Observations on *Science and Engineering Indicators 2010*
August 15, 2011

The National Science Foundation's *Science and Engineering Indicators 2010* (SEI) contains a wealth of information on science and engineering activity in the United States and other countries – statistics on R&D expenditures, educational achievement, science and engineering occupations, patents, scholarly articles, and a great deal more. This is a very valuable resource.

I read SEI looking for explanations for the decline in manufacturing employment in the United States and for what I fear may be an erosion of U.S. technological leadership. I did not find a smoking gun, although changes in the composition of R&D may have affected the sectors in which jobs are created. It is also striking the degree to which the United States looks to those born abroad for its advanced science and engineering (S&E) workforce. Making it easier for foreign-born S&E workers to become permanent residents and citizens would allow them to more fully develop their talents – to the benefit of all.

The most disturbing aspects of SEI are the international comparisons of educational attainment and achievement. The United States' educational advantage over the rest of the world is fast diminishing. This bodes poorly for future U.S. technological leadership, not just in manufacturing. And even if the United States is able to retain its innovative edge, by virtue of its economic and political systems, the poor performance of U.S. students on international tests and the lack of progress in raising educational attainment suggests that the fruits of U.S. innovative leadership are likely to be captured by relatively small numbers of highly trained professionals and executives and not by the public at large.

No Smoking Gun

SEI does not show major changes in U.S. science and engineering activity that one would expect to cause a decline in manufacturing prowess. R&D spending has not fallen relative to GDP or relative to expenditures in most other countries. Nor does one see a falloff in science and engineering graduates at U.S. colleges and universities. Although a substantial fraction of science and engineering students are foreign-born, particularly at the graduate level, most of these foreign students plan to stay in the United States – and seem to succeed in doing so. But some shifts provoke questions.

Research and Development

U.S. R&D spending was just under 3 percent of GDP in 2008. This share approaches or equals past highs in the 1960s, 1980s and late 1990s. The federal government's share of total R&D has fallen dramatically, however. Whereas the federal government accounted for about two-thirds of R&D spending in the 1960s, and close to half in the 1980s, it now accounts for about a quarter. Business funds most of the rest of R&D.

Most business spending on R&D is carried out by business. Additionally, some business R&D is funded by the federal government. (In 2008, the federally supported share was less than 10 percent – down from about half in the 1960s.) The big R&D performers in the business sector are chemicals (especially pharmaceuticals), computers and electronic products (especially semiconductors and instruments), software and computer services, aerospace and defense manufacturing, R&D services, and automotive.

Most business R&D is development, with some applied research and very little basic research. Despite the growth in business funding of R&D, however, the share of total R&D going to basic research has not declined over the past 40 years. Indeed, at 17 percent in 2008, the share of basic R&D was high by historic standards.

About 60 percent of federal spending on R&D is currently going to defense. The defense share was much higher in the 1960s and somewhat higher in the 1980s. It was lower in the 1970s and 1990s. The shares of nondefense (and total) federal R&D spending going to health have increased sharply over the past 30 years. The shares going to economic development R&D, including energy, have fallen sharply.

The U.S. ratio of R&D to GDP, at 2.7 percent in 2007, is higher than ratios in most counties, but not as high as the ratios in Japan and Korea. In the past ten or so years, South Korea's R&D share has risen rapidly to about 3.5 percent of GDP. R&D has also risen rapidly in China but from a much lower level. R&D is now about 1.5 percent of GDP in China. In terms of the dollar value of R&D spending (as measured by purchasing power parity), the United States ranked first by a very large margin in 2007. Japan was second and China was third. Excluding defense, the U.S. margin of superiority over most countries was not as wide. U.S. non-defense R&D spending was 2.2 percent of GDP in 2007, compared to 3.4 percent for Japan. (Non-defense R&D figures are not available for China and may not be relevant, given the importance of state–owned enterprises with links to the military.)

On the surface, at least, these trends do not seem hostile to innovation and technological progress in manufacturing in the United States. Indeed, one could argue that shifts to more business funding of R&D and away from defense, should result in more commercially practical applications. (I recall discussions in the late 1980s in which it was argued that Japan's greater focus on business research, as compared to defense, was a competitive advantage.) At the same time, the shift to more business R&D has not caused the share of R&D going to basic research to fall, suggesting that we are not trading away opportunities for major research breakthroughs in exchange for incremental gains.

The increasing focus of federal research on health is potentially meaningful. It makes sense for the federal government to emphasize research where the social payoff is large relative to private gain – although large R&D expenditures by the pharmaceutical industry indicate that private gains are also substantial. And it should not be surprising if the returns come in the form of health-related outcomes and not necessarily in employment-generating activities. However, it seems plausible that we have seen a payoff in employment generation. Surely, some of the growth in employment in the health care industry is due to innovative treatment options that have been made possible through health-related R&D. The job creation may even extend to manufacturing, as employment has held up better in medical devices and pharmaceuticals than in many other manufacturing industries. But the way in which health-related R&D affects the economy and generates employment is probably different from the stimulative effects of past R&D expenditures on, for example, information technology or aerospace. In particular, we tend to view the expansion of the healthcare system as a double-edged sword. While we value the improvements in health outcomes, we consider increasing health care costs to be a burden.

It is also rather striking how much the share of federal R&D going to economic development *including* energy has fallen, given all the rhetoric about the need for developing new energy sources over successive presidential administrations. In 1981, 36 percent of federal nondefense R&D and just over 15 percent of total federal R&D went to economic development. In 2007, 10 percent of nondefense and 4 percent of total R&D went to this category. Meanwhile, health and the environment increased from 31 to 55 percent of nondefense R&D (and from 14 to 23 percent of total.)

In sum, as a nation, we have not cut back spending on R&D. The federal government is doing relatively less and the business sector is doing relatively more. To the degree that business spending is more focused on commercially practical activities, this could be a positive for manufacturing. Federal spending has shifted towards health. Although job creation is not the objective, increased federal support for health research has probably contributed to the growth of the health care industry.

Science and Engineering Workforce

Explanations for the blossoming of the information industry in New England and its transformation of the regional economy emphasize three critical elements: new technologies that grew out of defense-related research in WWII and the Cold War; elite research universities where the brightest students from across the country performed much of this research; and the coming-of-age of the highly educated baby boom generation, which provided workers with cutting-edge skills for the new firms and industries built on the emerging technologies and which also contributed to the expansion of the research and education infrastructure.

Since a key part of the narrative is the entry into the labor force of large numbers of young adults trained in state-of-the-art science and engineering (S&E) disciplines, a natural question for someone concerned about the nation's innovative capacity is the current and future supply of scientists, engineers, and others with the skills needed by technologically advanced industries.

According to SEI, the number of BAs in S&E relative to the population of 20-24 year-olds has increased modestly since the 1970s, as has graduate enrollment in S&E relative to the population aged 25 to 29. Since the early 1990s, S&E BAs have accounted for just under a third of all degrees awarded. Engineering accounts for about 5 percent, natural sciences about 10 percent and the social sciences including psychology 16 percent. Biology (natural science) has become more popular. Computer science has had its ups and downs, increasing in popularity around the century date change and then decreasing. Foreign students on temporary visas account for about 4 percent of S&E BAs, although more in some fields.

The number of Master's degrees in S&E has increased since the early 1990s, but not as fast as Master's in other fields. Engineering has increased relatively slowly; biology and psychology have increased relatively fast. Foreign students on temporary visas account for about one-quarter of all science and engineering Master's (although just over 10 percent of all Master's degrees.) Almost 40 percent of engineering and computer science degrees go to foreign students on temporary visas. The number of doctoral degrees in S&E has also increased. Growth has been especially rapid in medical and life science, a category for which data only exist at the doctoral level. Interestingly, this field is made up almost entirely of U.S. citizens and permanent residents, with women outnumbering men two-to-one. In contrast, 60 percent of those receiving doctorates in engineering are foreign students on temporary visas. For all science and engineering doctoral degrees, a third go to foreign students on temporary visas.

A potential concern is that these students on temporary visas, who account for disproportionate shares of the most highly trained scientists and engineers produced by U.S. universities, will return to their countries of origin and the United States will not benefit from their advanced learning. However, surveys indicate that roughly three-quarters of foreign recipients of doctoral degrees planned to stay in the United States in 2007 and about half had job offers or post-doctoral research opportunities. Foreign students have accounted for a majority of post-doctoral fellows in the United States since the early 1990s.

About 5 million college educated workers are employed in science and engineering occupations – 4 percent of the total workforce. This is roughly one-third the number of workers who have degrees in science and engineering. The disparity between S&E occupations and degree holders is most pronounced for those in the social sciences, least for engineers. However, many S&E degree holders in non-S&E occupations are engaged in activities related to their degree, such as management or sales or other non-S&E activities for which their training was relevant.

About 25 percent of college-educated S&E workers are foreign and 40 percent of S&E workers with doctorates are foreign. Immigration of S&E workers trained abroad, as well as U.S. training of native and foreign-born students, has contributed to the number of people in S&E occupations, which has grown faster than the overall workforce since the 1950s.

Women and minorities account for increasing shares of the workforce with S&E degrees. In 2006, only 35 percent of workers with S&E degrees under the age of 30 were white males, while almost 60 percent of those with S&E degrees over age 50 were white males.

Almost half of all workers with S&E degrees work for for-profit firms. Interestingly, the next largest category – 17 percent – is self-employment. This is larger than the self-employed share of the total workforce (11 percent). Additionally, the self-employed with S&E degrees are more likely to have incorporated their businesses. Over half of S&E self-employed are incorporated, compared to one-third for all self-employed.

SEI points out that it takes a long time for foreign-born S&E workers to become U.S. citizens. Most of those who stay in the United States eventually do. In 2003, about 90 percent of foreign S&E workers who had arrived before 1980 were citizens; almost all the rest were permanent residents. However, only 42 percent of those who had arrived in 1993 had become citizens by 2003; 46 percent were permanent residents and 12 percent were on temporary visas. Among those who arrived in 1998, just 9 percent had become citizens by 2003, 43 percent were permanent residents and 49 percent were on temporary visas.

As in the case of R&D spending, these data on science and engineering workers do not seem especially ominous. Certainly, the ability of the United States to attract students in science and engineering, as well as trained professionals, from all over the world should be favorable to our technological leadership. On the other hand, the prominence of foreign-born workers in S&E occupations raises the question of why native-born workers do not pursue these careers to a greater degree.

Additionally, given U.S. dependence upon foreign-born scientists and engineers, the time required for these workers to become citizens or even permanent residents is excessive. Being in a temporary visa status not only limits the opportunities available to these individuals but also prevents the nation from fully benefiting from their talents. Most obviously, as SEI points out, many S&E jobs in the federal government require U.S. citizenship. Some private firms involved in defense and other classified work may also be restricted to hiring U.S. citizens. Additionally, foreigners who want to work in the United States and who do not have family members already in the country depend upon employers to apply for their visas. This dependence upon the employer for visa applications is an impediment to foreign workers on temporary visas changing jobs and restricts their advancement and productivity growth. Some may eventually return home. (Changing jobs is possible if the new employer makes a new visa application, but this is a serious barrier to securing employment and likely an impediment to looking.) Foreign-workers on temporary visas are also prevented from starting their own businesses – unless they have substantial financial resources and can take advantage of a special visa for immigrant investors. Yet, as noted above, being an entrepreneur is an attractive career choice for many S&E workers – one that may have substantial spillovers in terms of innovation and job creation. The bottom line is that the United States imposes significant hurdles to foreign S&E workers becoming permanent residents and citizens even though it has become dependent upon their skills.

A Future Smoking Gun

International Educational Attainment and Achievement

International comparisons of educational attainment and achievement are the truly scary message in *Science and Engineering Indicators.* Given U.S. global leadership in many indicators of technological achievement, such as patents, scientific articles, trade in intellectual intangibles – all documented in SEI, it is almost shocking to see how poorly U.S. students perform in international comparisons of proficiency in mathematics and science. Tests of students in Grades 4 and 8 (Trends in International Mathematics and Science Study – TIMSS) show the United States ranking in the lower middle of participating countries, while tests of 15 year olds (Program for International Student Assessment – PISA) show the United States ranking close to the bottom. TIMSS shows a slight relative improvement over time, while PISA does not. The United States is not the only country with a reputation as a high technology center that ranks poorly in these tests. Israel is another. But for the most part, most countries that the United States would regard as competitors in knowledge-intensive manufacturing and services industries (and many that it would not) rank higher in international educational performance. Interestingly, the United States rates worse on the PISA, which is said to place more emphasis on problem-solving skills than rote learning.

The United States has an advantage over most other countries in terms of the fraction of the population with college degrees. However, that margin has substantially diminished – and will diminish further - as can be seen by comparisons of educational attainment for younger adults (those aged 25 to 34) and the entire population of normal working age (25 to 64.)

In 2006, 29.9 percent of U.S. residents 25 to 64 had BAs (or its equivalent) or better, compared to an average of 19.3 percent for OECD nations. Only one nation, Norway, surpassed the United States, with 30.5 percent of its population having the equivalent of a BA or better. Israel at 29.8 percent was close.

For younger people (25 to 34), the United States has a lot more company. College educational attainment in the United States is the same for those 25 to 34 as it is for those 25 to 64. This means that younger people are no more likely to have a college degree than their parents. In contrast, in most other countries, the younger group is substantially more educated than their elders. A particularly striking case is South Korea. Only 23.5 percent of Koreans age 25 to 64 have BAs; but among younger adults (25 to 34), 32.9 percent have BAs – a higher fraction than in the United States. Thus, even if Korean young people make no further educational gains, the educational attainment of the Korean workforce will rise with the passage of time as older people retire and are replaced by more highly educated younger workers. Meanwhile, educational attainment in the United States stays the same.

For OECD countries, the average share of 25 to 34 year-olds with a BA was 24.6 percent in 2006 compared to 29.9 percent in the United States – half the gap for the population 24 to 65. In six countries the educational attainment of younger adults surpassed that in the United States – Norway (39.8), Israel (34.8), Netherlands (34.3), Korea (32.9), Denmark (31.7) and Sweden (30.6). Another five countries were close, with over 29 percent of younger adults having BAs.

If one includes those with associates degrees and advanced technical skills, the picture is essentially the same, although the list of countries surpassing the United States is somewhat different as some countries put more emphasis on technical training than others.

The challenge for the United States is that a major competitive advantage – a highly educated population - is eroding. Other countries are catching up in terms of educating younger adults, while the United States has not made much progress since the baby boom generation. At the same time, it appears that K-12 students in the United States are not mastering skills in mathematics and science as well as students in many other countries. This does not bode well for future U.S. leadership in knowledge intensive industries. But even if the United States is able to maintain its leadership position - perhaps because its economic system is more supportive of innovation or because of the quality of its research universities – these patterns are troubling. A population that is not improving its skill levels is unlikely to reap the financial rewards from these innovations to the degree that American workers did in the past. Rather, the fruits of innovation will go disproportionately to a relatively small elite of professionals and senior executives and the nation will continue to debate what to do about the loss of middle class jobs and rising income inequality.

Conclusions

For anyone interested in technology and innovation in the United States, the NSF's annual *Science and Engineering Indicators* is a valuable resource, containing information on a host of indicators relevant to U.S. performance over time and in comparison to other countries. This note summarizes my observations in three areas – R&D expenditures, the science and engineering workforce, and international educational comparisons. However, there is a lot more useful material, including data on individual states.

I was somewhat reassured by R&D patterns: there has not been a decline in R&D spending compared to GDP. Business is doing relatively more and the federal government is doing relatively less. Federal R&D spending has also shifted substantially towards health. These trends do not seem inherently worrisome, although the shift towards health seems likely to have affected the sectors that benefit most from federal R&D. Other countries, notably China and South Korea, have substantially increased R&D spending in the past two decades, but the United States still ranks relatively high.

Nor has there been a decline in the science and engineering workforce or in degrees granted. However, foreign students on temporary visas comprise a large fraction of the graduate student body in S&E fields and foreign workers make up a disproportionate share of workers in S&E occupations. Given the nation's dependence upon foreign-born scientists and engineers, U.S. immigration policy should be more welcoming. These highly educated workers, who are critical to U.S. future technological leadership, should be able to become permanent residents and citizens more rapidly.

What I did find disturbing were international comparisons of educational attainment and performance. While the United States still ranks high in terms of the fraction of the population with college degrees, its standing is not impressive if one just looks at younger adults. Other nations have made major advances, while the United States has stood still. Further, in tests of science and mathematics, U.S. teenagers compare poorly with their counterparts in many countries.