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The Spread of Science

When Clark Kerr wrote *The Uses of the University* in 1963, world scientific capacity was concentrated in North America, Great Britain, Western Europe, and Russia. There was limited exchange between the Western nations and science in Russia. Japan built its government science laboratories and research universities in the 1970s. Though from time to time nationals from other countries contributed important discoveries, they nearly always did so in the laboratories of one of the leading science powers. In some science systems, including those of the English-speaking nations, research capacity was primarily concentrated in large higher education institutions of the multiversity type. In others, including France, Germany, and Russia, separate public research agencies played the primary role in many fields of science, leading doctoral training or sharing it with the universities. In Russia many of the universities were specialist institutions confined to specific disciplines and linked to particular government ministries, though the national flagship Moscow State University was comprehensive in form. Following the Russian example, China also adopted the dual model of scientific research and established more specialist higher education institutions than multiversities. Before the 1990s, research in China was underdeveloped and had a negligible global role.

In sum, the spread of scientific capacity was limited, as was the reach of the multiversity, and they were not always in the same places. Some nations in Europe, Latin America, and Asia had comprehensive universities of the multiversity type in terms of disciplines but were minor players in the science literature. Many nations sent bright students to the United States, Britain, or Western Europe for doctoral training, but only some of those that returned remained active in research.

In the 1990s communicative globalization changed the structure of scientific practice. This was another development led from California: information and communications technologies at Stanford and Berkeley and in Silicon Valley in the 1980s led to the personal computer and then to the World Wide Web. In the early 1990s Internet penetration began to spread. In *The Rise of the Network Society,* first published in 1996, Manuel Castells explains the economic logic of network growth: "The morphology of the network seems to be well adapted to increasing complexity of interaction and to unpredictable patterns of development arising from the creative power of such interaction," states Castells. "Yet this networking logic is needed to structure the unstructured while preserving flexibility, since the unstructured is the driving force of innovation in human activity." Further, he argues, "when networks diffuse, their growth becomes exponential, as the benefits of being in the network grow exponentially, because of the greater number of connections, and the cost grows in a linear pattern. Besides, the penalty for being outside the network increases with the network's growth because of the declining number of opportunities in reaching other elements outside the network."[1]

In a partly networked environment, the opportunity costs of exclusion grow over time. Yet in electronic networks, the unit cost of each new connection is negligible. These two facts together drive explosive growth until universal coverage is reached. So it has been with the Internet. There were 14 million users worldwide in 1993, 121 million in 1997, and 501 million in 2001, 8.1 percent of the world's population.[2] Scientific communities and research universities were often early adopters, ahead of business and government. All research universities became immediately visible to each other as part of a single networked community. Cross-border e-mail ballooned. Potentials for active collaboration were much expanded. The Internet enabled complex data transfer and as bandwidths and technology improved, so did the use of video communications for meetings. In disciplinary conversations in research universities, suddenly everyone was in synchrony with everyone else. With journals and papers published on the Web instantly accessed from everywhere, the Internet soon came to constitute a single world library of scientific knowledge that was continually updated. Because of the dominance of the English-speaking countries (principally the United States) in business, research, and the Internet itself, that single world library and most cross-border research communication were in the English language. The older global roles of French, German, and Russian faded. Spanish, Chinese, and Arabic had global potentials but were yet to establish themselves in more than regional science.

Here the growth and diversification of disciplinary knowledge, with its endless multiplication of specialisms (a process long endemic to higher education, as Bob Clark had pointed out), became joined to the new multiplication of networks, nodes, and participants. Conversation splintered and combined within one communicative grid. In this setting, strategic institutional creativity and intellectual creativity catalyzed each other, though they were not the same process. Bob Clark captures the international dimension emerging in the late 1990s in *Creating Entrepreneurial Universities:*

> Internationally, no one controls the production, reformulation and distribution of knowledge. Fields of knowledge are the ultimate uncontrollable force. . . . Just by itself, the faculty of a university, department by department, expresses an inexhaustible appetite for expansion in funding, personnel, students and space. Rampaging knowledge is a particularly penetrating demand, rooted in the building blocks of the system: it shapes basic-unit orientation, organization and practice. Since it has no stopping place, it never ceases. As one field after another stretches across national boundaries and brings more parts of universities into a truly international world of science and education, growth in the knowledge specialities also becomes the ultimate internationalizing force for the higher education sector of society.[3]

THE GLOBAL SCIENCE SYSTEM

The Internet has mediated the emergence of a single system of global science and technology in English. Charles Vest calls this "an evolving global meta-university."[4] Prior to the Internet, there was a worldwide conversation in most disciplines. What has changed is the fluency and volume of that conversation, so that the visible pool of common knowledge has larger presence and coherence. In turn, this change has reworked the balance between national and global elements. Lex Borghans and Frank Cörvers note: "If the transferability of research findings increases, the costs of international research decrease, or the scale effects increase, researchers participating in the national debate will switch to the international debate when this threshold is reached."[5] The Internet increased transferability and decreased the costs of collaboration, while enhancing the number of researchers that could be brought in. It also rendered communications instantaneous. These effects were all substantial.

The global science system has not consumed national science systems. It has changed and relativized them. In all countries apart from the United States, the vast bulk of innovations, whether in basic research or in commercial applications, are sourced not from national science systems but from the global science system. Even in the United States, global knowledge has become crucial in most disciplines. The majority of high-citation papers are now published by non-Americans, a significant change. According to the National Science Foundation, 26.6 percent of the journal papers published in 2008–2010 had American authors, as did 46.4 percent of the leading papers by citation rate (the 1 percent of world papers most cited) through the year 2012. American science was very strong in 2012 but was not as dominant as it had been ten years before, in 2002, when 57.0 percent of the top 1 percent papers had American authors. In other words, the citation measure indicates that between 2002 and 2012 the role of non-American countries in leading science expanded from 43.0 to 53.6 percent of top 1 percent papers.[6]

Since World War II there has been a continuous expansion in the role of knowledge-intensive production, a trend that exercised Clark Kerr in *The Uses of the University.* For all nations, the ability to access the global science and technology system is now essential to scientific effectiveness and industrial competitiveness. To access the global science system, nations need their own trained scientific capability. They need to be able to interpret, understand, and apply global science; to do this, they must actively engage in it. This means that they need their own trained personnel, capable not only of understanding research but also of making it and collaborating with others who do so. This means that nations also need their own infrastructure, including doctoral training in at least some disciplines. Those that lack indigenous research capacity are locked into continuing dependence and locked out of new technologies and knowledge-intensive production. The outcome is that research science is no longer the preserve of North America, the United Kingdom, Western Europe, Russia, and Japan. It has moved from the margins to normal business in both established and emerging states. All nations need science capacity—though not all can pay for it—just as they need clean water, stable governance, and a globally viable finance sector.

In policy, the spread of science is imagined as an arms race in innovation. Yet states lack purchase on innovation. International comparisons in that domain are elusive and few governments direct business activity (China is one exception). Policy makers provide tax breaks and other schemes to encourage industry-related R & D but more directly focus on science output in universities and state-sector laboratories, where they provide the funds, enjoy policy sway, and have visible indicators. Global research rankings allow states to compare nations and identify their competitive position. It is ironic that the shift in the balance between national science systems and the global science system has fostered national capacity building in many countries, and the growing importance of research and commercial applications in industry and national security has strengthened the policy emphasis on building basic science.

Global rankings also point policy towards basic science. Emphasis on science has been central to American federal policy since the Manhattan Project, Hiroshima, and Vannevar Bush's report *Science: The Endless Frontier* (1945).[7] At a world level, the policy emphasis on science—not just research but education in the STEM disciplines (science, technology, engineering, and mathematics)—has been intensifying for the last fifty years. This tendency in policy is associated with the growth of total scientific output, the spread of science capacity to more nations, the growing impact of global rankings on state policies and institutional management and on increasing the number of high-prestige science universities, and the global hegemony of a post-Kerr version of the California multiversity—the large,

TABLE 10.1. Annual output of published journal papers in science, 1995–2011

	1995	2000	2005	2010	2011	2011 (1995=1.00)	Average annual growth 1995–2011
World	564,645	630,459	710,294	799,599	827,705	1.47	2.4%
United States	193,337	192,746	205,565	209,542	212,394	1.10	0.6%
European Union	195,897	222,688	235,121	250,031	254,482	1.30	1.6%
Russia	18,604	17,181	14,425	13,500	14,151	0.76	---
China	9061	18,479	41,604	79,991	89,894	9.92	15.4%

SOURCE: Adapted by Author using data from NSF 2014. Original data from Thomson-Reuters Science Citation Index and Social Science Citation Index

NOTE: Includes selected social science but not humanities.

comprehensive science university that is not only multiple but entrepreneurial and increasingly performance managed, to ensure that science output is maximized and brought into dock with industry.

The output of published journal papers in science and social science has grown steadily at world level in the last two decades. Output rose from 564,645 papers in 1995 to 827,705 in 2011, or 46.6 percent growth in sixteen years, at an annual rate of increase of 2.4 percent (table 10.1).[8] Part of the growth reflects an expansion of capacity. Part of the growth reflects pressures to publish in performance-oriented universities, especially in countries keen to accelerate their evidence of scientific progress: an expanding journal list feeds these ambitions. Nevertheless, signs of the new science countries are unmistakable. Most of the growth has been concentrated in emerging science systems in East and Southeast Asia, Southern and Eastern Europe, the Middle East and North Africa, and Latin America. The standout is China. In China between 1995 to 2011 the annual output of science papers rose by 892.0 percent, at the remarkable rate of annual increase of 15.4 percent. In Iran, journal paper numbers increased from just 280 in 1995 to 8,176 in 2011, constituting a growth rate of 23.5 percent a year, the highest in the world among significant research nations. Much of this output was concentrated in the physical sciences. Other nations with rapid growth in journal output included South Korea, Turkey, and Brazil. Table 10.2 has details. In 1995, thirty-seven nations each published at least one thousand research papers per year, a benchmark which indicates an indigenous capacity to generate science in at least some disciplines.[9] By 2011 the number of such nations with their own science system was fifty, now including Chile, Romania, Slovenia, Croatia, Serbia, Tunisia, Iran, Pakistan, Malaysia, and Thailand.

In the established research countries, some of the same performance pressures apply, but the growth of scientific output has been much more modest. Between

TABLE 10.2. Fastest-growing national science systems, by country, 1995–2011

	Published journal papers in:		Average annual growth, 1995–2011
	1995	2011	
Iran	280	8,176	23.5%
China	9,061	89,894	15.4%
Tunisia	143	1,016	13.0%
South Korea	3,803	25,593	12.7%
Thailand	340	2,304	12.7%
Malaysia	366	2,092	11.5%
Turkey	1,715	8,328	10.4%
Portugal	990	4,626	10.1%
Pakistan	313	1,268	9.1%
Singapore	1,141	4,543	9.0%
Brazil	3,436	13,148	8.7%
Taiwan	4,759	14,809	7.4%

SOURCE: Adapted by author, using data from NSF 2014.
CRITERIA: 1,000 papers in 2011, growth rate of more than 7.0% per annum.

1995 and 2011, there was low growth in journal papers in Germany and France and little change in the United Kingdom. U.S. journal-paper output, three-quarters of which was generated in universities, rose 9.9 percent, at an annual rate of 0.6 percent. In Japan, paper volume rose by 21.3 percent between 1995 and 2000 and then fell by 17.5 percent between 2000 and 2011. In Russia output fell dramatically, by 23.9 percent between 1995 and 2011. Research infrastructure built in the Soviet period has not been adequately renewed, and Russian science and technology are not as strongly engaged with global science as those of many other countries. In some sciences the published conversations are largely conducted in the Russian language.[10] However, Japan and Russia are exceptional. Elsewhere global scientific output has been stable or has grown.

At the same time, foreign collaboration has increased at pace within the expanding networks of global science, reflecting the ease of collaboration via the Internet. Between 1997 and 2012, the proportion of papers with international coauthorship rose from 16 percent to 25 percent. In many countries a majority of papers are coauthored across borders: in 2012 there was intensive coauthorship within the Europe Research Area and between Asian countries. People working in large science systems, such as that of the United States, are less likely to coauthor abroad because a high number of domestic partners are available. However, the United States had high-intensity collaboration in Canada, Mexico, Chile, Israel, China, South Korea, and Taiwan relative to the overall pattern of collaborations by each pair of nations.[11]