Does Globalization of the Scientific/Engineering Workforce Threaten US Economic Leadership?

Richard B. Freeman
Harvard and NBER
CEP, LSE

Draft: For Comment Only

For Innovation Policy and the Economy Conference
April 19, 2005
Washington DC

For the past half century the US has been the world scientific and technological leader and the pre-eminent market economy. With just 5% of the world's population, the US employs nearly one-third of the world's scientific and engineering researchers, accounts for 40% of research and development (R&D) spending, publishes 35% of science and engineeering (S&E) articles, obtains 44% of S&E citations, and wins numerous Nobel prizes.[1] Seventeen of the world's top 20 universities are American.[2] Indicative of US leadership, international students and scholars flock to the country to enhance their skills and collaborate with American researchers.

Leadership in science and technology gives the US its comparative advantage in the global economy. US exports are disproportionately from sectors that rely extensively on scientific and engineering workers and that embody the newest technologies. In 2003, with a massive national trade deficit, the smallest deficit relative to output was in high technology industries (NSF, Science and Engineering Indicators, 2004). Aggregate measures of scientific and technological prowess place the US at the top of global rankings.

Trade aside, the US is the leading capitalist economy because it applies new knowledge in more sectors than any other economy. Many companies on the technological frontier are American multinationals: IBM, Microsoft, Intel, Dupont, and so on. Analysts attribute the country's rapid productivity growth in the 1990s/2000s to the adaption of new information and communication technologies to production. Scientific and technological preeminence is also critical to the nation's defense, as evidenced by the employment of R&D scientists and engineers

[1] A substantial proportion of whom are immigrants: Physics 32%; Physio/Med 31%; Economics, 31%; Chemistry 26%

[2] This is according to the rating by Shanghai Jiao Tong University's Institute of Higher Education (http://ed.sjtu.edu.cn/rank/2004/2004Main.htm)

in defense related activities and in the technological dominance of the US military on battlefields. To be sure, other factors also contribute to US economic leadership,[3] but in a knowledge-based economy, leadership in science and technology contributes substantially to economic success.

This paper presents evidence that changes in the global job market for S&E workers is eroding US dominance in science and engineering and that the erosion will continue into the foreseeable future, diminishing the country's comparative advantage in high tech goods and services and threatening the country's global economic leadership. The paper assesses policies that could smooth the transition from the US being the superpower in science and engineering to being one of many centers of excellence.

The analysis can be summarized in four propositions, two relating to the job market for scientific and engineering talent, and two relating to the effects of that market on the economy.

The propositions regarding the science and engineering (S&E) job market are:

(1) The U.S. share of the world's science and engineering graduates is declining rapidly. The number of S&E PhDs from European and Asian universities, particularly from China, has increased while the number from US universities has stagnated. International students have, in addition, increased their share of advanced S&E degrees from US universities. As a result US reliance on foreign-born scientists and engineers has increased.

2) The job market for young scientists and engineers in the US has worsened relative to job markets in many other high-level occupations, which discourages US students from going on in these fields. At the same time, rewards are sufficient to attract large immigrant flows, particularly

[3] Among factors that presumably have some effect are: a high physical capital to labor ratio, public infrastructure, protection of property and rule of law, the education and skill of workers, incentives for work and supply responses to those incentives, openness to the employment of women, minorities, and immigration and an entrepreneurial culture.

from less developed countries.

The propositions regarding the impact of changes in the supply of science and engineering talent on the country's economic performance are:

3) By greatly increasing the number of scientists and engineers, highly populous low income countries such as China and India can compete with the US in technically advanced industries even though S&E workers are a small proportion of their work forces. This threatens to undo the traditional "North-South" pattern of trade in which advanced countries dominate high tech while developing countries specialize in less skilled manufacturing.

4. Diminished comparative advantage in high-tech will create substantial adjustment problems for US workers, of which the offshoring of IT jobs to India, growth of high-tech production and exports from China, and multinational development of R&D facilities in developing countries, are harbingers. The country faces a long period of adjustment to a less dominant position in science and engineering associated industries. To create a smooth transition to the new scientific, technological and economic reality, the US will have to develop new labor market and R&D policies that build on existing strengths and develop new ways of benefiting from scientific and technological advances in other countries.

The rest of the paper presents the evidence and arguments for the four propositions and examines the implications for policy.

Proposition 1: The US's share of the world's S&E work force is declining rapidly.

The US share of the world's S&E workers was disproportionately high in the latter half of the 20th century for historical reasons that include: the flight of many leading European scientists from the Nazis; the slow post-World War II recovery of higher education and science in Europe, which had dominated science before the War; the rapid expansion of mass college education in the

U.S. in the 1950s and 1960s; increased US spending on R&D and doctorate S&E education in response to Sputnik; the concentration of Soviet science and engineering on military technology; and the destructive effects of the cultural revolution on education in China. In 1970 US predominance was such that UNESCO statistics show that the country enrolled approximately 30% of tertiary level students in the world, whereas in 2000, the US enrolled just 14% of tertiary level students.[4] Over half of science and engineering doctorates were granted by US institutions of higher education.

Since then the rest of the world has begun to catch up with the US in higher education and in educating S&E specialists in particular. The number of young persons going to college has increased rapidly in other OECD countries and in many less developed countries, particularly China. Enrollments in college or university per person aged 20-24 and/or the ratio of degrees granted per 24 year old and in several OECD countries (Australia, New Zealand, Netherlands, Norway, Finland, the United Kingdom, and France) exceeded that in the US.[5] In most countries, moreover, a larger proportion of college students studied science and engineering than in the US, so that the US share of students in those fields was considerably lower than the US share overall. In 2000, 17% of all university bachelor's degrees in the US were in the natural sciences and engineering compared to a world average of 27% of degrees, and to 52% of degrees in China. [6]

---

[4] The UNESCO data from the global education database (http://esdb.cdie.org/cgi-bin2/broker.exe?_program=gedprogs.ged_theme_une.sas&_service=default). Tertiary level students are not always college students, so these data are imperfect. However, using data for college enrolments reported by individual countries, I obtain estimates of the US share comparable to the tertiary enrollment figures of UNESCO.

[5] NSF, Science and Engineering Indicators, 2004, appendix table 2-33 gives the degree data. OECD, Education Statistics gives enrollments. These data differ somewhat from the UNESCO tertiary enrollment figures.

[6] NSF, Science and Engineering Indicators, 2004, appendix table 2-33

At the graduate level, the PhD is the critical degree. Exhibit 1 records the ratios of PhDs earned in science and engineering in major PhD producing countries relative to the numbers granted in the US from 1975 to 2001 and extrapolates the numbers to 2010. PhDs in science and engineering outside the US rise sharply whereas the number granted in the U.S. stabilizes at about 18,000 per year. In 2001 the EU granted 40% more PhDs than the U.S. Trend data suggest that the EU will produce nearly twice as many S&E doctorates as the U.S. by 2010 or so.

But the greatest growth is for China. In 1975 China produced virtually no S&E doctorates. In 2003, the country graduated 13,000 PhDs, approximately 70% in science and engineering. Between 1995 and 2003, first year entrants in PhD programs in China increased six-fold, from 8,139 to 48,740. At this rate China will produce more S&E doctorates than the U.S. by 2010! The quality of doctorate education surely suffers from such expansion, so the numbers should be discounted to some extent, but as the new doctorate programs develop, the discount factor will decline.

Overall, the U.S. share of world S&E PhDs will fall to about 15% by 2010. Within the US, moreover, international students have come to earn an increasing proportion of S&E PhDs. In 1966, US-born males accounted for 71% of science and engineering PhDs awarded; 6% were awarded to US-born females; and 23% were awarded to the foreign-born. In 2000, 36% of S&E PhDs went to U.S.-born males, 25% to U.S.-born females and 39% to the foreign-born.[7] Looking among the S&E fields, in 2002, international students received 19.5% of all doctorates awarded in the social and behavioral sciences, 18.0% in the life sciences, 35.4% in the physical sciences, and

---

[7] R.B. Freeman, E. Jin, and C-Y. Shen. 2004. "Where Do New US-Trained Science-Engineering PhDs Come From?" Working Paper Series, Number 10544, NBER.

58.7% in engineering.[8] Since few US students earn S&E PhDs overseas, moreover, the ratio of S&E PhDs earned by US citizens or residents to those earned by citizens of other countries fell more rapidly than the ratio of degrees granted by US universities to degrees granted by foreign universities.[9]

Finally, the foreign-born share of science and engineering degrees earned in the US is also substantial for master's and bachelor's graduates. For physics , 6% of bachelor's degrees, 40% of master's degrees, and 42% of PhD degrees went to foreign-born students in 2003. [10] Among engineers, 42% of master's degrees and 49% of graduate students (most of whom are non-PhD students) were foreign-born/held temporary visas in 2001/2002.[11]

employment

The US relies on three sources for its graduate S&E work force: US-born /residents who choose S&E careers, international students who remain in the country after earning US degrees; and immigrant scientists and engineers.[12] Exhibit 2 records the number employed in science and engineering occupations from the 1990 and 2000 Censuses of Population and in the 2004 Current

---

[8]Data and taxonomies from the NSF Survey of Graduate Students and Postdoctorates in Science and Engineering (GSS) 2002, National Science Foundation. Life sciences includes biological sciences, agricultural sciences, and health fields; social sciences includes psychology; and physical sciences includes mathematics and earth sciences.

[9] Subtracting the number of foreign-born doctorates graduating in the U.S. from the US total, the EU advantage increases to 60%. Adding degrees granted in the US or other countries to Chinese citizens, while the Chinese earn 72% as many PhDs as are obtained by the U.S.-born.

[10] AIP Survey of Enrollments and Degrees (As Reported by Patrick Mulvey, Statistical Research Center American Institute of Physics, www.aip.org/statistics

[11]NSF, Science and Engineering Degreesby Race/Ethnicity of Recipients: 1992-2001, for degrees in 2001. NSF Graduate Students and Postdoctorates in Science and Engineering: Fall 2002, table 27, for enrollments in 2002, table 7.

[12] Some S&E workers, particularly in engineering, have less than college graduates, obtaining their skills from shorter training or working as technicians.

Population Survey, Merged Outgoing Rotation group files. The Census data show that in 2000, the foreign-born made up 17% of bachelor's S&E workers, 29% of master's S&E workers, and 38% of the PhD S&E workforce – huge increases over the comparable proportions in 1990. Indicative of the future, the foreign-born made up over half of doctorate scientists and engineers under the age of 45 in 2000 and approximately 60% of post-doctorate workers. Nearly 60% of the growth of PhD scientists and engineers in the country in the 1990s came from the foreign born. The 2004 CPS data show comparable percentages of foreign-born for bachelor's and doctorate degree employees, but a higher proportion of the foreign born among master's degree recipients.

Since neither the CPS nor the Census ask where someone earned their degree, these data do not distinguish between international students who chose to stay in the US and immigrants who come with foreign degrees. At the doctorate level, the Survey of Earned Doctorates shows that many international students remain in the US to work after they graduate. This is particularly true for students from developing countries, where earnings are lower and scientific facilities are not at US level. In the 2001 PhD graduates cohort, the proportion of foreign-born doctorates who remained in the United States for at least 2 years after receiving their degree was 71%. This compares to an estimated stay rate of 49% for the 1989 cohort. PhDs from China are especially likely to remain in the country.[13]

But immigrants with foreign degrees are also quite important. The 2000 Census reported a much higher number of foreign-born S&E workers than did the NSF's SESTAT data system, because the latter counts foreign-born recipients of US degrees but not immigrants with overseas

---

[13]Michael G. Finn. 2003. "Stay rates of foreign doctorate recipients from U.S. universities, 2001," Division of Science Resources Studies, National Science Foundation.

degrees between Censal years.[14] Among postdoctorate workers, who are a critical input in nearly all laboratories, about four-fifths of academic postdoctoral scholars holding temporary visas have non-US doctorates and around half of all academic postdoctoral scholars have non-US doctorates.[15] Finally, indicative of the growing reliance on the foreign born, NSF data show that foreign-born faculty who earned their doctoral degrees at US universities increased in number from 12% in 1973 to 20% in 1999. In engineering fields they increased from 18.6% to 34.7% in the same period.[16]

trade-offs in supplies

Because changes in the supply from one source affects the total number of S&E workers in the market, it necessarily impacts earnings and employment opportunities (Freeman, 1971, 1975, 1976; Borjas, 2003). As a result, changes in supply from any source affects the incentives for persons from that and from other sources to enter the S&E job market. The supply of US born/residents, particularly men, to science and engineering appears to be more responsive to labor market conditions than the supply of the foreign born. This reflects the fact that US born have access to other careers in the country, whereas science and engineering careers may be the only way for many talented foreign-born persons to enter the US job market. The ability to recruit international students and immigrant scientists and engineers for the US S&E job market benefits

---

[14] I estimate that approximately 7% of US S&E PhDs in 2000 Census were 1990s immigrants with foreign degrees. This implies that 1/3rd of the growth of foreign born PhDs in the period came from persons with overseas degrees.

[15] Mark Regets, July 19, 2004. Estimates based on the NSF Survey of Doctorate Recipients 2001 and the NSF Survey of Graduate Students and Postdocs 2001; Geoff Davis, Sigma Xi National Postdoctoral Survey, November 11, 2004.

[16] 2004 Science and Engineering Indicators, Appendix Table 5-24, National Science Foundation. Available on line at http://www.nsf.gov/sbe/srs/seind02/append/c5/at05-24.xls

the country by tapping a large and relatively inexpensive pool of talent at the cost of reduced incentives for native-born individuals to go on in science and engineering.

Trends in demography and in PhD production rates outside the US will reduce the U.S. share of S&E graduates at all degree levels. Assuming comparable training and ability around the world, US firms and universities who seek the most talented people will increase the foreign born share of their work forces in the future. But even with a sizable influx of foreign-born talent to the country, the share of science and engineering specialists working in the US will fall, reducing the country's dominance of science and technology.

Data on publications and citations by country of investigator show that the US predominance has already begun to drop in many areas. In spring 2004, the front page of *The New York Times* reported a fall in the U.S. share of papers in physics journals. In fall 2004, *Nature* reported an increase in the share of papers from China, while the NSF noted that Latin American countries were increasing their share of science publications. NSF data shows that the shares of scientific publications and citations have fallen as the U.S. share of the S&E work force has fallen. One aspect of the fall which has attracted attention is that it is associated not only with increased numbers of papers published from overseas locations but by a decline in publications from US-based scientists and engineers (Hicks, 2004).[17] The share of papers counted in the Chemical Abstract Service fell from 73% in 1980 to 40% in 2002.

Similarly, as the supply of S&E graduates has increased overseas, many high-tech companies have begun to locate major research installations outside the U.S. In 2004, the CEO of

[17] Other factors contribute to the falling U.S. share of papers. The average number of authors per scientific paper more than doubled over the past two or three decades, and U.S. scientists increasingly co-authored papers with people from other countries, so that the U.S. share of papers might have fallen even if the U.S. share of S&E resources had been constant.

Cisco declared that "Cisco is a Chinese company" when he announced that the firm was setting up its newest R&D facility in China. One of Microsoft's major research facilities is in Beijing. OECD data shows a large increase in U.S. outward R&D investment from 1994 to 2000. A 2004 survey of corporate executives by the Intelligence Unit of *The Economist* found that the five top countries in which firms intended to increase R&D outside of their home country were China, the U.S., India, the UK, and Germany. The three most critically important factors cited by executives when selecting R&D locales were "local R&D expertise in your industry," followed by "availability of R&D scientists with appropriate skills," and "cost of labour of R&D." As of mid 2004, the Chinese government registered over 600 multinational research facilities in the country, many from large US multinationals.[18] By contrast, in 1997 China registered less than 50 multinational corporation research center.

Proposition 2: Despite perennial concerns over shortages of scientific and engineering specialists, the job market in most S&E specialties is too weak to attract increasing numbers of US students.

Every few years or so, the scientific establishment and/or the top executives from major high technology firms proclaim that the US has a shortage of S&E workers and call for diverse policies to attract more Americans into the fields and/or to make it easier to bring foreign S&E workers into the country.

Economists have struggled to interpret claims that the U.S. had a shortage of scientific and engineering workers since the 1950s, when such claims first surfaced. In any market-clearing transaction where wages equilibrate demand and supply, there can no "shortage" or "surplus."

---

[18] "Multinational Corporations Establish 600 R&D Centers in China," Xinhua.net, August 23, 2004. See Kathleen Walsh, Foreign High Tech R&D in China, http://www.stimson.org/techtransfer/pdf/FrontMatter.pdf

There is disappointment about the price, either by suppliers (when a "surplus" reduces prices) or by demanders (when a "shortage" raises price), that can generate longer run responses in the form of investment to increase the supply or substitution of alternative inputs for the high-priced input. Arrow and Capron interpreted shortages as the result of sluggish wage adjustments. Stigler interpreted them as reflecting rapid changes in wages. Freeman stressed the cyclic nature of shortages and surpluses in the context of a cobweb model of market adjustment.

Wages are not, however, the only equilibrating force or indicator of the state of the labor market. In the market for researchers, the duration of postdoctoral work for PhDs, the probability of getting an independent research grant, or of landing a tenure track job at an institution of given quality, and so on, are also important mechanisms for market adjustment. In a loose labor market, young persons are likely to spend more years as post-docs at low post-doctorate pay than in a tight labor market. The American Institute of Physics used a graph that showed a fall in the fraction of young physicists taking post-docs and an increasing proportion taking jobs under the headline "The Physics Job Market: From Bear to Bull in a Decade: What a difference 8 years makes" to show that the physics job market had indeed improved.[19] New PhDs pay close attention to the quality of academic institutions making job offers. In a tight market, graduates end up in highly esteemed labs or universities. In loose markets, they accept jobs in places judged as lower quality.

Whichever indicator one examines, the evidence suggests that the job market for most scientists and engineers in the US has fallen short of the job markets in competitive high level occupations. Exhibit 3 records levels of pay and rates of change in pay from the Census of Population and CPS. It shows that scientists and engineers earn less than law, medical, and MBA

[19]Kate Kirby and Roman Czujko, December 1993 Physics Today, p 22 http://www.physicstoday.org/pt/vol-54/iss-4/p36.html

graduates, and that rates of increase in earnings for science and engineering in the 1990's fell short of the rates of increase for other specialized college graduates.

These figures, moreover, understate the earnings gap between persons who invest in S&E doctorates and those who choose other high-level careers. Doctoral graduate students typically spend 7-8 years earning their PhD – a quarter of their post-bachelors working life – at which they are paid stipend rates. In some disciplines, notably the life sciences, most spend 3 or so years doing postdoctorate work, again at stipend incomes that fall far below alternative salaries available to bachelors degree holders or those with professional degrees. Since postdocs work many hours, their pay is particularly low on an hourly basis for someone with their years of education. Given their lengthy training and post-doctoral work, many S&E doctorates do not enter the "real job market" until they are in their mid-30s, by which time many of their undergraduate classmates who chose other careers are well-established in their work lives.

Combining the pay differences between doctorate scientists and engineers and highly educated workers in other fields together with the difference in years of education and post-doctorate training produces huge differences in lifetime earnings. Translating Census of Population earnings by age group, per the data in exhibit 3, into lifetime incomes, discounted at 5%, biological scientists had lifetime earning on the order of $3 million dollars less per year than doctors and 1.8 million dollars less than lawyers. Doctors and lawyers pay for their education, while PhD scientists receive fellowships or stipends and rarely pay tuition, though they often work for their fellowship support, but this hardly equates the lifetime earnings. Physicists and mathematicians had higher discounted lifetime earnings, as did economists while engineers had the highest earnings among PhDs, but even those earnings fall considerably short of the earnings of doctors.

Looking beyond salaries, the demographics of the academic job market made it increasingly difficult for doctorate graduates to obtain faculty jobs even as older scientists retire. In 1973, roughly 73% of new PhDs obtained faculty jobs within three years of earning their degrees. By 1999, just 37% of new PhDs obtained faculty jobs within three years of earning their degrees. To see how the demographics of the job market operates to determine the probability of academic employment in the life sciences, consider the following model of demand and supply for new faculty, in which the proportion obtaining academic degrees rather than salary is the chief adjustment mechanism. Demand is the sum of demand for replacements for retiring faculty plus demand from growth of faculty, which occurs at r% per year. Assume steady state so that the retirement of existing faculty F is just 1/length of time of an academic career, which I take to be 30 years. Thus annual demand for new academics is

(1) F/30 + .0r F

On the supply side, assume that postdoctorate awards last 3 years, and the number of postdocs is PD, so the supply of postdocs will be PD/3. Let b be a variable that measures the proportion of postdocs who obtain academic jobs. Thus, supply of new academics is:

(2) bPD/3

Setting (1) = (2), the market clearing b = F/(10 PD) +3(.0r) F/PD = (1/10 +.0r) F/PD.

Exhibit 4 shows that the ratio of postdocs to tenured faculty rose greatly from 1987 to 1999 to reach 0.77, which gives a ratio of F/PD of 1.30. If faculty jobs were unchanged (r=0), just 13% of postdocs would find faculty positions. Even if the number of faculty jobs increased at 5% per year, just 20% of the postdocs would find faculty jobs. The implication is clear: a much smaller proportion of life science post-docs will move into academic jobs in the future than in the past. Universities and principal investigators therefore have a responsibility to prepare life science PhDs and postdocs for jobs outside of the standard academic track.

Finally, because NIH grants are awarded to faculty members rather than to postdoctorate scientists, the probability that young scientists obtain grants to work as independent investigators has fallen to negligible numbers. Exhibit 5 uses NIH data on the age distribution of recipients of R0-1 grants, and the age distribution of doctorate life scientists to show how the chances young investigators would get their own grants fell sharply in the past 20 or so years. The NIH data show that the proportion given to scientists less than 35 years old fell from 20% in 1980 to 4% in 2002 whereas the proportion of grants going to scientists aged 45 years and older rose from 22% to 60%. Dividing these proportions by the proportion of doctorates in the relevant age brackets gives the relative odds of obtaining an R0-1 grant. The relative odds drop from 1.21 to 0.30 for scientists less than 35 years old. In 1980 they had a greater chance of getting an award than older scientists, whereas in 2002 they had a much smaller chance. The relative odds rises for the oldest age group of scientists.

job market for bachelor's and master's graduates

Is there any evidence of shortages in the job market for bachelor's or master's graduates in science and engineering?

The BS in engineering is the key terminal bachelor's degree for scientists and engineers, and S&E employment in industry consists largely of bachelor's engineering graduates. Since the end of world war II, the job market for engineers has shown cyclic oscillations of the cobweb variety. (Freeman, 1971, 1975, 1976). Exhibit 6 shows the variation in numbers enrolled as first year engineering students from 1946 to 2001. Tight labor markets generate large increases in supply that depress the labor market approximately 4-5 years later. Similar patterns are observed in other fields. Starting salaries show that engineers make more than other bachelor's graduates, with however marked differences among specialties depending on how the industries that typically hire a given specialty are doing and the number of graduates. Cycles aside, the proportion of the work force in engineering has trended upward, from 0.9% of the work force in 1950 to 1.8% in 2003.[20] Engineering is the largest S&E occupation, by far.

Scientists and engineers traditionally have low rates of unemployment and reasonably secure job prospects. But in the 1990's, unemployment rose substantially for electrical engineers to rates that exceeded the national rate of unemployment. Since many engineers who lose jobs will find other work relatively quickly – albeit outside the field and at reduced earnings – the unemployment rate understates the weakness and risk involved in the job market for some specialties. A more striking indication of the weakness and risk in this job market is that between 2000 and 2002 the Bureau of Labor Statistics reduced its projections of the growth rate for employment of computer specialists (and mathematical scientists, a much smaller group) by one half. That means that it expects nearly a million fewer jobs in this area in the next decade. The reason appears to be the growth in offshoring computer work. This change in market prospects highlights the riskiness of S&E work in a global economy where other countries are producing many highly skilled substitutes for U.S. workers.

Exhibit 2 showed a huge flow of immigrant scientists and engineers with less than doctorate degrees. Some of this flow occurred as a result of the issuance of H1-B visas during the dot.com boom, when many high-tech firms complained about labor market shortages. But most was generated by normal immigration patterns. Given much larger numbers of engineering graduates in foreign countries, with huge increases in graduates in India and China, the pool of

---

[20] US Bureau of the Census Statistical Abstract, 2004, table 597 and US Statistical Abstract, 1953, table 224

potential foreign-born engineers is certain to increase. Although only a minority of these graduates are likely to be suitable for the work performed by major multinational firms, even a modest proportion of the increased supply will give more firms the choice between hiring immigrant engineers and scientists in their US facilities or hiring foreign-born specialists in their own countries.

If the labor market measures show that the job market for scientists and engineers has been relatively weak, what explains the large influx of international students and scientists and engineers from overseas into the country?

One reason that foreign born students and degree recipients are attracted to science and engineering work in the US while many US citizens or permanent residents do not find that work attractive is that the foreign-born have lower opportunity costs from other specialties than do Americans. The higher average incomes in the US, particularly compared to developing countries, and the greater dispersion of earnings in the US, particularly compared to other high income countries, means that US students, particularly the most able, have more lucrative non-S&E options than do foreign-born students. To many foreign-born students or workers, obtaining an S&E education or job is their ticket to the US job market, a green card, and possible citizenship. Their opportunities in their native country outside of science and engineering are far less attractive than are the opportunities outside of science and engineering to comparable Americans.

Indicative of the way in which the job market for young researchers operates, even huge increases in R&D spending in the US have not improved the well-being of new investigators enough to attract US students into post-doctorate positions. From 1995 to 2004 when NIH spending roughly doubled, the number of Americans accepting postdoctoral positions fell while the number of foreign-born PhDs accepting postdocs increased. As a result, the foreign-born share of postdocs rose to approximately 60%. At NIH itself − the largest single employer of scientists in bio-medical research – 46% of the doctoral level staff were foreign-born and 58% of the postdoctoral workers were foreign-born as of October, 2004. NIH reports that a substantial number of U.S. passport holders at the doctoral staff level were themselves naturalized immigrants.

Women and minorities

While S&E careers have attracted relatively fewer US men, the proportion of women and to a lesser extent under represented minorities choosing to major in science and engineering has risen from the undergraduate level to PhD levels. NSF data show that the female proportion in doctorate fields has trended upward from the 1970s through the early 2000s, albeit at different rates in different fields (Chang, Chiang, Freeman). Indicative of the growing influx of highly able women into the sciences, in 2004 women won 55% of National Science Foundation Graduate Research Fellowships. Decomposing the increased numbers of women earning science and engineering doctorates into the increased numbers of women obtaining bachelor's degrees in these fields and the increased likelihood that female bachelor's graduates go on to PhDs, Chang, Chiang, and I have found that it is the increased numbers in bachelor's programs that dominates the growth. With women earning 57% of all bachelor's degrees in the early 2000s and making up 63% of US persons taking the Graduate Record Exam, the proportion of women with science and engineering degrees is likely to continue to rise. This makes it critical that universities and other employers find ways to make career paths in scientific work more consistent with the work that women traditionally perform in family life, particularly child-bearing and child-rearing.

In addition, there has been an increase in the number of under represented minority groups going on in science and engineering. In 1976 blacks and Hispanics earned barely 2% of S&E

PhDs granted to US citizens or residents, whereas in 2001 they earned nearly 10% of S&E PhDs granted to US citizens or residents (Chang, Chiang, Freeman, slide 1.4).

Why have women and minorities chosen to enter science and engineering whereas white men have shifted to other fields?

There are two possible explanations. The first is that the proportions of women and minorities in science and engineering in the past was low because S&E did not readily welcome them – implicit or explicit discrimination. The supply of women and minorities was constrained or discouraged. The increased proportions are thus a movement toward a new equilibrium that more properly reflects interests and talents. The second is that the opportunity cost for women and minorities is lower due to less attractive opportunities in other high level occupations. For women, the large increase in the numbers in medical and law schools argues against this factor being as important as the national effort to equalize opportunities and increase diversity in S&E fields. Whatever the particular causes, it is striking that without an overall improvement in the overall S&E job market, more women and minorities have obtained S&E degrees and entered S&E occupations.

Reconciling the data and the shortage claims

Since labor market measures show no evidence of shortages of S&E workers, is there any way to make sense of continued claims that the US has a shortage of scientists and engineers and of calls for more young Americans to enter these fields rather than others? How can there be a shortage which does not show up in the job market?

One interpretation of the continual claims of a shortage is that they are disingenuous. Firms benefit from a greater supply of scientists and engineers at given wage rates, or better yet, at lower wage rates. H1-B visas allowed firms to hire trained specialists without the pay rises that would be necessary to attract more US workers. Foreign-born students and post-docs allow principal investigators to produce research at relatively low cost. The greater the supply of post-docs at current pay, the more cost-effective is US research spending. In the 1980s, NSF forecast shortages of scientists and engineers with the seeming goal of increasing supplies so that US firms could hire scientists and engineeers at lower wages. Congressional Hearings, which highlighted these forecasts, produced editorials in Science and Nature, and an apology from NSF that has made all analysts dubious of shortage claims (Weinstein).

A second interpretation, which I think more accurately captures current concerns, is that the US has an adequate supply of scientists and engineers only because of the sizeable influx of foreign-born students and employees. If, as I argue in point 3 below, US economic growth and comparative advantage depend substantially on the work of scientific and engineering workers, relying so much on foreign born supplies could be risky. Any interruption or change in the flow of immigrant scientists and engineers would certainly harm US research and development. Imagine NIH without foreign-born post-docs and scientists. From this perspective, the call for more US students to go into science and engineering reflects a belief that the balance between the supply of US born and of foreign-born scientists and engineers may have tilted too much toward the latter. It is not a shortage of scientists and engineers but of US entrants into the field. But many of the persons and firms who make these arguments do not face up to the potential trade-off issue: to attact more US citizens, earnings and employment opportunities have to get better, but that would be difficult to effectuate as long as the country can attract many scientists and engineers from overseas.

Proposition 3: Technological Edge and Global Competition When Numbers Count

The trade models developed in the 1980s and 1990s to explain the extensive trade among advanced countries with similar factor endowments focused on industries where countries gain advantages from being the first-mover on new technologies, which require R&D resources, and in which there are opportunities for improving productivity through learning or increasing returns. These models stressed that, since these economies have similar factor endowments, comparative advantage is likely to depend largely on particular investment decisions and technological prowess. In the Gomory and Baumol Ricardian model, there is a wide range of possible allocations of industries among advanced countries. Countries compete for the most desirable industries (the largest number of industries in the model), with the country that gains an edge obtaining higher GDP while the loser ends up with lower GDP. By contrast, trade between advanced countries and developing countries benefits both groups. Advanced countries compete with advanced countries in technology (and other societal attributes), but not in low cost labor.

The North-South version of trade models similarly postulates that the advanced area (the North) has the skilled work force and R&D to innovate new goods and services, while less advanced area (the South) could not compete in these areas. As a result the North innovates new goods while the production of older goods drifts to the South, as that area gains knowledge of how to produce the older products. Workers in the North were higher paid than workers in the South both because they are more skilled and because their countries have a monopoly on the new products. More rapid technological advance increases their wage relative to that of workers in the South while more rapid diffusion of technology has the opposite effect.[21] In these and other trade models, a country benefits when a trading partner or potential trading partner improves technology

---

[21] Connolly and Valderrama argue that the excessive imitation through reverse engineering by developing countries will reduce the North's incentive to invest and thus world living standards. They view intellectual property rights protection in trade agreements as a way to solve this problem.

in a sector in which the country does not compete, but can lose when another country improves its technology in a country's export sector. If someone improves the technology of banana production in hot climates, the US wins since the improved technology will lower cost and thus the price of bananas on world markets. In these models the South competes for older products by having low wages. The models rule out their competing with advanced countries in technology.

The increased supply of scientific and engineering workers, particularly doctorate researchers and others able to advance scientific and technological knowledge in large developing countries, threatens to obsolesce this vision of trade between advanced and developing countries. It creates the possibility of "human resource leapfrogging", in which large populous developing countries graduate and employ enough scientists and engineers to compete with the advanced countries in the high-tech vanguard sectors that innovate new products and processes. Even though a much higher proportion of Northern workers than Southern are scientists and engineers (presumed capable of innovating new products and processes), the North loses its monopoly in the high tech innovative sectors. Three factors would be necessary for human resource leapfrogging to shift the comparative advantage of the North to the South:

1. The Southern area is sufficiently populous that it has large numbers of S&E workers even though it deploys only a relatively small proportion of its work force in those fields. From the perspective of the US, there are only two countries with sufficiently large populations that they could develop larger S&E work forces: China and India;

2. Research and development productivity depends on the number of scientific and engineering workers applied to a problem. This seems plausible as a broad generalization, though the way a country organizes its R&D is also likely to affect productivity. The close ties between US universities and business and competition for research funding presumably gives the country

an advantage in turning research input into useful commercial output, though eventually numbers may dominate organization.

3. The South is able to develop leading edge commercial products even though the bulk of the Southern work force is less skilled. Again, this is most likely in highly populous countries that could recruit a substantial work force with any skill mix simply because it has lots of people. Under these circumstances, a populous developing country could compete in high-tech sectors and do what the traditional models have assumed the South could not do: compete effectively in R&D intensive high tech industries. Even if the developing country had somewhat lower quality scientists and engineers or lacked some infrastructure that gave its laboratories lower producitivity than those in advanced countries, it would have a cost advantage in R&D in terms of lower wages for scientists and engineers. Most important for the rest of the economy, innovative firms would have to be able to employ less costly production labor to produce the relevant commercial products.

Loss of comparative advantage in the high-tech sector to a low wage competitor could substantially harm an advanced country. It would have to shift resources to less desireable sectors, where productivity growth through learning is likely to be smaller. Wages and living standards would remain high in the advanced country because of its skilled work force and location-specific advantages, such as in infrastructure. But the monopoly rents from new products or innovations would shift from the advanced country to the poorer country.

The magnitude of the loss would depend in part on the number of persons working in the advanced sector, and their next best alternatives. If the low wage country were to use its scientists and engineers to take a global lead in astronomy or space exploration, there would be little impact on the economy of the advanced country. The next human on the moon or the first on Mars would speak Chinese or Hindi rather than English and would not plant the red, white, and blue, in the rocky terrain. Students interested in astronomy/space exploration might flock to the low wage country to learn from the new scientific leaders, which might lead some universities in advanced countries to close their astronomy or space science departments, forcing the astronomers and space scientists to find work elsewhere.

But if the low wage country were to use its scientists and engineers to take a global lead in sectors with sizeable employment and significant through-put to other economic sectors, the economic losses could be substantial. They would potentially be larger than those that might occur if the advanced country lost its technological advantage in an industry to an equally advanced competitor because wages might have to fall more to make some other sector competitive with the low wage competitor. In the extremum, if the only reason workers in the North were paid more than those in the South was that the North had a monopoly in innovating new products, the South would effectively become the North and the North would become the South, reversing their relative positions in wages. Technology would be like a gold mine, and whichever country possessed the mine would be wealthier than the other.

Does the loss of technological advantage to a lower wage country necessarily harm an advanced country? No. Jones and Ruffin have developed a set of models in which the loss of technological advantage could benefit the advanced country. In their analysis, the advanced country has an absolute advantage in all sectors, with a comparative advantage in the high tech sector. It loses this comparative advantage so that it is completely wiped out as an exporter of high tech and becomes an importer of high tech and exporter of the lower tech product. But it remains a high wage country and its living standards rise because the low wage country produces so much of the high tech at low prices that the terms of trade improve for the advanced country with the shift in comparative advantage. Of course, this occurs only under specified conditions: first, that the advanced country has a large absolute advantage in the low technology product, which becomes its new export product, as well as in the high technology product, and second, that the large populous country has a work force (presumably measured in effective skill units) that is "much" larger than the advanced country. In addition, the model does not give the "high tech" export sector whose production is lost any of the special features (greater rates of learning and productivity advance or economies of scale) that may make that sector particularly desireable. The Jones-Ruffin model has the flavor of an "immiserizing growth" model in which technical progress or factor accumulation leads to sufficiently acute deterioration in the terms of trade to reduce economic well-being. While it may seem as implausible that an advanced country would gain from the loss of technology, the model is worth empirical investigation,[22] and at the minimum the Jones-Ruffin models make the point that loss of technological superiority can generate benefits even if it leads to a massive shift in the locus of comparative advantage.

Looking at the technological edge that the US (and other advanced countries) have relative to developing countries from a different perspective, Donald Davis and David Weinstein have argued that the flow of immigrants and influx of capital into the US costs US natives sizeable amounts. These increases in factor supplies cost the US sizeable amounts because the immigrant labor and capital leads the US to exand the production of the hightech goods in which the country has a comparative advantage, and drives down the price of those goods. In this model, if foreign born workers remain overseas working with older or less productive technology, they are weaker

[22] The assumed absolute advantage of the advanced country in all areas of production and the relative sizes of the country's work forces merit furthur analysis. The work force assumption seems reasonable if one compares the number of workers in low wage countries with those in high wage countries, but unreasonable if one compares labor in efficiency units.

competitors for American workers. The implication is that it benefits the US to reduce immigrant flows. From one perspective the analysis of human resource leapfrogging parallels the Davis-Weinstein model, since it also makes the key determinant of US living standards a monopoly on advanced technology. But the analyses differ in important ways. My analysis makes technological superiority endogenous to the supply of scientists and engineers, not an exogenous given. Indeed, by contributing ideas, immigrant scientists and engineers improve US technological capital and thus improve overall US well-being, although their supply reduces the earnings or opportunities for American scientists and engineers. Even more important, the human resource leapfrog model assumes that the US technological superiority necessarily erodes as the foreign countries build up their science and engineering labor supplies, and as multinational firms locate where those supplies are cost effective. From this perspective, it would be better for US workers to have immigrants use US-created technology in the US rather than to use it overseas, where wages and labor standards are lower.

Real concerns or paranoi: the title question

So, to what extent, if at all, does globalization of the scientific/engineering workforce threaten US economic leadership?

The globalization of science and engineering education and the growth of the scientist and engineers' work force outside the US is real and inevitable. The rapid growth of the highly educated work force in the large populous developing countries of China and India is also real, though not inevitable. It is part of the development strategies that these countries have taken – a commitment to education and technology in the vanguard industries as part of their national growth plans, not simply to produce cheap plastic toys or low level call center responses to consumer inquiries. It is too early in the globalization of S&E activities to estimate formal models of the potential positive and negative effects on the US or other advanced countries, but there are enough "straws in the wind" or indicators that these developments are impacting the economic world to give a positive answer to my title question: yes, this form of globalization is, for better or worse, threatening US technological and economic leadership in high tech sectors.

The first indicator that the increased supply of scientific and technological workers in the large populous low wage countries has begun to attract technological advances is in the location of new R and D facilities by major firms in China and Inda. This is not a matter of locating facilities to develop products for the Chinese or Indian markets with little expectation that the technology will be used for products in advanced countries. Instead, these facilities are likely to produce advances that will affect global production. Microsoft's Advanced Technology Center, which opened in Biejing in 2003, is expected to help the company maintain its lead in technology and to develop and test new products.[23] To the extent that, as many believe, R&D location affects the locus of production, production and employment is likely to shift from the US and other advanced countries to these countries. At a minimum, the rate of technological catch-up should grow in high-tech sectors, reducing the North's lead.

The second indicator that the development of science and engineering work forces overseas affects the US economy is in the offshoring of some forms of skilled work. If educated workers in low wage countries can do similar tasks as educated workers in advanced countries, firms will try to offshore that work to the lower wage locale. While the US government does not have reliable data on the magnitude of the number of jobs offshored, business consultants and business leaders indicate that the number is non-negligible and growing (see Hira and Hira, 2005). Some experts estimate that on the order of 10%-15% of employment in the US is potentially off-shorable

[23] MIT Technology Review, Briefcase, March 2005, pp 25-30.

(Bardhan and Kroll, 2003). "If it is digital, it will go" at current US-India or US-China wage differentials. For diverse reasons, India has been the main locale for the off-shoring of high level activity, but eventually China will also attract jobs in these areas as well. Advising companies how to offshore is itself a rapidly growing industry, with management consultants telling firms that they can gain as much as 40% more in profits from selected activities.

Another sign that the growth of the science and engineering work force in developing countries is moving those countries toward the technological frontier that advanced countries have historically monopolized is that those countries, particularly China, have risen rapidly in various measures of technological prowess. The Technology and Policy Assessment Unit at Georgia Tech high tech index, which compare the technological competitiveness of 33 nations on the basis of a diverse set of measures, ranging from numbers of patents to measures of national orientiation and infrastructure to a survey of expert opinions about technological capabilities, shows a jump in China's position in the 1990s. [24] Exhibit 7 compares the position of China in 1993 and 2003 in the aggregate indicator produced by this group, and gives the indicators in three key sub-indices: high tech outputs, productive capacity, and technological infrastructure. To be sure, China is still below Japan and the US but the gain from 1993 to 2003 is impressive.

The fourth sign that "something big" is afoot is found in data on production and exports of high tech products. From 1989 to 2001 the US maintained a 31% share of world production in high industries, as the US economy outperformed the EU and Japan in these areas. But the US market share of exports fell from 24% to 17%. The big gainer in the world production and exports was China. Between 1989 and 2001 the ratio of China's high tech output to the US's high tech output rose from 7.1% to 27.3%. (NSF, Science Indicators, 2004, appendix table 6-1). The share

[24] See Alan Porter, David Roessner, Nils Newman, Alisa Kongthon, Xiao-Yin Jin Review and Revision of High Tech Indicators 2003 Final Report to the Science Indicators Unit, Science Resources Studies Division, National Science Foundation under Contract D020024 February 2004

of electronics, machinery, and transport equipment in China's exports increased from 18.1% in 1994 to 42.9% in 2003, with the export shares of office and data processing equipment (including computers and components) rising the greatest percentage points. In the first quarter of 2005, the Chinese Ministry of Commerce reported 84 billion US dollars of foreign trade of high-tech products, up 26.2 percent over the same period last year.[25]

Finally, consider the publication of papers on the technologies that experts view as the emerging or future technologies. Porter et al found that China was fourth in the world, after the USA, Japan and Gemany, in publications in four emerging technologies in 1999. Looking at the reputed "next big thing" in technology, nano-technology, the Nanotechnology Research Institute of Japan reported in 2004 that China was third and close behind Japan in publications and patents in this area.[26] In terms of R and D spending on nano, China is fourth after the US, Japan, and the EU taken as a whole, although monetary comparisons are difficult given differences in prices and potential effectiveness of research facilities.

In sum, research and technological activity are moving where the people are, even when they are located in the low wage "South". It is moving to China because China is graduating huge numbers of scientists and engineers and to India, as well.

Proposition 4: Adjustment Problems and Policies for a New Era

As the number of scientists and engineers working in foreign countries continues to increase, the US's comparative advantage in generating scientific and engineering knowledge and in the high-tech sectors and products associated with that knowledge will almost certainly decline. This will surely be good for the world. The spread of modern technologies to more economies will raise incomes in low income countries. The increased number of scientists and engineers will stimulate the growth of scientific and technical knowledge and thus the rate of technological advance, expanding the global production possibility frontier. The US will benefit from the

---

[25] http://news.xinhuanet.com/english/2005-04/11/content_2815390.htm

[26] http:/www.nanoworld.jp/apnw/articles/2-24.php

greater advance of new knowledge and the production of new goods and development of new processes and the reduced costs of products from innovations and products developed elsewhere.

But the US also risks facing economic difficulties as its technological superiority erodes. What is good for the world is not inevitably good for the US. The group facing the biggest danger from the loss of America's technological edge will be workers whose living standards depend critically on America's technological superiority. The decline in monopoly rents from being the lead country will make it harder for the US to raise wages and benefits to workers. The big winners from the spread of technology will be workers in developing countries, and the firms that employ them, including many US multinational corporations. In the long term, the spread of knowledge and technology around the world will almost certainly outweigh the loss of US hegemony in science and technology, but the transition period is likely to be lengthy and difficult – more formidable than that associated with the recovery of Europe and Japan after World War II. The more similar the production technologies and composition of output in lower wage countries becomes to that of the US, the greater will be the downward pressures on US wages – until the wages in those countries reach similar levels to those among advanced countries.

To minimize the costs of adjustment during what is likely to be a long transition, the US will have to consider new policies in the labor market to distribute the national product more equitably and new policies in the market for R&D and technology to build on existing strengths that will maintain scientific and technical leadership in some sectors and to remain close to the frontier in other areas. The country will also have to find ways to take scientific and technological advances from other countries and turn them into commercial products rapidly.

In the scientific and engineering job market, continued growth in the supplies of highly talented young people will stretch out the transition period and maintain the US as a center of scientific and technnological excellence, albeit a less dominant center. The country could do this in several ways. It could continue to encourage large numbers of foreign students and SE immigrants to study and work in the country, at the cost of depressing incentives for domestic supply. If it does this, it ought to think about policies to encourage these students and immigrants to obtain permanent residence and citizenship quickly, to reduce the danger that they might return to their origin country and develop industrial activities that compete with those in the US. The country could also take the opposite tack and seek to increase domestic supply by reducing the number of foreign students and immigrants. This would create shortages in the short run that would raise the costs of scientific and engineering workers – a shortage at last – that would attract more young Americans to the fields. Alternatively, the country could seek policies to increase domestic supplies without discouraging foreign students and immigrants. This would involve giving more and more lucrative graduate research fellowships (which go to US students or residents only) and improving opportunities to do independent research early in a career, which is likely to increase US supplies more than those from foreign countries.

On the demand side of the market, the US might consider concentrating S&E resources in a subset of R&D intensive sectors, developing policies to help US business stay abreast of technological advances. The country could also work to that partner US scientific and technological activity with that of other countries, so as to avoid competing in the same area, or so that US firms could benefit from advances overseas. To many economists these schemes will have the flavor of an industrial policy, where the government tries to save industries that suffer from competition and pick winners. But a policy for research and development in new technologies is a bit different, and more likely to prove successful. As long as the government is the main source of support for basic research directly through grants or indirectly through subsidization of universities, it already does this. The doubling of NIH research spending spurred the life sciences, where increased knowledge will be more beneficial to biotechnical firms and the health industries than to most others. The National Nano-tech initiative will spur engineering and physical sciences, which has the potential to benefit different sectors of the economy. On the other hand, a shift in R and D from areas likely to benefit the civilian economy toward military goals is likely to weaken US technological superiority in normal economic activity.

In adjusting to the globalization of science and engineering and the diminishment of US comparative advantage in high tech sectors, the US has some notable weaknesses. The country's labor and social insurance system is not well-developed for helping workers cope with a potentially long period of transition. The country has the lowest safety net for workers and the most expensive employment-linked health insurance system among advanced countries. It has done a relatively poor job in educating lower skill persons and ... you know the litany. But the country also has some great strengths for absorbing the loss of technological superiority in at least some sectors. The high mobility of the US work force should make some adjustments more palatable than would be the case if Americans were less willing to move location or change their occupation or industry. And the US has developed a set of insitutions and modes of scientific research that will help keep the country at the technological frontier. American scientists and engineers collaborate regularly with scientists and engineers in other countries. American universities are more closely linked to business and the economy than those in other countries. This should enable US higher education to continue its role in producing knowledge spills over to industries in local areas, through spin-offs or other forms of knowledge transfer.

If the country maintains or improves its efficiency in moving knowledge from university labs to commercial products, the US comparative advantage in high technology sectors will be maintained longer than would otherwise be the case. Speaking with a Harvard physicist, whose most readily commercializable work was done collaboratively with overseas scientist and engineers, I commented, “ah, so you are helping them catch up with us”, to which I received the reply, “no, they are helping us keep ahead of them”. The reason was that the US side of the collaboration found it easier to deal with industry and to attract venture capital and business entrepreneurship. Empirically, US firms spend more on R and D relative to GDP than do EU firms and contribute more to university research programs. While there are dangers with business-university linkages, about which Derek Bok has amply warned us, these links are likely to preserve leadership innovation and high tech even as the US share of world PhD researchers falls.

Bibliography

American Institute of Physics, Statistical Research Center. 2003. *Survey of Enrollments and Degrees*, AIP Pub. Number R-151.39 (August). As Reported by Patrick J. Mulvey and Starr Nicholson. (http://www.aip.org/statistics/trends/reports/ed.pdf)

Arrow, Kenneth J. and William M. Capron. 1959. "Dynamic Shortages and Price Rises: The Engineer-Scientist Case," *Quarterly Journal of Economics* (73)2:292-308.

Bardhan, Ashok D. and Cynthia Kroll. 2003. "The New Wave of Outsourcing," Fisher Center Resaerch Reports, Paper 1103. (University of CA, Berkeley: Fisher Center for Real Estate and Urban Economics).

Blank, David M. and George J. Stigler. 1957. *The Demand and Supply of Scientific Personnel.* (NY: NBER).

Borjas, G. 2003 "The Labor Demand Curve Is Downward Sloping: Re-examining the Impact of Immigration on the Labor Market" *Quarterly Journal of Economics* (November) pp 1335-1374.

Brezis, Elise S., Paul R. Krugman, Daniel Tsiddon. "Leapfrogging in International Competition: A Theory of Cycles in National Technological Leadership," *The American Economic Review* 83(5)(December): 1211-1219.

Chang, Tanwin, Hanley Chiang, Richard B. Freeman, and Jason Abaluck. 2004. "How Do Stipends Affect the Supply of PhD Scientists and Engineers?" with Tanwin Chang, Hanley Chiang, and Jason Abaluck. NBER SEWP Report, conference presentation for the *NSF/NIH/CGS Graduate Support Workshop*, June 17-18, AAAS, DC.

Coe, D.T., E. Helpman, A.W. Hoffmaister. 1997. "North-South R&D Spillovers," *The Economic Journal,* 107(44): 134-149.

Commission on Engineering and Technical Systems. 1986. *Engineering Infrastructure Diagramming and Modeling.*

Connolly, Michelle. 2003. "The Dual Nature of Trade: Measuring Its Impact on Imitation and Growth," *Journal of Development Economics*, 72(1): pp 31-55.

Connolly, Michelle, and Diego Valderrama. 2004. "North-South Technological Diffusion and Dynamic Gains from Trade," Federal Reserve Bank of San Francisco Working Paper 2004-24. (http://www.frbsf.org/publications/economics/papers/2004/wp04-24bk.pdf).

Davis, Donald R. and David E. Weinstein. 2002. "Technological Superiority and the Losses from Migration," NBER WP # 8971 (May).

Davis, Geoff. 2004. *Sigma Xi National Postdoctoral Survey*, November 11.

Finn, Michael G. 2003. "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2001," Division of Science Resources Studies, National Science Foundation.

Freeman, Richard B. 1971. *The Market for College Trained Manpower*. Harvard Univ. Press.

Freeman, Richard B. 1976. "A Cobweb Model of the Supply and Starting Salary of New Engineers," *Industrial Labor Relations Review* January.

Freeman, Richard B. 1975. "Supply and Salary Adjustments to the Changing Science Manpower Market: Physics, 1948-1975," *American Economic Review* 65(1): 27-39 (March 1975).

Freeman, Richard B., Tanwin Chang and Hanley Chiang. 2005. “Recent Progress in S&E Developments”. Presented at the NBER SEWP Conference, Diversifying the Science and Engineering Workforce: Women, Underrepresented Minorities, and their S&E Careers, January 14-15, http://www.nber.org/~sewp/events/2005.01.14/Agenda-1-14-05-WEB.htm

Freeman, Richard B., Emily Jin and Chia-Yu Shen. 2004. "Where Do New US-Trained Science-Engineering PhDs Come From?" NBER WP # 10554 (June).

Goldman, Erica and Eliot Marshall, “NIH Grantees: Where Have All the Young Ones Gone?” *Science* Vol 298 (October 4, 2002).

Gomory, Ralph E. and William J. Baumol. 2000. *Global Trade and Conflicting National Interests*. (Cambridge: MIT).

Hicks, Diana. 2004. “Global Research Competition Affects U.S. Output,” School of Public Policy, Georgia Institute of Technology, Atlanta (November 1). (C:_dh/work\New Folder\higher ed book chap.doc)

Hira, Ron and Anil Hira. 2005. *Outsourcing America: What’s Behind Our National Crisis and How We Can Reclaim American Jobs* (NY: AMACOM, American Management Association).

Jones, Ronald W. “Immigration vs. Outsourcing: Effects on Labor Markets,” University of Rochester. (http://www.aueb.gr/deos/papers/GeorgakopoulosVolume_Hmerida_Papers_Jones.pdf)

Jones, Ronald W. and Roy J. Ruffin. 2005. “Can a Country Gain by Technology Loss?” (http://gemini.econ.umd.edu/cgi-bin/conference/download.cgi?db_name=mwie2005&paper_id=48)

Kirby, Kate and Roman Czujko. 1993. “The Physics Job Market: Bleak for Young Physicists,” *Physics Today*, December, p 22. http://www.physicstoday.org/pt/vol-54/iss-4/p36.html

Krugman, Paul. 1979. “A Model of Innovation, Technology Transfer, and the World Distribution of Income,” *The Journal of Political Economy* Vol 87: 2 (April) pp 253-266.

MIT Technology Review. 2005. Briefcase (March).

National Academy of Science. 2000. *Enhancing the Postdoctoral Experience for Scientists and Engineers*.

National Science Foundation. 2004. *Science and Engineering Indicators, 2004* (Washington, DC: USGPO).

NSF SESTAT data system

NSF, Survey of Earned Doctorates (Washington DC:USGPO)

National Science Foundation. *Survey of Graduate Students and Postdoctorates in Science and Engineering (GSS) 2002*, (Washington, DC: USGPO).

National Science Foundation, Division of Science Resource Statistics. 2004. *Science and Engineering Degrees by Race/Ethnicity of Recipients: 1992-2001,* NSF 04-318. Project Officers, Susan T. Hill and Jean M. Johnson (Arlington, VA).

National Science Foundation. *Characteristics of Doctoral Scientists and Engineers in the United States*.

National Science Foundation, Division of Science Resource Statistics. 2005. *Graduate Students and Postdoctorates in Science and Engineering: Fall 2002,* NSF 05-310. Project Officers, Julia D. Oliver and Emilda B. Rivers (Arlington, VA).

National Science Foundation. "Undergraduate enrollment in engineering and engineering technology programs."

OECD. Education Statistics.

People's Daily. 2002. "China May Have More PhDs then the US in 2010". Http://peopledaily.com.cn/20021021_105393.htm

Porter, Alan L. and Scott Cunningham. 1995. "Whither Nanotechnology? A bibliometric study, Foresight Institute, Foresight Update 21 (June 1). http://www.foresight.org/Updates/Update21/Update21.4.html

Porter, Alan L., J. David Roessner, Xiao-Yin Jin and Nil C. Newman. 2002. "Measuring National 'Emerging Technology' Capabilities," *Science and Public Policy* Vol 20:3 (June).

Porter, Alan, David Roessner, Nils Newman, Alisa Kongthon, Xiao-Yin Jin. 2004. "Review and Revision of High Tech Indicators 2003: Final Report to the Science Indicators Unit," Science Resources Studies Division, National Science Foundation under Contract D020024 (February).

Regets. Mark. July 19, 2004. Presentation at the National Academy of Sciences, meeting on International Graduate Students and Postdocs, July 19, 2004 - July 20, 2004

Ruffin, Roy J. and Ronald W. Jones. 2004. "International Technology Transfer: Who Gains and Who Loses?" University of Rochester. (http://www.wallis.rochester.edu/jones04/Ruffin-Jones_Technology_Transfer.pdf)

Shanghai Jiao Tong University, Institute of Higher Education. 2004. "Academic Ranking of World Universities - 2004," (http://ed.sjtu.edu.cn/rank/2004/2004Main.htm)

Song, Weiguo and Zhaohui Xuan (2004). "Preliminary Analysis of China's Doctor Education," *OECD Careers of Doctorates Workshop*, September 2004.

The Economist Intelligence Unit. 2004. "Scattering the Seeds of Invention: The Globalisation of Research and Development," The Economist Intelligence Unit, The Economist (September).

UNESCO. "Global Education Data Base" (http://esdb.cdie.org/cgi-bin2/broker.exe?_program=gedprogs.ged_theme_une.sas&_service=default

)

U.S. Census Bureau, US Dept of Commerce, 2001. *Current Population Reports 2000.*

U.S. Census Bureau, US Dept of Commerce, 2005. *Current Population Reports 2004.*

U.S, Census Bureau, US Dept of Commerce. CPS IPUMS Data 1990.

U.S. Census Bureau, US Dept of Commerce. CPS IPUMS Data 2000.

U.S. Census Bureau, *Statistical Abstract, 2004*.

U.S. Census Bureau, *Statistical Abstract, 1953*.

Weinstein, Eric. "How and Why Government, Universities, and Industry Create Domestic Labor Shortages of Scientists and High-Tech Workers," (http://www.nber.org/~peat/PapersFolder/Papers/SG/NSF.html)

Xinhua.net, 2004. "Multinational Corporations Establish 600 R&D Centers in China. August 23.

EXHIBIT 1: Ratio of # S&E PhDs from Foreign Universities to # from US Universities

(Ratio of PhDs in each year)	**1975**	**1989**	**2001**	**2003**[a]	**2010**[a]
Asia major nations	0.22	0.48	0.96		
China	na	0.05	0.32	0.49	1.26
Japan	0.11	0.16	0.29		
EU major (Fr, Germ, UK)	0.64	0.84	1.07		
All EU	0.93	1.22	1.54	1.62[c]	1.92[c]
Chinese 'diaspora' vs. US 'stayers' (estimate)			0.72[b]		

[a] For 2003 and 2010, ratios calculated using US doctorates at 2001 production level.
[b] 'diaspora' includes estimates of Chinese doctoral graduates from UK, Japan, and US (with temporary visas). US 'stayers' include US citizens and permanent residents.
[c] EU data extrapolated from earlier years.

Sources: NSF *Science and Engineering Indicators 2004*, and primary sources referenced therein; Weiguo and Zhaohui, National Research Center for S&T Development (China) - private communication.

EXHIBIT 2: Trend in Foreign-born Share of S&E Employment

	1990	2000	2004
Bachelors	11%	17%	17%
Masters	19%	29%	32%
All PhD	24%	38%	37%
PhDs < 45	27%	52%	–
Post-Doc	51%	60%	--

Source: 1990 and 2000 post-docs from Census of Population; Post-Docs from NSF.
Note: FB% Post-Doc in 1987 was 45%. 2004 from CPS, MORG Files.

EXHIBIT 3: Income in Thousands of Dollars and % Change in Income, 1990-2000

	1990	**2000**	**% Change**
PhD			
Engineering	$64.6	91.1	41.0
Mathematics	58.3	86.6	48.5
Natural Science	56.3	73.0	29.7
Social Science	54.2	74.6	37.6
Life Science	45.6	62.7	37.5
MD	98.8	156.4	58.3
Lawyer	76.9	114.7	49.2
Managers (C+2 yrs)	61.3	84.9	38.5

Source: Tabulations from US Census of Population, IPUMS Data, 1990, 2000.

EXHIBIT 4: Ratio of Number of Postdocs / Number of Tenured Faculty in Life Sciences

Discipline	**1987**	**1999**	
	Postdocs / Tenured		**% ∆**
Life Sciences	0.54	0.77	43%
Physical Sciences			
Mathematics	0.20	0.19	-5%
Engineering	0.11	0.16	45%

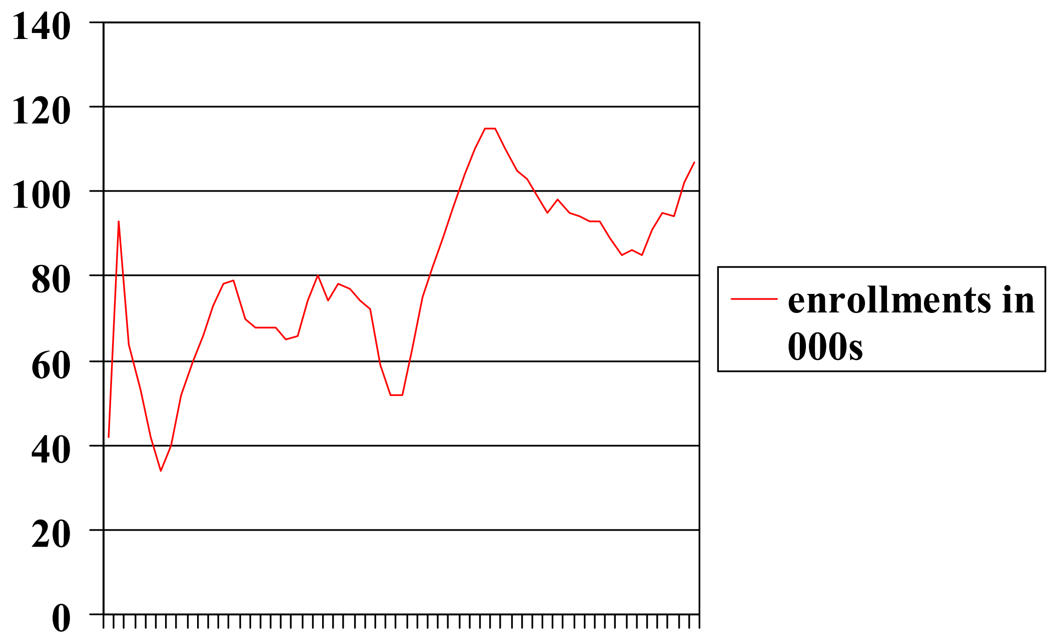
Source: National Academy of Science, *Enhancing the Postdoctoral Experience for Scientists and Engineers* 2000, table B-14.

EXHIBIT 5: Younger Scientists Don't Get NIH Grants

Share of NIH Grants	**1980**	**2001**
<35	23%	4%
>45	22%	60%
Relative Odds of Getting NIH, by age (ratio of shares of NIH grants to shares of PhDs)		
<35	1.21	0.30
>45	0.52	1.07
Younger/Older	2.33	0.28

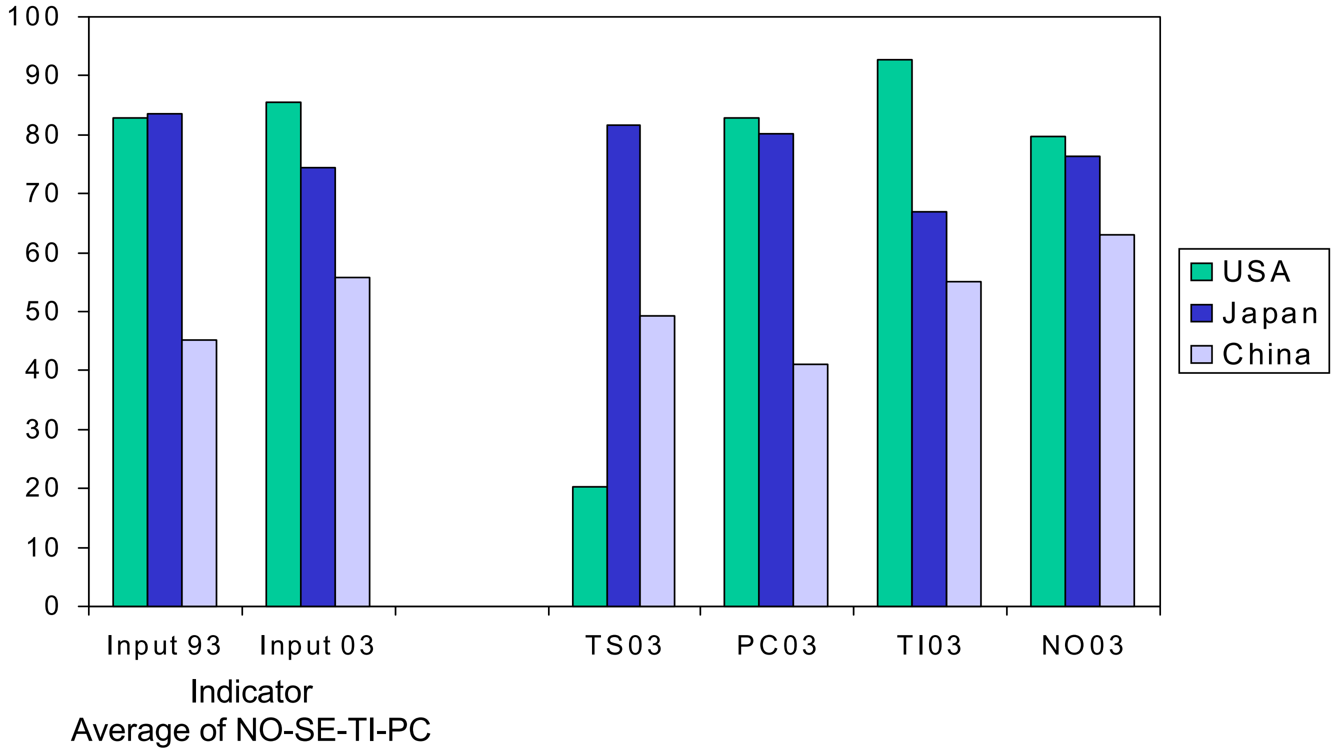
Source:
NIH: Erica Goldman and Eliot Marshall, "NIH Grantees: Where Have All the Young Ones Gone?" *Science* Vol 298 (October 4, 2002).
NSF: *Characteristics of Doctoral Scientists and Engineers in the United States*.

EXHIBIT 6: First Year Enrollments in Engineering Oscillate With Market Conditions, 1946-2001



Source: Engineering Infrastructure Diagramming and Modeling (1986)
Commission on Engineering and Technical Systems;
National Science Foundation, Undergraduate enrollment in engineering and engineering technology programs

EXHIBIT 7: High Tech Indicator Values: 1993, 2003



TS – Output Indicator Tech Standing
PC – Productive Capacity (Input Ind)
TI – Technological Infrastructure (Input Ind)
SE – Socio-Economic Infrastructure (Input Ind)
NO – National Orientation (Input Ind)