World Research: Networking, Growth, and Diversification

Simon Marginson

Abstract
Since the Internet began in 1990, there has been rapid worldwide growth in research funding and science paper output. Bottom-up global collaboration has expanded rapidly, many lower middle-income countries have their own science systems, and almost one-quarter of all papers have international coauthors. Research agendas are now often shaped in the global network, not national systems. Research power has become more diversified, with China and East Asia, India, Iran, Brazil, and others becoming stronger.

After the Internet began in 1990, universities and scientific institutes across the world became joined in a single collaborative research network, for the first time in history, and in the manner of networks, global science began to expand continually with exceptional speed. World research is shaped by five simultaneous trends that feed into each other and are transforming the processes whereby human societies create and share knowledge. First, rapid growth in investment in research and in science paper output. Second, expansion in the number of research-active countries with their own science systems. Third, growth in the proportion of papers coauthored from more than one country. Fourth, the increasing weight of the networked global science system compared to national systems. Fifth, the distribution of leading research power among more countries.

OECD data shows that between 1995 and 2018, almost every country expanded its spending on research. This more than doubled in the United States in real terms, almost doubled in Germany and the United Kingdom, and multiplied by 5.6 times in South Korea and by an incredible 16.5 times in China. This growing financial capacity was associated with proportional expansions in numbers of PhD graduates and employed researchers, and published science. Between 2000 and 2015, the number of doctoral graduates increased by 2.9 percent per year in the United States, 4.7 percent in India, and 10.9 percent in China. The total number of papers listed in Scopus rose from 1.072 million in 2000 to 2.556 million in 2018, a growth of 4.95 percent a year, which by historical standards is very rapid.

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Lower Middle-Income Science Countries

The networked global science system has developed as a common storehouse of knowledge. Nations need their own science capacity, including doctoral education, so as to be able to effectively access that storehouse. Collaboration between countries brings in more nations and quickens their development.

Science capacity is spreading across the world. There were 15 countries that published more than 5,000 papers in 2018, where between 2000 and 2018, the number of papers grew faster than the world average rate of 4.95 percent per year. In nine of these 15 fast-growing science countries, incomes per person were *below the world average of US$17,912 in 2018*—in other words, they were lower middle-income countries. In the year 1987, 20 wealthy nations accounted for 90 percent of all published science. By 2017, it took a more mixed group of 32 nations to make up the first 90 percent, indicating this process of global diversification of capacity.

The new science powers include Indonesia, the world's fourth largest country in population, where researchers had 26,948 papers in Scopus in 2018. Indonesia's annual output grew by an incredible 26.4 percent from 2000 to 2018. India, now the third largest producer of science after China and the United States, published 135,788 papers in 2018, and saw an annual growth of 10.7 percent a year in the period from 2000 to 2018. Other fast growing national science systems with more than 5,000 papers in 2018 were Brazil, Colombia, Egypt, Morocco, Nigeria, Pakistan, and Tunisia. Though the United States retains a long lead in the number of high-citation papers, China's published science expanded by 13.6 percent a year between 2000 and 2018 and it passed the total output of US research for the first time in 2016.

The growth of total science is also associated with growth in the number of "world-class universities" with large outputs. The Leiden ranking shows that between the four-year counts of 2006–2009 and 2014–2017, the number of universities with more than 5,000 science papers rose from 131 to 215.

Collaboration

Perhaps the most striking indication of the change in global research is the growing number of papers that involve international partners. In 1970, internationally coauthored papers constituted only 1.9 percent of articles indexed in Web of Science. By 2018, 22.5 percent of all papers in Scopus had more than one national affiliation. The proportion was very high in Europe, where the research grant system favors multicountry teams: for example, 50.2 percent in Italy, 61.7 percent in the United Kingdom, and 71.8 percent in Switzerland. It was 39.2 percent in the United States, well above average, but lower in emerging China, India, and Iran, where the number of potential domestic partners has been growing very rapidly.

International collaboration is especially important in disciplines where equipment is cost shared (e.g., telescopes, synchrotrons), or where the subject matter is intrinsically global (e.g., climate change, water management, epidemic disease). In 2016, 54 percent of all papers in astronomy were internationally coauthored, while in social sciences it was only 15 percent.

Research on the global network by Caroline Wagner, Loet Leydesdorff, and colleagues suggests that collaboration is driven primarily not by national science policy but by bottom-up cooperation among researchers themselves. It expands freely so as to take in new countries and research groups. Existing strong countries do not act as gatekeepers: Researchers in emerging systems often network directly with each other. Increasingly, the agenda of science is set at the global level rather than the national level.

Research is not a level playing field. The United States remains much the strongest player at the global level. English is the only global language, and work in other national languages, especially in the humanities and social sciences, is marginalized at world level. Scientific capacity and achievement are steeply stratified within and between countries. However, the growth and diversification of science are associated with a partial pluralization of research power.

The great change is the rise of East Asia, especially China, South Korea, and Singapore, joining Japan. East Asia is very strong in physical sciences and engineering, less so in life sciences and biomedicine. China is now number one in mathematics and computing research. Tsinghua University has joined MIT in the United States as one of the two top STEM universities in the world. India, Iran, and Brazil are also becoming increasingly important.

Good News

Global research collaboration is a good news story in a difficult time. It is not a dog-eat-dog market. Researchers who compete for status in science also collaborate freely across borders and respect each other. At this stage, global research has not been caught in the vortex of parochial nationalism, and the COVID-19 pandemic has heightened the intrinsic value of global cooperation and open science in biomedicine.

Cross-border research cooperation is less vulnerable than cross-border student mobility and has been maintained during the pandemic. While research benefits from conferences, site-based visits and exchange of personnel, and large laboratories and institutes are inhibited by social distancing protocols, most forms of research cooperation can be sustained for a time online.

The national pushback against globalization and common systems is severely affecting trade and technological cooperation and is a threat in science. It is likely that US–China relations in research, including joint appointments and foreign students in doctoral education, will be disturbed by the new cold war geopolitics between the two countries. However, researchers in each nation, the two powerhouses of world science, will continue to network elsewhere—and US–China cooperation may prove more potent than the Trump administration would want. Providing that the flow of resources supporting research is maintained, total research and collaboration at global levels will continue to increase. ◢

Simon Marginson is professor of higher education at the University of Oxford, director of the ESRC/OFSRE Centre for Global Higher Education in the United Kingdom, a leading researcher with the Higher School of Economics in Moscow, and editor-in-chief of Higher Education. *E-mail: simon.marginson@education.ox.ac.uk.*

This article is taken from chapter 3 of Claire Callender, William Locke, and Simon Marginson (2020), Changing Higher Education for a Changing World. *London: Bloomsbury. Some data has been updated.*