 'altruistic', not focused on economic development or national security at all (Klavans and Boyack et al, 2017).

So that's the relation between global science and national science. Nations have resource power and legal power. The global system has knowledge power. They often work together but are sometimes pulling apart. Now the paper will unpack the earlier statement: 'science is not a level playing field'. Here the argument will draw on Gramsci's (1971) concept of 'hegemony', dominance via consent, and the content of the hegemony.

Hegemony in global science

Table 2, derived from the Leiden ranking which uses Web of Science data on science output, lists the world's 25 leading research universities on the basis of production of highly cited science papers published between 2018 and 2021 inclusive (CWTS, 2023).

Table 2. Leading universities in high citation science, Web of Science papers 2018-2021 inclusive

university	country	top 5% papers	all papers	% papers in top 5% in field	cross-border papers	% papers cross-border
Harvard U	USA	4,256	36,355	11.7%	50,465	55.0%
Stanford U	USA	2,065	17,958	11.5%	21,421	48.1%
Zhejiang U	CHINA	1,974	33,090	6.0%	17,878	31.1%
Tsinghua U	CHINA	1,898	23,152	8.2%	17,882	37.4%
U Toronto	CANADA	1,833	25,295	7.2%	32,136	60.1%
U Oxford	UK	1,763	17,065	10.3%	32,681	71.7%
Shanghai Jiao Tong U	CHINA	1,716	31,789	5.4%	17,957	31.0%
Huazhong U Science &	CHINA	1,559	24,435	6.4%	10,866	27.0%
U Michigan	USA	1,488	20,120	7.4%	18,913	41.7%
U College London	UK	1,486	16,247	9.1%	30,997	69.3%
U Pennsylvania	USA	1,478	16,900	8.7%	16,160	39.7%
Johns Hopkins U	USA	1,457	18,416	7.9%	22,165	47.2%
MIT	USA	1,445	10,504	13.8%	18,235	59.1%
U Cambridge	UK	1,407	14,386	9.8%	27,091	72.1%
Central Southern U	CHINA	1,332	23,497	5.7%	9,719	25.2%
Peking U	CHINA	1,319	21,238	6.2%	16,491	36.5%
Cornell U	USA	1,299	13,673	9.5%	16,218	49.4%
U California – Los	USA	1,277	14,894	8.6%	17,857	47.8%
Imperial College	UK	1,264	12,864	9.8%	26,012	72.4%
U Chinese Academy	CHINA	1,255	19,751	6.4%	23,889	26.9%
Columbia U	USA	1,241	13,295	9.3%	18,168	50.0%
National U Singapore	SINGAPO	1,238	13,855	8.9%	23,603	72.0%
U California – San	USA	1,236	13,308	9.3%	16,093	48.4%
Yale U	USA	1,227	12,474	9.8%	15,053	47.2%
U Washington, Seattle	USA	1,225	15,363	8.0%	18,487	44.8%

Source: CWTS (2023). Most papers have multiple authors. The data for total papers and top 5% papers are based on fractional count: a single unit value of one per paper is allocated between different institutions on the basis of the proportion of total authorship. The data for international collaboration papers are based on total paper count, so that each authorship (regardless of the number of authors in the paper) = 1.

Citations measure recognition of research, not the quality of research, but an order based on recognition shows where authoritative science is concentrated. This list includes 12 universities from the United States, four from the UK, one from Canada, seven from China and one from Singapore. In the top ten there are four from the U.S., three from UK and three from China. There are no non-UK European universities in the top 10 or top 25 because the measure is partly size dependent and European research universities are typically smaller than are Anglophone and Chinese universities.

The top 25 list is changing. Five years earlier there were 17 from the U.S., two from Canada, none from Singapore and just two from China that were in 20th and 25th position. East Asia is coming on with a rush, especially the leading research universities in China. But the Anglophone countries were still somewhat stronger in 2018-2021, led by Harvard which produces twice as much high citation science as the number two university, Stanford, primarily because of the weight of the research output of the Harvard medical school.

This list explains much about global science. It is led from familiar universities where reputation, resources and talents are concentrated. Nominally, the high citation data capture the quantity of quality (science fire power) in these institutions so that performance is determined by a combination of scientific merit with size. However, 'scientific merit' is here dominated by Western and especially English speaking universities. Even the rising stars in China excel by being good at Western science. Does this mean that the West is the best and the rest are nowhere? It is not that simple.

First, much of the knowledge which is now reproduced as part of the Euro-American episteme in fact has plural cultural roots. The origin of the notion of zero in mathematics is disputed between advocates for India and for China. Arguably, in the development in mathematics and astronomy the world's leading zones, shaping later evolution of these fields, were India and Islamic West Asia (arguably also the Classical Maya civilisation in Mexico and Central America in 400-800 CE was also ahead of the medieval European world in astronomy). Song China created key applications of technology such as the nautical compass and gunpowder in warfare (and started the widespread use of paper and printing which became essential tools in the transmission of scientific knowledge everywhere). The West is by no means the only domain where even Western science originated, let alone the heterogenous knowledge from elsewhere. But the non Western roots of much knowledge used in the West are hidden beneath assumptions about natural Western superiority.

Second, the universities that dominate the comparison of performance in science also house the leading scientists who shape the basis of comparison. These agents determine what is legitimate as global science, interacting with the publishing companies that circulate global science, in journals edited by the same discipline leaders, and the two large bibliometric companies which are the repository for global science.

Through these processes, knowledge becomes rank ordered in terms of value and prestige. First, some knowledge is selected as legitimate and other knowledge is excluded. Second, there is a hierarchy within the selected global knowledge that is based on journal ranking and citation impact. Global science is real knowledge but that knowledge, and the prestige attached to it, are socially constructed - and much other knowledge is excluded.

Publishing

Global science publishing is largely monopolised by five large companies: Elsevier, Springer Nature, Taylor and Francis, Wiley-Blackwell and Sage. Like science they operate freely across national borders. Science is a public good but the publishing companies turn it into something owned by them. They are capitalist corporations that seek profit and market share as ends in themselves, absorbing academic networks, growing and diversifying journals and users, and differentiating value is the manner of markets. Open access publishing has become another way of monetarising science, via author processing charges. The networked scientific world provides publishers with their essential conditions of operation. Publishers extract papers from the larger body of formal and informal knowledge for digitally-based revenue creation, exercising proprietary control. The peer review systems that sanction and differentiate the value of published papers as science are managed digitally in publisher platforms and increasingly regulated by the publishers' systems.

The publishers actively encourage the publish or perish growth of science, regardless of content or originality, because this expands their market share and profitability. Is science thereby subsumed into capitalist production? Are scientists reduced to wage labour for publishers? There's a tendency to this at the margin, but largely, no. Publishers do not create knowledge. They are parasitic on knowledge, a public good that is produced in non-profit universities and research institutes. But they also help to create the rhythms of production of that public good and closely affect its use as a tool of institutional, national, economic and cultural power. Public goods are often captured and deployed by powerful social groups.

The bibliometric collections

The output of journals is fed into the two main bibliometric collections, Web of Science and Scopus, which are owned by companies specialising in scientific information and publishing: Clarivate Analytics and Elsevier respectively. Books play a minor role in the bibliometric collections: journal papers are more amenable to rank ordering based on peer review, journal selectivity and citation impact and are more readily accessed by users.

Table 3. The role of the main bibliometric collections in global ranking of universities

Rankings	**Publication-related indicators as proportion %**	**Databases**
Shanghai Jiaotong Academic Ranking of World Universities (China)	70.0	Clarivate Analytics' Web of Science
Times Higher Education World University Rankings (UK)	38.5*	Elsevier's Scopus
QS World University Rankings (UK)	20.0*	Elsevier's Scopus
Leiden Ranking (Netherlands)	100.0	Clarivate Analytics' Web of Science
Best Global Universities (US)	72.5	Clarivate Analytics' Web of Science

Source: Author, based on university ranking websites.
* Beyond bibliometrics, research performance has a further, indirect but important, effect through its impact on the surveys used by THE and QS, and in THE data on postgraduate studies and income – arguably, in total research performance constitutes more than two thirds of the THE index (Marginson 2014).

Bibliometrics have enabled the creation of a quasi-economy of science in which all outputs are assigned shadow values. These metrics then regulate the value of individuals, academic units, institutions, and countries as assessed on a comparative basis in higher education. Here value is differentiated on the basis of culture. 97 per cent of items in the bibliometric collections are in English and nearly all work in other languages is excluded.

This machinery has acquired its own momentum. Yet it still rests on decisions about inclusion and legitimacy made by faculty leaders and peer reviewers in the disciplines. The prime instruments of global hegemony are the faculty in those countries that exercise it.

A crucial part of this quasi-economy of science is global university rankings. The main component of the rankings is bibliometric data. Research metrics directly determine most of the Shanghai and Times Higher ranking and the prestige effects of research metrics indirectly determine the surveys used by Times Higher and QS. Rankings turn bibliometrics into the recognised hierarchy of universities, in which the Anglophone universities are dominant, and privileged social groups reproduce their inherited place in the world. This construction of science has moved a long way from the shared joys of grass-roots scientific collaboration. The collegial decisions of peer reviewers have not only been monetarised by publishers, they are also used to determine and reproduce university hierarchies.

Knowledge that is excluded

This is what global science has become. It is a multiple and contradictory beast. It remains a system of open collaborative knowledge creation grounded in disciplinary networks. It is also annexed to institutional and geo-political power and serves as an instrument of power and control. It is reproduced in circular fashion by the combination of national science infrastructures, leading universities, leading scientists, publishing companies, bibliometric companies, and university rankings. It is neo-imperial. It reproduces a global cultural hierarchy, inherited from the colonial era, which nurtures notions that some cultures, some languages, countries, people, are more highly valued, more creative and scientific, more objective, than others. Global science is seen as universal science and the rest of knowledge in whatever language is treated as 'just local' with no larger contribution to make.

What falls outside the charmed circle? Everything else. Issues of exclusion are by no means limited to fake data, fake news, raw ideology and propaganda. Much truth-oriented material is also excluded. There is the large body of research-based 'grey literature' in government and commerce that does not figure. Most of the research that is for local or national use, including most of the social sciences and humanities, is outside the main bibliometric collections. And as noted they omit nearly all knowledge in languages other than English, including all indigenous knowledge. English is the first language (L1) of 4.7 per cent of the world's population, the third L1 after Mandarin Chinese (11.6 per cent) and Spanish (5.9 per cent). English is the first or second language of 18.2 per cent of people. Yet 98 per cent of Web of Science and 96 per cent of Scopus is in English.

It is telling that the divide between knowledge that is inside global science, and outside global science, is the old colonial divide between the dominant powers and the rest.

> … the understanding of the world by far exceeds the Western understanding of the world and therefore our knowledge of globalization is much less global than globalization itself… the more non-Western understandings of the world are identified, the more evident it becomes that there are still many others to be identified and hybrid understandings, mixing Western and non-Western components, are virtually infinite. Post-abyssal thinking thus stems from the idea that the diversity of the world is inexhaustible and that such diversity still lacks an adequate epistemology. In other words, the epistemological diversity of the world does not yet have a form. … Post-abyssal thinking confronts the monoculture of modern science with the ecology of knowledges (de Sousa Santos, 2007, pp. 64-66).

The languages of the colonised are all excluded. Yet Anglophone and Western countries do not monopolise all wisdom or have all the answers. Quite the contrary – arguably the Western model of economic development, in which the base level freedom is the freedom to accumulate private capital and all else is organised on that basis, is destroying the earth. In the question of broadening the charmed circle of knowledge there is much at stake.

There are very significant benefits in a common language for science. This creates a single global conversation, and this too is essential to fostering effective global cooperation in domains such as the climate-nature emergency. These benefits are much reduced in terms of both epistemic richness and geo-political justice when the conversation so harshly privileges only knowledge in that single language. It is possible to achieve the benefits of both commonality and diversity, however. The essentials steps are (1) to translate all knowledge produced in other languages into the common global language and make both the original and the global version equally accessible; (2) to move to a multi-lingual publishing regime in which all knowledge produced in the main languages of use is published simultaneously in the other main languages of use. We have the software to do this, notwithstanding subtle problems of translation that arise. Scientific communities should demand that the commercial publishers move to a multi-lingual regime.

Signs of change

Fortunately, everything is always changing and no system of power is fixed in stone. In the last thirty years science and knowledge have evolved remarkably. In this lies the possibility of a more inclusive and diverse science conversation. There is also the possibility that science will increasingly close down, becoming more closely annexed to national interests as a tool of geo-politics, fracturing the global science system and stunting scientific creativity.

The paradox of global science is this. Open networking has fostered all round capacity development, but global hegemony, and the associated social, economic and institutional processes, have imposed hierarchy and closure on the network. Hegemonic power has not stopped broad-based scientific development, but it has imposed a hierarchy of value, and forced new science players to conform to the content requirements of the leading players. These content requirements reproduce patterns of dominance. Nevertheless, across the world there is significant pushback against the Anglophone control of science.

Pushback against hegemony in science

We see this in Latin America and Africa, and in the Chinese policy emphasis on moving beyond catchup to the West to develop higher education and research with 'Chinese characteristics'. Latin American scholars who focus on epistemic injustice point out that when science is defined as work in English, Latin America seems impoverished. But that is quite wrong. When work in Spanish and Portuguese is included the picture looks different.

> The mainstream has been self built on the supposition that outside there is backwardness and lack of academic value … The publishing system has become determinant in the distribution of scientific recognition by reinforcing a hierarchy built on the basis of a triple principle: institutional development, discipline and proficiency in English (Beigel 2014).
>
> Visibility alone is not enough. Effective presence requires being in such a state of visibility that anyone neglecting it will be faulted for carelessness, incompetence or ignorance. … While much good and even extraordinary science does exist in non-OECD countries, it needs to be integrated at its right place within (real) world science (Vessuri et al, 2014).

Global pluralisation of science capacity

In the long run all-round capacity development must foster a more inclusive and more diverse world of knowledge. Science output in China now massively exceeds that of the US. India has passed Germany, UK and Japan to become third largest producer of science papers in Scopus. Brazil, Iran, Turkey, South Korea, all operating outside the West, have achieved large-scale science infrastructure and output. But the pluralisation goes further than this.

The growing diversity of scientific capacity is made clearer in Figures 3a and 3b. These present two contrasting groups of national science systems. In the two charts, the volume of national science output is indicated by the size of the ball. The vertical axis shows the rate of annual growth in the number of science papers between 2003 and 2022. The horizontal axis shows national income per head which is a rough measure of the material capacity to provide scientific production. The dotted line is the world average income per head in 2022.

Figure 3a. Science output growing SLOWER than world average rate (5.38% per annum) in 2003-2022

Average annual growth in science papers in each country compared to GDP PPP per capita in each country. Dotted line is world average GDP per capita in 2022 (US $20,694 current prices). Total science papers in 2022 shown by size of ball

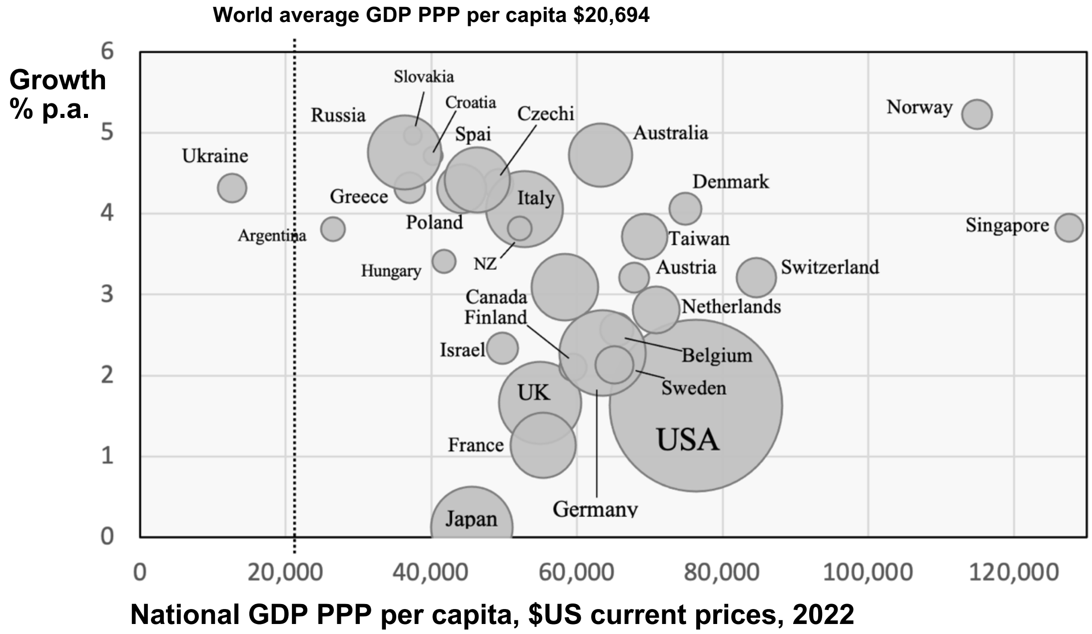
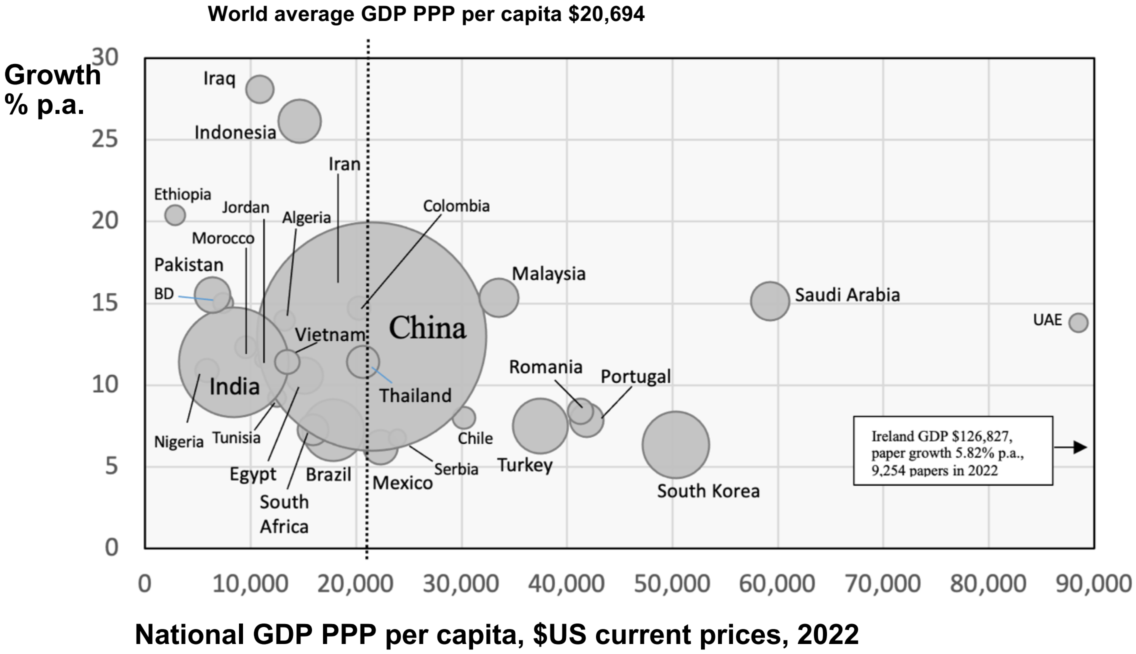


Figure 3b. Science output growing FASTER than world average rate (5.38% per annum) in 2003-2022



Source: World Bank (2024); NSB (2024); Statistics Times (2024).
Countries producing g more than 5,000 papers in 2022 only. NZ = New Zealand. UAE = United Arab Emirates. BD = Bangladesh

The first chart in Figure 3 shows science systems that after 2003 grew *more slowly* than the world average rate of 5.38 per cent per year. These systems were all established prior to 2003. They are mainly in Western countries with incomes well above the world average – in fact only one of the slower growing systems, Ukraine, had below average GDP per head.

The second chart in Figure 3 tells a different story. These are the national systems where science output is increasing *faster* than the word average rate. They are mostly relatively new science powers. Some of these countries have seen spectacular growth – almost 15.6 per cent per year in Iran, one of the larger science systems with 60,940 papers in 2022 - not far short of France - and an incredible 26.2 per cent in Indonesia where the number of papers grew from just 387 in 2003 to 31,947 in 2022. Further, consider the diversification in terms of the economic indicator. Nearly half of these fast growing science countries have incomes per head below the world average. The identifiable science systems include Ethiopia with a GDP of only $2,813 per head in 2022, Nigeria ($5,862), Pakistan ($6,351) and Bangladesh ($7,398). Like mass higher education (Cantwell et al. 2018), global science has spread to middle income countries and some low-income countries as well. This is empowering in the emerging countries, a process of democratisation on the world scale.

Pluralisation of leading science

There is another kind of pluralisation at the top levels of science. This becomes clear when we look at universities that lead high citation research, as measured by top 5 per cent papers, in the science, technology, engineering and mathematics (STEM) fields. Table 4 lists high citation papers in two broad discipline clusters, physical sciences and engineering on the left, mathematics and computing on the right. These lists are now absolutely dominated by China. The two leading Singapore universities also figure at the top of STEM research.

The top line of Table 4 represents a dramatic change in worldwide science power. Only five years earlier, 11 of the top universities in physical sciences and engineering were from the U.S .and one from China. Now ten are from China and two from the U.S. It is not that American science has declined. What has happened is that Chinese science, fed by state investment, has developed quickly and moved past the US. China is even more dominant in mathematics and the associated cluster of computing research.

Table 4. Top universities in STEM research, Leiden ranking.

Papers in top 5% by citation rate, 2018-2021, In (1) physical sciences and engineering, (2) mathematics and computing, (3) biomedial and health sciences, (4) life and earth sciences

University	System	(1) Physical sciences & Engineering
Tsinghua U	CHINA	1,054
Zhejiang U	CHINA	783
Shanghai JT U	CHINA	736
Harbin IT	CHINA	720
Huazhong U S&T	CHINA	687
U Science & Technol	CHINA	649
Tianjan U	CHINA	635
U Chinese Acad Sci	CHINA	621
MIT	USA	614
Xi'an Jiaotong U	CHINA	593
Hunan U	CHINA	582
Nanyang TU	SINGAPORE	557
Central Southern U	CHINA	551
National U Singapore	SINGAPORE	538

University	System	(2) Maths & Computing
Tsinghua U	CHINA	402
U Electron S&T	CHINA	402
Harbin IT	CHINA	265
Xidian U	CHINA	263
Huazhong U S&T	CHINA	259
Shanghai Jiao Tong U	CHINA	228
Zhejiang U	CHINA	228
Beihang U	CHINA	228
Southeastern U	CHINA	228
Nanyang TU	SINGAPORE	220
Northwestern Poly U	CHINA	219
Wuhan U	CHINA	212
MIT	USA	193
Beijing IT	CHINA	190

University	System	(3) Biomed & Health Sciences
Harvard U	USA	3,027
U Toronto	CANADA	1,154
Johns Hopkins U	USA	1,104
Stanford U	USA	1,017
U Pennsylvania	USA	1,009
U Calif San Fran	USA	921
U Oxford	UK	829
U College London	UK	816
U Michigan	USA	792
Yale U	USA	732
U Calif San Diego	USA	709
U Texas HSC Hous	USA	699
Cornell U	USA	692
U Wash - Seattle	USA	675

University	System	(4) Life & Earth Sciences
China Agriculture U	CHINA	343
Zhejiang U	CHINA	335
U Chinese Acad Sci	CHINA	288
Wageningen U	NETHERLANDS	287
Northwest Ag & For U	CHINA	285
China U Geoscience	CHINA	261
Harvard U	USA	241
U Calif Davis	USA	236
Cornell U	USA	235
Nanjing Agricultural U	CHINA	233
ETH Zurich	SWITZERLAND	232
Tsinghua U	CHINA	224
U Florida	USA	217
U Oxford	UK	215

Source: CWTS (2023)

These numbers have put the fear of god into the Trump and Biden administrations in the United States. It seems that previously it was acceptable in the U.S. for China's science to develop, a process long assisted by open mutually funded collaboration with U.S. science, because it was expected that the collaborative contact would lead to the Westernisation of China and it was never imagined that Chinese STEM research in the top universities would become stronger than in U.S. universities. No doubt the reversal of the leadership table has been one key factor driving the American policy of decoupling in research in science and technology. It is hoped that this decoupling will slow China's rise in STEM. However, while a weakening of collaboration tends to slow research development everywhere, China's science capacity is now well established, and the decoupling strategy is unlikely to achieve its goals.

However, China is by no means number one now in all research fields. As the bottom section of Table 4 shows the story outside STEM is different. On the left, in biomedicine and health Anglophone universities are still dominant. University of Toronto s number two in the world after Harvard. The first non-Anglophone university is Copenhagen at 22 and highest in China is Shanghai Jiao Tong at 66. Earth and life sciences on the right are more geographically plural.

Geo-politics and science

As the preceding discussion shows, in the last ten (and especially the last five) years governments have become more nation-bound and competitive about science. John Haupt and Jenny Lee (2021) refer to a tension between collaborative global science, 'scientific globalism', and 'scientific nationalism', sometimes referred to as 'technocratic nationalism' that is based on narrowly bordered interests. The geo-political tensions between the U.S, and China, and the rise of national competitiveness in other countries which is often associated nativism in identity, enhance technocratic or scientific nationalism. At its worst this stance can translate into stigmatisation of cross-border links simply because they are cross-border. Beyond that, the partial mental closure that is entailed in stigmatising broader scientific links begins to shade into the pathologies of climate change denial and populist rejection of science and expertise.

In the U.S. the China Initiative first established by the Trump government has entailed investigations shading into persecutions of some researchers with double scientific locations in the U.S. and China, and discouraged many others from establishing links. It has been associated with racial profiling of Chinese heritage American citizens. A large minority of American scientists are now reluctant to work with Chinese scientists.

> Scientific discovery, fundamentally borderless, is being politically bordered. Geopolitical tensions between the US and China have spilled over into academic science, creating challenges for many scientists' ability to fully engage in research and innovation (Lee and Li, 2021).

Visas for doctoral students from China have been restricted, especially in research domains regarded as strategically significant such as AI. The most recent data on research collaborations from the U.S. National Science Board saw a decline in the number of joint China-U.S. papers, from 62,904 in 2020 to 58,546 in 2022, reversing a long pattern of growth (NSB 2024). In many other Western countries, partly because of lobbying by U.S, representatives, research links into China have been problematised and the policy emphasis has shifted from encouraging open collaboration to security politics and risk management. For example, in Australia there has been a sharp decline in the number of China-Australia projects funded by the Australian Research Council. All of this discourages collaborative projects and joint authorship, and reduces university autonomy and academic freedom. Unregulated bottom-up cross-border relationships are less free to shape science.

From time to time, geo-politics have impacted science but this is the first time since the Internet began that the global science system has been compromised. The problems are not confined to relations between Euro-America and China. Scientific truth is the first casualty in war whether it is a cold war or a hot war: the present hot war in Ukraine has generated an extraordinary level of Russian government-instigated disinformation, as well as breaking ties between

Russian universities and their cross-border counterparts, driving some researchers out of Russia and halting much of the scientific investigation in Ukraine. The war between Israel and Palestine in Gaza has also touched academic conditions in many countries. Brexit took the UK out of the EU and researchers in the UK had no access to the European Horizon research programme. British participation has now resumed but has been weakened.

Conclusion: A more truly global science

So, where does global science go from here?

The science debate has just begun. Much will depend on it. Global science has great potential but presently has both upsides and downsides. Scientific knowledge is collective, collaborative and accumulative, a common good that crosses over the separated self-interests of individuals, institutions, companies and nations. At best it looks beyond a nation-bound perspective and thinks at the level of the world as a whole. It is vital to defend and advance this potential. Since the Internet began at the end of the 1980s global science has been open, largely free to evolve, and facilitated the emergence of diverse national nodes and scientific voices. Science can talk truth to power; cutting across all the rubbish in the political space and social media, the fake news and manipulative populism. The reflexivity of science, the mode of judging science, is the test of truth. This is tremendously valuable.

But global science is also culturally fixed, almost exclusively Western in its inherited traditions, language and norms, neo-colonial in form and in the assumptions and relations and worldviews that it fosters. Science is steeply hierarchical inside the global system and has generated a large hinterland, its ‘non-scientific’ other, of knowledge that is excluded. This ‘other’ includes the vast majority of human knowledge, including almost everything in languages other than English, and endogenous/indigenous knowledge from everywhere. This includes indigenous understandings of land, nature and ecology which are more constructive than accumulative capitalism. We lose so much by excluding this diversity.

In short, autonomous global science has been hegemonic and exclusive. Autonomous scientists have been the excluders, though aided and abetted by the publishing and bibliometric world. Now geo-politics threatens to undermine the autonomy of science, lock it into national silos, weaken or fragment the global system. So where do we go from here? We defend the autonomy of global science as best we can – from technological nationalism and from commercial publishers. We push for the further opening of science, not closure. We maintain open cooperation between scientists all over the world. No cold war in science.

The ways forward to more democratic relations of power in science are genuine open access publishing, not fake 'gold open access' where the authors have to pay charges to the publisher, and a global conversation based on multiple languages. Publishers can use the emerging software to translate knowledge in languages other than English into English, and knowledge in English into other languages. There is no reason not to publish all the leading disciplinary journals and books in multiple languages. In face of global problems, knowledge and cooperation are all we have. That makes it essential to bring all of the voices, all the different ways of seeing, all of the insights and ideas, into the common conversation.

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