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Exponential Growth and the Shifting Global Center of Gravity of Science Production, 1900–2011

Liang Zhang[a], Justin J.W. Powell[b] & David P. Baker[a]
[a] The Pennsylvania State University
[b] University of Luxembourg
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EXPONENTIAL GROWTH

and the Shifting Global Center of Gravity of Science Production, 1900–2011

By Liang Zhang, Justin J.W. Powell, and David P. Baker

Long historical trends in scientific discovery led mid-20th century scientometricians to mark the advent of "big science"—extensive science production (de Solla Price, 1961, 1963). They also predicted that over the next few decades, the exponential growth would slow, resulting in lower rates of increase in production at the upper limit of a logistic curve.

They were wrong. A new systematic estimate of the number of worldwide science publications from 1900–2011 shows that, in fact, "big science" was itself transformed by unprecedented production beginning just after mid-century, with no decline or slowing of exponential growth up to today. Two contrasting concurrent trends—rising competition across nations and international collaboration among scientists—have facilitated this remarkable growth.

Over the first four decades of the 20th century, the world's "center of gravity" of scientific publications moved steadily westward and slightly southward—reflecting the burgeoning science capacity of the United States, supported by its massive expansion of higher education, technological innovation, and overall economic growth.

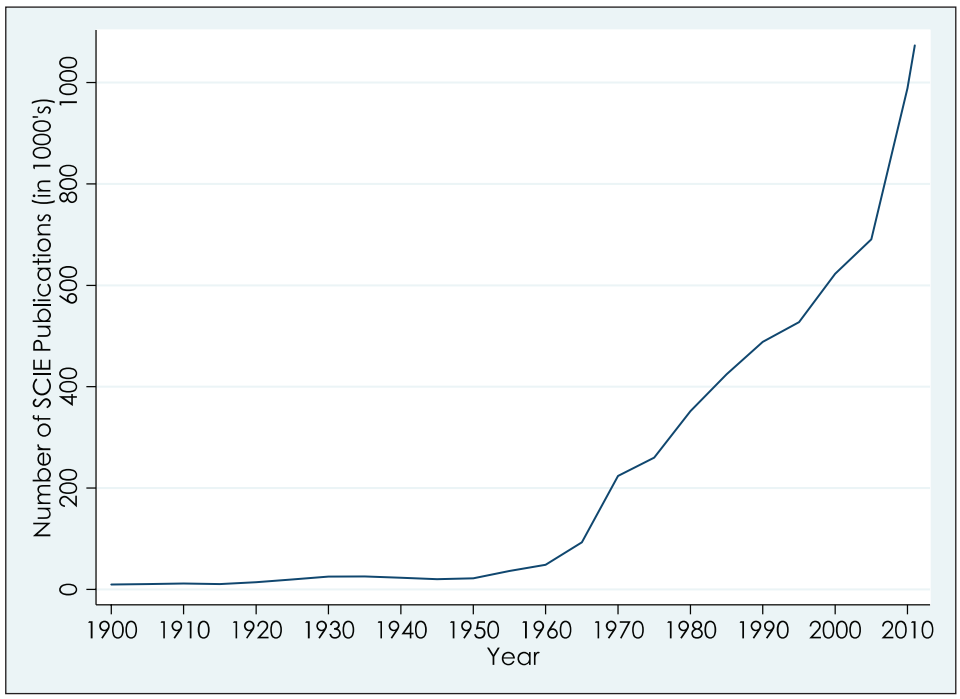
However, beginning in the 1950s and for the next 60 years, the global scientific center of gravity traveled eastward, first powered by rebuilt European science systems in the 1950s, then by expanded capacity in East Asia, especially in Japan (1970s–present), China (1980s–present), and South Korea (1980s–present). At the same time, there has been substantial and growing international collaboration, particularly from 1980 onward.

Our analysis of millions of Science Citation Index Expanded (SCIE) publications shows that the number of research papers published in scientific journals over the 20th century grew rapidly (see Figure 1). Starting from slightly below 10,000 in 1900, the annual number of new SCIE publications grew to about 50,000 in 1955. This early trend, often referred to as "big science," was then transformed into what can be called "mega global science": An exponential annual growth rate growth rate of 3.49 percent between 1980 and 2011 led to a half a million SCIE publications in 1990 and about 1.1 million new SCIE publications in the year 2011 alone.

> **New world pattern emerged in the middle of the century as the scientific center of gravity turned back east.**

Liang Zhang (lxz19@psu.edu) is an associate professor of education and labor studies at The Pennsylvania State University. Justin J.W. Powell (justin.powell@uni.lu) is a professor of sociology of education at the University of Luxembourg. David P. Baker (dpb4@psu.edu) is a professor of education and sociology at The Pennsylvania State University.

Figure 1. Annual Number of SCIE Publications Worldwide (1900–2011)



Source: Science Productivity, Higher Education Development and the Knowledge Society (SPHERE) database, based on Thomson Reuters' (TR) Web of Science Publication Data and its Science Citation Index Expanded (SCIE).

It is generally recognized that recent unprecedented science productivity is partially a result of a significant rise in the volume of SCIE publications from scientists in a growing number of nations (UK Royal Society, 2011). The ten countries that produced the most SCIE publications (in 1000s) in 2011 and their average annual growth rate between 1980 and 2011 are the United States (282, 2.63 percent), China (153, 17.61 percent), Germany (80, 3.35 percent), the United Kingdom (74, 2.99 percent), Japan (69, 3.60 percent), France (57, 3.31 percent), Canada (46, 3.80 percent), Italy (46, 5.79 percent), India (43, 4.80 percent), and Spain (41, 8.82 percent). What is not known is that these trends of global diffusion and regional differentiation began earlier in the 20th century.

This is evident in the shift of the global center of gravity of SCIE publications over the century shown by the red line in Figure 2 as the annual weighted geographic centroid of each country by the number of SCIE publications produced in that country.

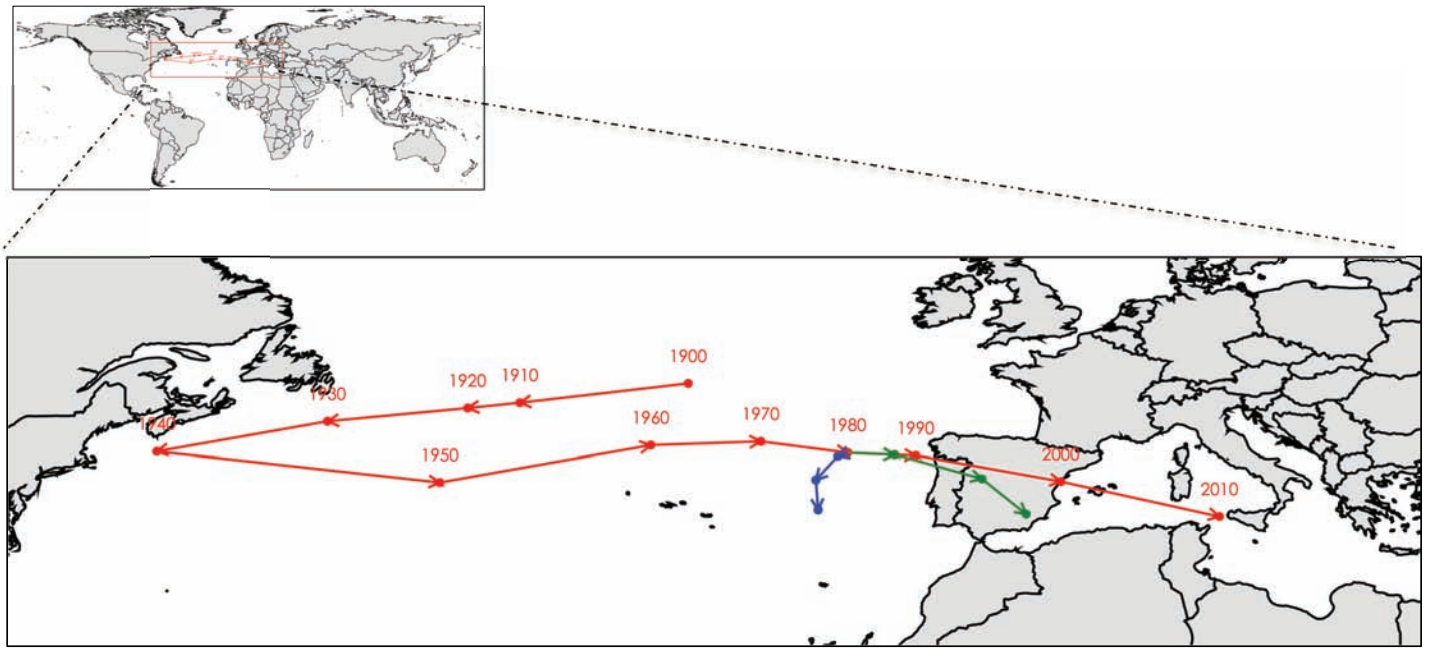
By 1900, the global center of SCIE production had already moved significantly west of the founding European centers of modern scientific inquiry. Early in the 20th century, France, Germany, the United Kingdom and the United States largely dominated scientific production, with the last in marked ascendancy.

Over the next 40 years, US universities, emulating the model of the German research university preeminent in the early 20th century, became increasingly productive (Baker, 2014; Geiger, 1986). But despite the victory of WWII and massive investments in higher education and science, American dominance began to decrease. Like the trajectory of the world's center of economic gravity (Dobbs et al., 2012), a new world pattern emerged in the middle of the century as the scientific center of gravity turned back east, beginning the trajectory it has charted for the ensuing 60 years.

Global competition for scientific impact is no longer solely an Atlantic battle but rather one that pits the superpowers—the United States and China—against each other, along with the many less populous countries of Western Europe with their highly productive science systems. Although growth in SCIE publications significantly decreased in Japan during the 1990s, the rise of other Asian countries—in particular China and South Korea (which ranked 11th in 2011, with an annual growth of over 20 percent since 1980)—pulled the center of gravity further eastward across the North Atlantic during the past two decades, at a pace of about 0.90 degree per annum, passing the prime meridian in 2000. This dramatic change in direction is a function of both fast growth in East Asian countries and slowing growth (in fact: *relative* decline) in scientific production in the United States, which has posted an average annual growth one full percentage point lower than the world average since 1980s.

The relative impact of contemporary growth in SCIE publications from scientists in more recently developed Asian nations is illustrated by the counterfactual analysis in

Figure 2. Evolution of the Global Center of Gravity of SCIE Publications (1900–2010)



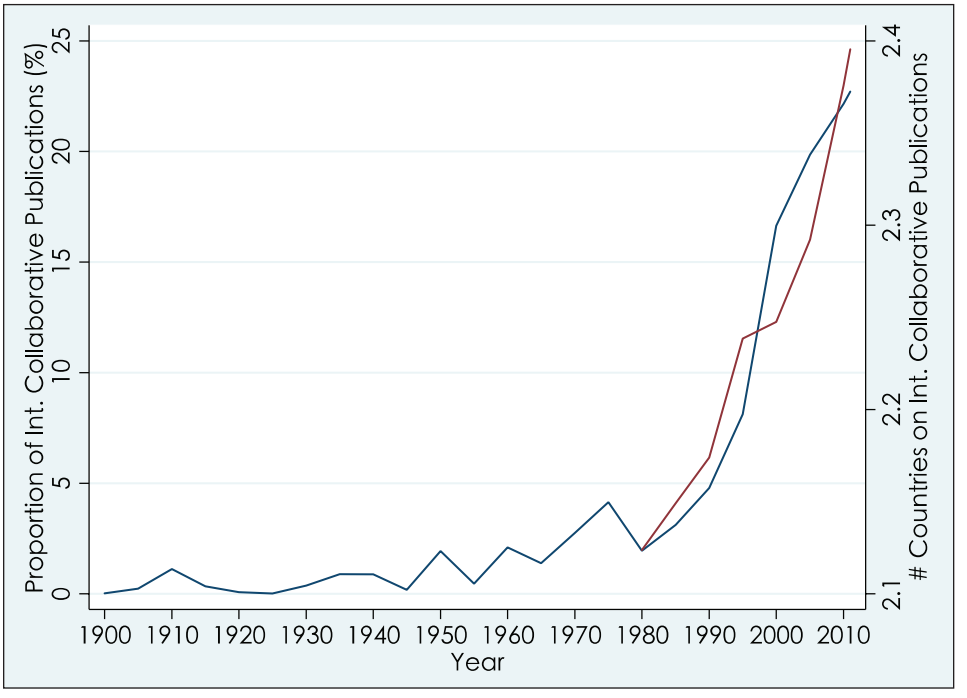
Source: Science Productivity, Higher Education Development and the Knowledge Society (SPHERE) database.

Figure 2, where the green line assumes that China and South Korea had grown at the same rate as the rest of the world from 1980 to 2010 and the blue line assumes that the United States, China, and South Korea all had grown at the same rate as the rest of the world.

The fact that these lines are pulled off of the actual red line indicates that the rapid growth in China and South Korea and relative decline in the US growth contribute about equally to the eastward shift in the center of gravity since 1980; further, without this dynamic between Asia and North America, the blue line travels south, pulled by strong SCIE publication growth from Brazil and Australia.

Concurrent with the development of much science policy aimed at advancing national capacity to compete globally,

Figure 3. Proportion of Internationally Collaborative SCIE Publications and Average Number of Countries Contributing to Collaborative Publications (1900–2011)



Source: Science Productivity, Higher Education Development and the Knowledge Society (SPHERE) database.

> **Cutting-edge knowledge production increasingly relies on building international and intercultural bridges between scholars.**

collaboration by teams of scientists based in multiple nations not only increased after mid-century but entered an uninterrupted period of exponential growth from 1980. The dark blue line in Figure 3 represents the proportion of all SCIE papers that have authors based in institutions from two or more countries—internationally collaborative papers.

Whereas in 1980, only about 2 percent of all SCIE publications were internationally collaborative, just three decades later, this proportion climbed eleven times. Currently, over one in five papers are internationally collaborative, driven by rising exchanges, the dominance of the English language, and Internet-based networks.

The maroon line represents the average number of national locations of authors writing those internationally collaborative papers; this increased from just over two countries in 1980 to almost two and a half in 2011. More than ever, scientific production reflects not only regional competition but also—in an era of heightened global flows of academics and scientific knowledge within strengthened worldwide networks—the growing collaboration among scientists worldwide.

The unprecedented, exponential growth in article production reflects the increased importance of science in countries worldwide. The shifting center of gravity away from the United States emphasizes its relative decline as Asian and European countries invest heavily in their national higher education and research capacity.

At the same time, cutting-edge knowledge production increasingly relies on building international and intercultural bridges between scholars. Thus, research and development requires investment not only in individuals within organizations but also in the networks, connections, and exchanges that facilitate discoveries. Competition is complemented by collaboration.

The simultaneous shift and eastward movement of the centers of economic prosperity (Dobbs et al., 2012) and scientific production since the 1950s is not surprising. Economic development provides the resources necessary for scientific production, which in turn spurs further economic growth. Although causality cannot be inferred from this concurrent movement, decades of economic research have shown that education, science, and technology have played crucial and mutually reinforcing roles in economic growth (Goldin & Katz, 2009; Romer, 1986; Solow, 1957). They are likely to do so even more in an increasingly knowledge-driven global economy. C

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Resources

- Baker, D. P. (2014). *The schooled society: The educational transformation of global culture.* Stanford, CA: Stanford University Press.
- de Solla Price, D. J. (1961). *Science since Babylon*. New Haven, CT: Yale University Press.
- de Solla Price, D. J. (1963). *Little science, big science, and beyond*. New York, NY: Columbia University Press.
- Dobbs, R., Remes, J., Manyika, J., Roxburgh, C., Smit, S., & Schaer, F. (2012). *Urban world: Cities and the rise of the consuming class.* McKinsey Global Institute. Retrieved from http://www.mckinsey.com/insights/urbanization/urban_world_cities_and_the_rise_of_the_consuming_class
- Geiger, R. L. (1986). *To advance knowledge: The growth of American research universities, 1900–1940*. New York, NY: Oxford University Press.
- Goldin, C. D., & Katz, L. F. (2009). *The race between education and technology*. Cambridge, MA: Harvard University Press.
- Romer, P. M. (1986). Increasing returns and long-run growth. *The Journal of Political Economy*, 1002–1037.
- Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics*, 312–320.
- UK Royal Society (2011). *Knowledge, networks, and nations: Global scientific collaborations in the 21 century*. London, UK: Author.