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Globalization of scientific and engineering talent: international mobility of students, workers, and ideas and the world economy

Richard B. Freeman[abc]
[a] Department of Economics, Harvard University, Cambridge, MA, USA [b] National Bureau of Economic Research/Sloan Science Engineering Workforce Projects, NBER, Cambridge, MA, USA [c] Centre for Economic Performance, London School of Economics, London, UK

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Globalization of scientific and engineering talent: international mobility of students, workers, and ideas and the world economy

Richard B. Freeman*

Department of Economics, Harvard University, Cambridge, MA, USA; National Bureau of Economic Research/Sloan Science Engineering Workforce Projects, NBER, Cambridge, MA, USA; Centre for Economic Performance, London School of Economics, London, UK

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This paper documents the five main ways in which globalization of scientific and engineering has proceeded: (1) expansion of mass higher education worldwide; (2) growth in number of international students; (3) immigration of scientists and engineers; (4) non-immigration trips: academic visitors, conferences; (5) greater international co-authorship and co-patenting. It is argued that by accelerating the rate of technological change and speeding the adoption of best practices around the world, these developments should benefit advanced and developing countries but that they threaten the comparative advantage of advanced countries in high-tech sectors and the edge that their citizens have in access to the highest quality university education and jobs; and risk creating greater divisions between modern and traditional sectors in developing countries. How economies around the world take advantage of the benefits and minimize the costs of globalization of knowledge will be a major determinant of economic progress.

Keywords: migration; international mobility of knowledge; scientists and engineers

JEL Classification: F16; F22; J61; I23

The spread of scientific and engineering (S&E) knowledge around the world is arguably the most potent aspect of modern globalization. Global trade alters the industrial composition of employment and relative prices in welfare-enhancing ways. Capital mobility and immigration change factor endowments in ways that should raise world output and reduce inequality among countries. But the globalization of science and engineering (S&E) has greater potential for improving productivity and incomes around the world than these more widely publicized elements of globalization. Rapid diffusion of knowledge worldwide can bring technically backward nations to the production possibility frontier. As scientists and engineers in those countries add to the stock of useful knowledge, the global production frontier should shift out more rapidly than it otherwise would.

*Email: freeman@nber.org

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This paper examines the recent globalization of S&E and its implications for labor markets, university systems, and economies writ large. I argue that the globalization of S&E should benefit advanced and developing countries by accelerating the rate of technological change and speeding the adoption of best practices around the world. This will lower the costs of production and prices for goods and services, thereby benefiting consumers worldwide. But the spread of knowledge threatens the comparative advantage of advanced countries in high-tech sectors and the edge that their citizens have in access to the highest quality university education and jobs. Given that the low cost of labor in developing countries will attract production, advanced countries need knowledge-based innovations that are 'sticky' in order to justify R&D investments to taxpayers. In developing countries, the spread of knowledge creates pressures to improve the infrastructure for advanced production and for R&D aimed at problems specific to them. The spread of knowledge also creates dangers of increasing inequality between the modern sector and traditional sectors. How economies around the world adjust to the globalization of knowledge will be a major determinant of economic progress.

1. Five fingers of globalization of S&E knowledge

The globalization of S&E has proceeded rapidly along five related tracks.

1.1. Expansion of mass higher education worldwide

First, as Table 1 documents, countries around the world invested massively in university education in the past two–three decades. Between 1970 and 2006 the number of students enrolled in higher education increased from 29 million to over 141 million. In 1970, approximately 29% of the world's college students were in the USA and 46% in advanced countries (including the USA). This despite the fact that the USA had just 5–6% of the world's population and advanced countries had about 20% of the world's population. Thereafter, the US share of world college enrollments dropped rapidly so that by 2006 it was 12% of the world total, whereas the share of the other advanced countries slightly increased to 17.7%

Table 1. Millions of enrollments and shares of world enrollments in higher education, including enrollments for less than 4 years, by country, 1970–2006.

	1970	1980	1990	2006
Millions of enrollments				
World	29.4	55.3	67.6	141.5
USA	8.5	12.1	13.7	17.5
Other advanced	4.9	8.2	12.9	29.5
Developing	16	35	41	102.5
China	<0.1	1.7	1.8	23.4
India	2.5	3.5	5	12.9
Shares of world enrollments				
USA (%)	29.00	22.00	20.00	12.00
Other advanced	16.70%	14.8	20.3	17.7
Developing	54.4	63.3	60.7	72.4
China	0	3.1	2.7	16.5
India	8.5	6.3	7.4	9.1

Source: UNESCO Institute for Statistics, online files: Statistics (http://www.uis.unesco.org/en/stats/centre.htm); Tertiary education: Graduates by ISCED level (http://www.uis.unesco.org/pagesen/DBGTerIsced.asp).

of the world total enrollments in higher education. But the biggest increases in enrollments were in developing countries. In 2006, nearly three quarters of the world's tertiary level students were enrolled in developing countries. Chinese statistics show an increase in total enrollment in institutions of higher education from 5% of 18–22 year olds in 1993 to 22% of 18–22 year olds in 2006 (Ministry of Education of the People's Republic of China 2007). In 2008, China graduated approximately 6 million bachelor's students, a large proportion in S&E fields.

Behind the growth of enrollments have been massive increases in the number of degree-granting institutions. Regression analyses show that changes in enrollments across countries are more strongly associated with changes in the number of universities than with any other single factor (Hwang 2009). Data on over 12,000 institutions of higher education around the world (International Association of Universities 2008) show that between 1985 and 2005 virtually every country in the world created many new institutions of higher education or upgraded lower level institutions into baccalaureate granting colleges or universities. As examples, consider the data on institutions of higher education in Bangladesh and Chile. Bangladesh reported 29 universities, of which 17 were formed post-1985, most in the 1990s, and an additional five institutions upgraded to university status in the period. The new Bangladesh universities were primarily in the public sector, including an Open University. Chile developed 27 new institutions of higher education from 1985 to 2005, including a substantial number of private sector institutions, while it upgraded another 18 institutions. Thus, three quarters of the institutions of higher education in Bangladesh and Chile in 2005 were post-1985 creations. Many universities in both countries and in other developing countries reported partnership arrangements or links with universities in advanced countries.

Turning to S&E, in 2005 the huge number of engineering degrees granted in China and India attracted considerable attention in the USA when top executives from high-tech firms cited reports that China graduated as many as 10 times the number of engineers as the USA and that India also graduated more engineers than the USA. Further investigation found that part of the China/India to USA gap in engineering degrees was due to incomparability in the statistics (Duke University 2005; Wadwha, Gereffi, Rissing, and Ong 2008).[1] Correcting the data for statistical problems still does not, however, overturn the trend growth of degrees in China and India compared with the USA or other advanced countries. It simply displaces the increase in the production of 4 year comparable degrees 2–3 years behind the publicized figures. Data for 2004 show 433,000 engineering bachelor's graduates in China compared with 80,000 in the USA. Looking beyond China, Table 2 compares the number of all first university degrees and first university degrees in natural S&E from 1995 to 2004 in the USA and the three regions (Asia, Europe, North America (USA included)) for which the US National Science Board reports data. The rates of growth in degrees overall and in the natural sciences and engineering is markedly faster outside the USA than in the USA, indicating a sharp drop in the US share of degrees. Data on degrees for the entire world would presumably show the US share declining more rapidly than indicated in the statistics in Table 2 since enrollments grew rapidly in areas with missing degree data for 1995 – South America, Africa, and Oceana.

At the PhD level, S&E degrees granted have also expanded rapidly worldwide. From 1975 to 2004, the number of PhDs graduated in S&E outside the USA increased relative to those in the USA. In 2004, the EU granted 78% more S&E PhDs than the USA. Among developing countries, the greatest growth in PhDs was in China. In 1975, China produced essentially no S&E doctorates. In 2004, the country graduated 23,000 PhDs, approximately 63% in S&E. Between 1995 and 2003, first year entrants in PhD programs in China increased six-fold, from 8139 to 48,740. At this rate China will produce more S&E

Table 2. Numbers and percent changes of first degrees and first degrees in natural science and engineering in the USA compared with three regions (Asia, Europe, and North America), 1995–2004.

	1995	2004	Percent change 1995–2004
First degrees, total (in 000s), USA	1,174,436	1,407,009	19.8
First degrees, total (in 000s), three regions	5,208,205	9,143,893	75.6
First natural S&E degrees (in 000s), USA	192,836	235,781	22.2
First natural S&E degrees (in 000s), three regions	1,503,871	2,410,860	60.3

Source: 1995, calculated from National Science Board (1998, Appendix table 2-1), where the number of degrees is for 1995 or the most recent year. 2004, calculated from National Science Board (2008, Appendix table 2-37) and National Science Board (2006, Appendix table 2-37), for Asia, Europe, and North America.

doctorates than the USA by 2010 (Freeman 2006). The quality of doctorate education surely suffers from such rapid expansion so the numbers should be discounted to some extent but as the new doctorate programs in China and other lower income countries mature, quality will undoubtedly improve.

In any case, the growth of university education and spread of scientific knowledge around the world has greatly increased the number of S&E researchers in the global economy. Using OECD data, I estimate that the number of researchers in the world increased by approximately 67% between 1990 and 2005, with the number in China rising from about 390,000 to over 1,100,000 while the number in the former Soviet Union fell.[2]

1.2. Growth in number of international students

Table 3 shows that the number of international students grew nearly five-fold from 1975 to 2007 (column 1). This raised the international student share of world enrollments even as those enrollments grew rapidly (column 2). Although the number of international students to the USA increased, the US share of international students fell (column 3).

Countries differ in the extent to which they recruit and/or attract international students at the undergraduate or graduate level. Some countries like Australia and the UK specialize in undergraduate education for international students. The US intake of international students consists disproportionately of graduate students and of post-doctorate students/workers. Most US international students are from Asia, with India and China being the largest source countries. The foreign-born share of enrollments and degrees in the USA is particularly high in graduate (Master and Doctorate) S&E and increased greatly in those areas from 1985 to 2005 (Table 4).

Table 3. Millions of international students worldwide and in the USA, and US share, 1975–2007.

Academic year	Millions of international students in world	Millions of international students in the USA	US share of international students (%)
1974–1975	0.6	0.15	25.00
1979–1980	0.8	0.29	36.25
1984–1985	0.9	0.34	37.80
1989–1990	1.2	0.39	32.50
1994–1995	1.3	0.45	34.60
1999–2000	1.9	0.51	26.80
2006–2007	2.9	0.58	20.00

Source: For millions of international students worldwide, OECD (2008a, Box C31); for international students in the USA, Institute of International Education, Figure 1B International students and the USA. Higher Educational Enrollment Trends (Open Doors 2008b).

Table 4. Percentage of US degrees to non-citizens/non-permanent residents, 1985–2005.

	Bachelor's	Master's	Doctorates
All			
1985	3.00	9.4	25.3
2005	3.1	12.8	39.3
Natural science and engineering			
1985	5.4	27.2	33.1
2005	5.2	38.6	50.9
Engineering			
1985	7.2	26.2	59.6
2005	8	39.7	68.8

Source: Degrees, National Science Board (2008, chapter 2, Tables 2-28, 2-30, and 2-31).

In the aftermath of 9/11, the USA tightened visa requirements in ways that threatened to reduce the number of international students coming to the country. The State Department rejected more visa applicants than in the past, particularly from China, and made it difficult for international students to travel outside the USA. The number of international students fell from 2002/03 through 2005/06, breaking an upward trend that stretched back at least four decades. But responding to complaints from academic institutions, high-tech firms, and international students, the State Department remedied many of the problems (National Academy of Sciences 2005), so that the number of international students began increasing again from 2005/06 to reach a record high of 623,805 in the 2007/08 academic year (Open Doors 2008c).

1.3. Immigration

Increased numbers of university graduates worldwide provide an increased number of potential immigrants in S&E and other fields to countries able to attract such specialists. The 1990s US economic boom shows the extent to which a large immigrant-receiving country can increase its S&E labor supply in times of great demand. From 1990 through the mid-2000s, the expansion of IT, biotechnology, nanotechnology, and the dot.com revolution raised demand for S&E workers in the USA. Employment grew rapidly, with nearly 60% of the *growth* in the number of PhD scientists and engineers coming from the foreign-born. Between 1990 and 2005 the foreign-born share of bachelor's S&E workers rose from 11 to 18%; the foreign-born share of master's S&E workers rose from 19 to 32%, and the foreign-born share of doctorate S&E workers rose from 24 to 40%. In 2005, the foreign-born made up over half of doctorate scientists and engineers under the age of 45.

Advanced countries outside the USA also receive sizable flows of S&E immigrants (OECD 2007a). In 2005, the European Union established the EU Scientific Visa, a fast track procedure for researchers outside the EU to obtain residence permits (OECD 2008c, 97). Examining the country of birth of over 1500 of the most highly cited scientists, Ioannidis (2004) found that 32% resided in a country other than their country of birth, with Canada, France, Australia, the USA, and Switzerland having the highest proportions of foreign-born highly cited scientists and with China, India, Taiwan, Hungary, and Canada being major sources of highly cited migrants to other countries.

A large number of US S&E immigrants come from scientists and engineers who studied as international students in the country. Table 5 shows that the majority of foreign-born

Table 5. Proportions of US science and engineering workers that are foreign-born and the proportion of the foreign-born that have highest degree in the USA, 2005.

	Foreign-born share of workers (%)	Share of foreign-born with highest degree in the USA (%)
Bachelor's	15.2	54.3
Master's	27.2	68.5
Doctorates	34.6	64.00

Source: National Science Board (2008, Table 3-8).

scientists and engineers working in the country had obtained their highest degree in the USA. The foreign-born proportion of degree recipients was larger at the PhD and master's level than at the bachelor's level. But even among bachelor's graduates over half of foreign-born S&E workers were US university educated. Across all degree levels, the majority of foreign-born S&E workers from China, Taiwan, South Korea, Mexico, and Germany were educated in the USA. Since non-US-born persons with S&E degrees in the US earn less than 5% of S&E degrees granted to non-US-born persons worldwide,[3] it is clear that at least for S&E graduates, international students to the USA are far more likely to immigrate to the USA than students trained elsewhere.

Two factors presumably explain the high proportion of US S&E immigrants who were international students to the USA. The first is that students who study in the USA did so in part because they were especially attracted to the country and thus more likely to immigrate in the future. The second is that, conditional on the attractiveness of the USA, being an international student in a country increases the chances of migrating there. The best estimates of the causal impact of international student status on the future location of work come from studies of the European Union's Erasmus program – a program developed in the late 1980s to encourage academic mobility in the EU by providing students with fellowships for studying in other EU and related countries (Erasmus Programme, http://en.wikipedia.org/wiki/ERASMUS_programme). Comparing similar students before and after the program was introduced or who were eligible/ineligible due to the timing of their university's involvement with the program, Parey and Waldinger estimated that the program raised the proportion of students who later worked outside their country on the order of 20% points. Other studies of EU student migration (Oosterbeek and Webbink 2009; De Grip, Fouarge, and Sauermann 2008; Dreher and Poutvaara 2005) find similar magnitudes for the impact of being an international student on future work in a foreign country.

But the estimated impacts of short periods of study in European countries on the migration decisions of Europeans surely understates the impact on migration decisions of the 4–6 or so years of study that international students take to earn degrees. Longer stays presumably build up job and social connections, so that the decision to return home becomes more like a migration decision than does the decision to remain and work in the country in which one is studying. Parey and Waldinger (2008, Table 11) give survey data which show that social factors, such as a partner in the destination country and assessments of career prospects there, influence the decision to work overseas. International students from developing countries are also more likely to immigrate to high-wage advanced countries than international students from high-income countries. In the USA, rates of stay for PhD graduates are much higher for persons from lower income countries than for persons from higher income countries (Finn 2007).

1.4. Non-immigration trips: academic visitors, conferences

Scientists and engineers typically exchange ideas by visiting universities in various parts of the world and by attending diverse international conferences and meetings. In 2007–2008, the USA hosted 106,123 'international scholars', largely in S&E, who had explicitly come to the USA to engage in research under J-1 scholar visas. Chinese scholars made up 22.4% of the international scholars, many supported by Chinese government programs that cover the expenses of scholars who obtain invitations from US universities. The USA's best universities – Harvard, Stanford, Berkeley, etc. – had particularly large number of international scholars as visitors.[4]

The annual Gordon conferences are among the most famous in the natural sciences for the exchange of ideas. Developed in the USA, the conferences were initially held at US schools or universities, many in New England, during the summer when facilities are underutilized (Gordon Research Conferences (GRC), A brief history of GRC), but over time the conferences have spread to non-US venues as well. In 2009, 30 of the 180 Gordon conferences were held outside the USA (GRC 2009). While there are no estimates of the time scientists and engineers spend at conferences nor of the extent to which these meetings successfully transmit knowledge or generate new ideas, their continued importance in a world with video-conferencing, web-conferencing, and other forms of electronic communication suggest that they are indeed highly productive.

1.5. Greater international co-authorship and co-patenting

The globalization of knowledge can be seen in several measures of the national location of scientific and innovative activity. First, it can be seen in a substantial decline in the concentration of papers by country with the dominance of the 'market leader' USA and other major advanced countries declining over time. The top 10 countries in terms of publications in 1995 accounted for 78% of articles in that year but accounted for 67% of articles in 2005. China, Korea, India, Taiwan, and Brazil had large percentage increases in papers (National Science Board 2008, Appendix table 5-34). Second, globalization can be seen in the decline in the share of the top 1% of cited papers attributed to the USA, which declined from 62 to 55% over the 1995–2005 period. Third, there has been a substantial increase in the proportion of papers with co-authors from different countries (National Science Board 2008, Table 5-35). Fourth, globalization also shows up in an increased proportion of persons with US patents who have names indicative of different national and ethnic backgrounds. Fifth, there has been an increase in the proportion of founders of companies in the USA who are born overseas. While no study has estimated how immigrants might have fared if they remained in their own country, it is reasonable to expect that many would have made a smaller contribution to knowledge and innovation absent the globalization of opportunity. MacGarvie and Khan (2009) show that foreign-born scholars working in the USA produce more scholarly papers than otherwise comparable scholars that returned to their home country.

2. Economic impact of globalization of knowledge

The increased number of S&E (and other highly educated) workers worldwide should accelerate the growth of scientific and technological knowledge and the economic progress that flows from this knowledge. This in turn offers the best opportunity for the world to overcome the challenges of global warming, possible pandemics, and shortfalls of energy, water, and various natural resources associated with economic growth and an expanding world population.

Illustrative of the way in which the globalization of S&E benefits the world, China's Xinhua news agency (China View 2009) had a story in 2009 on the research response of health researchers to the avian flu threat under the title 'Researchers worldwide race against A/H1N1 virus'. The Xinhua article notes the role of scientists in five countries in pushing the research frontier to understand the virus and develop ways to reduce the danger of a pandemic: Canada's National Microbiology Laboratory; the US Lawrence Livermore National Laboratory; Japan's National Institute of Infectious Diseases; University of Rochester in the US; France's Pasteur Institute; US Centers for Disease Control and Prevention; and researchers in China. A full rendering of the world effort would add other countries and laboratories to the list and would show that many scientists working in the US and other advanced countries were born in developing countries while many scientists working in China and other developing countries had been educated in the advanced countries.

Another example of how the globalization of S&E operates to impact lives is the ongoing effort to develop small molecule drugs targeted at the sirtuin proteins associated with aging and whose activity could lead to longer and healthier lives. Australian scientist David Sinclair discovered that sirtuin proteins are increased by caloric restriction, which is known to expand the life-span of some organisms, and that resveratrol impacts the sirtuin enzymes. Sinclair came to MIT as a postdoc and then joined the Harvard Medical School. He teamed with bio-tech entrepreneur Christof Westphal, who came to the USA with his German immigrant parents, to found the biotech startup Sirtris that discovered key molecules that impacted the sirtuins. Sirtris offshores some tests of the effectiveness of compounds to chemists in China. It employs scientists from many countries in its labs. Glaxo-Smith-Kline, the British pharma giant, acquired Sirtris to bring the discoveries to human trial and the market. Other firms have entered the market in search of medicines to deal with diseases associated with aging. Ponce de Leon, beware.

Potential miracle drugs aside, the increase in productivity associated with the spread of knowledge benefits people worldwide by reducing the costs of production and thus prices of goods and services. If Romanian scientists and engineers find ways to improve the production of shoes, the price of shoes on the global market will fall to the benefit of everyone except competitors in the shoe business. One need not be a devotee of Ray Kurzweil's 'singularity' view of technological progress[5] to believe that the spread of scientific knowledge associated with three or so times as many university graduates in S&E and more researchers than two or three decades ago *could* combine with the Internet, and increasingly powerful computers to produce a golden age for humanity. But to approach that ideal state, both advanced and developing countries will have to surmount a set of challenges from the spread of knowledge that will strain their economies, labor markets, and higher education systems.

2.1. The challenge of changing comparative advantage

Perhaps the most important challenge for advanced countries is that the globalization of S&E knowledge reduces their comparative advantage in producing high-tech goods and services, including research and development, vis-à-vis developing countries. This obsolesces the North–South or product cycle model of trade that economists have used to analyze trade between high-income economies and low-income economies. The North–South model posits that the advanced North has a monopoly on the R&D that produces innovative products and thus dominates education-intensive high-tech industries while the developing

South produces goods and services with older technologies using low-wage, less-skilled workers (Krugman 1979). The huge absolute numbers of relatively lower paid scientists and engineers with access to the most advanced technologies in developing countries reduces that advantage. As Gomory and Baumol (2000) and Samuelson (2004) have reminded economists, a country that loses its comparative advantage due to improved capabilities of trading partners can lose income as terms of trade worsen and as its mix of industries and jobs shifts toward less desirable ones.

The weakening of comparative advantage is in fact occurring. In the 1990s, China increased its share of export markets in high-tech goods (National Science Board 2008). Multinationals invested in R&D facilities in China and India to a greater extent than ever before (Freeman 2006) as well as shifting production to those and other developing countries. Between 1994 and 2004 R&D employment in US multinationals increased by 94% in majority owned foreign affiliates while employment in the parent firm increased by 39%.[6] Even though highly populous countries like China and India have many fewer scientists and engineers per capita than advanced countries, they can deploy large number of scientists and engineers in high-tech and compete in those sectors.

The challenge to the advanced countries is to maintain comparative advantage in some niches/sectors/areas through investments in R&D that lead to production and jobs for non-R&D workers. Immigration of S&E workers from developing countries can help the advanced economies maintain comparative advantage in high-tech, as US high-tech firms continually argue in policy debate. But even the USA will be unable to maintain technological dominance across the board. It will have to choose which technologies in which to invest substantially almost as a form of 'industrial policy', to gain or hold comparative advantage in particular areas.

2.2. *The challenge of maintaining topflight higher education*

International ratings of universities place advanced country universities ahead of those of lower income countries, with US institutions of higher education at the top of the tables.[7] Associated with the dominance of the US university system is its ability to attract outstanding foreign-born scientists and engineers, many of whom first came to the country as international students. In 2003, a large proportion of full-time doctoral instructional faculty in research institutions in the physical sciences/math/computer sciences/engineering were foreign-born – 47% of compared with 38% in 1992 (National Science Board 2008, Appendix table 5-21).

The expansion of higher education worldwide impacts the higher education systems of advanced countries in several ways. Increased numbers of bachelor's graduates from other countries raises demand for places in graduate and professional schools. If international students seek admission to any given university in large numbers and if admissions treat foreign and domestic applications equally the proportion of native graduates admitted will surely fall. In 1969, the bright US graduate from, say, Haverford would compete with US-born graduates of other US colleges and universities for admission to graduate studies at say Berkeley or MIT. In 2009, the comparable student would be competing with students from China, Brazil, India, France, Germany, and so on. The July 2008 *Chronicle of Higher Education* reported that the three leading major undergraduate institutions for US PhD programs were Tsinghua, Beijing, and Seoul National University (Brainard 2008). Given that the top US graduate and professional schools did not increase the number of graduate slots much (Freeman, Jin, and Shen 2007), the chances of graduates of US institutions gaining admission to these programs fell.

But this does not mean that overseas applicants push native-born students from postgraduate education in the USA or elsewhere. Many less prestigious US institutions have developed new graduate programs or increased their graduate enrollments, and many foreign-born graduate students enroll at new or less prestigious universities (Freeman, Jin, and Shen 2007). Higher education institutions in other advanced countries have also expanded graduate programs, often with English as the language of instruction to appeal to international students. Among the developing countries, China's Project 985 policy for creating a number of first-rate universities of international advanced standing represents a bold effort to leapfrog to the forefront of higher education. It involved providing sizable financial grants to nine universities – Beijing Fudan, and Nanjing among traditional universities and to Tsinghua and five other institutions oriented to science and technology. In 2004, the government expanded financial support to an additional 30 institutions. By 2008, China had improved its attractiveness to students worldwide enough to become the fifth top college destination for international students, particularly attracting those from Asia (Hvistendahl 2008).

An increase in the number of top quality universities benefits students around the world by giving them greater choice of places to attain first-rate education. The Haverford student can apply to Tsinghua or Nanjing or any of the major universities in Europe as well as to Berkeley. It also raises demand for faculty in a period when the supply of PhDs is growing rapidly. The challenge to advanced countries is to maintain excellent university systems, to work with the improving universities in the developing world, so that the knowledge flows in all directions, and to stimulate application of the knowledge in ways that benefit the taxpayers who fund it, through for instance, creation of new businesses based on it.

2.3. The challenge of a global labor market: offshoring vs. immigration of S&E workers

The expansion of higher education worldwide and increased number of international students has created a global labor market for university trained specialists. Multinationals that once hired largely nationals in their home country now source globally for employees. As an example of the globalization of demand for university graduates, in May 2008 the American multinational Caterpillar, headquartered in Peoria, Illinois, which employs some 100,000 workers worldwide, held a Caterpillar China Employment Opportunities job fair in the Levis Faculty Center at the University of Illinois in Urbana-Champaign. Jointly sponsored by the University's Career office and Chinese student association, the company was seeking engineers, business majors, and marketing majors, among others, for work in China or elsewhere.

To see the extent to which the graduates from developing country universities are competitive in the job market with those from advanced countries, McKinsey Global Institute (2005) asked recruiters for multinational firms to estimate the proportion of graduates from different countries that might be suitable candidates for their firm in terms of language, skills, and potential mobility. The recruiters estimated that in engineering 10% of graduates from China and 25% of graduates from India were so qualified (McKinsey Global Institute 2005, 8, exhibit 2). But the survey did not ask whether graduates could perform successfully for subcontractor firms in their native country nor explore at what point firms would prefer to subcontract work to firms with less qualified graduates at the lower pay in those countries. And it did not ask for the proportion of graduates from US engineering schools that recruiters viewed as qualified.

The expanded supply of S&E graduates affects the job market in advanced countries in two ways.

First, the increased supply in advanced countries due to international students graduating and choosing to work in those countries or through immigrants trained in their home country reduces the payoff to investing in higher education by natives, which in turn will lower the number studying in fields where the core knowledge is universal, as in S&E. The increased number of foreign-born S&E students in the USA in the 1990s and 2000s reduced the employment opportunities and earnings of S&E doctorates graduates (Borjas 2006). This in turn presumably contributed to the sluggish growth of enrollments by the US-born in S&E over the period. In a similar vein, the supply of programmers in India and other developing countries willing to work at lower pay than Americans dampened the growth of the supply of programmers in the USA and presumptively contributed to a drop in computer science majors in universities.

Second, graduates who remain in their home country or who return to the country from study abroad also alter the demand for labor. The multinational firms in the forefront of technology can locate R&D and production facilities anywhere in the world where they can find the requisite skilled labor and can offshore some activities overseas even when they maintain the main center of work in their home country. From this perspective, the policy issue for advanced countries is whether it is better to attract immigrant S&E workers so that the foreign-born work in the advanced country, or to have multinationals move facilities to less costly sites or offshore to low-wage workers in developing countries so that the foreign-born specialists work there.

Grossman and Rossi-Hansberg (2008) argue on the basis of the lower wages in developing countries that offshoring is generally better. They view offshoring as a form of improved technology that allows native workers to do more efficiently tasks complementing those done overseas. Ruffin and Jones (2007) argue that under some conditions, it is even desirable for advanced countries to give the best technology to low-wage foreign countries because they will produce desired goods and services at the lowest cost. The implication is that as long as costs are lower in developing countries, it may be better for citizens in advanced countries to encourage multinationals and even government to shift their R&D overseas than to do it in expensive OECD countries.

But there are arguments on the other side. Holmes and Snider (2009) model offshoring as reducing the market power of labor and thus lowering wages. Kremer and Maskin's (2006) model of the mixing of low- and high-skilled workers in globalization gives conditions for the sorting of workers between advanced and developing countries. The answer depends on relative numbers, productivities, and the complementarity in production of skilled and less skilled workers working together compared with working apart. As long as working in direct contact with someone increases the likelihood of learning from them, there are advantages to having complementary workers in the same locale. That the huge pay and productivity difference between workers in the USA and in developing countries cannot be explained by human capital or capital/labor ratios, or any other observable measure suggests that complementarities between workers and institutions and culture that are not easily imitated may also play an important role. Analyzing research papers, MacGarvie and Khan (2009) show that the number of papers written is higher for nominally similar international students who stay to work in the USA than for those whose fellowships make them return to their native countries. To the extent that someone's productivity is higher in an advanced country than in a developing country for reasons beyond factor proportions and technical knowledge immigration raises output more than offshoring and is thus to be preferred.

3. Conclusion: sticky knowledge and globalization

Globalization of S&E knowledge occurred at an extraordinary pace in the 1990s–2000s. This creates the potential for faster diffusion of best practice technology around the world and for more rapid advances in S&E than would otherwise occur. But if knowledge flows instantly from one locale to another, and if firms produce goods and services using the latest technology in the lowest wage locales, workers in high-income countries are likely to gain little of the returns to R&D. Indeed, it is even imaginable that the newest technology may cost those workers their job rather than help them maintain high-wage employment. If this were today's world, we might expect to see substantial free riding behavior in knowledge creation and taxpayer opposition to spending on S&E. In fact, countries and localities within a country exhibit the opposite behavior. They compete for R&D intensive activities.

One reason why globalization of S&E has not led to massive free riding against R&D is that even with globalization there is sufficient 'stickiness' to knowledge that, as economic geographers find, local areas obtain some benefits from being the site of the innovation. The local benefits may be due to the difficulty of transferring tacit knowledge beyond a given locality or to the scale benefits of having a substantial number of scientists, engineers, and entrepreneurs in the same locale. Whatever the mechanism, paradoxically perhaps it would seem that for the globalization of knowledge to proceed as successfully as it has, it has to be accompanied by some stickiness in knowledge and in the benefits that follow from it.

Notes

1. Chinese and Indian data included graduates from short courses comparable to US 2-year degree programs while the US data excluded computer science degrees that the other countries counted with engineering.
2. The data are patchy. For 2005, I use OECD (2007b), Researchers in non-OECD countries Figure Ed. 2007 B10.4, http://dx.doi.org/10.1787/117384133584. The number is 3.866 million for OECD and 2.038 million for non-OECD. For 1990, I use OECD (2008b) figures for 1990 or nearest year and National Science Foundation (1993, Table A-19). My estimate is that 2.284 million in OECD in 1990 and 1.278 million in non-OECD countries. The totals thus increased from 3.562 to 5.904 million for a gain of 65.7%. As the counts for non-OECD countries are incomplete, these statistics are crude. For 2005, I also use OECD (2008b). For 1990, I use OECD (2008b) and National Science Foundation (1993) and National Science Foundation (1996). Figures differ slightly for the same countries and years among these sources.
3. The USA accounts for about 10% of the world's S&E degrees (from 8.5% of bachelor's to 17.6% of PhDs) and the foreign-born account for about 11% of US S&E degrees (from 6% of bachelor's degrees to 47% of PhDs (National Science Board 2008)).
4. Open Doors (2008a). Data on international scholars, Table 35, Figure 12C, Tables 33 and 34.
5. Technological singularity, http://en.wikipedia.org/wiki/Technological_singularity
6. In 1994, RD employment was 92,400 in majority-owned foreign affiliates of US MNCs and 591,200 in US parent firm (Research and development intensity of nonbank U.S. parents and MOFA's and of all U.S. businesses, by industry, 1994, http://www.bea.gov/scb/account_articles/international/1296iid/table17.htm). In 2004, it was 179,300 in majority-owned foreign affiliates and 818,7000 in parent firm (Yorgason 2007, Tables 1 and 3).
7. The Institute of Higher Education, Shanghai Jiao Tong University (2009) rates eight of the top 10 universities as American, nine of the next 10, and 37 of the top 50. In its league tables, the *Times* of London places more UK universities among the top but the UK numbers still fall far short of those for the USA (Times Higher Education 2009).

References

Borjas, G. 2006. Immigration in high-skill labor markets: The impact of foreign students on the earnings of doctorates. NBER Working Paper 12085, National Bureau of Economic Research (NBER), Washington, DC.

Brainard, J. 2008. Graduates of Chinese universities take the lead in earning American Ph.D.'s *The Chronicle of Higher Education*, 14 July. http://chronicle.com/news/article/4822/graduates-of-chinese-universities-take-the-lead-in-earning-american-phds

China View. 2009. Researchers worldwide race against A/H1N1 Virus, 17 May. http://news.xinhuanet.com/english/2009-05/17/content_11390117.htm

De Grip, A., D. Fouarge, and J. Sauermann. 2008. What affects international migration of European science and engineering graduates? Research Memoranda 006, Research Centre for Education and the Labour Market (ROA), Maastricht.

Dreher, A., and P. Poutvaara. 2005. Student flows and migration: An empirical analysis. IZA Discussion Paper 1612, Institute for the Study of Labor (IZA), Bonn.

Duke University, Master of Engineering Management Program. 2005. Framing the engineering outsourcing debate: Placing the United States on a level playing field with China and India. Duke University, 12 December.

Erasmus Programme. http://en.wikipedia.org/wiki/ERASMUS_programme

Finn, M. 2007. *Stay rates of foreign doctorate recipients from US universities 2005*. Oak Ridge, TN: Oak Ridge Institute for Science and Education.

Freeman, R. 2006. Does globalization of the scientific/engineering workforce threaten US economic leadership? In *Innovation policy and the economy*, vol. 6, ed. A.B. Jaffe, J. Lerner, and S. Stern, 123–58. Cambridge: MIT Press.

Freeman, R., E. Jin, and C.-Y. Shen. 2007. Where do new US-trained science-engineering PhDs come from? In *Science and the university*, ed. R.G. Ehrenberg and P.E. Stephan, chapter 10. Madison: University of Wisconsin Press.

Gomory, R., and W. Baumol. 2000. *Global trade and conflicting national interests*. Cambridge, MA: MIT Press.

Gordon Research Conferences. A brief history of GRC. http://www.grc.org/history.aspx

Gordon Research Conferences. (2009). GRC past meetings. http://www.grc.org/meetings.aspx?year=2009

Grossman, G.M., and E. Rossi-Hansberg. 2008. Trading tasks: A simple theory of offshoring. *American Economic Review* 98: 1978–97.

Holmes, T.J., and J.T. Snider. 2009. A theory of outsourcing and wage decline. NBER Working Paper 14856, National Bureau of Economic Research (NBER), Washington, DC.

Hvistendahl, M. 2008. China moves up to fifth as importer of students. *The Chronicle of Higher Education*, 19 September.

Hwang, J.E. 2009. MIT or Tsinghua? A panel data analysis of the determinants of domestic higher education and international student mobility. Harvard College Bachelor of Arts Thesis, Harvard University, Cambridge, MA.

Institute of Higher Education, Shanghai Jiao Tong Univeristy. (2009). Academic ranking of world universities. http://www.arwu.org/ARWU2009.jsp

International Association of Universities. 2008. *The international handbook of universities*. 20th ed. New York: Palgrave Macmillan.

Ioannidis, J. 2004. Global estimates of high-level brain drain and deficit. *The FASEB Journal* 18: 936–39.

Kremer, M., and E. Maskin. 2006. Globalization and inequality. http://www.economics.harvard.edu/faculty/kremer/files/GlobalizationInequality_Oct06.pdf

Krugman, P. 1979. A model of innovation, technology transfer, and the world distribution of income. *Journal of Political Economy* 87: 253–66.

MacGarvie, M., and S. Khan. 2009. How important is U.S. location for research in science? Boston University Working Paper, Boston, MA.

McKinsey Global Institute. 2005. *The emerging global labor market: Part I*. White Papers 2005-06-01.

Ministry of Education of the People's Republic of China. 2007. *Gross enrollment rate of schools by level. Age Group 2007 for enrollments relative to 18–22 year olds*. Beijing: Ministry of Education of the People's Republic of China. http://www.moe.edu.cn/edoas/website18/level3.jsp?tablename=2233&infoid=33487

National Academy of Sciences. 2005. *Policy implications of international graduate students and postdoctoral scholars in the US*. Washington, DC: NAS Press.

National Science Board. 1998. *Science and engineering indicators 1998*. National Science Foundation (NSF 98-1). Arlington, VA: National Science Foundation.

National Science Board. 2006. *Science and engineering indicators 2006*. 2 Vols (Vol. 1, NSF 06-01; Vol. 2, NSF 06-01A). Arlington, VA: National Science Foundation.

National Science Board. 2008. *Science and engineering indicators 2008*. 2 Vols (Vol. 1, NSF 08-01; Vol. 2, NSF 08-01A). Arlington, VA: National Science Foundation.

National Science Foundation. 1993. *Human resources for science & technology: The Asian region.* NSF 93-303. Arlington, VA: National Science Foundation.

National Science Foundation. 1996. *Human resources for science & technology: The European region*. NSF 96-316. Arlington, VA: National Science Foundation.

OECD. 2007a. *International migration outlook 2007*. SOPEMI 2007 Edition. Paris: OECD.

OECD. 2007b. *Science, technology and industry scoreboard 2007*. Paris: OECD.

OECD. 2008a. *Education at a glance: OECD indicators.* Paris: OECD.

OECD. 2008b. *Main science and technology indicators (MSTI) 2008*. 2nd ed. Paris: OECD.

OECD. 2008c. *Science, technology and industry outlook*. Paris: OECD.

Oosterbeek, H., and D. Webbink. 2009. Does studying abroad induce a brain drain? *Economica*, December: 1–20.

Open Doors. 2008a. Data tables. http://opendoors.iienetwork.org/page/131530/

Open Doors. 2008b. International student and U.S. higher education enrollment trends. http://opendoors.iienetwork.org/?p=131533

Open Doors. 2008c. International students on U.S. campuses at all-time high. Press release. http://opendoors.iienetwork.org/?p=131590

Parey, M., and F. Waldinger. 2008. Studying abroad and the effect of international labor market mobility: Evidence from the introduction of ERASMUS. IZA Discussion Paper 3430, Institute for the Study of Labor (IZA), Bonn.

Research and development intensity of nonbank U.S. parents and MOFA's and of all U.S. businesses, by industry, 1994. http://www.bea.gov/scb/account_articles/international/1296iid/table17.htm

Ruffin, R.J., and R.W. Jones. 2007. International technology transfer: Who gains and who loses? *Review of International Economic* 15: 209–22.

Samuelson, P. 2004. Where Ricardo and Mill rebut and confirm arguments of mainstream economists supporting globalization. *Journal of Economic Perspectives* 18: 135–46.

Technological singularity. http://en.wikipedia.org/wiki/Technological_singularity

Times Higher Education. (2009). Top 200 world universities. http://www.timeshighereducation.co.uk/hybrid.asp?typeCode=438

UNESCO Institute for Statistics. Statistics. http://www.uis.unesco.org/en/stats/centre.htm

UNESCO Institute for Statistics. Tertiary education: Graduates by ISCED level. http://www.uis.unesco.org/pagesen/DBGTerIsced.asp

Wadwha, V., G. Gereffi, B. Rissing, and R. Ong. 2008. Getting the numbers right: International engineering education in the United States, China, and India. *Journal of Engineering Education* 97, no. 1: 13–25.

Yorgason, D. 2007. Research and development activities of US multinational companies. *Survey of Current Business* 87: 22–39.