U.S. Competitiveness in Science and Technology

Titus Galama, James Hosek

Prepared for the Office of the Secretary of Defense
Approved for public release; distribution unlimited

RAND NATIONAL DEFENSE RESEARCH INSTITUTE

The research described in this report was prepared for the Office of the Secretary of Defense (OSD). The research was conducted in the RAND National Defense Research Institute, a federally funded research and development center sponsored by the OSD, the Joint Staff, the Unified Combatant Commands, the Department of the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community under Contract W74V8H-06-C-0002.

Library of Congress Cataloging-in-Publication Data is available for this publication.
ISBN 978-0-8330-4424-2

Published 2008 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
4570 Fifth Avenue, Suite 600, Pittsburgh, PA 15213-2665
RAND URL: http://www.rand.org
To order RAND documents or to obtain additional information, contact
Distribution Services: Telephone: (310) 451-7002;
Fax: (310) 451-6915; Email: order@rand.org

Summary

The purpose of this report is to present and consider information related to whether the United States is losing its edge in science and technology (S&T). Claims have been made about insufficient expenditures on research and development (R&D) (particularly on basic research), problems with U.S. education in science and engineering (S&E),[1] a shortage of S&E workers in the United States, increasing reliance on foreigners in the workforce, and decreasing attractiveness of S&E careers to U.S. citizens. A loss of leadership in S&T could diminish U.S. economic growth, standard of living, and national security.

This report cites arguments made to support the contention of a creeping S&T crisis in the United States, contrasts the arguments with relevant data, and considers them from additional angles. Specifically, we review literature on the topic of U.S. leadership in S&T and input from various experts who attended the November 8, 2006, meeting, organized by the National Defense Research Institute (NDRI) at the RAND Corporation, to review the evidence on the perception that the United States is losing its edge in S&T and on the potential implications for national security.[2] The literature research

[1] We use the terms *science and technology* (S&T) and *science and engineering* (S&E) mostly interchangeably. When referring to science prowess indicators, one commonly refers to science and technology indicators, but when referring to people or the workforce, it is common to refer to scientists and engineers (rather than scientists and technologists).

[2] Throughout this report, we refer to this meeting as the "NDRI meeting on U.S. competitiveness in S&T" or simply the "NDRI meeting."

encompasses reports published by U.S. and international S&T, economic, and governmental organizations as well as academic research publications, newspaper articles, opinion pieces, Congressional testimony, and Web logs. NDRI meeting participants included analysts, policymakers, military officers, professors, and business leaders. In addition to the literature review and expert input, this report draws on various data analyses, e.g., of time-series data on R&D investment and other S&T indicators, and of Current Population Survey (CPS) and Census data on salaries, size, composition, and education of the S&E workforce, data that distinguishes between U.S.- and foreign-born scientists and engineers.

Questions We Consider

We have sought to address the following research questions:

1. **What are the implications of the globalization of S&T and the rise of other nations for U.S. performance in S&T?**
    1.1. *What facts suggest that other nations or regions are developing significant strength in S&T while the United States is falling behind?* Is R&D rapidly increasing in major nations or regions other than the United States? Is S&T employment growing more rapidly in other nations or regions? Are other nations or regions educating their populations in S&T more rapidly than the United States? Is innovation and scientific discovery increasingly taking place elsewhere? Are other nations or regions becoming more capable of acquiring and implementing new technology and information?
    1.2. *Will the globalization of S&T and the rise of other nations make it more difficult for the United States to be successful in S&T?* Are American S&T jobs likely to go overseas? Does the changing nature of innovation pose a threat to America's strong performance in S&T?

2. **What evidence suggests that the United States has been underinvesting in S&T?**
   2.1. *Is the United States investing enough in R&D to return to, or sustain, its leadership position in S&T?* Are total R&D expenditures growing more slowly than in the past? Are R&D expenditures on basic research—both federally and privately funded—in decline? Has federally funded research in general decreased? Has funding for academic research slowed? Has federal funding for research in the physical sciences, mathematics, and engineering declined?
   2.2. *Will the U.S. K–12 education system be able to generate the talent in science and math to meet the future demands of the global marketplace?* How does U.S. spending on education compare with other nations? How are K–12 students performing in science and math—both by national standards and relative to other nations? What is the past, present and future education attainment of the U.S. population?
   2.3. *Can America continue to meet the demand for well-trained, well-prepared S&E workers?* Have S&E careers become increasingly unattractive to U.S. citizens? Is there a shortage of qualified scientists and engineers? Is the United States becoming increasingly reliant on foreign S&E professionals? Are foreign scientists and engineers working in the United States increasingly returning home? Do foreign professionals working in the United States appear to be as productive as native S&E professionals? Do foreign professionals working in the United States reduce wages for S&E jobs?

Findings

We find that the United States continues to lead the world in science and technology. The United States grew faster in many measures of S&T capability than did Japan and Europe, and developing nations such as China, India, and South Korea showed rapid growth in S&T output measures, but they are starting from a small base. These developing nations do not yet account for a large share of world innovation and scientific output, which continues to be dominated by the United States, Europe, and Japan.

The United States accounts for 40 percent of total world R&D spending and 38 percent of patented new technology inventions by the industrialized nations of the Organisation for Economic Co-operation and Development (OECD), employs 37 percent (1.3 million) of OECD researchers (FTE), produces 35 percent, 49 percent, and 63 percent, respectively, of total world publications, citations, and highly cited publications, employs 70 percent of the world's Nobel Prize winners and 66 percent of its most-cited individuals, and is the home to 75 percent of both the world's top 20 and top 40 universities and 58 percent of the top 100.

A comparison of S&T indicators for the United States with those of other nations/regions reveals the following:

- Other nations/regions are not significantly outpacing the United States in R&D expenditures. China and South Korea, which are showing rapid growth in R&D expenditures, are starting from a small base, and the EU-15 and Japan are growing slower than the United States.
- Other nations/regions are not outpacing the United States in S&T employment, as growth in researchers in the EU-15 was comparable to, and that of Japan considerably lower than, that of the United States. China, however, added about the same number of researchers as the United States did and overtook Japan during the period 1995 to 2002.
- Other nations/regions are rapidly educating their populations in S&T, with the EU-15 and China graduating more scientists and engineers than the United States.
- China, India, and South Korea are starting to account for a significant portion of the world's S&T inputs and activities (R&D funding in dollars at purchasing power parity, research jobs, S&T education, etc.) and are showing rapid growth in outputs and outcomes, yet they account for a very small share of patents, S&T publications, and citations.

- One sign of U.S. slippage is a 3-percentage-point loss in world share in publications, citations, and top 1 percent highly cited publications between 1993–1997 and 1997–2001.
- On measures such as additions to the S&T workforce and patented innovations, U.S. growth in S&T was on par with, or above, world average trends. By comparison, Japan grew more slowly in additions to the S&T workforce, and both the EU-15 and Japan had slower growth in patented innovations.

High growth in R&D expenditures, patents, and S&E employment, combined with continuing low unemployment of S&E workers, suggest that U.S. S&E has remained vibrant. These signs do not support the notion that jobs are being lost at substantial rates as a result of the outsourcing and offshoring of S&T. U.S. gains in S&T occur against a backdrop in which R&D expenditures, S&E employment, and patents are also increasing in the EU-15, Japan, China, Korea, and many other nations/regions. Studies of the offshoring of high-skill work suggest that it does not result in job losses in the originating country, as it is increasingly driven by the need to access scarce talent, but rather that the overall number of jobs is increasing.

A future in which a significant share of new technologies is invented elsewhere will benefit the United States as long as it maintains the capability to acquire and implement technologies invented abroad. Technology is an essential factor of productivity, and the use of new technology (whether it was invented in the United States or elsewhere) can result in greater efficiency, economic growth, and higher living standards. The impact of globalization on U.S. innovative activity is less clear. On the one hand, significant innovation and R&D elsewhere may increase foreign and domestic demand for U.S. research and innovation if the United States keeps its comparative advantage in R&D. On the other hand, the rise of populous, low-income countries may threaten this comparative advantage in R&D in certain areas if such countries develop the capacity and institutions necessary to apply new technologies and have a well-educated, low-wage S&T labor force.

Looking only at federal expenditures on R&D a few years ago might have left the impression that the United States was underinvesting in R&D at the end of the Cold War: Total federal R&D spending grew at 2.5 percent per year from 1994 to 2004, much lower than its long-term average of 3.5 percent per year from 1953 to 2004 (in real terms, i.e., after correction for inflation). Yet federal R&D accounted for only $86 billion of $288 billion total U.S. R&D expenditures in 2004. Industrial R&D expenditures, the largest source of R&D, grew rapidly, at an average rate of 5.4 percent and 5.3 percent per year for the periods 1953–2004 and 1994–2004, respectively, and accounted for most of the growth in total R&D (4.7 percent and 4.4 percent for the periods 1953–2004 and 1994–2004, respectively). As a result, growth in total R&D was on par with the world's average growth: Measured in dollars at purchasing power parity (PPP), U.S. R&D expenditures grew at an average rate of 5.8 percent per annum from 1993 to 2003, close to the world's average of 6.3 percent. Further, total basic research showed the greatest rate of increase, at an average of 6.2 percent and 5.1 percent per year (4.7 percent and 4.4 percent for total R&D) for the periods 1953–2004 and 1994–2004, respectively. Also, federally funded basic research grew by 3.4 percent per year over the period 1970–2003 and 4.7 percent per year over the period 1993–2003. As industrial and federal R&D grew, universities and colleges managed to increase their R&D by an average of 6.6 percent and 5.1 percent per year for 1953–2004 and 1994–2004, respectively. This is reassuring, given the importance of basic and academic research to innovation.

However, most of the increase in federally funded basic research was in the life sciences, whereas basic research funding for the physical sciences was essentially flat. The allocation of federal R&D dollars presumably was based on an assessment that the potential payoffs were far higher in the life sciences than in the physical sciences, just as physical sciences had received the major portion of federal R&D funds in the decade after Sputnik. Still, taken as a whole, total basic research and federally funded basic research have increased rapidly in real terms (constant dollars) on average, by between 3 percent and 6 percent per year for the last three decades.

U.S. expenditures per student on elementary and secondary education are comparable with those of other industrialized nations and commensurate with the high U.S. per capita gross domestic product

(GDP). In postsecondary education, the United States spends significantly more per student than other industrialized nations (nearly twice the OECD industrialized nations' average). U.S. students performed relatively well in reading literacy, i.e., their scores were similar to those of other OECD industrialized nations. U.S. students compare relatively well in mathematics and science at the lower grades, but older students demonstrate lower achievement than most of their peers in other industrialized nations. Various high-level groups have pointed to the low student achievement of older students in mathematics and science as a matter of concern. In addition, recent research has emphasized the importance of early childhood education as a crucial foundation for cognitive, social, and emotional development, and there is reason to consider increasing public and private investments in children.

The education attainment of the U.S. population has continued to increase. The percentage of the U.S. population (ages 25–64) that has attained at least upper secondary education, 88 percent, compares favorably with an average of 67 percent for the OECD industrialized nations. Trends in the United States and abroad suggest that global competition for college-educated workers will intensify in the future, as a result of forecasted changes in demographics. Past research shows that between 1980 and 2000 the United States added 20 million workers with college degrees to the labor force, which more than doubled the college-educated workforce, but between 2000 and 2020 only 8 million additions to this workforce are anticipated, as baby boomers are beginning to retire and fewer prime-age workers will join the labor force. The United States is not the only region with an aging population, however, and Europe, Japan, and China appear to be worse off in this respect.

Scientists and engineers are paid substantially more (about a 25 percent wage premium) and have the same unemployment as the non-S&E workforce for similar levels of education. Judging by recent versus past wage and unemployment trends, there is no evidence of a current shortage of S&E workers. At any given time, a firm or set of firms within an industry may be unable to fill their S&E job openings, but that is true for non-S&E positions as well. More broadly, despite the higher wages available in S&E jobs, the number of U.S.-born graduates in S&E has grown slowly. Much of the growth in S&E employment has come from foreign-born S&E workers who have studied in the United States or who migrated to the United States after completing graduate studies in their home country. The share of non-U.S. citizens in the science and engineering workforce increased from 6 percent in 1994 to 12 percent in 2006.[3] But alternative pathways, such as an increasing share of S&E graduates entering S&E jobs, the return of individuals holding S&E degrees who had earlier left for non-S&E jobs, and individuals without S&E degrees entering S&E jobs, may have also contributed.

Given the current choice of many U.S.-born students to not study S&T, some observers are skeptical that scholarships and improved elementary and secondary science teaching will do much to expand the number of students studying S&T. The reasoning is that students will ultimately not enter (and stay) in S&E jobs unless their pay and intangible rewards are increased relative to non-S&E jobs.

With rapid growth in R&D worldwide and aging populations, increased global competition for skilled S&E workers may result in slower growth of the workforce, more firms unable to fill their S&E job openings, and higher wages for S&E workers (i.e., increased cost of conducting R&D). While not apparent in the data yet, such potential trends are worth monitoring.

The United States has benefited from the inflow of foreign S&E students. Foreigners have helped to enable the fast growth in S&E employment (about 4.2 percent per year since 1980) in the face of relatively slow growth in S&E degree production (about 1.5 percent per year). This also suggests that foreigners have helped to hold down S&E wage increases, thereby reducing the cost of U.S. research. Further, because many foreign students come to the United States with a secondary education or a college education, the United States has not had to bear the cost of that education. Technological and scientific innovation is the engine of U.S. economic growth, and human talent is the main input that generates this growth. Immigration of highly skilled scientists and engineers allows the United States to draw the best and

---

3 In contrast, the share of non-U.S. citizens in the non-S&E workforce remained constant at 5 percent for similar levels of education (bachelor's degree and higher).

brightest from a global rather than domestic pool of talent. Finally, wage data suggest that the quality of the foreign S&E workforce is as good as that of U.S. citizens, in that comparable workers are paid the same.

However, the diminishing share of degrees awarded to U.S. citizens, particularly for the higher degrees such as doctorate and master's, suggests that S&E careers are becoming less attractive to U.S. citizens or, alternatively, that U.S. citizens encounter more competition (from foreigners) in applying for a limited number of desirable spots at S&E colleges and universities. The case for increasing the number of U.S.-born S&E graduates rests on whether the increased employment of foreign-born S&E workers makes the U.S. economy and its national security vulnerable to foreign competitors and adversaries. Wage data, for example, do not show a premium for U.S.-born graduates, i.e., there appears to be no market preference for native versus foreign-born scientists and engineers. National security–related jobs requiring U.S.-born S&E workers are apparently a small portion of the market (Butz et al., 2004). Further, while some immigrants eventually return home, many remain in the United States indefinitely. While anecdotal evidence may suggest that foreign scientists and engineers are increasingly returning home, various studies indicate that the numbers are still small and that the United States remains a net recipient of highly skilled foreign talent. Today, about 70 percent of foreign recipients of U.S. doctorate degrees in S&E stay in the United States for at least two years, up from 50 percent in the 1990s. Research has further shown that long-term (ten-year) stay rates do not differ much from short-term stay rates, suggesting that about 70 percent of recent PhD graduates in S&E may stay in the U.S. indefinitely. Nevertheless, it is worth watching trends in the number of foreign S&E workers returning home. The recent reduction of the annual cap on H1-B visas for skilled labor could reduce stay rates and skilled immigrant worker inflows. In addition, given that stay rates are currently higher for developing than for developed nations, significant economic development of China and India, whose nationals contribute significantly to the U.S. S&E workforce, could offer increasingly attractive opportunities "back home," which may increase return migration and reduce stay rates.

Wage and unemployment trends do not show the traditional signs of a shortage of scientists and engineers. Unemployment has not been decreasing but has been steadily low, as is typical in professional occupations. Also, wages have not been increasingly rapidly relative to trend. Nevertheless, low unemployment, the relatively steady wage growth in S&E, and claims of shortages can plausibly be reconciled by off shoring and outsourcing. If firms cannot fill their S&E positions in the United States, they may decide to offshore or outsource R&D to take advantage of foreign S&E labor pools. In addition, firms may prefer to set up foreign production and research activities as part of a strategy of gaining entry to foreign markets. Moving operations to foreign countries and drawing on their S&E workers may be less costly and strategically more advantageous than bidding up S&E wages in the United States in an effort to hire S&E workers. Thus, offshoring and outsourcing are options that can slow wage increases and remove shortages. That is, shortages in the United States have not materialized, or have been mitigated, by these means. Under this explanation, it also follows that reducing the inflow of foreign high-skilled S&E workers (e.g., by reducing the H1-B visa cap) will likely increase offshoring and outsourcing. It may not even induce sufficient numbers of U.S. citizens to join the S&E workforce, as wage growth will still be slowed by the decision to offshore or outsource the work. Increasing the inflow of foreign high skill S&E workers may, in contrast, increase investment and employment at home as well as provide local spillover benefits.

Given the benefits associated with the foreign S&E workforce, the United States would likely be worse off if foreign access to U.S. graduate education and S&E jobs were limited. Presumably, to establish the opposite, i.e., that the United States is negatively affected overall by its growing reliance on foreign-born S&E graduates, a case would have to be made along any of the following lines (and perhaps others): that the expansion of foreign-born scientists and engineers in the U.S. workforce has led to faster and more widespread transmission of U.S. technological discoveries to foreign countries, who are now capitalizing on them by developing new or cheaper products to the detriment of U.S. firms; that sensitive technology and know-how are flowing to potential adversaries, who will use it against the United States; or that by holding down wage growth in S&E, the expansion of the foreign-born S&E workforce has reduced the supply of new U.S.-born S&E workers, some of whom would have entered hard-to-fill national security positions. Possibilities such as these may warrant further study.

In this report, we have focused primarily on U.S. competitiveness in S&T, without considering the implications for national security. Past research indicates that globalization of S&T complicates national security: The United States is less capable of denying other nations access to advanced technology to maintain a wide military capability gap between itself and potential adversaries. Technological capability is more widely diffused to potential competitors and may provide adversaries with capability to pursue nontraditional strategies and tactics on the battlefield or through insurgency and terrorism. Nevertheless, past research concludes that attempts to regulate or limit the diffusion of some (but not all) sensitive defense technology might have harmful long-term consequences and might not even be beneficial in the short term.

In short, our assessment of the measures we have examined indicates that the U.S. S&T enterprise is performing well. We find that the United States leads the world in S&T and has kept pace or grown faster than the rest of the world in many measures of S&T. Although developing nations such as China, India, and South Korea showed rapid growth in S&T, these nations still account for a small share of world innovation and scientific output. Furthermore, we find that the consequences of the globalization of S&T and the rise of S&T capability in other nations are more likely to be economically beneficial to the United States than harmful. We also find that the United States has continued to invest in its S&T infrastructure and that the S&E workforce has managed to keep up with the demand for highly skilled S&E workers through immigration. However, there are potential weaknesses in the persistent underperformance of older K–12 students in math and science, in the limited attractiveness of S&E careers to U.S. students, and in the heavy focus of federal research funding on the life sciences, and we do not yet fully understand the consequences of an increasing reliance on foreign-born workers in S&E.

While the United States is still performing at or near the top in many measures of S&T leadership, this leadership must not be taken for granted. Institutions and incentives to foster the creation of new S&T discoveries, the education and training of new generations of S&T workers, the nurturing of academic and industrial research centers of excellence, the protection of intellectual property, and, at the same time, the production and dissemination of basic scientific discoveries have all contributed to the unparalleled S&T leadership of the United States. Such institutions need to be sustained and, as needed, adapted to the global economy. We make the following recommendations for policy and decisionmakers to consider:

- Establish a permanent commitment to a funded, chartered entity responsible for periodically monitoring, critically reviewing, and analyzing U.S. S&T performance and the condition of the S&E workforce.

  Fundamental steps toward ensuring that the United States continues to benefit from its strength in S&T are to sustain U.S. leadership in basic and applied research and to keep salaries and job conditions competitive so that the United States remains an attractive place for the world's scientists and engineers to live and work. Regular monitoring and analysis of S&T performance and the condition of the S&E workforce will provide timely, relevant, objective information to policymakers to aid them in addressing adverse trends and improving U.S. S&T.

  The National Science Foundation (NSF) already collects and monitors relevant information, the Office of Science and Technology Policy (OSTP) advises the President and others within the Executive Office of the President on the effects of science and technology on domestic and international affairs, and numerous organizations have established committees of experts and stakeholders that provide their assessment of particular issues relating to U.S. S&T. Yet critical review and assessment of information on S&T performance and the condition of the S&E workforce has proved difficult. For example, shortages of S&E workers have been predicted, but the predictions have proved inaccurate.

The plethora of advice, the sometimes fragmented nature of the advice (that is addressing one particular issue rather than S&T as a whole), and the closeness of some organizations to stakeholders or the executive office points to the need for a coherent, centrally coordinated, objective and independent research agenda with a long-term view on S&T and the S&E workforce.

The entity to carry out the agenda could be, for example, a nonpartisan commission appointed every four years by the President, an interagency commission, or a nonfederal, nonprofit foundation. The commitment to convene such an entity should be permanent because U.S. leadership in science and technology and the strength of the U.S. science and engineering workforce are enduring concerns. The entity should be funded so that it can commission and fund studies relevant to whatever issues are current. Such studies, conducted by experts in academia and research organizations, should be published and also would serve as input into a final, published report on U.S. S&T performance and the condition of the S&E workforce. Finally, the entity should be chartered not only as a matter of defining its purpose, objective, and scope but also to enable it to operate independently and produce objective, rigorous, nonpartisan analyses. Research topics that could be covered are the demand and supply of S&E workers, education, quality of education, training, employment, career progression, wages, in-migration, out-migration, offshoring, outsourcing, and the condition, performance, and economic impact of the S&T enterprise, e.g., in terms of patents, publications, citations, and innovative products and services.

- Facilitate the temporary and indefinite stay of foreigners who graduated in S&E from U.S. universities, for example, by offering them one-year automated visa extensions to seek work in the United States after completion of their study. Research on stay rates of foreign recipients of U.S. doctorate degrees suggests that conditions (employment and immigration) at the time of completing the doctorate degree are crucial in determining the likelihood of a long stay.

- Facilitate the immigration of highly skilled labor, in particular in S&E, to ensure that the benefits of expanded innovation, including spillovers, accrue to the United States and to ensure that the United States remains competitive in research and innovation. Immigration allows the United States to draw from the best and brightest of a global rather than national talent pool, likely reduces the offshoring of R&D (being driven by the need both for cost reductions and to access highly skilled talent), and keeps the cost of research down. While immigration may reduce the attractiveness of S&E careers to U.S. citizens, at the same time, the total number of highly skilled individuals (foreigners plus U.S. citizens) has likely increased through immigration, and human talent is the main input that generates growth in today's knowledge driven economy.
- Increase capacity to learn from science centers in Europe, Japan, China, India, and other countries to benefit from scientific and technological advances made elsewhere. The United States could do this by promoting joint ventures, encouraging collaborative research with researchers in other countries, supporting U.S. researchers and students to participate in foreign R&D centers (e.g., through fellowships, positions in foreign laboratories of multinationals, graduate studies abroad, sabbaticals, postdoctoral positions, etc.), and establishing informal networks with S&E workers who studied in the United States. Foreign-born S&E workers may also help in establishing links to foreign centers of R&D excellence.
- Continue to improve K–12 education in general and S&T eduction in particular, as human capital is a main driver of economic growth and well-being. In this regard, recent research on early childhood development emphasizes the importance of certain investments during early childhood as a foundation for investments during later childhood. This new research on childhood development offers a novel viewpoint that substantially alters and enlarges the usual perspective regarding "interventions" to develop science and math skills and understanding in children and teens. It raises the possibility of placing more emphasis on early child-

hood development as a means to improve education attainment in general and more specifically in S&T. This possibility may deserve rigorous investigation through pilot programs or through the analysis of data from naturally occurring treatments.

In this research, we have encountered additional areas for which substantial knowledge appears to be lacking and that may benefit from further research. We recommend that consideration be given to research on the following:

- factors affecting the recruiting and retention of foreign S&E talent (i.e., a study on the decision of foreign students to do graduate and undergraduate work in the United States and to seek work in the United States after graduation, and on the decision of foreign S&E employees or recent graduates to seek work in the United States and to stay in the United States)
- the idea that U.S. leadership in S&E resides in a relatively small number of highly talented individuals (i.e., studying the nature of this leadership, the ability of the United States to continue to attract these individuals, and the consequences of not being able to do so)
- whether and how increased employment of foreign-born S&E workers makes the United States vulnerable even as such workers add to the strength of the U.S. economy.