# A Bigger Bang for the Buck: Trends, Causes, and Implications of the Globalization of Science and Technology

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The world has changed rapidly in many respects, but for scholars studying advances in science and technology (S&T) and its commercialization through innovation within firms, the rapid globalization of S&T since the 1990s has been both remarkable and also something of a puzzle in at least two respects.[1] First, the speed of the globalization of S&T in the private and public spheres is unprecedented. Second, the direction of globalization marks a distinct break from past trends because it has encompassed some fast-growing urban regions in countries (e.g., some regions in Ireland, India, and China) that, until very recently, have not engaged in activities near the scientific frontier that depend on a substantial scientific infrastructure.

Despite the increasingly global nature of S&T activity, most technological activity is still overwhelmingly concentrated in developed, high-income countries. Although some middle-income countries have gained, most low-income countries have remained outside the ambit of international technological activity. Many S&T indicators reveal the existence of this divide. Even middle-income countries still depend on technology transfers from developed economies for solutions to mainly domestic problems (e.g., combatting diseases such as malaria or securing cheaper energy sources—issues that concern primarily middle-income countries). Some lower-middle-income countries have been able to take advantage of greater openness in international trade and in the expansion of cross-border intellectual property markets to build basic technological capabilities as measured by licensing revenues, although generally they have not been able to acquire the more advanced capabilities associated with R&D and patents.[2]

These trends are not surprising: technological catch-up and technology diffusion are slow evolutionary processes. Nevertheless, the rapid internationalization of S&T in the 1990s is still remarkable and differs from earlier periods in its globalization. Studying the factors that influence this process and what they imply for policy is the focus of this chapter.

## The internationalization of S&T

S&T activities are traditionally thought of as 'sticky' to the context of development and also as dependent on networks of scientists that are often bound to particular schools of thought. For quite a long period, such schools of thought were local or even regional; more recent times saw scientific communities competing in a race to discover particular solutions to common problems.[3] Firms, using technology as a competitive tool, also tended to keep much of their R&D effort in a single location quite close to their headquarters, leading some authors to contend that private R&D was a curious 'case of non-globalization'.[4]

A large number of S&T indicators confirm that this picture is changing and scientific endeavours are becoming increasingly global, although this globalization of S&T is limited to high-income and middle-income countries. One common indicator used to look at the internationalization of public science is the *international co-authorship of publications*. Based on data from Elsevier's Scopus database, the Royal Society (2011) estimates that over 35% of all scientific articles were internationally co-authored in 2011—up from 25% in 1996. Using a slightly different database of published work, the ISI Web of Science, Wagner and Leydesdorff (2005b) estimate that the share of international co-authored publications doubled between 1990 and 2000, rising from 8.7% to 15.6% of all published scientific papers.

Wagner and Leydesdorff (2005a) also show that the rise in international collaboration in public science is marked both by an increased participation of countries and by greater interaction by those participating countries. Thus the core of collaborating countries rose from 37 countries in 1990 to 54 in 2000. This growth is largely the result of the entry of Eastern European 'transition' economies and the Commonwealth of Independent States (CIS) economies, Latin American countries such as Mexico and Chile, and East Asian economies such as Singapore, Taiwan (Province of China), and the Republic of Korea.[5] Even more interesting is the documentation of the rise in collaborative country pairs—the number of countries that collaborated with at least one other country rose from 103 in 1990 to 128 in 2000 (representing about 58% and 65%, respectively, of all countries producing published papers); while those collaborating with more than one country rose from 41 to 61 countries in the same period.[6]

These trends towards the internationalization of public science should not mask the fact that most publications still emerge largely from high- and middle-income countries. UNESCO shows that high-income countries still accounted for over 70% of all publications in 2014,[7] even though this share fell from 79% in 2008. During the same period, upper-middle-income countries saw a huge boost in share, climbing from just under 21% to over 32%. The growth registered by lower-middle-income countries was modest (1 percentage point, from 5.7% to 6.8%), and low-income countries saw hardly any change in shares (from 0.4% to 0.6%). China clearly dominates the result for upper-middle-income countries, with a doubling of its share of publications from 10% to 20% between 2008 and 2014.

Similarly, it has sometimes been argued that the strategic importance of R&D activities within firms to the competitiveness of those firms makes such activities notoriously 'non-global' and more likely to be local.[8] Yet the trends noted for the globalization of public science are mirrored in the growing *share of international R&D* by firms. Dunning and Lundan (2008) estimate that, in 1982, 30% of production and 12% of innovatory capacity of the world's largest companies were located overseas. By 2005, European firms were conducting over 40% of their R&D overseas. On average, smaller countries were more internationalized in their R&D activities than larger countries.[9] Thus, although US firms doubled their overseas R&D, their share rose from only 7% in 1982 to 15% in 2005.

Even more striking is the *dispersion of international R&D activity* across regions. Dunning and Lundan (2008) estimate that until 1994, more than two-thirds of overseas R&D by US firms was based in just six countries: Canada, France, Germany, Japan, Sweden, and the United Kingdom. Since 1994 this group has grown to include four new destinations: China, Israel, Ireland, and Singapore. Many of these are the same countries that are increasingly opening up for collaboration in public science, as noted by Wagner and Leydesdorff (2005a).

A third type of indicator frequently used to demonstrate the increasingly global nature of (private) inventive activity is the *incidence of co-invented patents.* Kerr and Kerr (2015) found, based on an exhaustive study of US patent documents, that global inventor teams have become surprisingly prominent and that, on average, 6% of the worldwide patents of US multinational corporations in 2004 are co-invented. They find that the ethnic composition of the United States of America (USA)-based firm's inventive workforce is an important factor in whether the firm engages in international collaboration.

Higher shares of collaborative patents are also observed when a US publicly held (private) company is entering into a new foreign region for innovative work; Branstetter et al. (2015) show this to be especially true of R&D work undertaken in India and China. In a large fraction of these cases, an inventor moving across borders within the firm is also evident, suggesting that the migration of scientists is part and parcel of the new internationalization of private R&D.

## Long-term causes of the most recent globalization of S&T

These trends in the globalization of S&T in the 1990s (observed in a variety of different indicators, as noted above) reflect the influence of several long-term factors that have dramatically shifted innovation from a local phenomenon to an increasingly global and networked one.

The first of these factors is the opening up of the world economy, which took place for several reasons. The countries that had been part of Communist Europe desired institutional reform and greater integration into the global economy. Many developing countries were disenchanted with the import-substituting model of growth and development. Even large economies such as China, India, and Brazil, which had developed strong industrial bases for economic growth using the import substituting model, could no longer continue without opening up their economies to international trade and foreign investments. A key common factor across the large developing economies and former Eastern European countries was that they had access to new technologies and new knowledge networks that were more and more international in character. In other words, these countries—although technologically more capable—could no longer stand alone and depend on reverse engineering to meet their technological needs.

In the technological sphere, the development of a new techno-economic paradigm driven by advances in information and communication technologies (ICTs) was already transforming the industrial landscape; this proved to be the second important factor driving the tendency towards the internationalization of S&T. Advances such as powerful computers and new forms of technological convergence made technologies more complex than they had been in the past. The impact of ICTs is seen in several dimensions. First, products became multi-technology.[10] Cars were no longer exclusively about mechanical engineering but included sophisticated electronics that improved the travel experience with music and air-conditioning and many other features that we now take for granted. Another product that exemplifies the technological complexity caused by ICT convergence is the telephone. It was transformed from a receiver and sender of analogue radio waves to a mini, mobile office by the end of the 20th century.

The impact of the new techno-economic paradigm also extended to the costs of innovation. Powerful computers drove down these costs. Expensive trial-and-error processes and prototyping were replaced by simulation and computer-aided design (CAD) technologies.[11] The falling costs of communication and the dramatic connectivity allowed by Internet technologies have enabled specialization based on global markets. What began as a quest for efficiency in production soon snowballed into the fragmentation of production systems where value chains become more and more subdivided and specialized across different nations and geographies.

Third, ICT use in firms became progressively associated with the use of external knowledge and the development of global R&D teams rather than local R&D teams. This was inevitable because knowledge bases became more interlinked and interdependent. The best example of this growing openness in innovation is the pharmaceutical industry, long upheld as the canonical example of R&D-based closed innovation. Developments in biotechnology pointed to the existence of different pathways for achieving the same therapeutic effect. The impact of this on the pharmaceutical industry was to force the drug companies to be more open to other complementary knowledge bases. Patent data reveal this interdependence of knowledge bases most starkly. In the 1970s, backward citations to patents (which reflect the scientific and technological knowledge upon which the focal patent is building) most often came from the same technology field as the focal patent. Today two-thirds of the backward citations in a focal patent come from outside its own field.[12]

A fourth (more subtle) factor driving the internationalization of S&T is the growing demographic divide in the world economy, which increasingly has dictated where global R&D is located. Even as new technologies such as ICTs and advances in biotechnology raised the premium for scientific skills in the workforce, the populations of the advanced countries within which these technologies have developed are ageing. This demographic change makes the accumulation of such skills in large enough quantities to meet the skills needs of industries expensive unless the country resorts to globalization through the in-migration of scientific labour or the internationalization of R&D.

Demographers at the United Nations Population Division project that, over the next four decades, most of the large decreases in working-age populations will be concentrated in the economies in the Organisation for Economic Co-operation and Development (OECD). Of the advanced economies, Japan is projected to lose the most by this trend; the USA is projected to lose the least. Although the beginnings of this decline in fertility are different in different economies, evidence presented by Kent and Haub (2005) suggest that, for some EU countries (such as France and Italy) the process had already begun by the mid-1970s; in Japan, it gathered pace beginning in the mid-1980s. Kent and Haub estimate that, from 2005 to 2050, EU-27 countries will lose 19% of their working-age population (or 64 million workers), while Japan will lose twice as much. Only four EU countries—Ireland, Luxembourg, Sweden, and the United Kingdom (UK)—along with the USA are projected to see some growth in their working-age population. A large part of the ability to avert the crisis in these nations is attributed to a higher birth rate among migrant populations.

Although the impact of a greying population has been at the forefront of concerns about how best to limit welfare spending and address a pending pensions crisis, scholars have not linked these long-term demographic trends and the private and public responses in favour of increasing globalization of S&T. With a shrinking working-age population, many OECD countries would need a larger proportion of their population to study science and engineering to generate the existing stock levels of national science and engineering graduates. Yet many advanced countries currently face a vocational decline in science and engineering: in many countries, the number of available places is often not matched by qualified applicants. Therefore other complementary, short-term measures have been put into place to raise the size and availability of a diverse scientific workforce. In Australia, Canada, the UK, and the USA, a selective migration policy encouraging the in-migration of scientific labour has been key to resolving skill shortages and maintaining the competitive edge of these nations. Arslan et al. (2014) estimate that, in 2010–11, the number of working-age migrants (15 years and older) was 106 million; this represents a 38% growth from 2000–01. Most were African and Asian migrants (about 50%), but in the OECD region, Mexican, Indian, Romanian, Chinese, and Polish migrants accounted for a quarter of all migration. Furthermore, about 35 million migrants in the OECD nations had a tertiary education, and a third of these came from Asia. This level of tertiary educated migrants represents an unprecedented increase of 70% from 2000 to 2010.

The migration of skilled labour to technology centres and the migration of capital investment to regions with large numbers of scientifically skilled workers have been almost as important as the growing international trade in goods.[13] With the large-scale movement of educated people and the fall in communication costs resulting from the growth of ICTs, the rapid internationalization of S&T is hardly a surprising result. Indeed, it has created a virtuous circle.

The internationalization of universities in OECD countries has, in turn, had a profound effect on public science. Sociologists now speak of communities of practice as generating social networks of scientists that are almost as important as local communities in their effect on innovation. Such communities share a passion or problem that they are prepared to address together, often using communication platforms such as fairs and conferences and, increasingly, Internet platforms.[14] Evidence of the effect of such communities is evident in many metrics, but a notable one is that the growth of citations to papers has been far greater than the growth in published papers. The Royal Society (2011) finds that the career paths of several Nobel Prize–winning scientists evidence the impact of global education and global collaboration in the advance of cutting-edge scientific work.

The private sector of many advanced countries reacted to the growing shortages in skilled labour differently than universities and public-sector labs: by moving capital to locations where scientific labour is abundantly available. The availability of scientific labour is seen as a key driver of R&D offshoring to emerging economies and countries in Asia. Not surprisingly, private firms responding to the cost and availability of scientific labour choose to locate their R&D where these constraints are most alleviated. The stickiness of technology and context is still a problem, but one that is increasingly being managed globally through inventors crossing borders and through knowledge management in global teams.

## Implications for S&T policy

The globalization of S&T that began in the 1990s has been marked by a greater interconnectivity in economic activity between different regions—both because new ICTs enabled this connectivity and because economic circumstances surrounding many innovations required drawing on dispersed but specialized science capabilities. In the policy domain, these trends in the internationalization of S&T have stoked new anxieties. The emergence of new nations as contributors to public science and as destinations for international R&D has inevitably meant a loss of publication and patent shares by OECD countries in favour of the new S&T regions. Many developed economy governments now worry about the 'hollowing out' of innovative capability and loss of competitiveness to the emerging scientific nations, increasingly seen as contenders rather than collaborators.

This analysis of the causes of the internationalization of S&T suggests that the interdependence of knowledge (and therefore geographies) is its key driver. Existing data on collaborations, patents (both co-invention and citations), and alliances are all available at a national or technology-specific level of analysis. Geographical interdependence may not always be at national levels but instead may be seen at regional levels, as indicated by the literature on clusters that are centres of innovation (such as Silicon Valley in the USA; the Hsinchu Region in Taiwan, Province of China; and Bangalore in India). On the other hand, data for regions or cities do not always capture the international dimension of economic and social relationships, although such data are probably being collected by the administrators of major cities. To fully comprehend the extent and consequences of knowledge interdependence, better metrics drawn from disparate sources are needed.

A related point is that the frameworks of analysis have not kept pace with the reality of the unfolding phenomenon of connected innovation. Interconnectivity means that the rewards of activity in one location positively influence actors in another location. This being the case, firms and nations can expect to reap the benefit of several sources of positive externalities—but certain old ways of thinking about innovation need to change. The conventional contemporary social science approach of attempting to isolate the determinants of some specified outcome variable while supposedly controlling for other influences on that received outcome needs to be replaced with evidence of the dispersion of innovation that is supported by a process-based analysis of change in an increasingly complex (interdependent) global system over time (with substantial endogenous feedback effects). For example, while discussing the globalization of R&D, 'location choice' models are often used. These models suggest that the gain of location A is at the expense of alternative location B (or vice versa).

Other examples may be seen in the R&D offshoring debate. Citibank developed a captive software subsidiary in India in order to computerize its global network. Within a decade of being set up, the subsidiary developed a financial product (I-flex) based on its experience of computerizing other developing-country operations; this became a successful product sold to other financial firms wanting to computerize their own operations in developing economies (such as in Africa) that had similar financial systems. It would be very difficult to attribute this development in R&D offshoring to India alone, but certainly that offshoring led to a chain of events that created a whole new product in the financial software space.

This example helps illustrate a more general point about knowledge interdependence and technological complexity. Knowledge generated in one part of the world in a given field can have rapid and unpredictable consequences or contagion effects for other industries and locations because of the fundamental interconnectivity of knowledge. It takes only an entrepreneurial spark anywhere in the chain to catalyse such a process.

Frameworks of analysis that do not recognize interdependencies give rise to the policy notion that national innovation is a zero sum game. This notion is built in to the logic of the argument and the way of thinking (it is not the underlying evidence that is necessarily the cause of the difficulty, but instead it is the overly simplistic analytical framework within which the evidence is examined). Using the earlier example of location choice theory, if location A is an alternative to location B, then location A can gain only at the expense of location B. If instead locations A and B are closely connected in a wider system, then they may well rise or fall together in what the Cambridge economists such as Nicholas Kaldor, John Eatwell, and Geoff Harcourt used to call a 'process of cumulative causation'. This is a positive sum game.[15]

The increasing relevance of global knowledge dispersion and connectivity has underlined the positive sum characteristics of innovation across countries, and, in turn, the positive sum characteristics carry vital implications for national science and technology policies. In the contemporary international economic environment in the information age, it is imperative that national governments move away from the closed national innovation system perspectives that characterize what have been called 'techno-nationalist policies',[16] and instead move towards policies that support the openness of local innovation systems. In a world in which cross-border knowledge connectivity is essential to innovative effort, actors must be willing to be knowledge providers if they also wish to enjoy the benefits of being knowledge recipients from the rest of the world.

In this interconnected world, the incentives to engage in international knowledge exchange are aligned in mature industrialized countries and emerging market countries despite their different levels of development and the differing degrees of sophistication of their stocks of scientific and technological knowledge. Each country has its own specific types of differentiated expertise and forms of knowledge. Many innovation opportunities now depend on moving new applications across both industries and markets, including between markets with different proportions of high-income and low-income consumers, and with different challenges for innovation.[17] Therefore the policy agenda must be to move away from the inward-looking approach of techno-nationalism towards a philosophy of mutual or shared interest in protecting and sustaining the entire international ecosystem of technological knowledge, which reaches well beyond any individual country or place.

The world looks less rosy for those developing countries that have not yet joined this club of participating nations in international S&T. The closing digital divide in ICTs, thought insurmountable in the 1980s, offers hope for the future. As Chapter 3 shows more conclusively, technology-driven foreign direct investment between Southern countries is in its infancy, but it has been led by investments in digital technology made by other developing countries. Could higher-middle-income countries such as China draw in poorer countries into their own network of technology-driven foreign investments and thus extend the win-win paradigm? There is no crystal ball that will tell us, but the new policy thinking proposed here may turn that idea into reality.

## Notes

1 There is a subtle difference between globalization and internationalization. In general, internationalization precedes and is a precondition for globalization. 'Internationalization' refers to international flows of people or resources or to the international spread or dispersal of activity, while 'globalization' refers to the international integration of activities, or international interdependence of actors or activities located in different places.

2 Athreye and Cantwell, 2007.

3 Examples in public science include the race to find a solution to the problem of establishing a longitude for sailors at sea for which prizes were offered in 1567 and 1598 in Spain and in 1717 in the UK, or more recently the race to find a solution (and protocol) to the problem of computer connectivity, which involved Computer Science departments in the UK and the USA.

4 See the title of Patel and Pavitt, 1991. Cantwell (1995) argued that this generalization applied more to large US, Japanese, German, and French firms than it did to the largest British, Swiss, Belgian, or Dutch firms.

5 Wagner and Leydesdorff, 2005a, Table 3.

6 Wagner and Leydesdorff, 2005a, Table 4.

7 UNESCO, 2015, Table 1.4.

8 Patel and Pavitt, 1991.

9 But see Cantwell and Kosmopoulou (2002) for some qualifications to this generalization.

10 Granstrand et al., 1997.

11 Arora and Gambardella (1994) called this the 'changing technology of technological change'.

12 Cantwell and Zhang (2011) provide evidence on cross-field versus within-field patent citations and knowledge complexity, using 56 technological fields.

13 Economic historians such as O'Rourke and Williamson (1999) emphasize the similarities between the globalization of the 1880s and the globalization of the l990s. Standage (1998) also shows how the increase in connectivity due to the telegraph was very similar to the increase in connectivity due to the growth of the Internet.

14 Lave and Wenger, 1991; Wagner, 2008; Wenger, 1998; Wenger et al., 2002.

15 See Kaldor, 1985. The use of the term 'cumulative causation' (what might now be referred to as 'positive and negative feedback effects in non-linear dynamics' or 'chaotic dynamics') is generally credited to Gunnar Myrdal (1957). Reference to cumulative causation in the context of FDI, the international location of technology development, patterns of industry growth, and decline in host locations can be found in Cantwell (1987).

16 Ostry and Nelson, 1995.

17 See, for example, Govindarajan and Ramamurti, 2011.

## References


Arora, A. and A. Gambardella. 1994. 'The Changing Technology of Technological Change: General and Abstract Knowledge and the Division of Innovative Labour'. *Research Policy* 23 (5): 523–32.

Arslan, C., J.-C. Dumont, Z. Kone, Y. Moullan, C. Ozden, C. Parsons, and T. Xenogiani. 2014. 'A New Profile of Migrants in the Aftermath of the Recent Economic Crisis'. *OECD Social, Employment and Migration Working Paper* No. 160. Paris: OECD Publishing.

Athreye, S. S. and J. A. Cantwell. 2007. 'Creating Competition? Globalisation and the Emergence of New Technology Producers'. *Research Policy* 36 (2): 209–26.

Branstetter, L., Q. Li, and F. Veloso. 2015. 'The Rise of International Coinvention'. In *The Changing Frontier: Rethinking Science and Innovation Policy*, eds. A. Jaffe and B. Jones. Chicago and London: University of Chicago Press. 135–68.

Cantwell, J. A. 1987. 'The Reorganisation of European Industries after Integration: Selected Evidence on the Role of Multinational Enterprise Activities'. *Journal of Common Market Studies* 26 (2): 127–51.

———. 1995. 'The Globalisation of Technology: What Remains of the Product Cycle Model?' *Cambridge Journal of Economics* 19 (1): 155–74.

Cantwell, J. A. and E. Kosmopoulou. 2002. 'What Determines the Internationalisation of Corporate Technology?' In *Critical Perspectives on Internationalisation*, eds. V. Havila, M. Forsgren, and H. Håkanson. Oxford: Pergamon. 305–34.

Cantwell, J. A. and F. Zhang. 2011. 'Technological Complexity and the Evolving Structure of MNC Subsidiary Knowledge Accumulation'. *Economia e Politica Industriale* 38 (4): 5–33.

Dunning, J. and S. Lundan. 2008. *Multinational Enterprises and the Global Economy*. Cheltenham: Edward Elgar Publishing.

Govindarajan, V. and R. Ramamurti. 2011. 'Reverse Innovation, Emerging Markets, and Global Strategy'. *Global Strategy Journal* 1(3–4): 191–205.

Granstrand, O., P. Patel, and K. L. R. Pavitt. 1997. 'Multi-Technology Corporations: Why They Have "Distributed" Rather Than "Distinctive Core" Competencies'. *California Management Review* 39 (4): 8–25.

Kaldor, N. 1985. *Economics without Equilibrium*. Armonk, NY: M.E. Sharpe.

Kent, M. and C. Haub. 2005. 'Global Demographic Divide'. *Population Bulletin* 60 (4). Washington, DC: Population Reference Bureau.

Kerr, S. P. and W. Kerr. 2015. 'Global Collaborative Patents'. *HBS Working Paper* 16-059. Cambridge, MA: Harvard Business School.

Lave, J. and E. Wenger. 1991. *Situated Learning: Legitimate Peripheral Participation*. Cambridge: University of Cambridge Press.

Myrdal, G. 1957. *Economic Theory and Underdeveloped Regions*. London: University Paperbacks, Methuen.

O'Rourke, K. and J. Williamson. 1999. *Globalization and History*. Cambridge, MA: MIT Press.

Ostry, S. and R. R. Nelson. 1995. *Techno-Nationalism and Techno-Globalism*. Washington, DC: The Brookings Institution.

Patel, P. and K. Pavitt. 1991. 'Large Firms in the Production of the World's Technology: An Important Case of "Non-Globalisation" '. *Journal of International Business Studies* 22 (1): 1–21.

The Royal Society. 2011. 'Knowledge, Networks and Nations: Global Scientific Collaboration in the 21st Century'. RS Policy document 03/11. London: The Royal Society.

Standage, T. 1998. *The Victorian Internet*. London: Phoenix Books.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2015. *UNESCO Science Report: Towards 2030*. Paris: UNESCO.

Wagner, C. 2008. *The New Invisible College: Science for Development*. Washington, DC: The Brookings Institution.

Wagner, C. and L. Leydesdorff. 2005a. 'Mapping Global Science Using International Co-Authorships: A Comparison of 1990 and 2000'. *International Journal of Technology and Globalization* 1 (2): 185–208.

———. 2005b. 'Network Structure, Self-Organization and the Growth of International Collaboration in Science'. *Research Policy* 34 (10): 1608–18.

Wenger, E. 1998. Communities of Practice: Learning, Meaning, and Identity. Cambridge, UK: Cambridge University Press.

Wenger, E., R. McDermott, and W. Snyder. 2002. *Cultivating Communities of Practice: A Guide to Managing Knowledge*. Cambridge, MA: Harvard Business School Press.